Pipeline Flow Behavior of Water-In-Oil Emulsions

by

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Author’s declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Ali Omer

Abstract

Water-in-oil (W/O) emulsions consist of water droplets dispersed in continuous oil phase. They are encountered at various stages of oil production. The oil produced from an oil-well usually carries a significant amount of water in the form of droplets. In enhanced oil recovery techniques involving the injection of polymer solution, the aqueous phase of the water-in-oil emulsions produced from the oil well consists of polymeric additive. A good understanding of the flow behavior of emulsions in pipelines is essential for the design and operation of oil production-gathering facilities and emulsion pipelines.

A number of studies have been reported on simultaneous flow of oil and water in pipelines. However, the studies reported in the literature are mainly focused on either oil-water flow patterns and separated flows (annular and stratified flow of oil and water phases) or oil-in-water (O/W) emulsion flows. The pipeline flow of water-in-oil (W/O) emulsions has received less attention. Also, little work has been carried out on the effect of additives such as polymer.

In this study, new experimental results are presented on the pipeline flow behavior of water-in-oil (W/O) emulsions, with and without the presence of polymeric additive in the aqueous phase. The emulsions were prepared from three different oils, namely EDM-244, EDM-Monarch, and Shell Pella of different viscosities (2.5 mPa.s for EDM-244, 6 mPa.s for EDM-Monarch, and 5.4 mPa.s for Shell Pella, at 25 ^{0}C). The water-in-oil emulsions prepared from EDM-244 and EDM-Monarch (without any polymeric additive in the dispersed aqueous phase) exhibited drag reduction behavior in turbulent flow. The turbulent friction factor data of the emulsions fell well below the standard Blasius equation for smooth pipes. The water-in-oil emulsions prepared from EDM-244 exhibited stronger drag reduction as compared with the

EDM-Monarch emulsions. The Shell Pella emulsions (w/o type) did not exhibit any drag reduction in turbulent flow; the friction factor data followed the Blasius equation. The Shell Pella emulsions were more stable than the EDM-244 and EDM-Monarch emulsions. When left unstirred, the EDM-244 and EDM-Monarch emulsions quickly coalesced into separate oil and water phases whereas the Shell Pella emulsions took significantly longer time to separate into oil and water phases. The Shell Pella oil emulsions were also milkier than the EDM emulsions.

The addition of polymer to the dispersed aqueous phase of water-in-oil emulsions had a significant effect on the turbulent drag reduction behavior. Emulsions were less drag reducing when polymer was present in the aqueous droplets.

The effect of surfactant on the pipeline flow behavior of water/oil emulsions was also investigated. The surfactant-stabilized water-in-oil emulsions followed the single phase flow behavior. The presence of surfactant in the emulsions caused the dispersed droplets to become significantly smaller. It is believed that the droplets were smaller than the scale of turbulence when surfactant was present and consequently no drag reduction was observed.

Acknowledgements

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Chapter 1 Introduction and Objectives

1.1 Emulsions and Emulsions Classification

An emulsion is a system containing two immiscible liquids such as water and oil. One of the phases of an emulsion system is dispersed as globules in the other. The phase that is present in the form of globules is referred to as the dispersed phase, and the phase that forms the dispersion matrix in which these droplets are suspended is called the continuous phase. Emulsion droplets generally have a diameter of 0.5 μm or larger (Pal, 1994).

1.1.1 Classification of Emulsions

In principle two types of emulsions are readily distinguished, depending upon the liquid that forms the continuous phase as shown in figure 1.1.

Oil-in-water (o/w) emulsion where oil droplets are dispersed in continuous water.

Water-in-oil (w/o) emulsion where water droplets are dispersed in continuous oil.

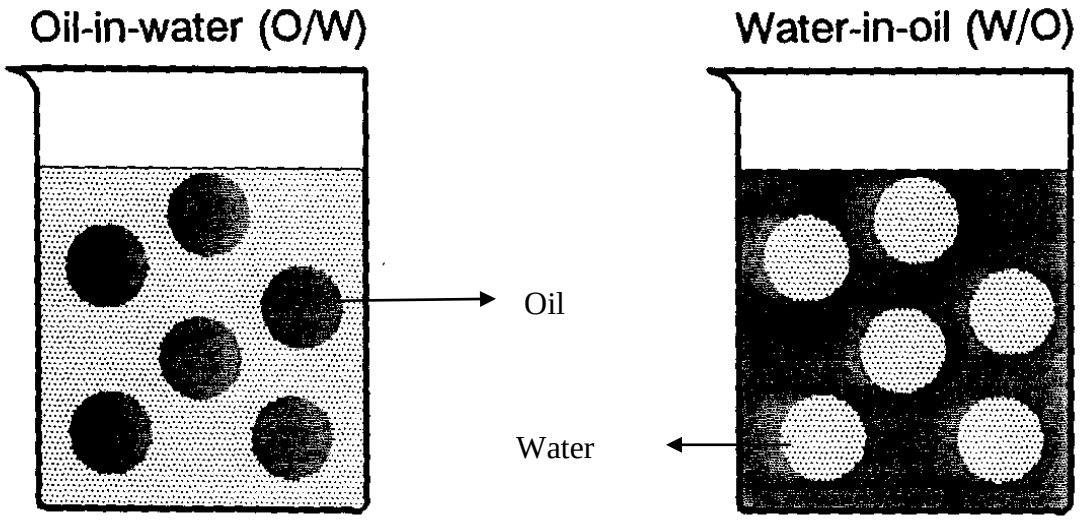

Figure1.1: The two simplest kinds of emulsions (reprinted without permission from Schramm, 1992)

In addition, an uncommon type of emulsion that is referred to as multiple emulsion consists of multiple droplets; for example, a W/O/W multiple emulsion consists of one or more small water droplets entrapped within large oil droplets, which, in turn, are suspended in a continuum of water (Schramm, 1992; Pal, 1994).

1.2 Application of Emulsions

Because of their common occurrence in daily life, emulsions are of great practical interest. Some examples of important and familiar emulsions are those occurring in foods (milk, mayonnaise, etc.), cosmetics (creams and lotions), pharmaceuticals (soluble vitamin and hormone products), and agricultural products (insecticides and herbicide emulsion formations). In industry, petroleum emulsions also are equally widespread, long-standing, and important. Emulsions may be encountered at all stages in petroleum recovery and industrial processing (drilling fluids, production, process plants, and transportation of emulsions) (Schramm, 1992; Pal, 1994).

The main components of crude oils are a range of hydrocarbons (alkanes, naphthens, and aromatic compounds) as well as phenols, carboxylic acids, and metal, and may include a significant fraction of sulfur and nitrogen compounds. These components have carbon numbers ranging from 1 (methane) though 50 or more (asphaltenes). Some of these components have the ability to form films at oil surfaces, and others are surface active, so it is not surprising that the tendency to form stable and unstable emulsions of different types varies greatly among different oils. Crude oils can exhibit a wide range of viscosities and densities as a sequence of the wide range of possible compositions, so much so that viscosity and density properties are used to distinguish light, heavy, and bituminous crude oil (Lissant, 1974; Schramm, 1992; Pal, 1994).

Petroleum emulsions may be desirable or undesirable as shown in table 1.1. An emulsion may be desirable in one stage of the oil production process but undesirable at the next stage (Schramm, 1992; Pal, 1994).

Table 1.1: Examples of emulsions in the petroleum industry (Schramm, 1992)

Occurrence	Usual type
Undesirable emulsions	
Well-head emulsions	W/O
Fuel oil emulsions (marine)	W/O or O/W
Oil sand flotation process, froth	O/W/O
Oil sand flotation process, diluted froth	W/O
Oil spill mousse emulsions	O/W
Tanker bilge emulsions	
Desirable emulsions	
Heavy oil pipeline emulsion	O/W
Oil sand flotation process slurry	O/W
Emulsion drilling fluid, oil-emulsion mud	O/W
Emulsion drilling fluid, oil based mud	W/O
Asphalt emulsion	O/W
Enhanced oil recovery in site emulsions	O/W

For example, in oil fields, an in situ emulsion that is purposely created in a reservoir as a part of an oil recovery process may change to a different, unwanted type of emulsion (water dispersed in oil) when produced at the wellhead. This emulsion may have to be broken and

reformulated as a new emulsion to make it suitable for transportation by pipeline to a refinery. Before the refining process, the new emulsion will have to be broken and water from the emulsion removed to avoid process problems caused by water. Some emulsions are made to reduce viscosity so that oil can be made to flow. Emulsions of asphalt, a semisolid variety of bitumen dispersed in water, are formulated to be both less viscous than the original asphalt and more stable so that they can be transported and handled economically in pipelines over large distances (Schramm, 1992; Pal 1994).

As mentioned earlier, understanding the flow behavior of emulsions in pipelines is important for the design and operation of oil production-gathering facilities and emulsion pipelines. While a good progress has been made on oil-water flow patterns and separated flows (annular and stratified flow of oil and water phases) and oil-in-water (O/W) emulsion flows, the pipeline flow of water-in-oil (W/O) emulsions has received less attention. Thus, more work needs to be done to enable optimal design of emulsions pipelines.

1.3 Objectives

The broad objective of this work is to study the pipe flow behaviour of water-in-oil emulsions with and without additives. The specific objectives are as follows:

1. To study the pipeline flow behavior of unstable (without additives) water-in-oil emulsions.

In the existing literature, the pipeline flow behavior of water/oil mixtures is mostly studied as separated flow (annular and stratified flow of oil and water phases). The pipeline flow of water-in-oil (W/O) emulsions has received less attention.

In this work, pipeline flow behavior of well-dispersed water-in-oil emulsions is studied. The effects of oil viscosity and oil volume fraction are determined using three oils of different viscosities.

2. To study the effect of polymer additives on the flow behavior of unstable water-in-oil emulsions.

The only work in the literature on the emulsion pipeline flow in the presence of polymer is reported by Al-Wahaibi et al. (2007), and this work is limited to separated flow (annular and stratified flow of oil and water phases). Furthermore, the polymer was added to the continuous phase. To date, no work has been published on the effect of polymer additives on the pipeline flow behavior of water-in-oil emulsions.

In this study, the influence of polymers (added to the dispersed phase) on the pipeline flow behavior of unstable water-in-oil emulsions is investigated. The effect of polymers at different concentrations was examined.

3. To investigate the influence of surfactants on the pipeline flow behavior of water-in-oil emulsions.

The effect of surfactant is of great importance when studying the pipeline flow behavior of water-in-oil emulsions due to the fact that most crude oils contain natural surfactants. The present experimental investigation was focused on acquiring a general understanding of the effect of surfactant and surfactant concentration on the pipeline flow behavior of water-in-oil emulsions.

1.4 Overview of the Research

This thesis is divided into six chapters counting this introduction. Chapter 2 gives the background on fluid flow. Chapter 3 reviews the literature on pipeline flow behavior of emulsions. The literature review on both separated and well dispersed flows is presented. In addition, chapter 3 presents a brief literature review on the effect of additives on oil-water flow.

The experimental set-up, the equipment, and experimental procedures are described in chapter 4. Chapter 5 presents the experimental results. The conclusions and some recommendations for future work are listed in chapter 6.

Chapter 2 Background

2.1 Types of Fluid Behavior

Depending upon the nature of the fluid, different behavior may be observed when the measured values of shear stress or viscosity are plotted as a function of shear rate (see figure 2.1).

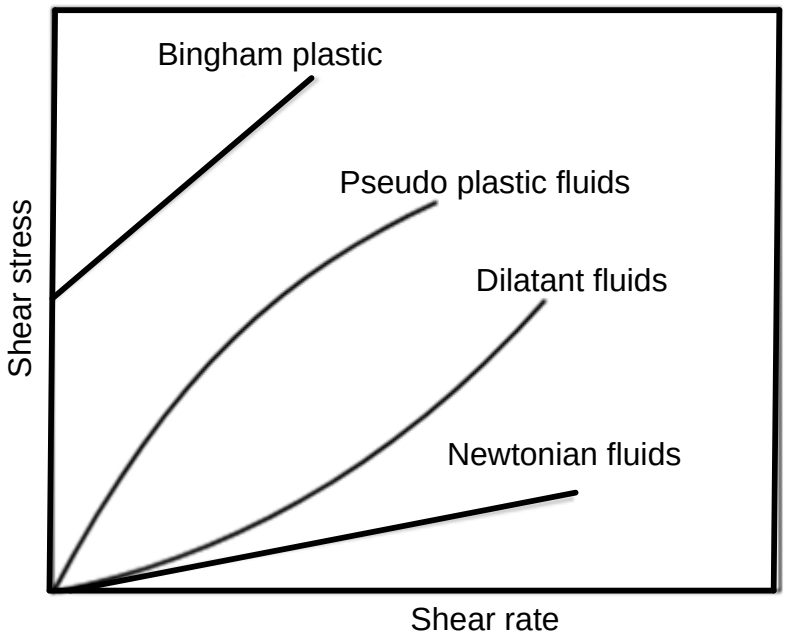

Figure 2.1: Shear stress vs. Shear rate for various fluids (reprinted without permission from Darby, 1996)

For the Newtonian fluids, the plot of shear stress vs. shear rate is a straight line through the origin or straight line with a slope of unity on a log-log plot. Newtonian fluids obey the Newton law of viscosity, given by:

$$\tau = \eta \dot{\gamma} \tag{2.1}$$

where τ is the shear stress (Pa or N/m^2 , force per unit area), $\dot{\gamma}$ is the shear rate exerted on the fluid (s^{-1}), and η is fluid viscosity ($kg/m.s\ or Pa.s$).

Some fluids behave as shear-thinning fluids and do not obey the Newton law of viscosity. The variation of the shear stress, τ , versus the shear rate, $\dot{\gamma}$, for shear thinning fluids is shown in figure 2.2. At very low or very high shear rates, a plot of τ versus $\dot{\gamma}$ is linear. The slope at very low shear rates gives the viscosity at zero shear rate (η_0). The slope of the linear portion of the curve at high shear rates gives the viscosity at infinite shear (η_∞). The viscosity is a variable at the intermediate range of shear rates and it decreases with shear rate; in this region of τ versus $\dot{\gamma}$ curve, the power law is used to correlate the shear stress and shear rate (Pal et al., 1992; Darby, 1996; Wilkes, 1999). The power law can be represented as:

$$\tau = k\dot{\gamma}^n \tag{2.2}$$

The two rheological properties are: k, the consistency coefficient, and n, the flow behavior index, which should be less than 1 for a shear-thinning fluid. In the region where the power law is valid, a log–log plot of τ versus $\dot{\gamma}$ gives a straight line with a slope of n (Pal et al., 1992).

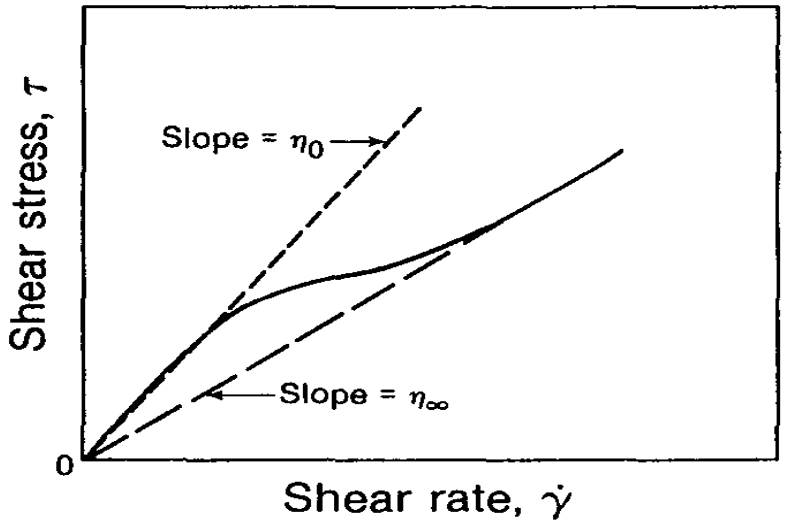

Figure 2.2: Shear diagram for a pseudoplastic fluid (reprinted without permission from Pal et al., 1991)

2.2 Flow of Fluids in Pipes

2.2.1 Flow of Newtonian Fluids

Friction losses in laminar flow of Newtonian fluids can be obtained from the Hagen-Poiseuille equation (Darby, 1996; Wilkes, 1999):

$$f = \frac{16}{N_{Re}} \tag{2.3}$$

where f is the friction factor and N_{Re} is the Reynolds number.

The friction factor (f) is defined as

$$f = \frac{2\tau_w}{\rho V^2} \tag{2.4}$$

where τ_w is the shear stress at the wall of the pipe, ρ is fluid density, and V is average velocity in the pipe. The friction factor can be also expressed in terms of the pressure gradient (ΔP/L). For steady flow, a force balance gives

$$\frac{\pi}{4} D^2 \Delta P = \pi D L \tau_w \tag{2.5}$$

$$\tau_w = \frac{D \Delta P}{4L} \tag{2.6}$$

Substituting equation (2.6) into equation (2.4) gives

$$f = \frac{D}{2\rho V^2}\left(\frac{\Delta P}{L}\right) \tag{2.7}$$

The shear at the wall $\left(\dot{\gamma}_w\right)$ for laminar flow in a pipe can be calculated from

$$\dot{\gamma}_w = -\left.\frac{du(r)}{dr}\right|_{r=\frac{D}{2}} \tag{2.8}$$

where $u(r)$ is the local fluid velocity and r is the radial position. The velocity profile for fully developed steady flow of a Newtonian fluid in laminar region is

$$u(r) = \left(\frac{\Delta P}{L}\right)\left(\frac{R^2}{4\mu}\right)\left[1 - \left(\frac{r}{R}\right)^2\right] \tag{2.9}$$

where R is pipe radius and μ is fluid viscosity.

Combining equations 2.3, 2.7, 2.8, and 2.9 gives the shear rate at the wall of the pipe:

$$\dot{\gamma}_w = \frac{8V}{D} \tag{2.10}$$

In a fully developed turbulent flow of Newtonian fluid in smooth pipes, the friction factor can be calculated by the Blasuis equation (Darby, 1996; Wilkes, 1999):

$$f = 0.079 / N_{\mathrm{Re}}^{0.25} \tag{2.11}$$

Alternatively, the friction factor can be calculated from the Prandtl-Karman equation

$$\frac{1}{\sqrt{f}} = 4.0 \log_{10}\left(N_{\mathrm{Re}}\sqrt{f}\right) - 4.0 \tag{2.12}$$

For rough pipes in turbulent flow, the Prandtl-Karman equation was modified by Colebrook to indicate the effect of the wall roughness as follows (Darby, 1996; Wilkes, 1999):

$$\frac{1}{\sqrt{f}} = -4.0 \log_{10}\left[\frac{\varepsilon/D}{3.7} + \frac{1.255}{N_{\mathrm{Re}}\sqrt{f}}\right] \tag{2.13}$$

where ε/D is the relative roughness.

2.2.2 Flow of Shear-Thinning Non-Newtonian Fluids

The shear stress (τ) and shear rate $\left(\dot{\gamma}\right)$ for shear-thinning fluids can be related by a power law model (Darby, 1996; Wilkes, 1999):

$$\tau = k\dot{\gamma}^{n} \tag{2.14}$$

where n is the flow behavior index ,n < 1 for shear-thinning fluids.

Metzner and Reed suggested a method for determining friction losses for the flow of non-Newtonian shear thinning fluids under laminar flow conditions as follows (Darby, 1996; Wilkes, 1999):

$$f = \frac{16}{N'_{\mathrm{Re}}} \tag{2.15}$$

where N'_{Re}, the Metzner-Reed modified Reynolds number, is defined as

$$N'_{\mathrm{Re}} = \frac{D^{n'} V^{2-n'} \rho}{k' (8)^{n'-1}} \tag{2.16}$$

where n' and k' are the Metzner-Reed modified power law constants for pipe flow. These constants are related to the power law constants obtained with a viscometer as following (Darby, 1996; Wilkes, 1999):

$$n' = n \tag{2.17}$$

$$k' = k\left[\frac{1+3n}{4n}\right]^n \tag{2.18}$$

The shear rate at the wall in smooth pipes for laminar flow can be calculated as follows (Darby, 1996; Wilkes, 1999):

$$\dot{\gamma}_w = \frac{8V}{D}\left[\frac{1+3n}{4n}\right] \tag{2.19}$$

For n= 1 (Newtonian fluids), equation (2.19) reduces to equation (2.10).

Dodge and Metzner extended Prandtl-Karman's work on turbulence friction factors to include the power law non-Newtonian fluid and they developed the following expression (Darby, 1996; Wilkes, 1999):

$$\frac{1}{\sqrt{f}} = \frac{4}{n'^{0.75}} \log_{10}\left(N_{\mathrm{Re}} f^{1-\frac{n'}{2}}\right) - \frac{0.4}{n'^{1.2}} \tag{2.20}$$

2.3 Viscosity of Emulsions

Emulsion viscosity, which is the ratio of the shear stress to shear rate, depends on the following factors (Pal et al., 1992):

1. The continuous phase viscosity

2. The dispersed phase volume fraction
3. The dispersed phase viscosity
4. The shear rate
5. The temperature
6. The nature and the concentration of the emulsifying agent (if there is one)

All the viscosity equations proposed in the literature are written in terms of relative viscosity (η_r) because emulsion viscosity is directly proportional to continuous phase viscosity (η_c).

The most important factor that affects emulsion viscosity is the volume fraction of the dispersed phase. Einstein showed that emulsion viscosity is a function of the dispersed phase volume fraction. The viscosity of the emulsion increases as the volume fraction of the dispersed phase increases.

$$\eta_r = \frac{\eta}{\eta_c} = 1 + 2.5\Phi \tag{2.21}$$

Here, Φ is the volume fraction of the dispersed phase.

On the basis of the analogy with the influence of variable pressure on a material that obeys Hooke's law, Richardson (1933) calculated the compressibility of an emulsion whose dispersed phase volume concentration increased from Φ to $\Phi + \Delta\Phi$. He derived from this calculation an expression for the relative viscosity of concentrated emulsions:

$$\ln \eta_r = k\Phi \tag{2.22}$$

where k is a constant that depends on the system. Richardson's equation was modified by Broughton and Squires (1938) to

$$\ln \eta_r = k_1\Phi + k_2 \tag{2.23}$$

where k_1 and k_2 are constants that depend on the system.

For concentrated emulsions, Hatschek (1911) developed the following equation:

$$\eta_r = \frac{1}{\left(1-\Phi^{1/3}\right)} \tag{2.24}$$

Eilers (1941) proposed the following empirical equation to fit his data on polydisperse bitumen emulsions:

$$\eta_r = \left[1 + \frac{1.25\Phi}{1-k\Phi}\right]^2 \tag{2.25}$$

Pal and Rhodes (1989) used an empirical approach to correlate the viscosity data of emulsion and proposed the following correlation:

$$\eta_r = \left[1 + \frac{(\Phi/\Phi^*)}{1.187-(\Phi/\Phi^*)}\right]^{2.49} \tag{2.26}$$

where Φ^* is the dispersed phase concentration at which relative viscosity becomes 100. Both the Newtonian and non-Newtonian emulsions were correlated by equation (2.26).

Figure 2.3 shows a comparison of the correlation with experimental data. As can be seen, the correlation describes the experimental data quite adequately.

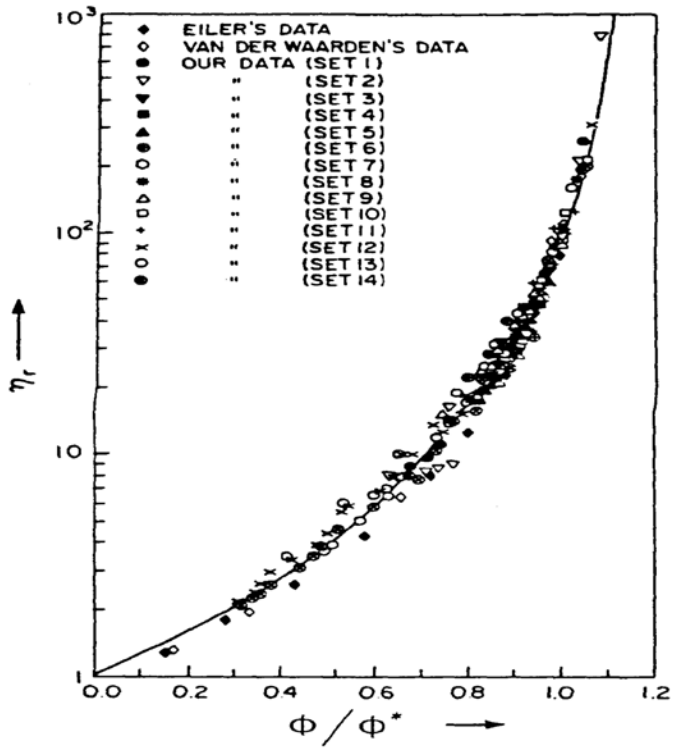

Figure 2.3: Relative viscosity vs. (Φ/Φ^*)correlation for emulsions (reprinted without permission from Pal and Rhodes, 1989)

The volume fraction normalization with Φ^* in equation (2.26) for emulsion tends to suggest that the ratio of (Φ/Φ^*) is a better way of correlating the relative viscosity, η_r , than the simple use of the volume fraction (Φ) alone. Such normalization takes into account the effect of the forces other than the hydrodynamic forces (Pal and Rhodes, 1989).

Pal (2000, 2001and 2003) has made successful efforts to develop theoretical equations to predict the viscosity of emulsions. The model proposed by Pal (2003) for the relative viscosity of emulsions takes into account a number of parameters, namely; viscosity ratio (λ), capillary number (N_{Ca}), and volume fraction of dispersed phase (Φ):

$$\eta_r = \eta_r(\lambda, N_{Ca}, \Phi) \tag{2.27}$$

Here, the capillary number is the ratio of the viscous stress to the interfacial stress, $N_{Ca} = \frac{\dot{\gamma}_c}{\sigma/R}$,

η_c is the continuous phase viscosity, σ is the interfacial tension and R is the droplet radius.

The model is given by:

$$\eta_r \left[\frac{M-P+32\eta_r}{M-P+32}\right]^{N-1.25} \left[\frac{M+P-32}{M+P-32\eta_r}\right]^{N+1.25} = \exp\left[\frac{2.5\Phi}{1-\frac{\Phi}{\Phi_m}}\right] \quad (2.28)$$

where

$$M = \sqrt{(64/N_{Ca}^2) + 1225\lambda^2 + 1232(\lambda/N_{Ca})} \quad (2.29)$$

$$P = (8/N_{Ca}) - 3\lambda \quad (2.30)$$

$$N = \frac{(22/N_{Ca})+43.75\lambda}{M} \quad (2.31)$$

Φ_m is the value of the maximum packing volume fraction of undeformed droplets that varies with the type of packing arrangement of droplets. For example, it is 0.52 for simple cubic packing of uniform spheres, it is approximately 0.64 for random close packing, and it is 0.74 for hexagonal close packing of uniform hard spheres (Pal, 2003).

In the low N_{Ca} limit, the Pal model reduces to:

$$\eta_{r,0} \left[\frac{2\,\eta_{r,0}+5\lambda}{2+5\lambda}\right]^{3/2} = \exp\left[\frac{2.5\Phi}{1-\frac{\Phi}{\Phi_m}}\right] \quad (2.32)$$

where $\eta_{r,0}$ is the limiting relative viscosity at low N_{Ca}. In the high N_{Ca} limit, the Pal model gives:

$$\eta_{r,\infty} \left[\frac{\lambda-\eta_{r,\infty}}{\lambda-1}\right]^{-2.5} = \exp\left[\frac{2.5\Phi}{1-\frac{\Phi}{\Phi_m}}\right] \quad (2.33)$$

where $\eta_{r,\infty}$ is the limiting relative viscosity at high N_{Ca}.

2.4 Turbulence and Turbulence Suppression

Turbulence plays an important role in the distribution and mixing of the phases during the pipeline flow of oil/water systems. It also affects the break-up and coalescence of the droplets.

In turbulent flow the velocity components are fluctuating with time. In figure 2.4, a typical plot is shown of the variation of axial velocity, u(t), at a given location in turbulent pipe flow. The irregular, random nature of u(t) is the distinguishing feature of turbulence.

The turbulence is generally characterized by two average parameters: turbulence intensity and scale of turbulence.

The turbulence intensity is a measure of the speed of rotation of the eddies and the energy contained in the eddies. Intensity is measured in terms of the root mean square of a fluctuating velocity (see figure 2.4) and is defined as:

$$I = \sqrt{\overline{(u')^2}} \Big/ \bar{u} \qquad (2.34)$$

where $\bar{u}$ is the time-averaged axial velocity

The second parameter is a measure of the size of the eddies and is referred to as length scale of turbulence (l). It is determined from the kinematic viscosity (ν) and the rate of energy dissipation (∈):

$$l = \left(\frac{\nu^3}{\epsilon}\right)^{\frac{1}{4}} \qquad (2.35)$$

In pipe flows the mean energy dissipation, ∈, is given:

$$\epsilon = \frac{f U_c^3}{2D} \qquad (2.36)$$

where f is the friction factor, u_c is the continuous phase velocity(taken t be the same as emulsion velocity) and D is the pipe diameter.

In turbulent flow of emulsions, the interaction between the droplets and the liquid (continuous phase) turbulence could result in turbulence suppression. The turbulence suppression could be defined as the phenomenon where local kinetic energy in two-phase flow becomes smaller than that in single phase flow at the same averaged liquid flux (Gore and Crowe, 1989).

Bin et al. (2006) studied the variations of axial mean and turbulence velocity profiles of the continuous phase caused by the introduction of a dispersed phase during vertical flows of water-in-oil and oil–in-water emulsions. They found that dispersed phase tends to flatten the turbulence intensity profile and results in a more uniform distribution of the turbulent energy over the pipe cross-section. With the increase in the mixture velocity, the turbulence intensity found to increase. They concluded that the local dispersed phase concentration, and size and dispersed phase velocity affect turbulent characteristics in oil–water flows.

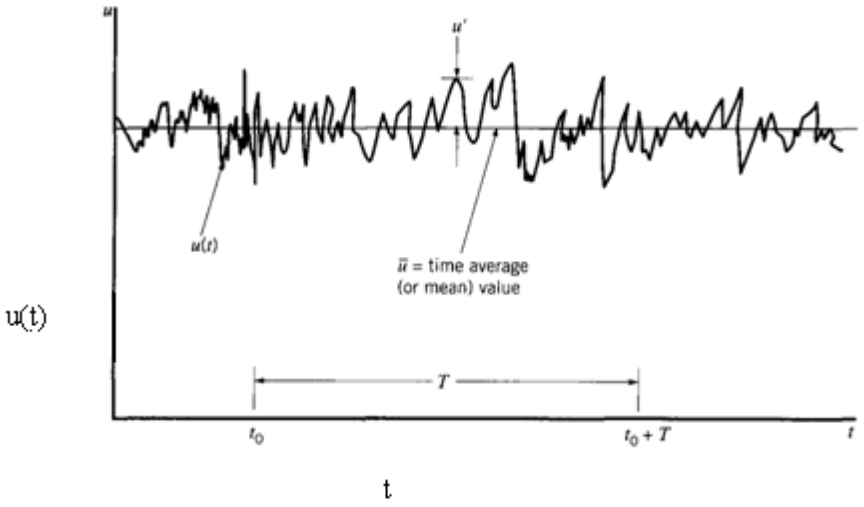

Figure 2.4: The time averaged velocity, $\bar{u}$, and fluctuating, u' , **in** turbulent flow (reprinted without permission from Darby, 1996)

Chapter 3 Literature Review on Oil/Water Pipeline Flow Behavior

Simultaneous flow of oil and water in pipelines has attracted the interest of researchers ever since it was found that under certain conditions the injection of water into a crude oil pipeline results in a significant reduction of pressure loss, thereby facilitating oil transportation. A number of studies have been reported on simultaneous flow of oil and water in pipelines (Russell et al., 1959; Charles et al., 1961; Guzhov et al., 1973; Laflin and Oglesby, 1976; Arirachakaran et al., 1989; Pal, 1993 and 2007; Nadler and Mewes, 1997; Angeli and Hewitt, 1998 and 2000; Masalova et al., 2003; Al-Wahaibi et al., 2007). However, the studies reported in the literature are mainly focused on either oil-water flow patterns and separated flows (annular and stratified flow of oil and water phases) or oil-in-water (O/W) emulsion flows. The pipeline flow of water-in-oil (W/O) emulsions has received less attention.

3.1 Oil-Water Flow Patterns

Flow regimes, also called flow patterns, describe the various shapes and spatial distributions of the deformable interface which appears during the pipeline flow of oil/water. The flow patterns depends on a number of parameters, namely the input phase ratio, the mixture velocity, the viscosity and density of both phases, the pipe geometry and its material (wetability properties), the inlet design, the interfacial tension and other interfacial properties. The flow patterns are generally defined in terms of areas on a graph with axes as two independent system parameters. The flow patterns maps are important because in each regime the flow has unique hydrodynamic characteristics.

3.1.1 Flow Pattern Identification Methods

Numerous methods have been developed for identification of liquid-liquid flow patterns, however, the most commonly used method among researcher is to visualize the flow in a transparent channel or through a transparent window on the wall of the pipe.

3.1.1.1 Visual Observation

This method is one of the most popular methods to identify flow patterns in liquid-liquid flow. Photographic or video techniques are used to view through the transparent pipe wall. However, for high mixture velocities high speed camera is necessary to see the flow patterns. One of the disadvantages of visualization method is that it is somewhat subjective and not always reliable. Also, the photographic/video techniques usually record the flow from outside the pipe, close to the pipe wall, which can be misleading especially close to the flow pattern boundaries, where the visual differences between two flow patterns can be very small.

3.1.1.2 Conductivity Probes

Nadler and Mewes (1997) used the conductivity probe in order to indentify the continuous phase of the dispersed flow. The use of local probes to give the volume fraction distribution over a pipe cross section can also indicate the different flow patterns (Trallero, 1995; Angeli and Hewitt, 1998). Angeli and Hewitt (1998) also used the conductivity probe to determine phase continuity. The probe consists of two copper needles insulated with enamel leaving only a tip free. The needles are mounted in line in the pipe normal to the direction of flow. The needles can move relative to each other while a micrometer determines their exact positioning. When an electric current is applied to the needles there will be a voltage output when the needles are immersed in water and no signal when the needles are immersed in oil.

3.1.1.3 Hot-Film Anemometer

A novel computer-based hot-film anemometer measurement technique was developed by Farrar et al. (1995) for the investigation of the local structure of two-phase flows. The technique enables the total signal to be separated into the parts corresponding to bubbles and continuous phase, from which the local volume fraction can be evaluated. The hot-film anemometry was used to investigate the structure of a vertical pipe flow of a kerosene–water mixture flow and obtained turbulence characteristics and dispersed phase sizes.

3.1.2 Flow Pattern Maps

Guzhov et al. (1973) developed a flow pattern map for horizontal pipe flow of oil and water with mixture velocity and water volume fraction as axes for oil with viscosity 21.7 m.Pa.s and density of 896 kg/m^3 at 20 ^{0}C in a 39.4 mm pipe, as shown in figure 3.1. They identified an emulsion of water/oil and oil/water, a separate flow with a thick layer of emulsion at the interface with a lower layer of water, and a separate flow with a thick layer of emulsion at the interface with a lower layer of dilute o/w emulsion. At low mixture velocities and for increasing oil fraction, the pressure drop reached a maximum at about 40% oil during the transition from water continuous dispersed patterns to separate flow with a thick layer of emulsion, while at high mixture velocities this maximum disappeared and a new one was reached at about 70– 90% oil, for water/oil and oil/water flows; at intermediate mixture velocities both maximum existed.

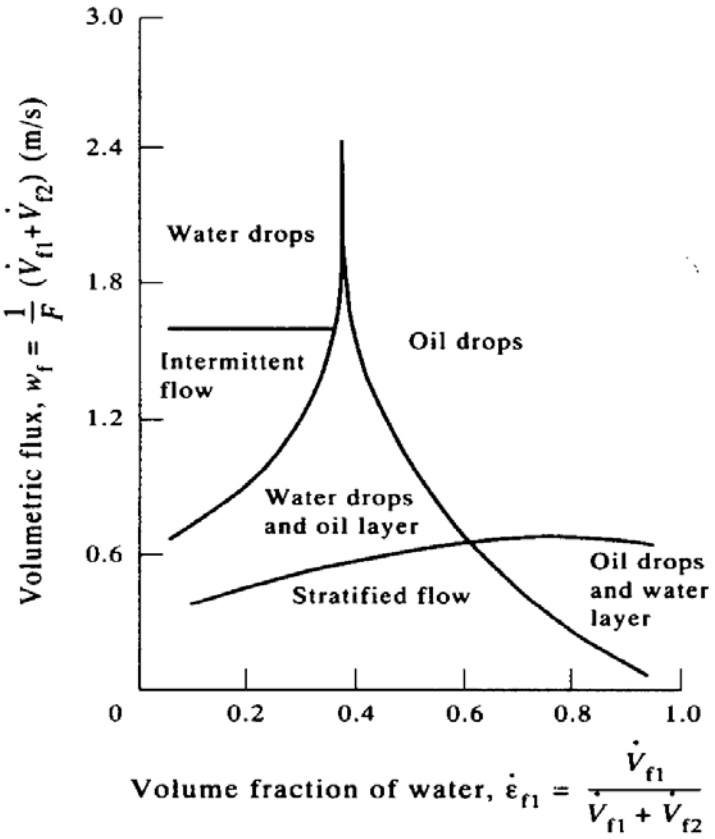

Figure 3.1: Flow pattern map for two immiscible liquids (reprinted without permission from Guzhov et al., 1973)

Oglesby (1979) conducted experiments on oil/water flow in 0.038 m diameter pipe using three oils with viscosities of 32 mPa.s, 61 mPa.s and 167 mPa.s and densities of 857 kg/m^3, 861 kg/m^3 and 868 kg/m^3 at 20 ^{0}C. Interestingly, he reported up to fourteen flow patterns and classified them as follows: stratified, semi-stratified, semi-mixed (oil dominant or water dominant), dispersed (oil dominant or water dominant), semi-dispersed (oil dominant or water dominant) and fully dispersed/homogenous mixture (oil dominant or water dominant).

Arriachakaran et al. (1989) reported different types of flow patterns in their map including the annular flow pattern by varying the total flow rate and the phase input ratio. They observed stratified flow, mixed flow, annular flow, intermediate flow, and dispersed flow, five

flow patterns of oil–water flow in two horizontal pipes with 0.038 and 0.0251 m diameter, respectively. In their flow pattern map, intermediate flow exists under very narrow flow conditions. Figure 3.2 shows their results.

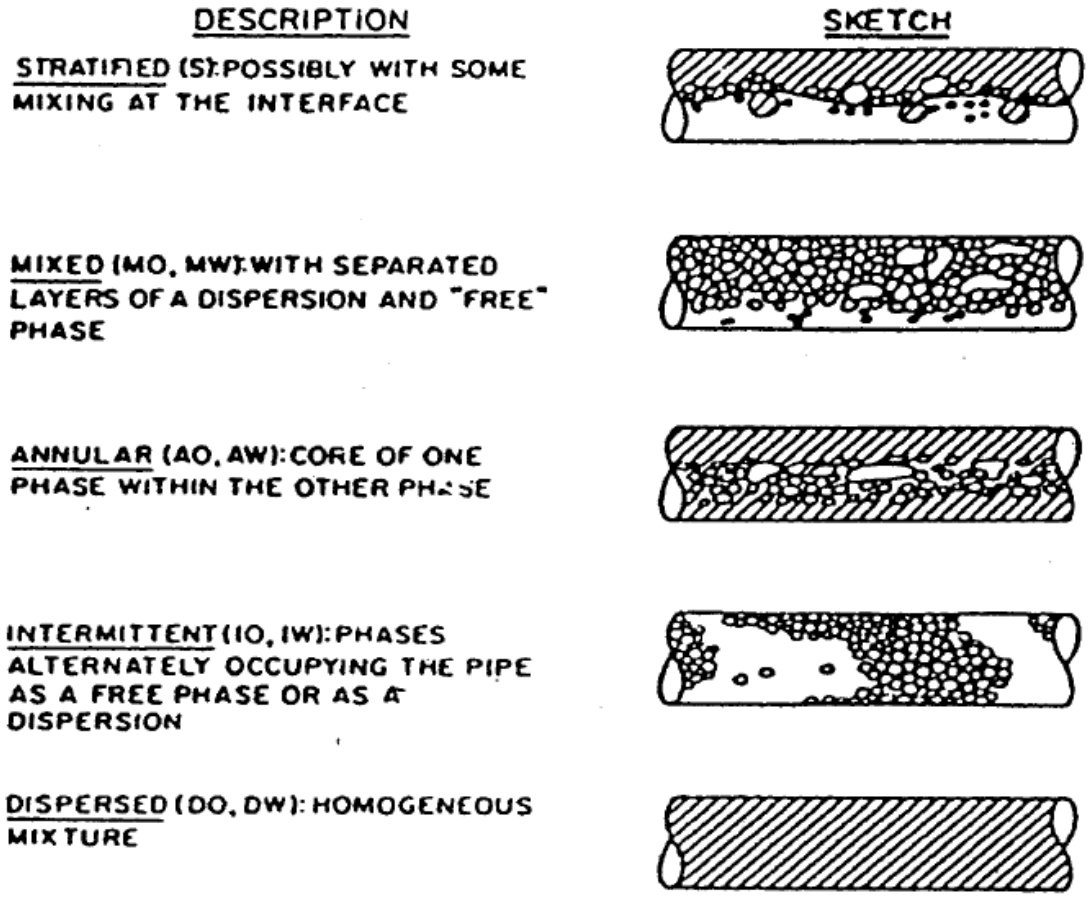

Figure 3.2: Flow patterns in oil/water flow (reprinted without permission from Arriachakaran et al., 1989)

Figures 3.3 and 3.4 show a schematic diagram of oil/water flow patterns and flow pattern map of water/oil flow proposed by Nadler and Mewes (1997). They used oil of a viscosity 20 mPa.s and density of 841 kg/m^3 in a 59 mm perspex pipe. A conductivity measurement was used to observe regions (IIIa and IIIb in figure 3.4) where continuous layers of both phases (oil and

water) occurred simultaneously, according to them, these zones appeared between region II (the oil continuous dispersed flow) and region V (the water continuous dispersed flow).

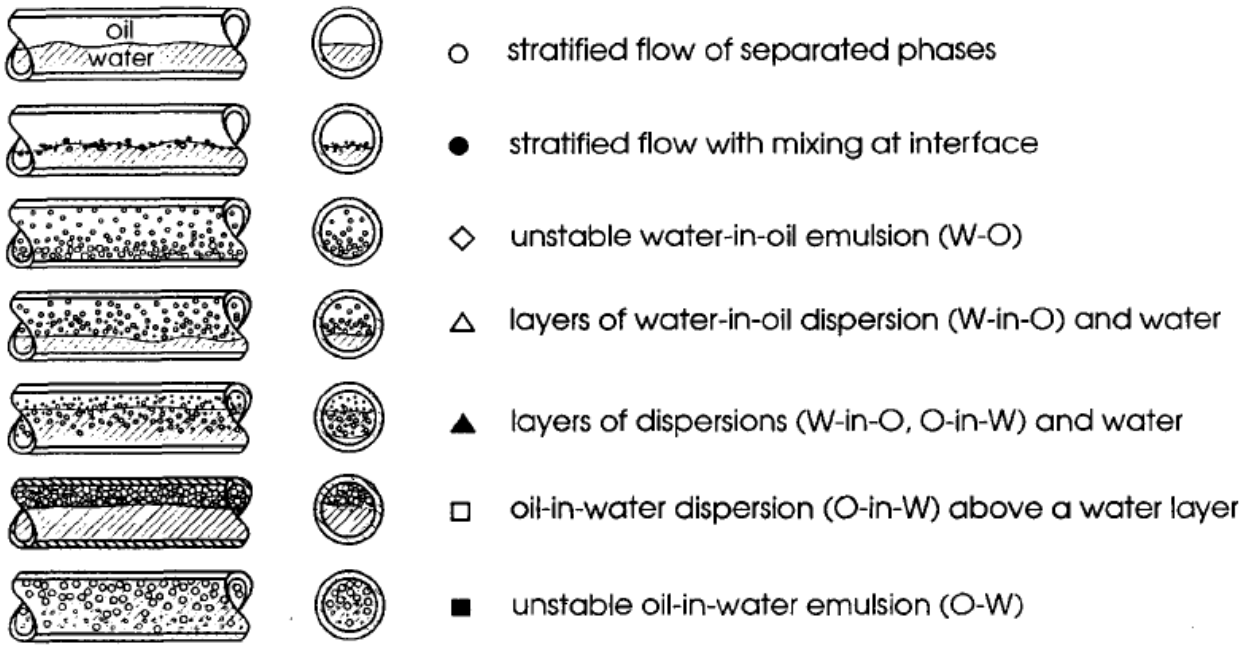

Figure 3.3: Schematic diagram of oil/water flow patterns (reprinted without permission from Nadler and Mewes, 1997)

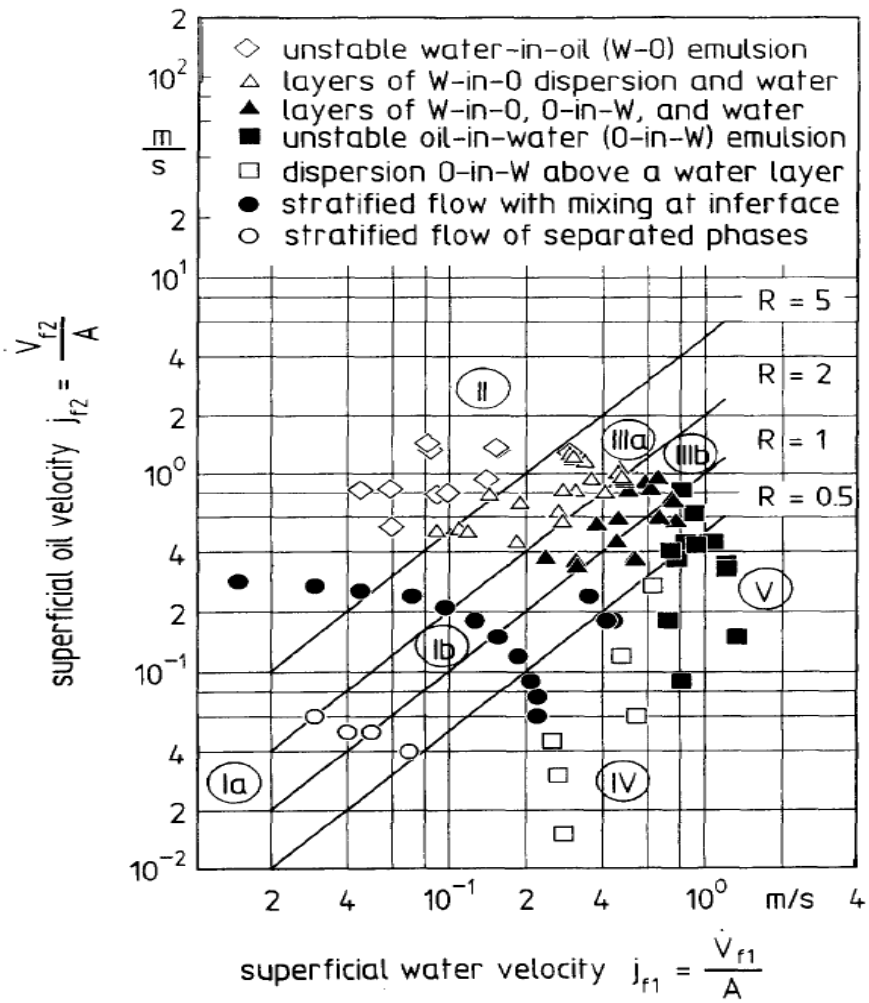

Figure 3.4: Flow pattern map of water/oil flow (reprinted without permission from Nadler and Mewes (1997)

Andreini et al. (1997) reported results on the effect of pipe material on the flow patterns during oil/water flow. Their experiments were performed on oil–water two-phase flow patterns in small horizontal pipes with inner diameters of 0.003 and 0.006 m, respectively. The ratio of oil to water viscosity ranged from about 560 to 1300 and different pipes glass, steel, copper and PVC were used. A number of flow patterns were observed and reported in terms of dispersed, intermittent and annular flow. Oil was observed, in most cases, to flow in the core of the pipe,

while water flowed around the wall perimeter. The pipe wall was found to influence the flow patterns for relatively low ratios of flow rates of water to oil (less than 0.12–0.3).

Angeli and Hewitt (2000) used 1.6 mPa.s viscosity oil and water to investigate the flow structure in co-current flow. They used two pipes with different materials: 0.0254 m stainless steel and acrylic resin pipe. They reported that over a wide range of conditions, different flow patterns were observed, ranging from stratified to fully mixed but they did not observe any annular flow. Their main finding is that the mixed flow pattern appeared in the stainless steel pipe at lower mixture velocities as compared with the acrylic pipe and under some conditions the distribution of the phases differed significantly in the stainless steel and acrylic pipes.

Yao and Gong (2004) conducted experiments on heavy oil/water flow; the oil viscosity was 614.7mPa.s and its density was 968.82 kg/m3. The flow patterns were divided into 4 categories (1) oil dominated; (2) water dominated; (3) intermittent flow region; (4) segregated flow region.

Bannwart et al. (2004) studied the flow patterns in flow of heavy crude oil with a viscosity of 488 mPa.s at 20 ^{0}C and water in vertical and horizontal pipes of diameter 0.0284 m. They visually (glass test section) characterized the flow pattern and observed annular flow pattern in both horizontal and vertical test sections. According to them, the annular flow patterns occur in heavy oil/water flow at low water input fractions.

Conan et al. (2009) reported two main flow patterns in oil/water flow. They used 8 m long transparent pipe with a 5 cm diameter. The first flow pattern was composed of two layers- a pure water layer flows under an oil-in-water dispersion layer; this flow pattern was observed when the dispersed phase fraction was low. The second flow pattern occurred at high dispersed fraction where a third layer appeared in the upper part of the pipe composed of pure oil in

addition to the two layers present at low dispersed fraction (Conan et. al., 2009). According to them the coalescence of the oil droplets created the third layer above the dense dispersion.

Although a significant progress has been made in understanding the flow patterns in oil–water flow in recent years, a review of the literature shows that there is no agreement among the researches on the classification of flow patterns in horizontal flow of two immiscible liquids. Based on a comparison of flow pattern maps proposed in the literature, a more comprehensive flow pattern classification was proposed by Trallero (1995). Most of the published data on oil/water flow patterns can fit into this classification summarized in figure 3.5. There are six flow patterns classified into two major categories:

1. Separated flow
    - Stratified flow
    - Stratified flow with mixing at the interface
2. Dispersed flow
    - Dispersion of oil-in-water and water
    - Oil-in-water emulsion
    - Dispersion of water-in-oil and oil-in-water (multiple emulsions)
    - Water-in-oil emulsion.

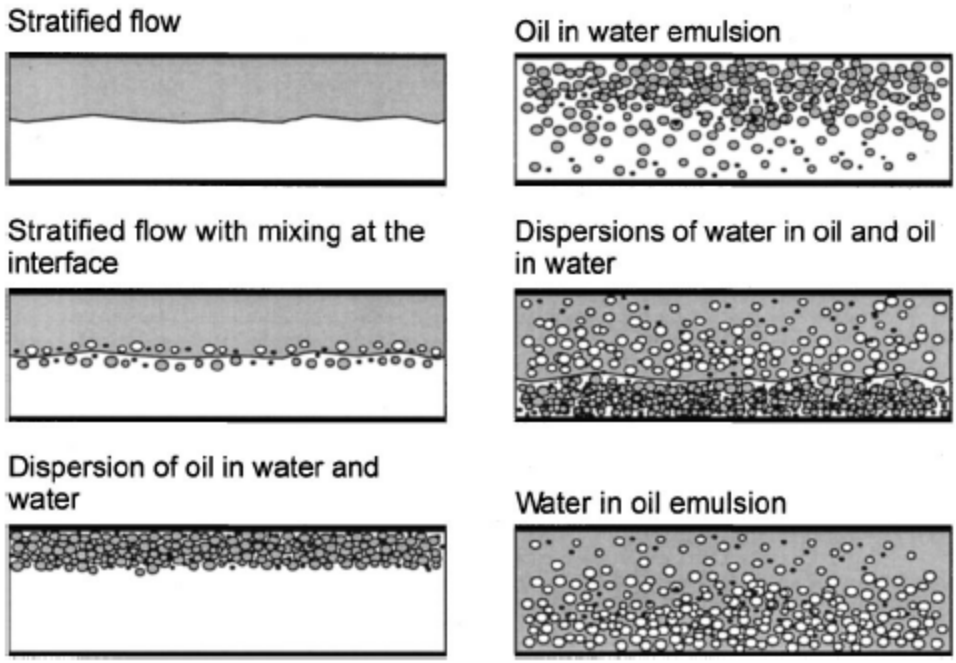

Figure 3.5: Oil-water flow patterns (reprinted without permission from Trallero, 1995)

The effect of a drag-reducing polymer on oil–water flow patterns was studied by Al-Wahaibi et al. (2007). Their results showed a strong effect of drag reducing polymer on flow patterns. The presence of a drag reducing polymer extended the region of stratified flow and delayed transition to slug flow. They identified the following five flow patterns during the oil/water flow in a 14 mm diameter pipe horizontal acrylic pipe:

1. Stratified (stratified smooth, SS, and stratified wavy, SW), where both fluids flow in layers at the top and bottom of the pipe respectively.
2. Dual continuous, where both oil and water form continuous layers at the top and bottom of the pipe respectively but drops of one phase appear into the continuum of the other phase.
3. Annular, where water forms an annular film and oil is in the pipe core.
4. Slug, where the oil flows in elongated bubbles (slugs) close to the top of the pipe.

5. Bubbly, where the oil appears in the form of elongated drops (smaller than the slugs) inside the water continuous phase.

3.2 Phase Inversion

Phase inversion of dispersion is defined as the transition of a phase from being dispersed to continuous. Phase inversion is important because during the oil/water dispersed flow, an increase in the viscosity and pressure gradient occurs at the phase inversion point, rendering its prediction to be necessary. For two immiscible liquids there is a range of volume fractions where phase inversion may occur, known as the ambivalent range. Within the ambivalent range a variety of factors, like the volume ratio of the two liquids, their density difference, viscosities, interfacial tension, temperature, etc. will determine the exact phase inversion point. Apart from interfacial tension and density differences, investigators agree that the viscosities of the phases play an important role on the phase inversion point.

Experiments were conducted by Mukherjee et al. (1981) with diesel oil of density 852 kg/m3 and viscosity of 3.65 mPa.s and water at various angles of inclination from ±30° to 90°. The phase inversion point, identified by a peak in pressure gradient, was found to occur at input water fraction between 0.4 and 0.5 for all inclination angles except −30°. For −30°, the phase inversion occurred at an input water fraction of between 0.7 and 0.8. They attributed this to the observed maximum slippage at this inclination angle.

Arirachakaran et al. (1989) gave an explanation as to how the phase inversion takes place. As shown in figure 3.6, the water droplets become more concentrated and start to coalesce. As the water droplets coalesce, they entrap the oil phase and the inversion happens. A

dramatic drop in viscosity occurs when the inversion occurs due to water becoming the continuous phase.

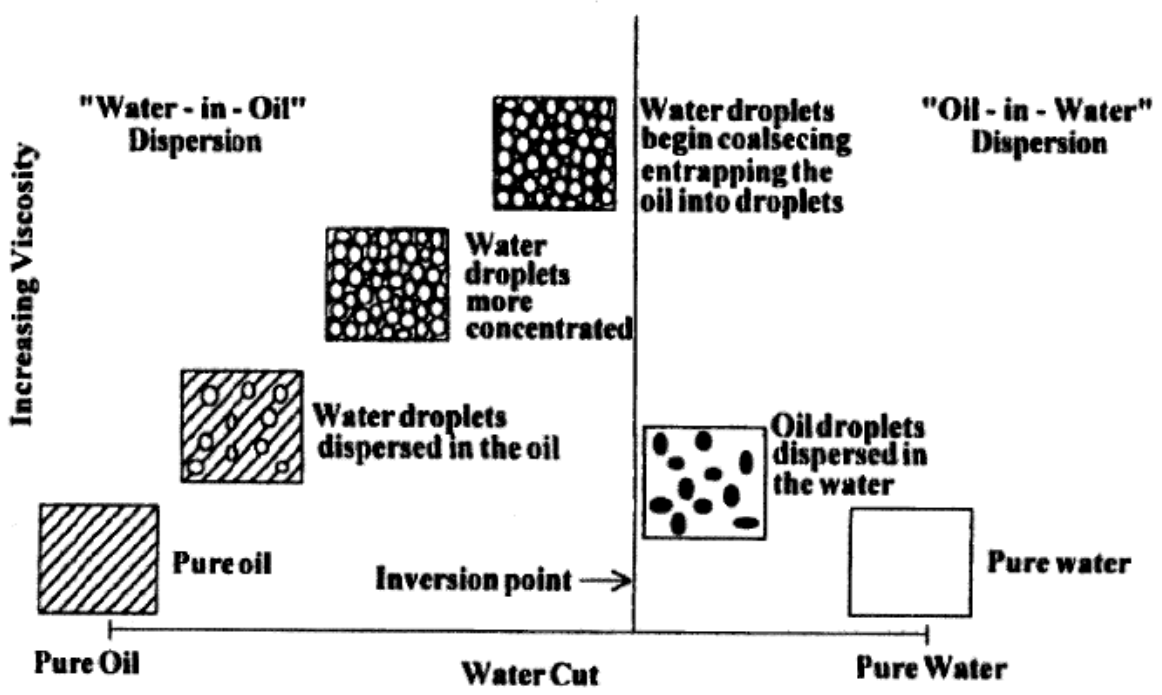

Figure 3.6: Inversion process during Oil/water dispersion flow (reprinted without permission from Arirachakaran et al., 1989)

Since coalescence is one of the phenomena that controls phase inversion, the construction material of the container in which the dispersion is held, can affect the inversion point through preferential wetting by one of the phases. The way in which the dispersion is initialized can also affect the phase inversion point. For pipe flow the inlet conditions can affect the inversion point. Furthermore, impurities in the phases may also affect the limits of the ambivalent range. Temperature has also been observed to cause the inversion from water continuous system to oil continuous system (Arirachakaran et al., 1989).

Brooks and Richmond (1991) studied the phase inversion of oil/water emulsion stabilized by non-ionic surfactant. They reported that, for given oil, phase inversion is affected by surfactant type, surfactant concentration, oil/water ratio and temperature. Mixing conditions can also be important.

Researchers agree that the viscosity of the dispersion changes at the phase inversion point (Martinez, 1988 and Pal, 1993). Guzhov et al. (1973) in pipeline flow experiments observed a peak in pressure drop at input water fraction of about 40%, which they attributed to an inversion from oil continuous system to water continuous system. Nadler and Mewes (1997) in their experiments observed two peaks in pressure gradient; the first peak was related to the transition from a water-in-oil dispersion to stratified/dispersed flow pattern and the second was related to a transition from stratified/dispersed flow pattern to an oil-in-water dispersion.

Angeli and Hewiit (1998) reported phase inversion in oil-water flow at around 37% to 40% of input water volume fraction for both steel and acrylic pipes. Their inversion point observation was made at high mixture velocity, where dispersed flow exists.

Piela et al. (2006, 2008) reported an experimental study of the phase inversion process in oil/water flow through a 0.016 m diameter acrylic pipe. They found that inversion does not happen at one particular volume fraction but is a transition occurring over a range of fractions during which complex multi dispersion structures form. According to them, during inversion the concentration of drops of the (originally) dispersed phase becomes so high, that they coalesce at certain places in the flow field and form relatively large, rather complex, morphological structures. With a further increase in concentration of the (originally) dispersed phase these morphological structures grow in size and start to form the new continuous phase in which again complex structures are present, but this time consisting of the (originally) continuous phase.

Pal (1993) also found that the formation of multiple droplets occurs during the inversion process.

3.3 Hold Up

In two phase flow, the in situ average velocities of the phases are not essentially identical. Consequently, the in situ volume fractions (hold ups) of the two phases maybe different from the input volume fractions. The hold up of a phase in a multiphase system is defined as the in situ volume fraction of that phase in the conduit. Water Hold up is a function of the cross section area occupied by water as follows:

$$H_w = \frac{A_w}{A} \tag{3.1}$$

where H_w is the in-situ hold up of water, A is the pipe cross sectional area, and A_w is the cross sectional area occupied by the water.

In oil/water flows, the following equation is valid

$$H_w + H_o = 1 \tag{3.2}$$

Here H_o is the in-situ hold up of oil.

Very few workers have presented experiential data on the hold up in oil/water flows. Mukherjee et al. (1981) correlated hold up and frictional pressure drop data to the input fraction, pipe inclination, and Reynolds number. They developed two empirical water hold up correlations for both uphill and downhill flows. According to them, the correlations are good for the range of data studied. The extrapolation of the results to greatly different pipe size, inclination angles, oil properties and mixture velocity is not recommended.

Vigneaux et al. (1988) investigated the effect of inclination, mixture velocity, and input water concentration on hold up. Kerosene and water mixture were used in 0.01 and 0.02 m

diameter pipe for mixture velocities in the range of 0.1 to 0.5 m/s. They found that at high oil fractions, the upper part is occupied by oil phase, and nearly all the water gathers at lower part of the pipe. At intermediate oil fractions, oil droplets are present across the whole pipe section. At low oil fractions, oil droplets often gather in the upper part of the pipe section and move faster than the mean flow velocity. At very high inclination, continuous oil channel may appear in the upper part of the pipe with water droplets and water films carried by it. The mean volume composition of the mixture and inclination are the only parameters affecting the water volume fraction profile.

In a study by Malhotra (1995), it was found that the in-situ water hold ups were much less than the input fractions, and the water hold up is lower for high viscosity oil. A water layer at the bottom of pipe was always present for the whole velocity range from 0.4 to 1.4 m/s. Also, increases in the mixture velocity caused the thickness of the water layer to increase for the same input oil-water ratios.

3.4 Droplet Size Distribution

The drag reduction phenomenon in pipeline flow of emulsions is likely influenced by the droplet size; droplets larger than size of turbulent eddies can suppress turbulence leading to drag reduction. The droplet size and droplet size distribution are determined by break-up and coalescence processes (Collins and Knudsen, 1970; Kubie and Gardner, 1977; Hesketh et al., 1987; Angeli and Hewitt, 1998; Brauner and Ullmann, 2002). Many theoretical and experimental studies exist in the literature for predicting the maximum droplet size, d_{max}, in dispersed flow of oil and water. However, most of these studies are based on the model of Hinze (1955):

$$\frac{(d_{max})}{D} = 0.55\left(\frac{\rho_c u_c^2 D}{\sigma}\right)^{-0.6} f^{-0.4} \tag{3.3}$$

where, ρ_c is the continuous phase density, U_C is the continuous phase velocity, σ is the interfacial tension. D is the pipe diameter and f is the friction factor.

Ward and Knudsen (1967) earlier reported a study where they investigated the distribution of oil drops in water with fractions up to 47% during downward vertical flow. The dispersions were formed in stirred vessels before entering the test section. They used a photographic technique to measure the Sauter mean drop diameter (d_{32}) and found that d_{32} increased with increasing dispersed phase fraction. Also, d_{32} initially increased and then decreased with increasing velocity.

Swartz and Kessler (1970) also studied the break-up of a single droplet in oil/water turbulent pipe flow. They considered the initial droplet diameter, and the distance the droplet traveled in the pipe as the most significant parameters that can affect droplet beak-up process. They correlated the increase in the interfacial area due to droplet beak-up with the above parameters using regression analysis.

Collins and Knudsen (1970) used photography to investigate the effect of pipe turbulence on drops formed by injecting an oil phase at low concentrations (0.6–10%) into the flowing water. The initial distribution formed at the injection nozzle was modified by turbulence further down the pipe. They concluded that increasing the dispersed phase viscosity delayed droplet deformation and break up. Also breakage occurred at a greater frequency near the pipe wall than at the pipe center.

Kubie and Gardner (1977) studied the role of injector type on the droplet size in horizontal pipes and found that the type of injector had little effect on drop size distribution. Photographic technique was used to obtain the droplet size distributions. The maximum droplet size d_{max} was found to decrease with an increase in the continuous phase velocity. They also

suggested that when the drops have sizes larger than the length scale of the energy containing eddies, the fluctuating turbulent velocity should be used in the calculation of the maximum drop size. They proposed the following model for $d_{max:}$

$$\left[\frac{d_{max}\,\rho_c\,U_c^2}{\sigma}\right]\left[f\frac{d_{max}}{D}\right]^{2/3} = 0.369 \tag{3.4}$$

This model gives different values of the maximum drop size for different pipe diameter and continuous phases.

Hesketh et al. (1987) proposed the following equation for the maximum drop size

$$d_{max} = 1.38(We_{cr})^{0.6}\left(\frac{\sigma^{0.6}}{\rho_c^{0.5}\mu_c{}^{0.1}}\right)\left(\frac{\rho_c}{\rho_d}\right)^{0.2}\left(\frac{D^{0.5}}{U^{1.1}}\right) \tag{3.5}$$

where We_{cr} is the critical Weber number, $We_{cr} = \frac{\tau d_{max}\left(\frac{\rho_d}{\rho_c}\right)^{1/3}}{\sigma}$, τ is the stress on the droplet due to turbulent fluctuating eddies in the continuous phase, μ_c is the viscosity of the continuous phase and U is the average velocity.

Angeli (2001) reported some interesting results on the effect of pipe material on droplet size distribution. A video recorder coupled with an endoscope attached to a camera was used to study the droplet sizes at different locations inside the pipe. The d_{max} was found to generally decrease with increasing continuous phase velocity. Also, water drops in oil were smaller than oil drops in water. Smaller drops were formed in the steel test section when compared with acrylic test section under the same flow conditions. The results on maximum droplet diameters were represented satisfactorily by the following equation which takes into account the effects of continuous phase velocity, the nature of the continuous phase, and the pipe material through the friction factor:

$$d_{max}\,U_c^{1.8} = 4.2 * 10^{-2} * f^{-3.13} \tag{3.6}$$

The experimental results were compared with the Kubie and Gardner model (equation (3.4)). The Kubie and Gardner model over-predicted the maximum droplet diameters.

Brauner and Ullmann (2002) proposed a new correlation for predicting the maximum drop diameter (d_{max}). The model is given as:

$$d_{max} = 2.22 C_H D \left(\frac{\rho_c U_c^2 D}{\sigma}\right)^{-0.6} \left(\frac{\rho_m}{\rho_c (1-\Phi_d)} f\right)^{-0.4} \left(\frac{\Phi_d}{1-\Phi_d}\right)^{0.6} \quad (3.7)$$

where C_H is a tunable constant, Φ_d is the dispersed phase concentration, ρ_m is the mixture density, and ρ_c is the continuous phase density.

Razzaque et al. (2003) published the only study on bubble collision phenomenon in two-phase flow in horizontal pipes. Their experimental study was performed in a 25.4 mm copper tube to evaluate the development of the bubble size distribution in horizontal turbulent flow of air–water system. A photographic technique with high-speed camera was used to measure the bubble size. The effects of average water velocity, air volume fraction and injector diameter on the initial bubble size distribution and its evolution along the length of the pipe were studied. According to the authors it is the coalescence, not breakage, that plays the dominant role. The air volume fraction had a significant effect on the bubble size only when the water velocity was small. The injector size had a minor effect on the development of bubble size distribution through its role in generating the initial bubbles.

Sanders et al. (2004) studied the effects of average water velocity, air volume fraction, and nozzle diameter on the evolution of bubble size distribution in air- water system flowing in a 100 mm horizontal pipeline. A high-speed digital camera was used to measure the bubble size distributions. The diameter of the injection nozzle did not affect the equilibrium bubble size

distribution. The equilibrium bubble size distribution was a function of the average water velocity.

Lovick and Angeli (2004) studied the droplet size and distribution in horizontal non-homogeneous oil/water flow. The flow consisted of separate water and oil layers with oil/water dispersion in the middle. They found that the drop size decreased with increasing distance from the interface between separate layer and dispersion. They also found a slight effect of layer velocity on the maximum droplet size.

3.5 Pressure Drop in Pipeline Flow of Separated Water and Oil

Russell et al. (1959) reported a reduction in pressure gradient in oil pipelines when water was introduced to the system and they concluded that the flow rates and the viscosities of the liquids are the main influencing parameters on pressure gradient in oil-water pipeline flow.

Charles et al. (1961) reported a study on the flow of oil-water mixtures in a horizontal 2.6 cm pipe. The density of oil and water was equal. Three oils having viscosities of 6.29, 16.8 and 65 mPa.s at 77 ℃ were used. The input water concentrations varied from 10 to 90%. The flow patterns for increasing water fractions observed were: concentric-oil-in water, oil-slugs-in-water, oil-bubbles-in-water and oil-drops-in-water. They concluded that the flow patterns were observed to be independent of the oil viscosity, for the equal density mixture. They also observed that the pressure gradient fell when water was added to the laminar oil stream up to a certain limit, beyond which adding water increased the pressure gradient (even above the gradient observed for single oil phase).

Charles (1961) compared laboratory data of crude oil and water flow in a 2.6 cm inner diameter pipe with data obtained from a 6.2 cm inner diameter field pipe. The average viscosity

of the oil used was approximately 700 mPa.s and the average specific gravity was 0.95. The pressure drop was independent of the oil flow rate and the maximum pressure drop occurred at 40-60% water concentration.

Guzhov et al. (1973) studied the flow of water-oil mixtures in a 4 cm pipe. They used oil of viscosity 21.7 mPa.s and tap water. The mixture velocity was varied from 0.2 to 1.7 m/s with the input water volume fraction varying from 0 to 100%. They observed a peak pressure gradient at 60% water concentration and explained it in terms of phase inversion of oil continuous to water continuous emulsion.

Oglesby (1979) performed experiments on oil/water flow in a 0.038 m diameter pipe using three oils of viscosities 32 mPa.s, 61 mPa.s and 167 mPa.s and densities of 857 kg/m^3, 861 kg/m^3 and 868 kg/m^3, respectively at 20 ℃. The velocity was varied from 0.6m/s to 3.6 m/s. A drastic change in the pressure drop was observed at the inversion point and the magnitude of this change increased with the increase in mixture velocity and oil viscosity. The input water fraction at the inversion point decreased as the oil viscosity increased. For the oil-in-water dispersion, the oil viscosity seemed to have a relatively small effect on the overall pressure loss.

Malinowsky (1975) conducted experiments on oil/water horizontal flow through a 3.8 cm transparent pipe. The oil used had a viscosity of 4 mPa.s. The pressure gradient was observed to be a function of the input water fraction and it increased dramatically near the inversion point of the oil/water dispersion. The effective viscosity of the oil-water mixture was largely dependent on the viscosity of the external phase, thus resulting in a jump at the phase inversion point. It was also reported that the area of contact with the pipe was not a direct function of the input concentrations due to the formation of dispersion. Also there was little difference between the input and the in-situ concentrations for both segregated and dispersed flows.

Laflin and Oglesby (1976) studied the flow of oil-water using oil of 4.9 mPa.s viscosity. The input water concentration was in the range of 30 to 80% and liquid velocities varied from 0.5 to 1.5 m/s. The measured pressure drop was used to back calculate the effective viscosity for the oil-water system. They concluded that the maximum effective viscosity occurred at the phase inversion point and that the effective viscosity at the inversion point increased as the total mixture velocity increased. The effective viscosity was also found to be proportional to the velocity of the mixture.

Arirachakaran (1983) used two oils of viscosities 176 and 1445 mPa.s at 27 ℃ in his experiments with oil-water flow in a horizontal pipe of inner diameter 2.54 cm and length 6 m. The pressure drop was found to be a function of the mixture velocity, input water fraction, oil viscosity and the temperature. When water was the continuous phase, temperature and oil viscosity had small effects on the pressure drop whereas when oil was the continuous phase, the temperature influenced the pressure drop due to the changes in the physical properties of the mixture especially the viscosity of the oil. A significant change in the pressure drop was observed at the phase inversion point. Mixture pressure drop was the same as the single-phase water pressure drop under the same flowing conditions and that slippage between phases played an important role when oil was the external phase. An increase in the mixture velocity increased the pressure drop. The apparent viscosity decreased with an increase in temperature; the viscosity of the mixture approached the viscosity of the external phase and it reached the maximum value at the inversion point.

Arirachakaran et al. (1989) developed a pressure gradient model for stratified flow based on experimental results of water/oil flow in 2.54 and 3.87 cm pipes. They carried out experiments over a wide range of flow rates, temperatures, water concentrations and oil

viscosities and concluded that the pressure gradient is strongly affected by the continuous phase type (water or oil).

Nadler and Mewes (1997) conducted experiments on the flow of oil/water emulsions in a pipe with an inner diameter of 59 mm. They used oils of viscosities 22, 27 and 35 mPa.s. Under the flow conditions investigated, the maximum pressure drops were observed in the region of phase inversion which occurred at input water fractions between 10 and 20%. The reduction in pressure drop in the flow of oil-water emulsions was caused by a continuous water layer flowing at the pipe wall. According to them (Nadler and Mewes, 1997) this water layer encapsulate parts of the viscous oil phase so that viscous dissipation is decreased.

Angeli and Hewitt (1998) also studied the pipeline behavior of water/oil emulsions; they used oil of viscosity 1.6 mPa.s and density 801 kg/m^3. The pipeline test sections were made from stainless steel and acrylic resin. Emulsions exhibited drag reduction behavior in both pipes. However, the degree of drag reduction was strongly influenced by the pipe material. The acrylic resin pipe exhibited a higher degree of drag reduction.

Bensakhria et al. (2004) studied flow of heavy oil (viscosity of 4.74 Pa.s) and water in a horizontal pipeline of 12 m length and 0.025 m inner diameter pipe. They reported a maximum of 90% reduction in pressure drop during annular flow. They also showed that density difference is responsible for particular evolution of the pressure drop with the flow rate.

Lovick and Angeli (2004) performed experiments on water-oil flow in a 0.038 m diameter steel less stain pipe at mixture velocities raging from 0.8 to 3 m/s. The oil used was petroleum oil with a viscosity of 6 mPa.s and density of 828 kg/m^3 at 25 ℃. The input oil volume fraction was varied from 10% to 90%. They found that the pressure gradient during oil/water flow was lower than that of single phase oil at the same mixture velocity. However, at the lowest

mixture velocity, they reported only little variation of the pressure gradient with volume fraction. This minimum in pressure gradient was observed only at a volume fraction where oil occupied either all or a large part of the pipe and also had a high concentration of dispersed water.

Chakrabarti et al. (2005) investigated the flow of kerosene-water mixture through a 0.025m diameter horizontal pipe. The velocity was varied from 0.03 to 2 m/s. They found that an increase in the measured pressure drop as a result of an increase in the superficial velocity. They attributed this to the fact that when the water flow rate is increased, a larger fraction of the pipe wall is covered by a rough interface formed between the water and oil. The presence of a rough surface leads to an increased friction factor and pressure gradient.

Sotgia et al. (2008) conducted experiments on flow of water and mineral oil in horizontal pipe of diameters ranging from 0.021 to 0.040 m. The oil used had a viscosity of 678 mPa.s and density of 886.3 kg/m^3 at 20 ℃. They found that the pressure drop reduction is a function of the water volume fraction.

3.6 Pressure Drop in Pipeline Flow of Unstable Emulsions

3.6.1 Water-in-Oil Emulsions

Pal (1993) studied the pipeline flow behavior (laminar and turbulent) of unstable (without any added surfactant) water-in-oil emulsions. The oil used had a viscosity of 2.41 mPa.s at 25 ℃ and a density of 780 kg/m^3. The measured pressure loss data were used to calculate the effective viscosities from the Hagen-Poiseuille equation (equation 2.3) in laminar region. The emulsion viscosity was found to increase with an increase in the dispersed phase concentration. At a water concentration of 41.7% volume, a sudden jump in the emulsion viscosity occurred. The reason for this was given to be the inversion of water-in-oil emulsion to oil-in-water emulsion. With

further increase in water concentration, the viscosity decreased due to dilution effect. The relative viscosities calculated from laminar data and those obtained from turbulent data using Blasius equation (equation 2.11) were compared. The relative viscosity obtained from the turbulent data was a function of the dispersed phase concentration, the flow rate (Reynolds number), and pipe diameter whereas, the relative viscosities obtained from laminar data varied with dispersed phase concentration only and agreed with the Einstein equation (equation 2.21).

In the turbulent flow region unstable w/o emulsions exhibited strong drag reduction characteristics and the measured friction factor fell well below the Blasius equation (equation 2.11). Also, there was clearly some diameter dependence present; the smaller diameter pipe gave larger drag reduction when comparison was made at the same Reynolds number. Furthermore, drag reduction increased substantially with the increase in the dispersed phase (water) concentration. The degree of drag reduction in w/o emulsions was found to be higher than that in the case of o/w emulsions at nearly the same dispersed phase concentration as shown in figure 3.7.

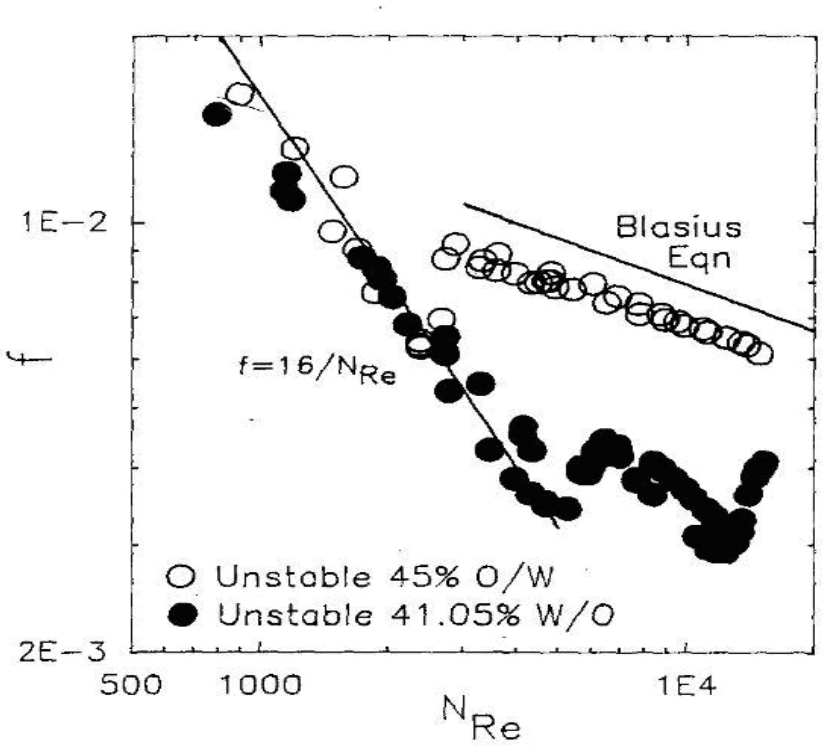

Figure 3.7: Friction factor vs. Reynolds number for unstable w/o and o/w emulsions (reprinted without permission from Pal, 1993)

Pal (1993, 2007) has proposed two mechanisms for drag reduction observed in the pipeline flow of emulsions. According to one mechanism (Pal, 1993), drag reduction in emulsions occurs due to turbulence modification of the continuous-phase liquid when droplets are introduced. According to the other mechanism (Pal, 2007), emulsions exhibit drag reduction because of a significant decrease in emulsion viscosity when the flow regime is changed from laminar to turbulent. In turbulent flow, viscosity reduction occurs because of stretching and elongation of droplets.

Masalova et al. (2003) studied the pipeline flow behavior of high concentrated w/o emulsions. The concentration of the water dispersed phase was 90% volume. Two pipes with internal diameters of 64 mm, and 89 mm were used. The rheological data were measured using a rotational viscometer. They measured wall shear stress, $\tau_w = \Delta P.D/4L$, and apparent shear rate at

the wall, $32Q/\pi D^3$, where ΔP is the pressure drop, Q the volumetric flow rate, D is the pipe diameter, and L the pipe length. They found that the data for pipe with D = 64 mm fell systemically lower than the data for 89 mm pipe diameter. The explanation of this observation was given in terms of the wall slip. They recommended that the effect of wall slip must be considered for small diameter pipes, although for pipes of large diameter wall slip can be neglected.

This work provides new experimental results on the pipeline flow behavior of unstable water-in-oil emulsions prepared from three oils of different viscosities and contributes to the current understanding of the pipeline flow behavior of unstable water-in-oil emulsions.

3.6.2 Oil-in-Water Emulsions

A fairly comprehensive literature review of the pipe line flow behavior of oil-in-water emulsions can be found in the publications of Pal (Pal, 1987; Pal, 1993).

Baron et al. (1953) studied experimentally the turbulent flow behavior of unstable (without any additives) oil-in-water emulsions in pipelines. They applied the usual single phase flow equations using averaged fluid properties considering the emulsion to be pseudo-homogenous. Carbon tetrachloride and tap water were used for the preparation of emulsions. The effective viscosities of emulsions were calculated from the single-phase friction factor vs. Reynolds number relation using the experimental data of pressure loss vs. flow rate. The effective viscosities calculated in this manner were compared with the values predicted from the empirical viscosity equation proposed by Eilers (1941) (equation 2.25) and the agreement was found to be good.

Cengel et al. (1962) investigated the laminar and turbulent flow behaviors of unstable o/w emulsions. The effective viscosities were calculated from the measured pressure loss data using the single phase flow equations: Hagen-Poiseuille equation in laminar flow, and Blasius equations in turbulent flow. They found that the viscosities calculated from vertical turbulent flow data were lower than the corresponding laminar viscosities, and the emulsions exhibited drag reduction behavior in turbulent region. This drag reduction increased as the dispersed phase (oil) concentration increased.

Faruqui and Knudsen (1962) studied the vertical turbulent flow of unstable o/w emulsions. They used the velocity profile data and pressure loss data to calculate the effective viscosities of emulsions from the logarithmic velocity equation:

$$u^+ = 5.75\log_{10}\left(y^+\eta\right) + 5.5 - 5.75\log_{10}\eta \tag{3.8}$$

where u^+ is the dimensionless velocity, y^+ is the dimensionless distance, and η is the emulsion viscosity. The viscosities obtained from the intercept of u^+ vs. $y^+\eta$ (on a semi-log scale) were found to be independent of the flow rate.

Ward and Knudsen (1967) measured the velocity profile, pressure losses, and the droplet size distributions in vertical turbulent flow of unstable o/w emulsions. They used three different types of oil: shellsolv that has viscosity of 0.95 mPa.s at 23.3 ℃, light oil that has viscosity of 13 mPa.s at 23.3℃, and heavy oil with a viscosity of 162 mPa.s at 23.3℃. The effective viscosities of the emulsions were obtained from the logarithm velocity equation (equation 3.8) and the Blasius friction factor equation (equation 2.11). It was found that the heavy oil effective viscosity obtained from the Blasius friction factor equation (equation 2.11) was independent of the oil concentration and showed a tendency to decrease at high concentrations while the effective

viscosity of other emulsions increased with the increase of oil concentration. Also, the effective viscosities of heavy oil emulsions calculated from the logarithmic velocity equation (equation 3.8) were found to vary significantly with the flow rate. This strange behavior of the heavy oil in water emulsions was thought to be due to the droplet size effect. According to the droplet size information of the emulsions, the droplet sizes of the heavy oil emulsions were larger than those of the other emulsions (shellsolv and light oil emulsions).

Pal (1987) studied the laminar and turbulent flow behaviors for unstable o/w emulsions. Horizontal hydraulically smooth pipes with three different internal diameters of 8.9 mm, 12.6 mm, and 15.8 mm were used. For unstable o/w emulsions, the effective viscosities calculated from the turbulent flow using Blasius equation were found to be lower than those obtained in the laminar region using the Hagen-Poiseuille equation. This means that the emulsions exhibited drag reduction behavior in turbulent flow. The difference in viscosities increased with an increase in the dispersed phase (oil) concentration.

3.7 Pressure Drop in Pipeline Flow of Surfactant-Stabilized Emulsions

The effect of surfactant is of importance when studying the pipeline flow behavior of water/oil emulsions due to the fact that most crude oils contain natural surfactants. Also, the transport of heavy crude oil through pipelines requires the formation of stable emulsions in order to reduce viscosity. Emulsions of asphalt, a semisolid variety of bitumen dispersed in water, are formulated to be both less viscous than the original asphalt and more stable so that they can be transported and handled economically in pipelines over large distances.

Oil-water emulsions are unstable thermodynamically. As the oil droplets are hydrophobic they tend to separate from the water layers. In order to form a stable emulsion a surfactant must

be introduced. In the making and stabilization of the oil/water emulsions the surfactant reduces the interfacial tension and establishes the repulsive forces among the oil droplets. This makes the formation of smaller droplets easier. The surfactant molecules in the water phase travel to interface and form a surfactant interfacial film. Note that the increase of surfactant concentration in the aqueous phase will decrease the interfacial tension until the surfactant concentration reaches a critical micelle concentration (CMC). The overload surfactant molecules above the CMC form micelles of diameter of 5nm to 40 nm. Micelles are non-surface active material but can provide the emulsion with surfactant molecules so that micelles are an important source of stock surface active substance (Schramm, 1992).

Experiments on the flow of Triton X-14 surfactant stabilized emulsions were conducted by Rose and Marsden (1970). The oil used was Prudhoe Bay oil of viscosity 80 mPa.s at 65°C and the aqueous phase used was brine to make emulsions containing 25-60% volume oil. The emulsions were tested in 0.635 cm copper tubing. The outcome of this study was to be used in the design of the trans-Alaska pipeline. Their main findings were; the emulsion viscosity and flow resistance increased exponentially with oil percentage in the emulsion (oil volume fraction) and the emulsions had much lower viscosities than the oil itself.

Zakin et al. (1979) investigated the laminar and turbulent flow behaviors of surfactant stabilized o/w emulsions. Various oil concentrations (from 50 to 75% wt.) were investigated. The rhelogical data indicated that the emulsions were non-Newtonian and in laminar region, the data followed the non-Newtonian relation:

$$f = \frac{16}{N'_{\mathrm{Re}}} \tag{3.9}$$

where f is the friction factor, and N'_{Re} is a generalized Reynolds number. The drag reduction behavior was observed in the turbulent region, and it was thought to be due to viscoelastic effects in emulsions. Individual droplets or a microstructure formed between the droplets can introduce viscoelastic effects in emulsions.

Pal (1993) also investigated the influence of surfactant on the pipeline flow behavior of water-in-oil emulsions. The oil used had a viscosity of 2.41 mPa.s at 25 ℃ and a density of 780 kg/m^3. The surfactant-stabilized w/o emulsions were Newtonian up to a water concentration of 25.85 % volume. With further increase in water concentration, inversion of w/o to o/w emulsion occurred. From the friction factor vs. Reynolds number plots, shown in figure 3.8, it can be seen that the surfactant stabilized w/o emulsions exhibit little or no drag reduction. In the laminar region the friction factor data from various diameter pipes follow the commonly used equation for single phase flow (Hagen-Poiseuille equation). Also, in turbulent region the friction data follow the Blasius equation well. Therefore, the pipeline flow behavior of the surfactant stabilized w/o emulsions could be predicted reasonably well using the usual equations of single phase flow (Pal 1993).

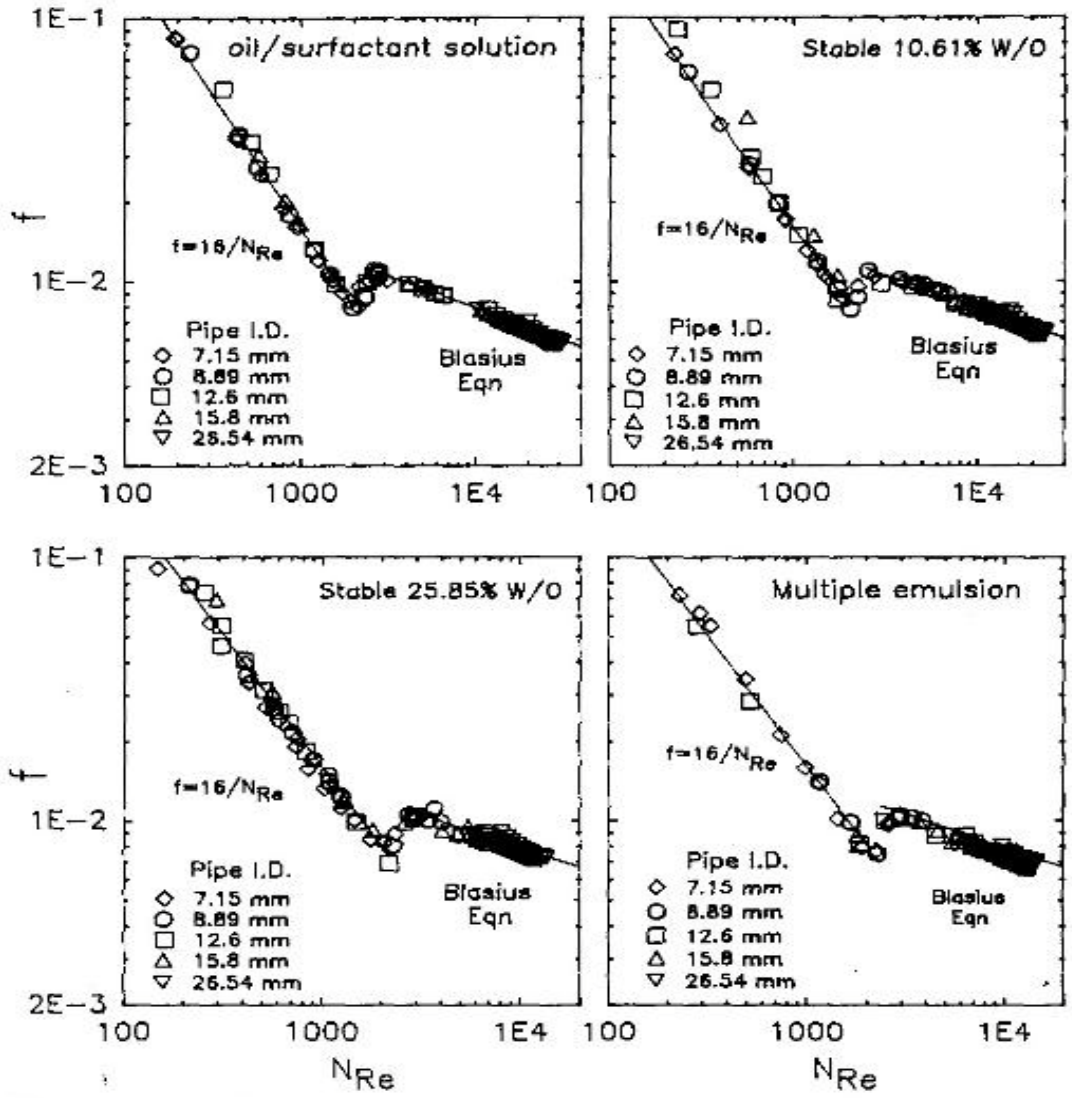

Figure 3.8: Friction factor vs. Reynolds number for surfactant-stabilized emulsion (reprinted without permission from Pal, 1993)

For the stable o/w emulsions, Pal (1993) used a nonionic surfactant named Triton x-100. Its concentration in water was kept at 1 % wt. The dispersed phase (oil) concentration was varied from 0 to 72.21% vol. In addition to the pipeline data the rheological data were measured using a coaxial cylinder viscometer. The rheological data indicated that the emulsions were Newtonian up to an oil concentration of 55.14 % volume. The higher concentrated emulsions were non-Newtonian shear thinning: the viscosity decreased with an increase in the shear stress. At an oil

concentration of 72.21 % vol., emulsion showed the presence of a yield stress. The laminar pipeline data for the stable emulsions followed the Hagen-Poiseuille equation. In turbulent region, the friction factor data for stable o/w emulsions followed the Blasius equation indicating the absence of significant drag reduction.

This work extends and expands the current understanding of the effect of surfactant concentration on the pipeline flow of emulsions, as new experimental data on the effects of surfactant and surfactant concentration on emulsion pipeline flow behavior are obtained.

3.8 Pressure Drop in the Pipeline Flow of Water/Oil Emulsions with Polymeric Additives

The only work reported in the literature on the influence of polymer additives in simultaneous flow of oil and water in pipes is due to Al-Wahaibi et al. (2007). Al-Wahaibi et al. (2007) studied the effect of drag-reducing polymer addition to horizontal annular and stratified flows of oil and water mixtures in a 14 mm diameter acrylic pipe. Oil with a viscosity of 5.5 mPa.s and density of 828 kg/m3`was used. The polymer used was Magnafloc 1011 –a copolymer of acrylamide and acrylate. According to them, the addition of the polymer clearly dampens the interfacial waves. The drag reducing polymer caused a decrease in pressure gradient; the maximum drag reduction of about 50% was achieved when the polymer was introduced into annular flow of oil and water. On the effect of polymer concentration, two polymer concentrations were tested (20 ppm and 50 ppm) and the authors reported almost negligible differences in pressure drop at different polymer concentrations.

To our knowledge, no work has been published on the pipeline flow of water-in-oil emulsions consisting of polymeric aqueous phase.

The addition of polymers to the dispersed droplets is especially important in enhanced oil recovery operation including polymer flooding.

Chapter 4 Experimental Set-Up and Procedures

4.1 Flow Loop

4.1 Flow Loop

A schematic diagram of the experimental set-up is shown in figure 4.1. The test fluids are prepared in a large mixing tank equipped with three baffles, a heating/cooling coil and a temperature controller to maintain a constant temperature throughout the experiments. For the circulation of the test fluids in the flow loop, a centrifugal pump is used. The pump (model AA6) has a capacity of 60 USGPM with 3500 rpm and 60 ft head and is manufactured by Hayward Gordon Limited. The test sections consisted of five different diameter straight pipes installed in a horizontal position. The geometric characteristics of the test sections are summarized in table 4.1. Pressure taps are made by making small holes through the pipe walls. To ensure fully developed flow in the measurement section, sufficient distance lengths are provided for the test sections. The flow rate is controlled by the two valves (V1 and V2 shown in figure 4.1). At the entrance of the pipeline test sections, globe valves (model 9326) manufactured by Watts Regulator company were used to further control the flow. The mixer (model PDV-13) consisted of ½ hp variable speed motor and was manufactured by Hayward Gordon Limited. The type of impeller used was AH Hydrofoil shown in figure 4.2. The distance from the top of the tank to the impeller was 42 cm and the distance from the impeller to the bottom of the tank was 38 cm. The overall view of the experimental set-up is shown in figure 4.3.

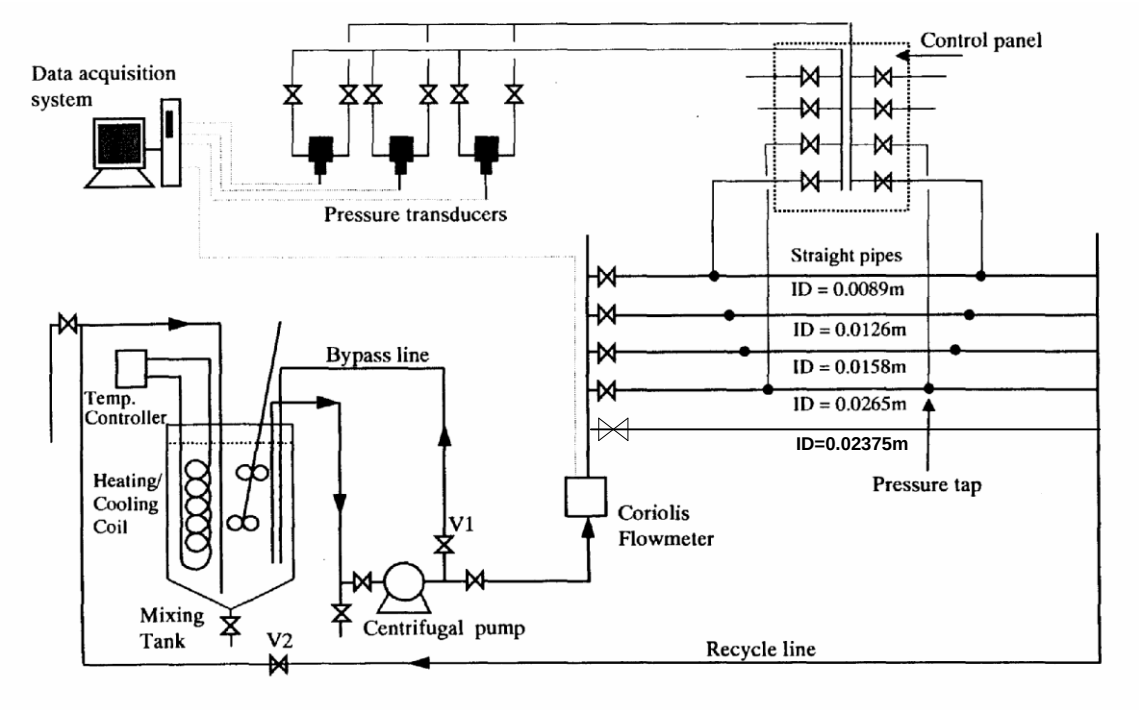

Figure 4.1: Schematic diagram of the experimental set-up

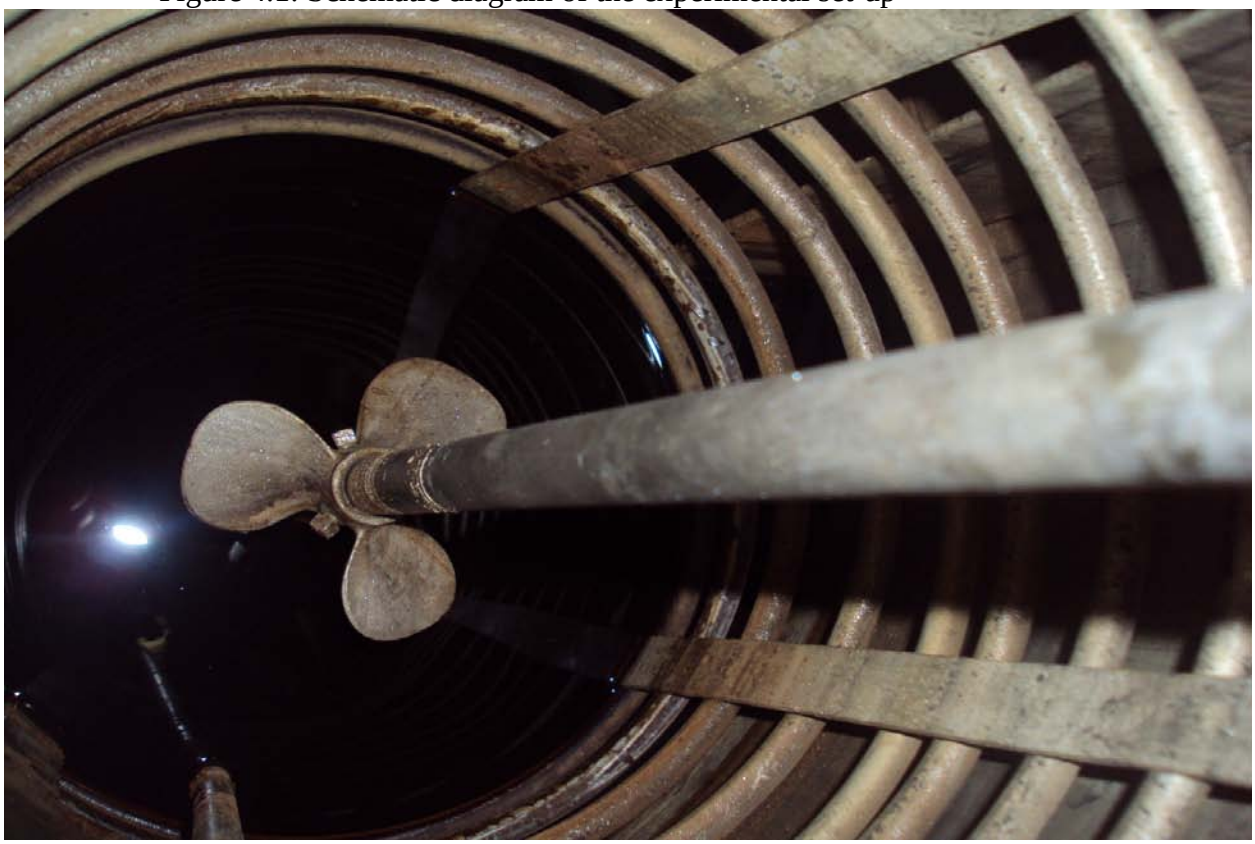

Figure 4.2: Impeller used for mixing of the emulsions

Figure 4.3: The overall view of the experimental set-up

Table 4.1: Geometric characteristics of the test sections

Pipe	Nominal I.D.	I.D	Entrance length ($L_{entrance}$/ D)	ΔP measuring length
#1	¼”	0.0089 m	2.73 m	3.353 m
#2	½”	0.0126 m	3.44 m	2.743 m
#3	¾”	0.0158 m	3.59 m	2.591 m
#4	1”	0.0265 m	3.75 m	2.438 m
#5	1” P.V.C	0.023735 m	3.75 m	2.438 m

4.2 Measurement the Viscous Properties

A coaxial cylinder viscometer is used to measure viscous properties of the fluids. This instrument consists of a stationary inner cylinder surrounded by a rotating outer (concentric) cylinder. The gap-width between the inner and the outer cylinder of the viscometer is 0.117 cm. The solution is sheared in the annular space between the coaxial cylinders by rotating the outer cylinder at a known speed. The torque, generated on the inner stationary cylinder due to viscous drag exerted by the solution, is transmitted to a spring. The deflection of this spring is measured on a dial indicator.

4.3 Measurement of Flow Rate

A coriolis flow meter was used. The coriolis flow meter directly measures the mass flow rate of a fluid flowing through the metering tubes by detection of a very small force which is generated by the fluid as it passes through parallel sensor tubes shown in figure 4.4. The force, which is analogous to the coriolis force, is caused by the acceleration and deceleration of the fluid particles as the sensor tubes are vibrated perpendicular to the direction of the fluid flow (Cox, 1987).

The meter is constructed from two U-shaped tubes which are vibrated at their natural frequency. As the fluid flows through each of the tubes, the vibrating fluid particles cause an angular deflection of the U-tubes which is detected by the two magnetic position detectors. The deflection angle is determined by measuring the relative times that the sensors detect the mid-point of each tube as shown in figure 4.5. The mass flow rate is related to deflection angle θ by:

$$\dot{m} = \frac{K_s}{4\omega r}\theta \qquad (4.1)$$

where ks is spring stiffness of U-tubes, ω is angular velocity of U-tubes, and r is the radius of U-tubes.

The velocity for the tubes at their mid-point of travel (v_t), multiplied by time difference (Δt), is related to θ by geometry:

$$tan\,\theta = \frac{v_t}{2r}\Delta t \qquad (4.2)$$

However, if θ is small, it is almost equivalent to tan θ while at the same time v_t, is equal to the product of the angular velocity of the U-tubes (ω) and the tube length (l).

Therefore,

$$\theta = l\frac{\omega}{2r}\Delta t \qquad (4.3)$$

Combing equations 4.1 and 4.3 gives:

$$\dot{m} = \frac{K_s l}{8r^2}\Delta t \qquad (4.4)$$

Thus it can be seen that the mass flow rate is proportional only to the time interval and various tube constants (Cox, 1987).

The physical characteristics of the used flow meter are shown in figure 4.6

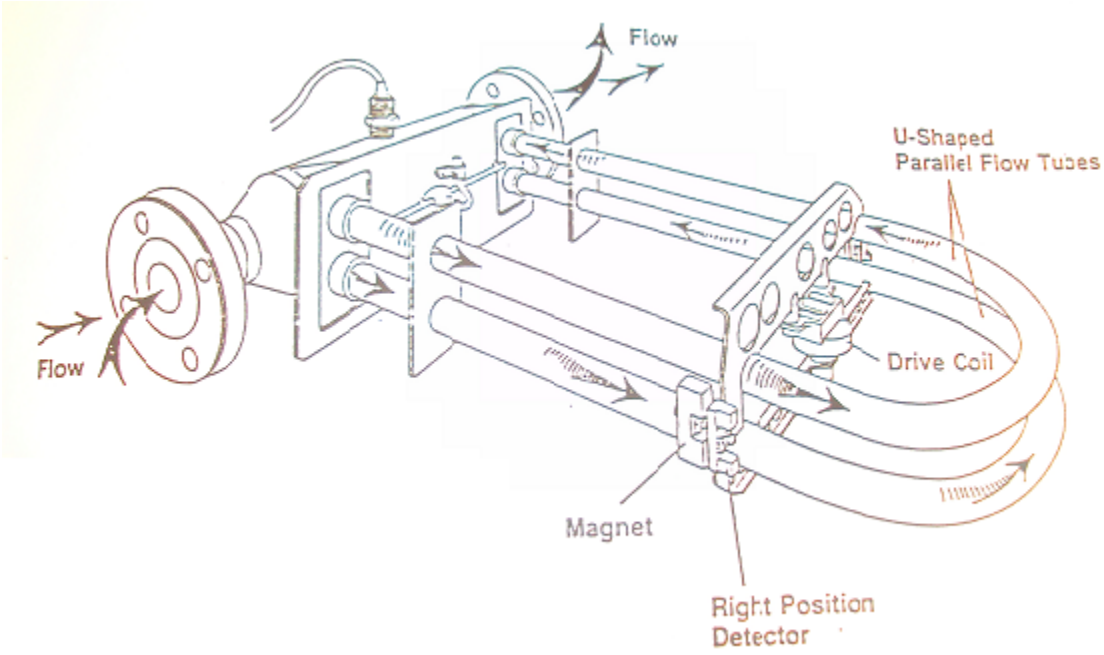

Figure 4.4: Schematic of coriolis meter (reprinted without permission from micro motion instruction manual, 1980 and Cox, 1987)

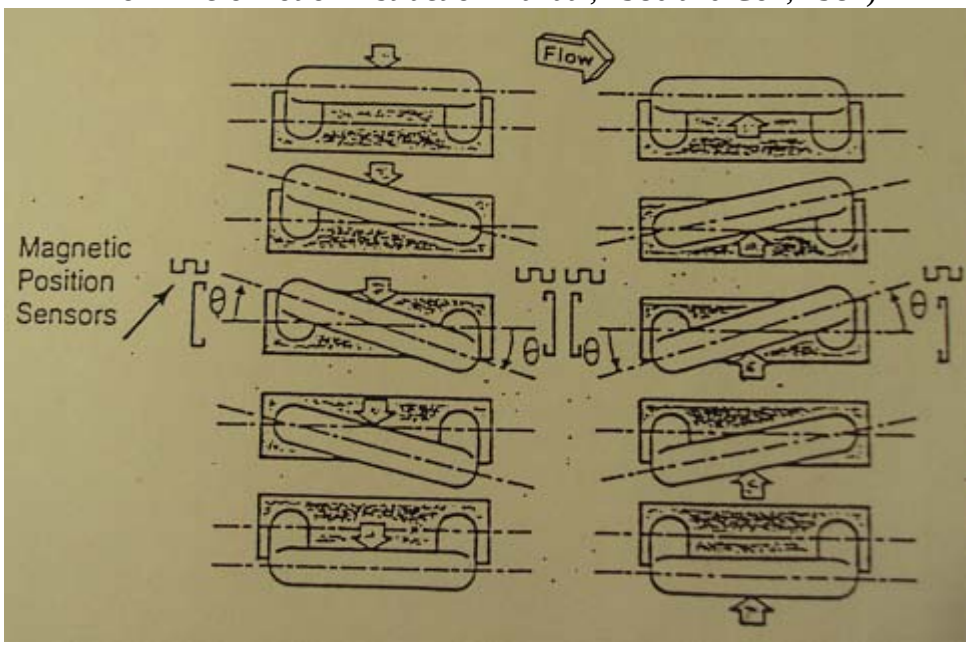

Figure 4.5: Measurement of angular deviation (reprinted without permission reprinted without permission from micro motion instruction manual, 1980 and Cox, 1987)

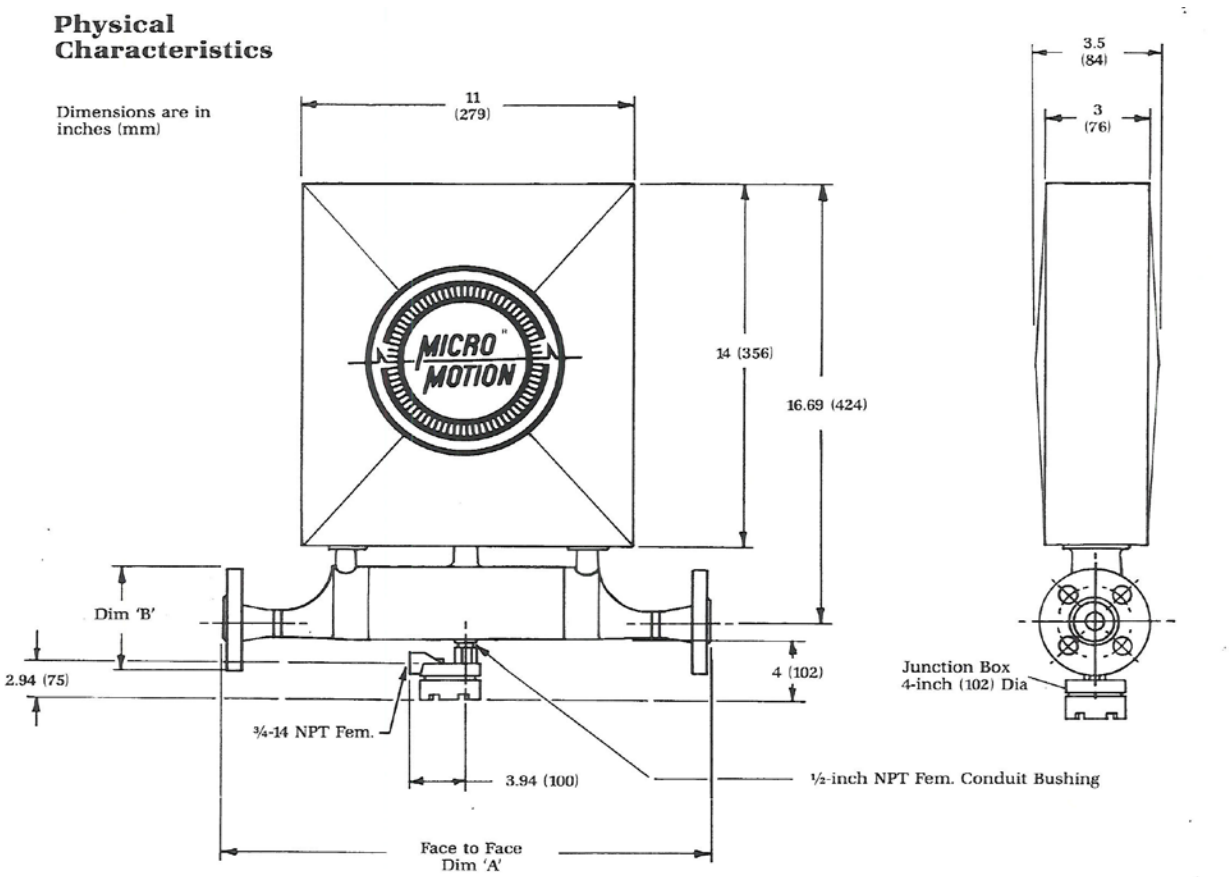

Figure 4.6: The physical characteristics of the coriolis flow meter (reprinted without permission from micro motion instruction manual, 1980 and Cox, 1987)

4.3 Calibrations

4.3.1 Calibration of the Flow Meter

A Coriolis mass flow meter is used for the measurement of flow rate of the test fluids circulating in the flow loop. The flow meter is connected to a microcomputer data acquisition system to read the output signals. The Coriolis mass flow meter was supplied by Micro Motion Inc. It is calibrated using water by diverting the flow into a weighing tank. The calibration data obtained for the flow meter are plotted in figure 4.7 as mass flow rate versus voltage reading. As

shown in this figure, the calibration curve is linear. The calibration equation that was used to obtain flow rate values from the voltage reading is as follows:

Mass flow rate (kg/s) = 0.7456 (voltage reading) - 1.5077 (4.5)

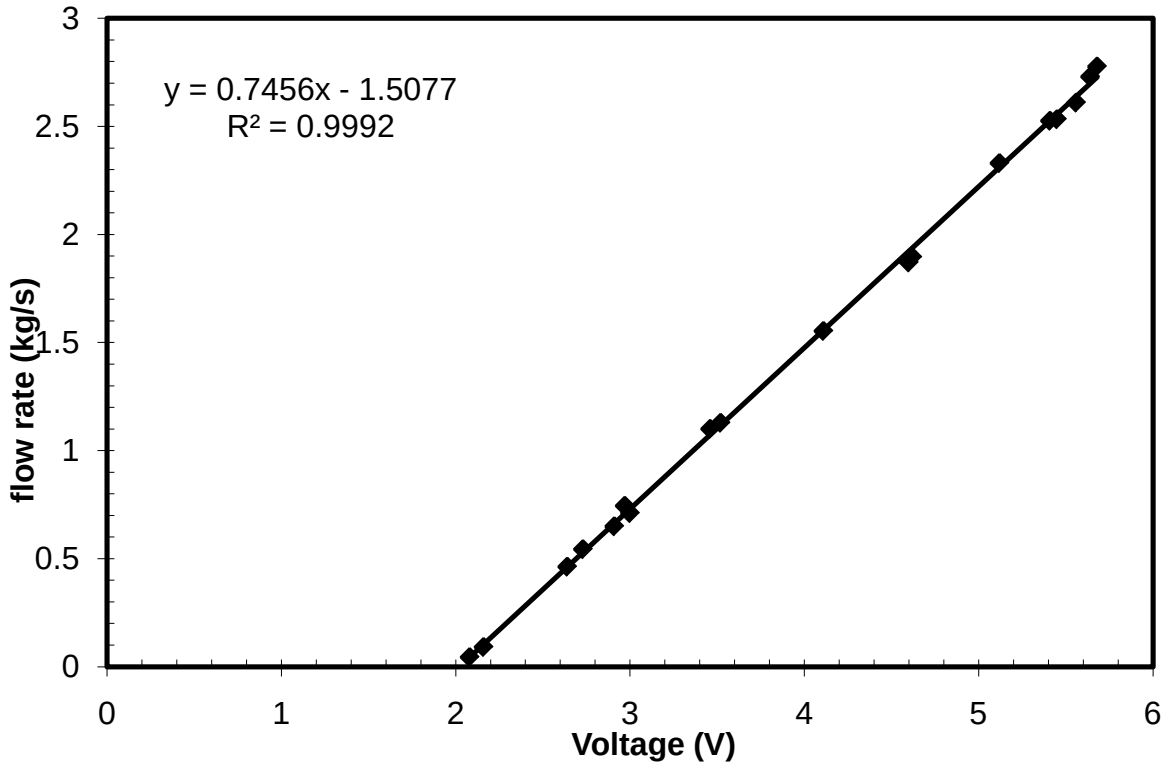

Figure 4.7: Calibration curve of the mass flow meter

4.3.2 Calibration of the Pressure Transducers

For pressure drop measurements Validyne and Rosemount types differential pressure transducers are used.

The Validyne pressure transducer consists of a rectangular stainless steel case, a diaphragm, four inductance coils, two E-shaped core, two inconel discs, two pressure ports, and

AC signal output wire as shown in figure 4.8. The diaphragm is made with magnetically permeable steel. Each E-shaped has two inductance coils and is covered by an inconel disc, which has a corrosion resistant surface. In the undeflected position, the diaphragm is centered with equal gaps about 0.005 inch between it and the legs of each E-shaped core to provide equal reluctance for the magnetic flux paths of each coil. When a pressure difference is applied through the pressure ports, the diaphragm deflects toward the cavity with lower pressure, which causes an inductance variation in the coils. The magnetic reluctance varies with the gap and determines the inductance value of each coil.

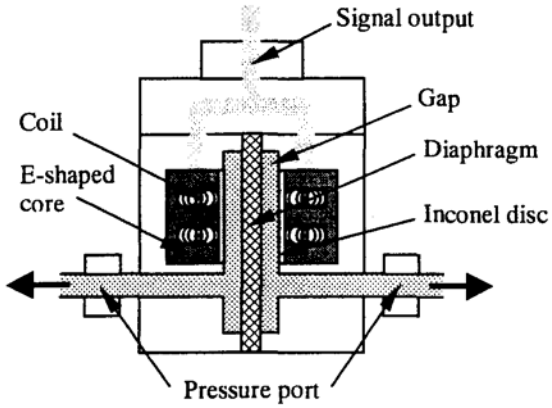

Figure 4.8: Simplified cross-sectional view of pressure transducer

The diaphragm deflection increases the inductance of one coil and decreases that of the other. The signal wire transfers the AC signal to a carrier demodulator which translates it into a +/- DC voltage output, which is eventually received by the computer data-acquisition system. The diaphragm displacement and the voltage reading vary linearly with applied pressure. A valve arrangement for the DP transducer is shown in figure 4.9.

The principle of Rosemount type differential pressure transducers is similar to that of Validyne transducers except that they measure capacitance variation with the diaphragm deflection (rather than reluctance variation).

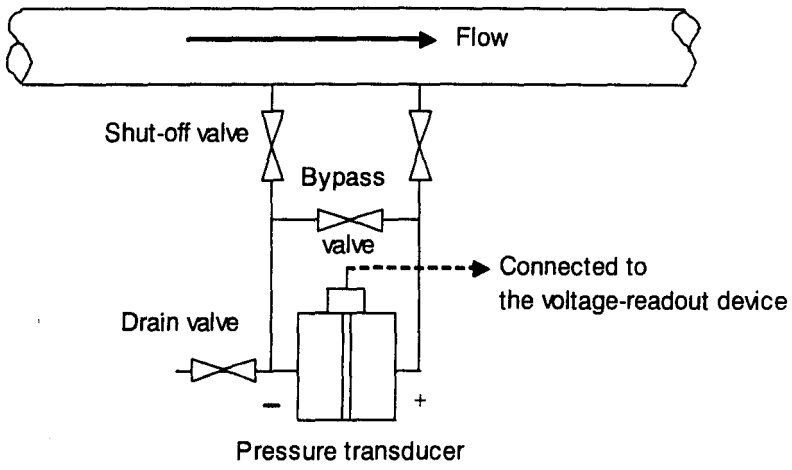

Figure 4.9: Pressure transducer connection system

The calibration of pressure transducers was performed using a Meri-cal digital manometer as shown in figure 4.10. The following calibration procedure was followed:

1. The pressure transducer with a known ΔP -range diaphragm was fixed upwards on a horizontal smooth surface to avoid the voltage reading from being affected by gravitational deflections;
2. The transducer was connected to a voltage-readout device, a computer data-acquisition system, a digital manometer and an air pressure source such that the same pressure was applied to both transducer and manometer;
3. The voltage readout device was set to a low value (0 to 0.5V) for a zero pressure drop across the transducer;

4. Air pressure was slowly applied to the setup to increase the manometer reading using a pressure control valve. The voltage readout device was then adjusted to a high voltage value (9 to 10V) for maximum pressure drop across the transducer;
5. More data points relating pressure drop versus volt between zero and maximum pressure drop were collected by changing the air pressure.

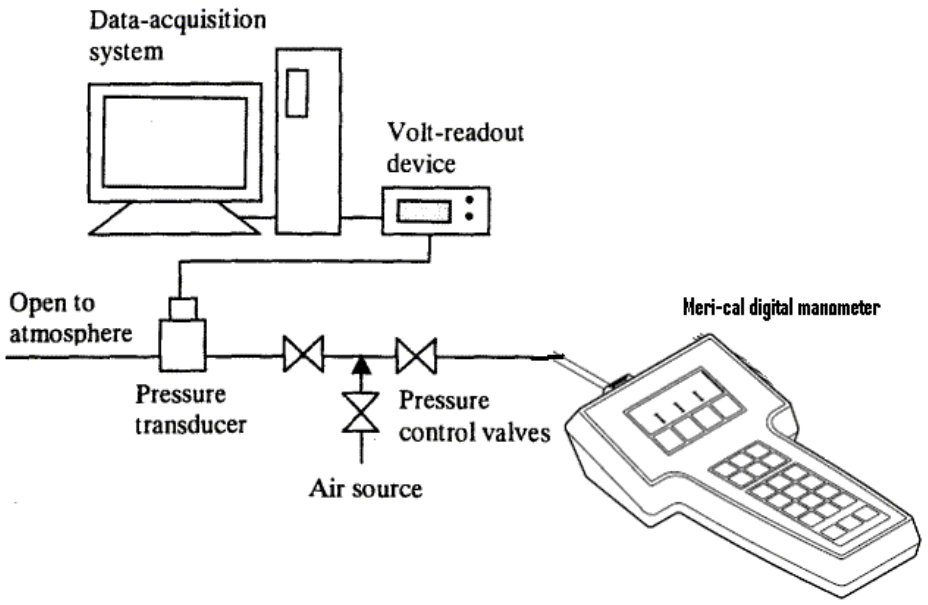

Figure 4.10: Set-up for calibrating the pressure transducers

Calibration results for the pressure transducers are shown in figures 4.11 through 4.14 where pressure differentials (kPa) are plotted against voltage reading (V).

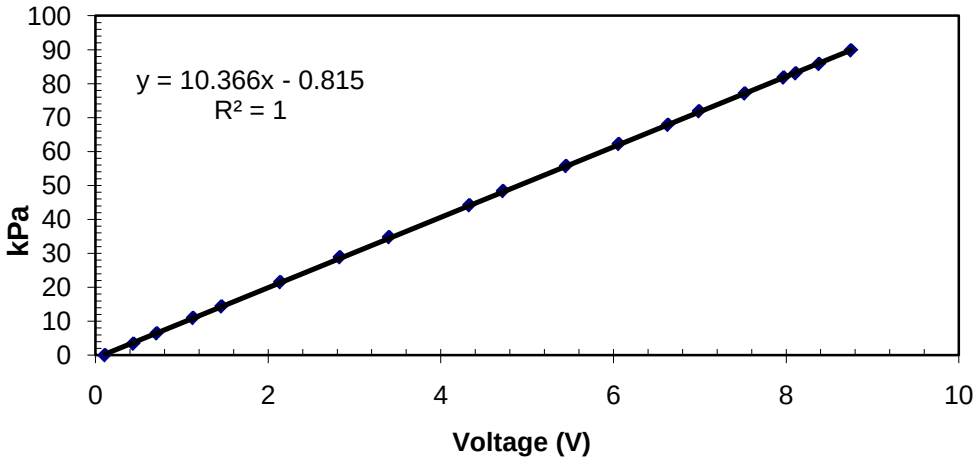

Figure 4.11: calibration curve of 87 kPa validyne pressure transducer

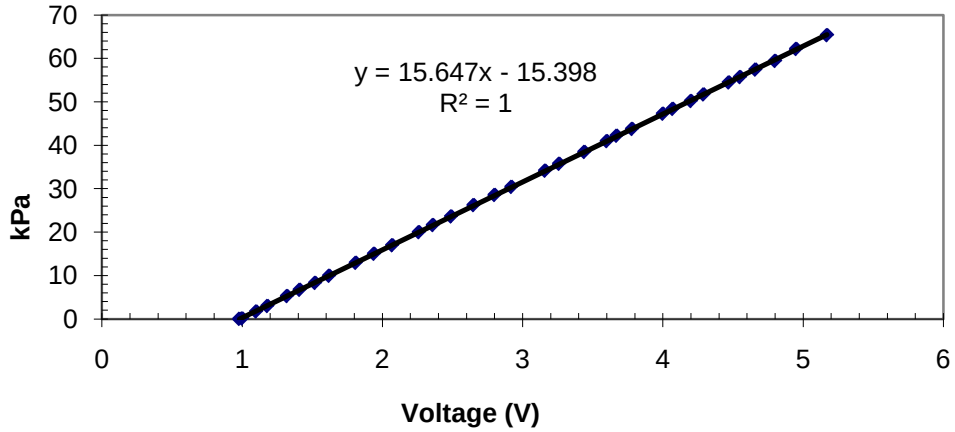

Figure 4.12: calibration curve of 65 kPa Rosemount pressure transducer

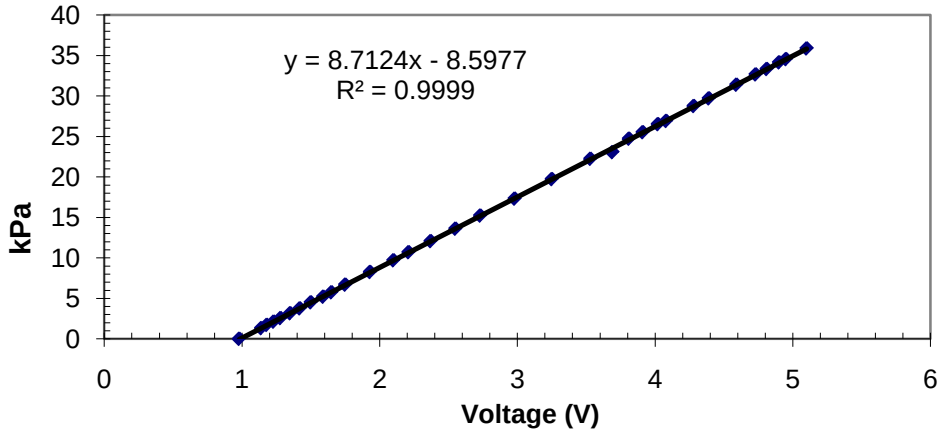

Figure 4.13: calibration curve of 35 kPa Rosemount pressure transducer

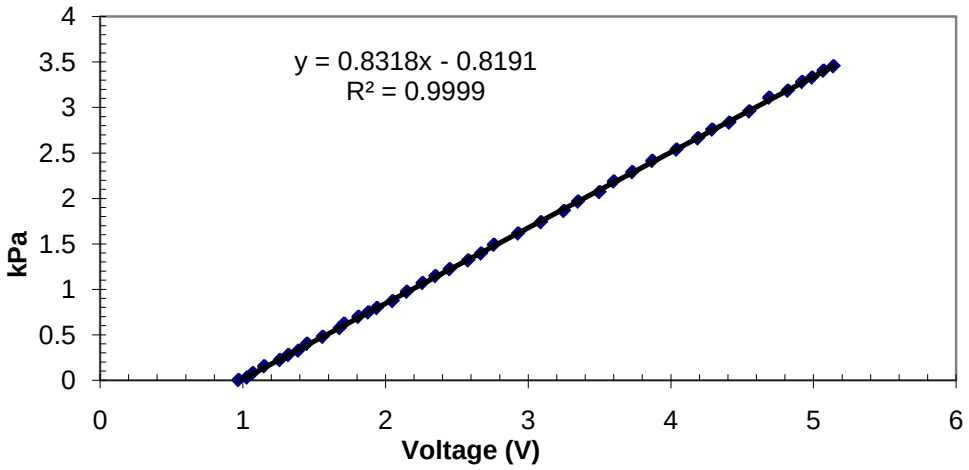

Figure 4.14: Calibration curve of 3.5 kPa Rosemount pressure transducer

The calibration equations were obtained using linear regression. These equations were later used to obtain ΔP values from the voltage read -out during the pipe flow experiments. The calibration equations for the pressure transducers are as follows:

87 kPa transducer (range: 0-87 kPa): $\Delta P = 10.366 \times (\text{voltage}) - 0.815$ (4.6)

65 kPa transducer (range: 0-65 kPa): $\Delta P = 15.647x (\text{voltage}) - 15.398$ (4.7)

35 kPa transducer (range: 0-35 kPa): $\Delta P = 8.7124 \times (\text{voltage}) - 8.5977$ (4.8)

3.5 kPa transducer (range: 0-3.5 kPa): $\Delta P = 0.8318 \times (\text{voltage}) - 0.8191$ (4.9)

4.3.3 Calibration of the Co-axial Cylinder Viscometer

A Co-axial Cylinder viscometer with a gap-width between the rotor and bob of 0.117 cm was used. Two different viscosity standards (8.7 and 98.2 mPa.s) were used to carry out the calibration. The dial-reading versus speed of the rotation data were collected for these known viscosity standards. The shear rates at the bob surface were calculated at different rotation speeds from the following equations:

$$\dot{\gamma} = \frac{2S^2}{S-1}\Omega \tag{4.10}$$

$$\Omega = \frac{2\pi(rpm)}{60} \tag{4.11}$$

where S is the ratio of rotor to bob radii $\left(R_\circ / R_i\right)$ and Ω is the speed in rad/sec

From a known viscosity, the shear stresses at the bob surface were calculated at different shear rates by using the Newton's law of viscosity. Accordingly, the calibration plot of the viscometer is the plot of τ versus the dial-reading. Table 4.2 gives the calibration data obtained for the viscometer while figure 4.15 shows the calibration plot of the viscometer as shear stress (Pa) versus dial-reading.

Table 4.2: Calibration data of Co-axial Cylinder Viscometer

Standard #1 viscosity (mPa.s) =			8.7	
RPM	Dial Reading	Omega	Shear Rate (1/s)	Shear Stress (Pa)
30	10.5	3.141592654	58.16434399	0.506029793
60	14.5	6.283185307	116.328688	1.012059585
90	19.5	9.424777961	174.493032	1.518089378
180	34.5	18.84955592	348.9860639	3.036178756
3	4.5	0.314159265	5.816434399	0.050602979
6	6.5	0.628318531	11.6328688	0.101205959
100	21	10.47197551	193.8811466	1.686765976
200	37.5	20.94395102	387.7622932	3.373531951
300	54	31.41592654	581.6434399	5.060297927
600	104.5	62.83185307	1163.28688	10.12059585
Standard #2 viscosity (mPa.s) =			98.2	
30	58	3.141592654	58.16434399	5.711738579
60	112.5	6.283185307	116.328688	11.42347716
90	168	9.424777961	174.493032	17.13521574
3	9.5	0.314159265	5.816434399	0.571173858
6	16	0.628318531	11.6328688	1.142347716
100	187	10.47197551	193.8811466	19.0391286

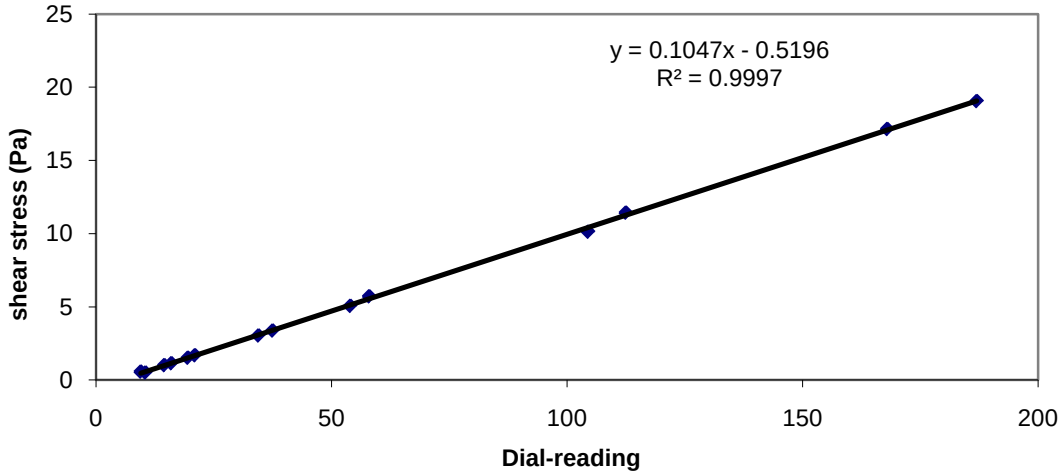

Figure 4.15: Calibration curve of the viscometer

The following calibration equation was obtained using regression analysis:

$$\tau = 0.1047 \text{ (dial-reading)} - 0.5196 \qquad (4.12)$$

4.4 Preparation of Emulsions

The emulsions were prepared from three different oils: EDM-244, EDM-Monarch, and Shell Pella. EDM-244 is a paraffinic hydrocarbon supplied by Commonwealth Oil Company. It has a viscosity of 2.5 mPa.s at 25 ^{0}C. EDM-Monarch is a petroleum oil supplied by Monarch Oil Company and has a viscosity of 6 mPa s at 25 ^{0}C. Shell Pella oil, supplied by Shell Canada, is a mineral seal of viscosity 5.4 mPa.s at 25 ^{0}C. Table 4.3 summarizes the physical properties of the oils used. The mixing process was carried out in the 250L tank equipped with variable speed mixer and a heating/coaling coil (the temperature was kept at 25 ^{0}C) as shown in figure 4.1. The experiments were started with pure oil, and then a required amount of tap water was added to prepare the emulsion.

Table 4.3: Properties of the oils used

Oil type	Viscosity (mPa.s)	Density (kg/m^3)	Interfacial tension (mN/m)	Oil Nature
Shell Pella oil	5.4	816	11.3	paraffinic hydrocarbon
EDM Monarch	6	785	37.8	petroleum oil
EDM 244 oil	2.5	753	40.5	paraffinic hydrocarbon

For water-in-oil emulsions containing polymeric additive, the water-in-oil emulsions were prepared using EDM 244 oil. The polymers used were polyethylene oxide of two different molecular weights and carboxymethyl cellulose (CMC). Polyethylene oxide resins named Polyox WSR-301 and Polyox WSR-303 were supplied by Dow Chemical Co. The reported molecular weights of these polymers were $4x10^6$ and $7x10^6$, respectively. The other polymer, CMC (type 7H4F PM), was supplied by Hercules Company. The reported molecular weight of CMC was $7x10^5$.

For surfactant stabilized emulsions, the water-in-oil emulsions were prepared with EDM-244 oil. Emsorb 2503 was used as a surfactant. Emsorb 2503 is manufactured by Henkel Corporation; Emery Group. The hydrophile-lipophile balance (HLB) value of Emsorb 2503 is 2.1 and its viscosity is 230 mPa s at 23 ^{0}C. A known amount of the emulsifier (Emsorb 2503) was added to the oil, this solution was mixed by a variable speed homogenizer (Gifford-Wood Model 1-LV) then the solution was added to the known volume of water/oil emulsions. The water used throughout the experiments was tap water.

4.5 Detection of Emulsion Type

To detect the type of emulsion (W/O or O/W), an in-line conductance cell was used to monitor the electrical conductance of emulsions continuously. The design of the conductance

cell is described in Pal's thesis (Pal, 1987). Water-in-oil emulsions have a very low conductance (as nonconductive oil forms the continuous phase), whereas oil-in-water emulsions have a high conductance value. A sudden change in the conductance occurs when inversion of phases takes place (Pal, 1993). A phase dilution test (Becher, 1977) was also performed to detect the emulsion type from time to time. This test is based on the fact that an emulsion is readily dispersed in the liquid that forms the continuous phase. A small amount of the emulsion was added to the two beakers containing pure oil and pure water, respectively. When the emulsion readily dispersed in oil but did not disperse in water, it indicated that the emulsion was water-in-oil type. If the emulsion is readily dispersed in water, the emulsion was oil-in-water type.

Chapter 5 Results and Discussion

This chapter presents the experimental results and discussion on the pipeline flow behavior of water-in-oil emulsions with and without the presence of polymeric and surfactant additives. Two hundred sets of pipeline experiments were carried out in the flow rig described in Chapter 4.

5.1 Single Phase Fluids

Prior to the tests using the w/o emulsions, calibration runs were conducted using single-phase fluids (water and oil). To validate the experimental apparatus and the overall experimental procedures, the friction factor in the fully developed region of the test section were checked. The measured pressure drop data were compared with Hagen-Poiseuille equation in laminar flow region, and Blasius equation in turbulent flow region, which served as the criteria with which to check the validity of the current experimental work. Experimental results for the friction factor in the fully developed region of the test section for water and oil are presented in figure 5.1, where the friction factor, f, is plotted against the Reynolds number. The friction factor values for single-phase fluids (water and oil) obtained in the fully developed region of the test section are in excellent agreement with the Hagen-Poiseuille and Blasius equations.

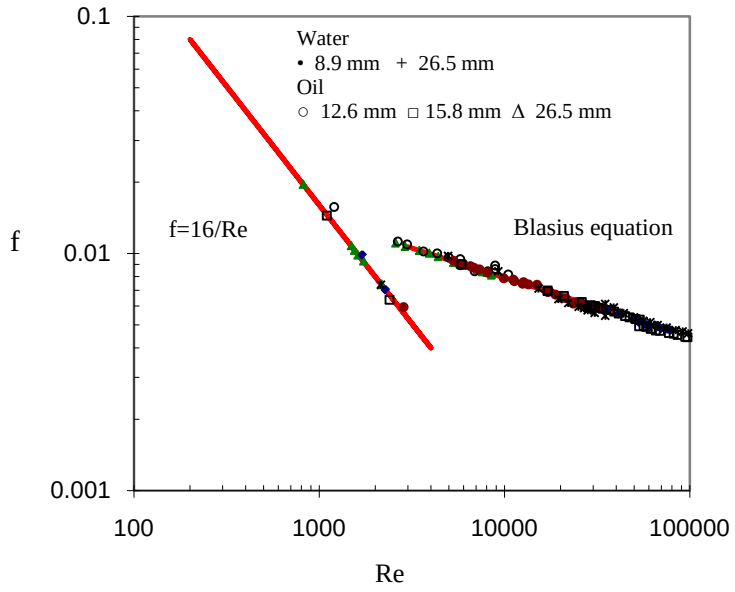

Figure 5.1: Friction factor data for pure fluids (water and oil)

5.2 Unstable Water-in-Oil Emulsions

5.2.1. Pipeline Flow of Unstable Water-in-EDM Oil Emulsions

Figures 5.2 and 5.3 show the pipeline data for water-in-oil (W/O) emulsions prepared from EDM-244 oil. The data are shown for different volume fractions of water. The Reynolds number is based on the viscosity determined from laminar flow data using equation (2.3). In the turbulent flow region, W/O emulsions prepared from EDM 244 oil exhibit strong drag reduction; the measured friction factors fall well below the Blasius equation (equation (2.11)). The data show some diameter dependence as well; the degree of drag reduction is somewhat larger in a smaller diameter pipe when comparison is made at the same Reynolds number. Also, it should be noted that the higher the Reynolds number, the higher the degree of drag reduction. This behavior is similar to that observed by Pal (1993) for unstable water-in-oil emulsions.

The degree of drag reduction also increases with the increase in dispersed phase (water) volume fraction in the same diameter pipe. The largest drag reduction occurs at 40% water volume fraction shown in figure 5.3(D).

Figure 5.4 shows pressure gradient data for water-in-EDM 244 oil emulsions. The data are plotted as a function of velocity for different dispersed phase volume fractions and different diameter pipes. The pressure gradient increased with velocity for a given pipe and dispersed phase volume fraction. As expected, the pressure gradient is higher in smaller diameter pipes.

The effect of dispersed phase volume fraction on the pressure gradient of water-in-EDM 244 oil emulsions can be seen more clearly in figure 5.5. The data for pure oil and different dispersed phase concentrations (5%, 10%, 30% and 40%) obtained in a 0.0265 m diameter pipe are shown. As the dispersed phase concentration is increased from 0 to 30% by volume, the pressure gradient decreases significantly. For example, at a velocity of 3.6 m/s, the pressure gradient for 30% water volume fraction is 2.5 kPa/m whereas for pure oil the pressure gradient is much higher, that is, 8.3 kPa/m. The decrease in the pressure gradient with the addition of dispersed phase becomes more apparent as the emulsion velocity is increased. The pressure gradient at 40% water concentration is similar to that observed at 30% water concentration. No distinct peaks in the pressure gradient data are observed for the emulsions and therefore, there is no indication of phase inversion taking place in the system.

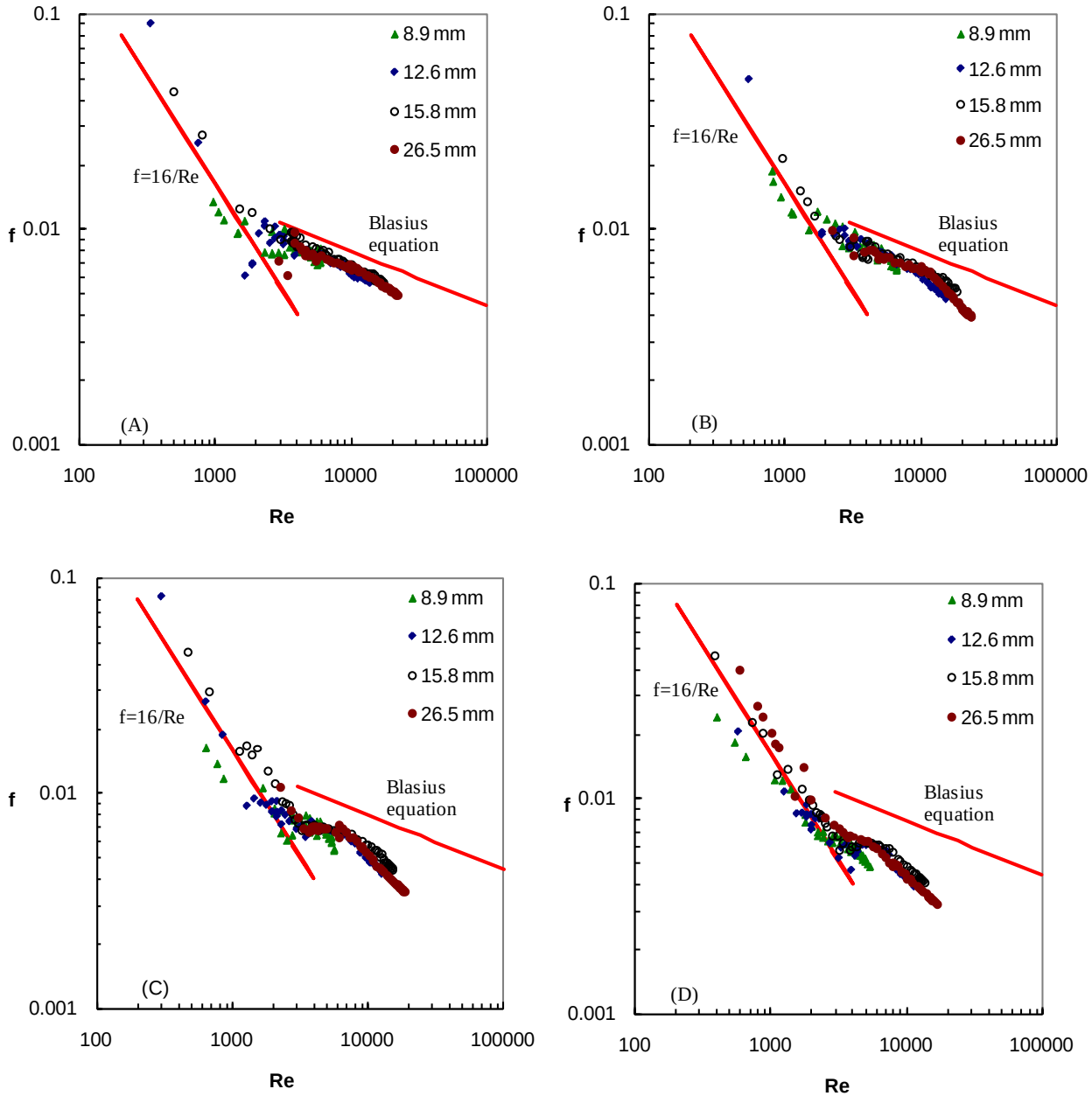

Figure 5.2: Pipeline data for unstable water-in-EDM 244 oil emulsions
(A) 5% W/O, (B) 10% W/O, (C) 15% W/O, (D) 20% W/O

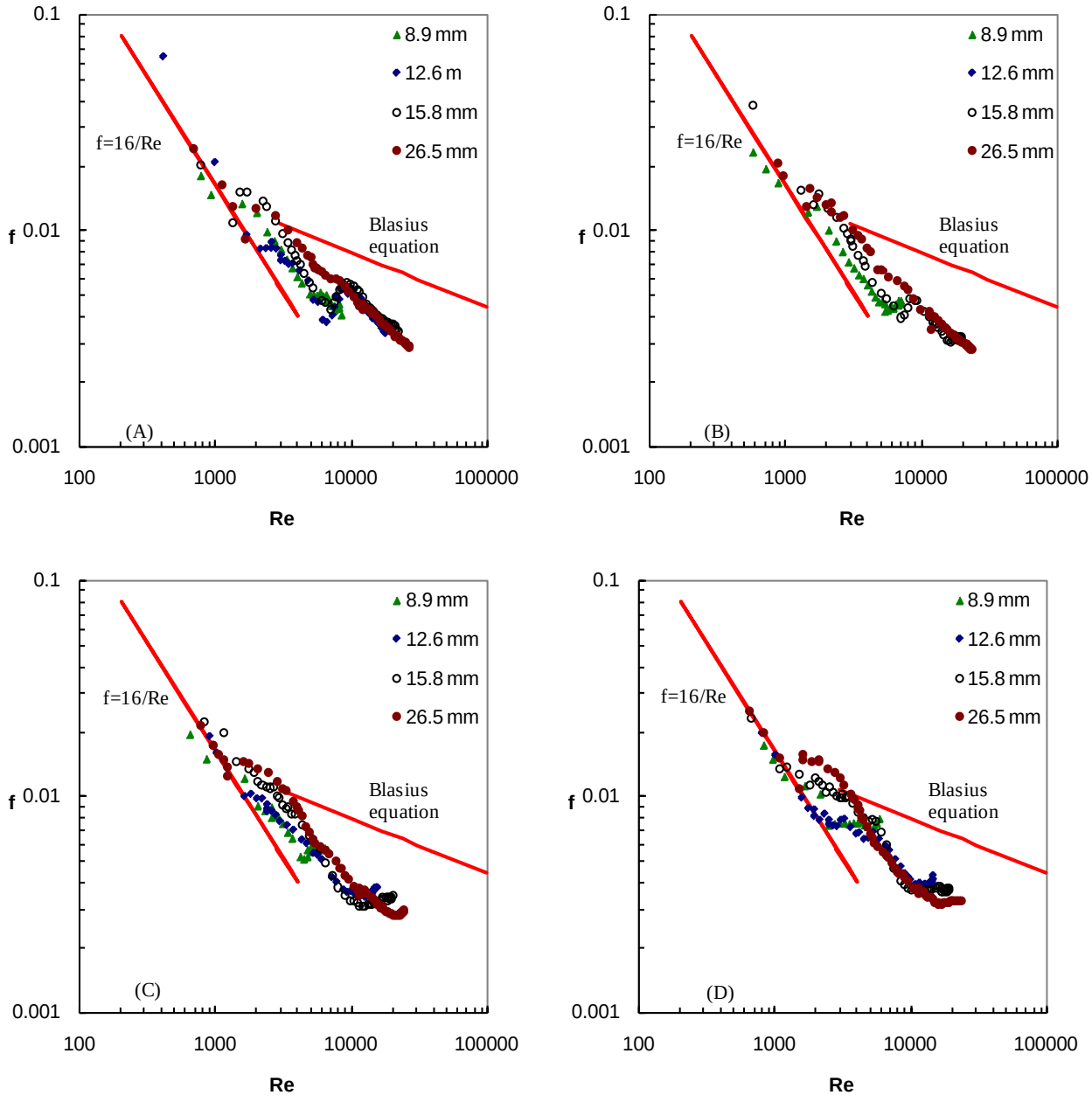

Figure 5.3: Pipeline data for unstable water-in-EDM 244 oil emulsions
(A) 25% W/O, (B) 30% W/O, (C) 35% W/O, (D) 40% W/O

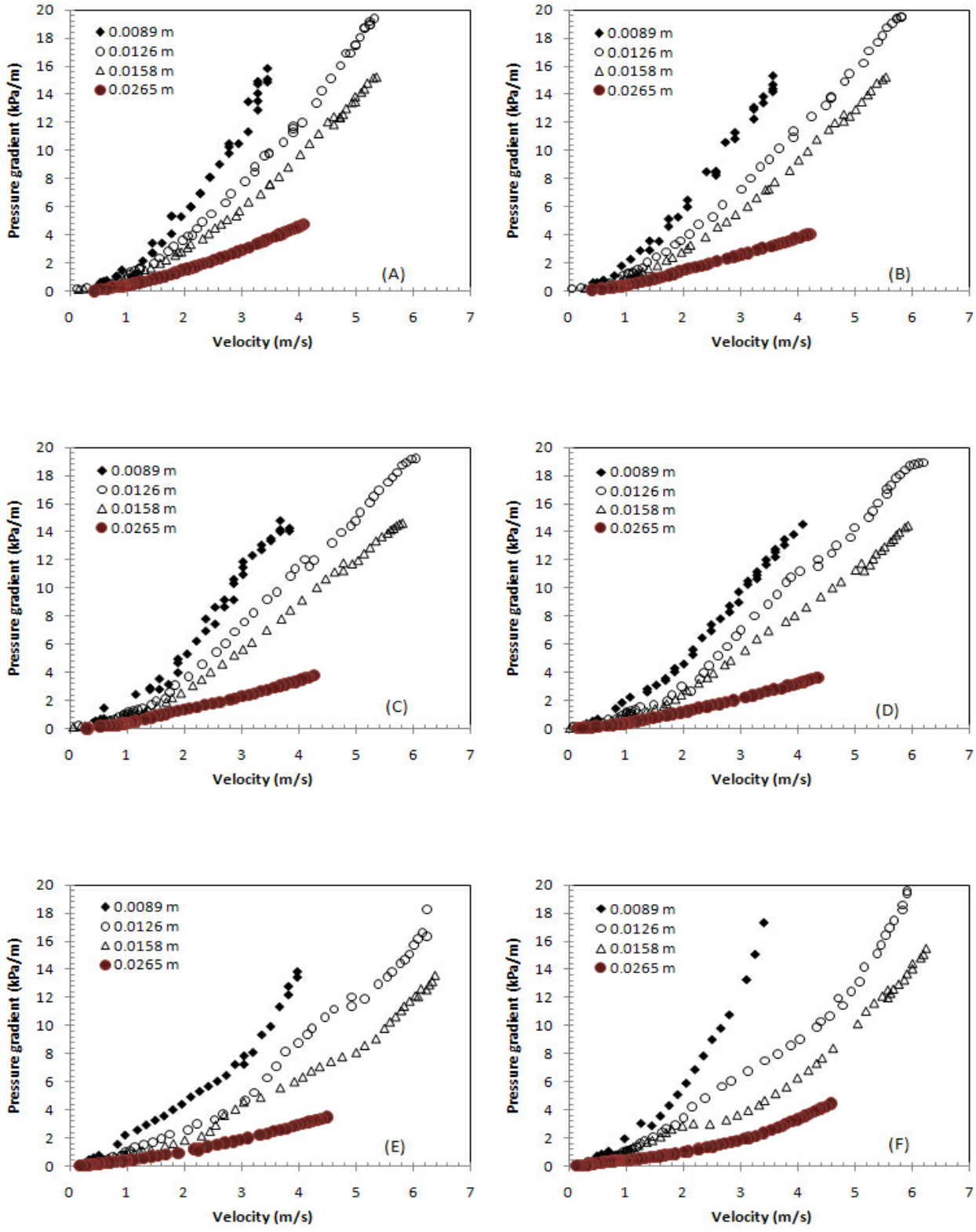

Figure 5.4: Pressure gradient as a function of velocity for water-in-EDM 244 oil Emulsions (A) 5%W/O, (B)10% W/O, (C)15% W/O, (D)20% W/O, (E)30% W/O, (F) 40% W/O

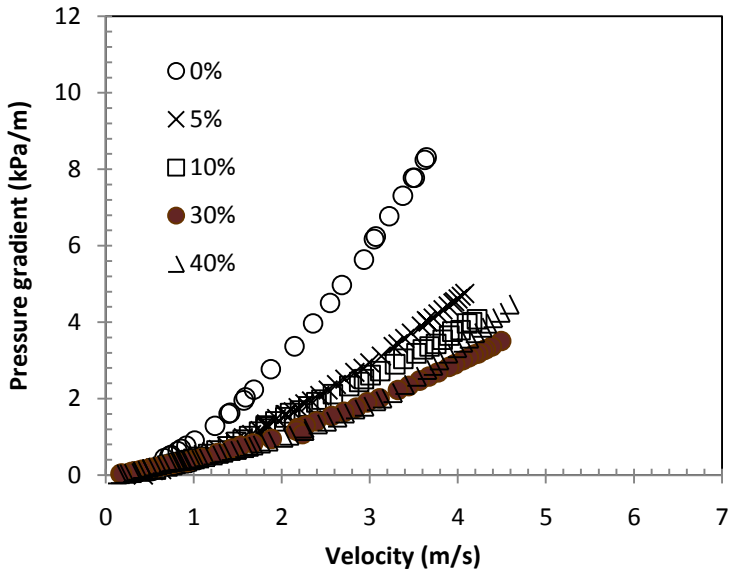

Figure 5.5: The effect of dispersed phase volume fraction on pressure gradient of water-in-EDM 244 oil emulsions in a 0.0265 m diameter pipe

5.2.2 Pipeline Flow of Unstable Water-in-EDM Monarch Oil Emulsions

The friction factor vs. Reynolds number data for the W/O emulsions prepared from EDM-Monarch oil are shown in figures 5.6 and 5.7. The emulsions prepared from EDM-Monarch oil also exhibit drag reduction in turbulent flow. However, the drag reduction activity exhibited by EDM-Monarch emulsions is significantly less than that of EDM-244 emulsions. It should be noted that the viscosity of the continuous phase of EDM-Monarch emulsions is 6 mPa.s whereas the corresponding viscosity of EDM-244 emulsions is 2.5 mPa.s.

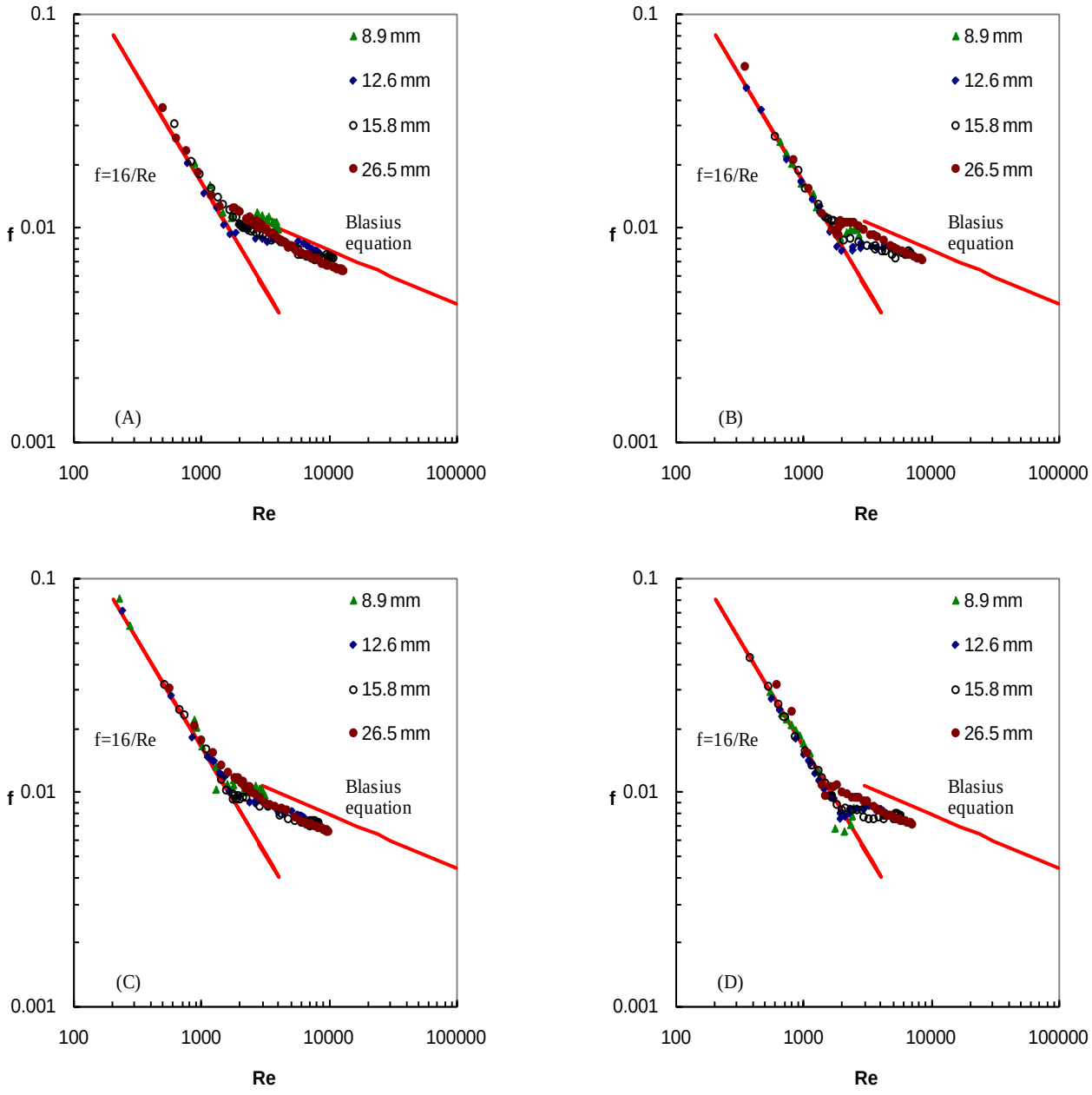

Figure 5.6: Pipeline data for the unstable water-in-EDM Monarch oil emulsions
(A) 5% W/O, (B) 10%W/O, (C) 15% W/O, (D) 20% W/O

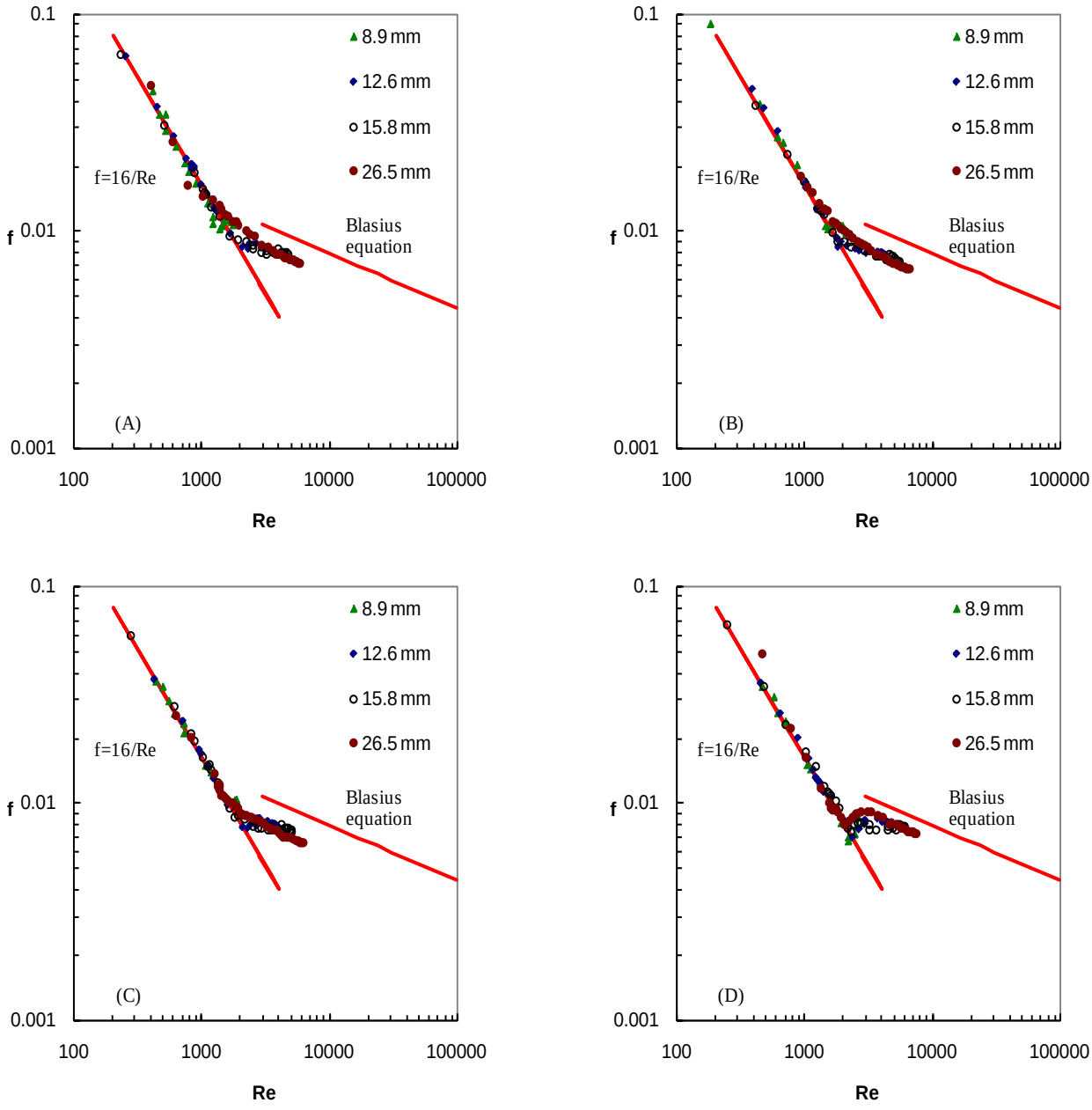

Figure 5.7: Pipeline data for the unstable water-in-EDM Monarch oil emulsions
(A) 25% W/O, (B) 30%W/O, (C) 35% W/O, (D) 40% W/O

Figure 5.8 shows the pressure gradient of EDM-Monarch oil emulsions as a function of velocity for different dispersed phase volume fractions. At a given emulsion velocity, the pressure gradient in EDM-Monarch emulsions decreases with the increase in dispersed phase concentration. However, the decrease in the pressure gradient with the dispersed phase concentration is not as strong as found in the case of EDM-244 emulsions.

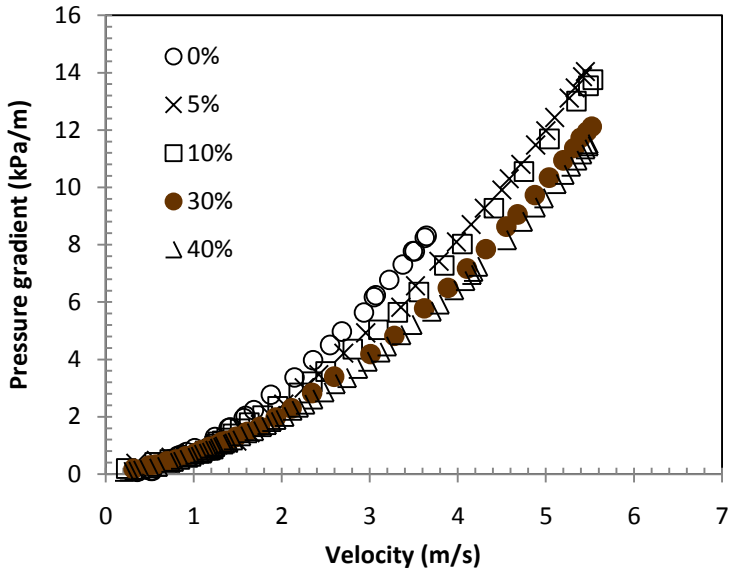

Figure 5.8: The effect of dispersed phase volume fraction on pressure gradient of water-in-EDM Monarch oil emulsions in a 0.0265 m diameter pipe

5.2.3. Pipeline Flow of Water-in-Shell Pella Oil Emulsions

Figures 5.9 and 5.10 show the pipeline data for W/O emulsions prepared from Shell Pella oil. Interestingly, the Shell Pella oil emulsions exhibit little or no drag reduction in turbulent flow. The friction factor data generally follow the commonly used single-phase Blasius equation (equation (2.11)).

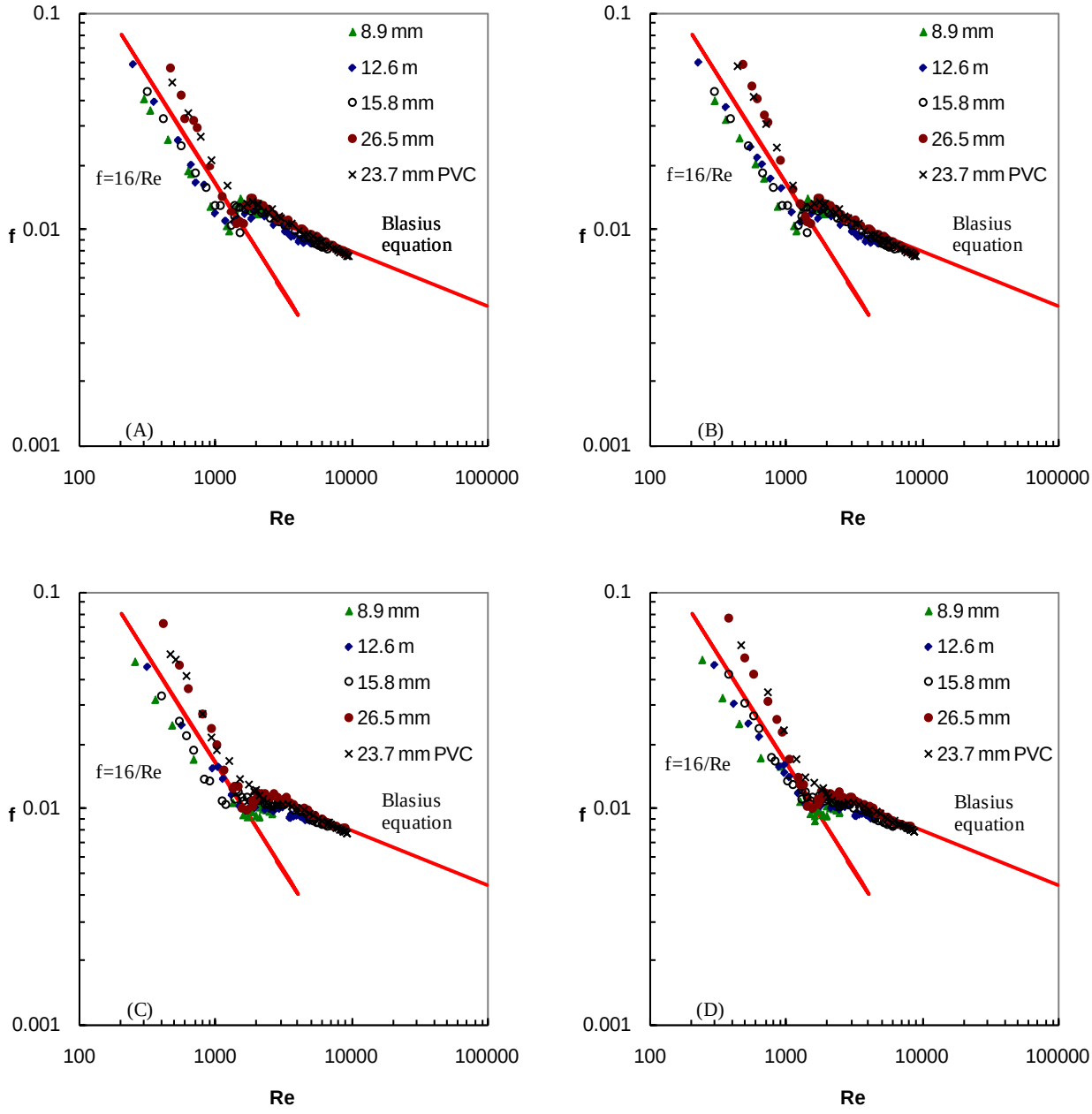

Figure 5.9: Pipeline data for the water-in-Shell Pella oil emulsions
(A) 5% W/O, (B) 10% W/O, (C) 15% W/O, (D) 20% W/O

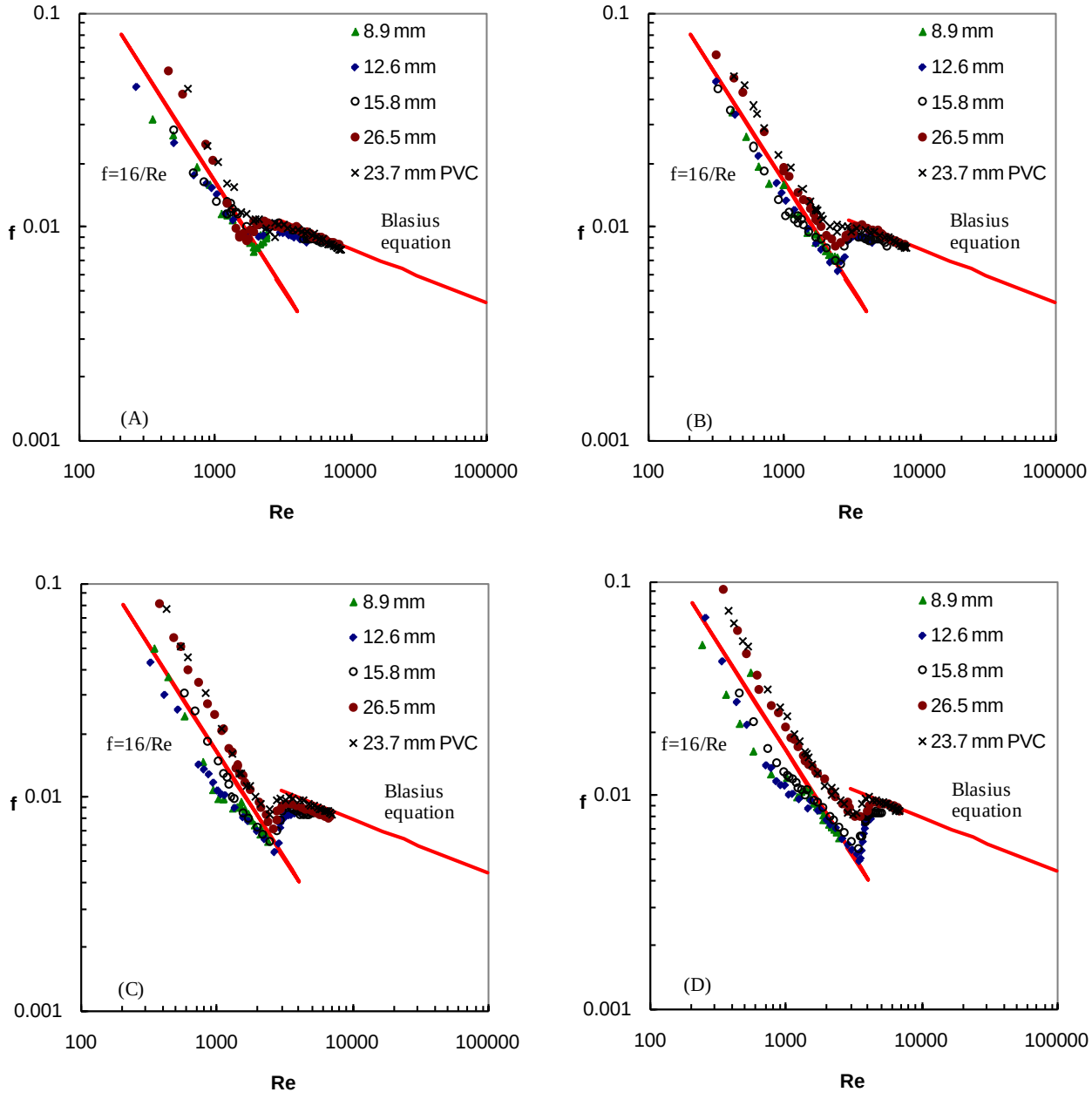

Figure 5.10: Pipeline data for the water-in-Shell Pella oil emulsions
(A) 25% W/O, (B) 30%W/O, (C) 35% W/O, (D) 40% W/O

Pressure gradient data for Shell Pella emulsions at different dispersed phase volume fractions are shown in figure 5.11. The decrease in pressure gradient with the increase in dispersed phase concentration is very small. This behavior is consistent with the friction factor data for Shell Pella oil emulsions.

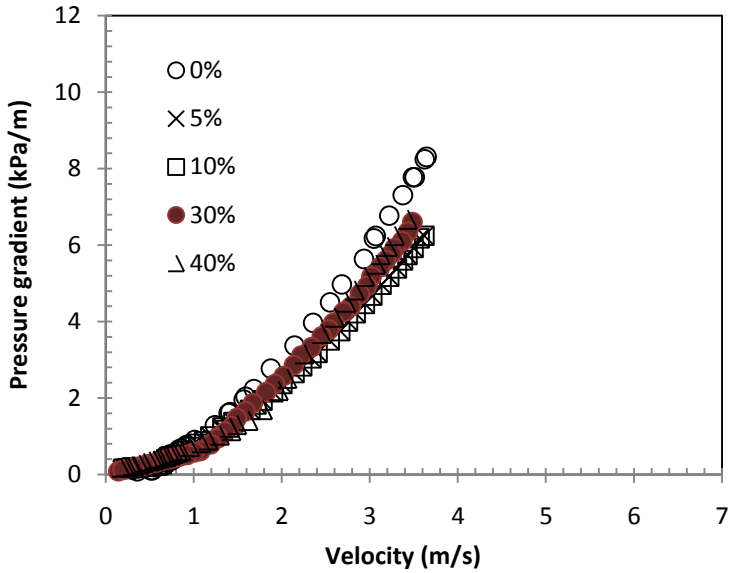

Figure 5.11: The effect of dispersed phase volume fraction on pressure gradient of water-in-Shell Pella oil emulsions in a 0.0265 m diameter pipe

5.2.4 Discussion of Results

Drag reduction in unstable emulsions is partly due to suppression of turbulence caused by dynamic break-up and coalescence of droplets. The dynamic break-up and coalescence of droplets is expected to be influenced by factors such as the continuous-phase viscosity and the presence of surface active additives in the emulsion. Figure 5.12 shows the comparison of pressure gradient between different emulsions. The emulsions prepared from EDM-244 oil exhibited larger drag reduction than the EDM-Monarch emulsions as the continuous-phase (oil)

viscosity of EDM-244 emulsions was much smaller than that of EDM-Monarch emulsions. The emulsions prepared from Shell Pella oil exhibited negligible drag reduction as these emulsions were relatively stable with respect to coalescence. The interfacial tension of Shell Pella oil was found to be significantly smaller than those of EDM oils (see table 4.3) indicating that the Shell Pella oil contained some surface active agent.

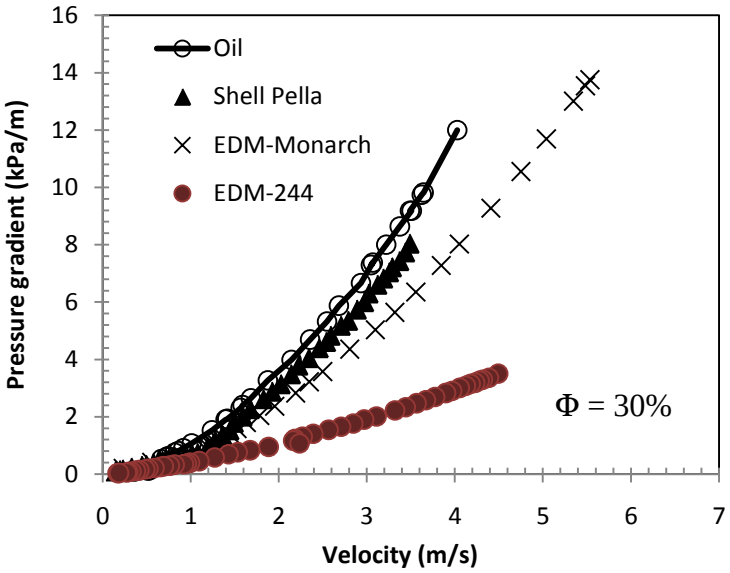

Figure 5.12: The comparison of pressure gradient between different emulsions in a 0.0265 m diameter pipe (Φ = 30% vol.)

The physical appearance of the emulsions prepared from Shell Pella oil was also quite different from that of the EDM oil emulsions; the Shell Pella oil emulsions were milkier. Furthermore, Shell Pella emulsions took much longer to undergo phase separation (when left unstirred) as compared with EDM emulsions. As an example, figure 5.13 shows the pictures of emulsion samples taken 20 seconds after the mixing was stopped. The left hand side picture is

that of EDM-244 oil emulsion and the right hand side picture is that of Shell Pella oil emulsion at the same volume fraction of water. As can been seen, the EDM 244 oil emulsion undergoes almost complete separation into clear oil and water phases in 20 seconds whereas the Shell Pella oil emulsion does not separate as much in the same duration of 20 seconds.

Figure 5.13: Emulsions 20 seconds after mixing was stopped

Figure 5.14 shows the thickness (height) of the clear water layer separated from emulsion as a function of time. The clear water layer thickness increases much more rapidly in the case of EDM-244 oil emulsion as compared with the Shell Pella oil emulsion. Stable emulsions (Shell Pella emulsions in the present case) are expected to exhibit normal single-phase behavior with little or no drag reduction. In turbulent flow of stable emulsions, the dynamic coalescence/break-up processes are almost absent and therefore, negligible suppression of turbulence takes place.

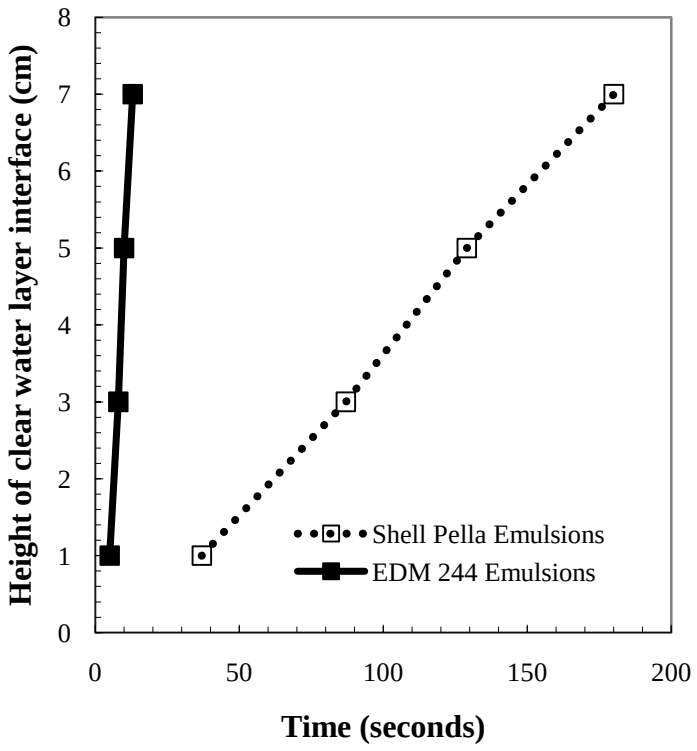

Figure 5.14: Settling behavior of water-in-oil emulsions

Figure 5.15 shows the viscosity of water-in-oil emulsions. The viscosity of emulsion was determined from laminar pipeline flow data by fitting the data with equation (2.3). The emulsion viscosity increases with the increase in the water volume fraction. For any given volume fraction of water, the viscosity of EDM-Monarch emulsion is higher than that of the EDM-244 emulsion due to the fact that the continuous phase (oil) viscosity of EDM-Monarch emulsion is 2.4 times that of EDM-244 emulsion. Although the Shell Pella oil (viscosity = 5.4 mPa.s) is less viscous than the EDM-Monarch oil (viscosity = 6 mPa.s), the emulsions prepared from the Shell Pella oil are more viscous than the EDM-Monarch emulsions because the Shell Pella oil contained some

surface-active agent. The presence of surface-active agent at the surface of the droplets is expected to increase the rigidity of the droplets leading to higher emulsion viscosity.

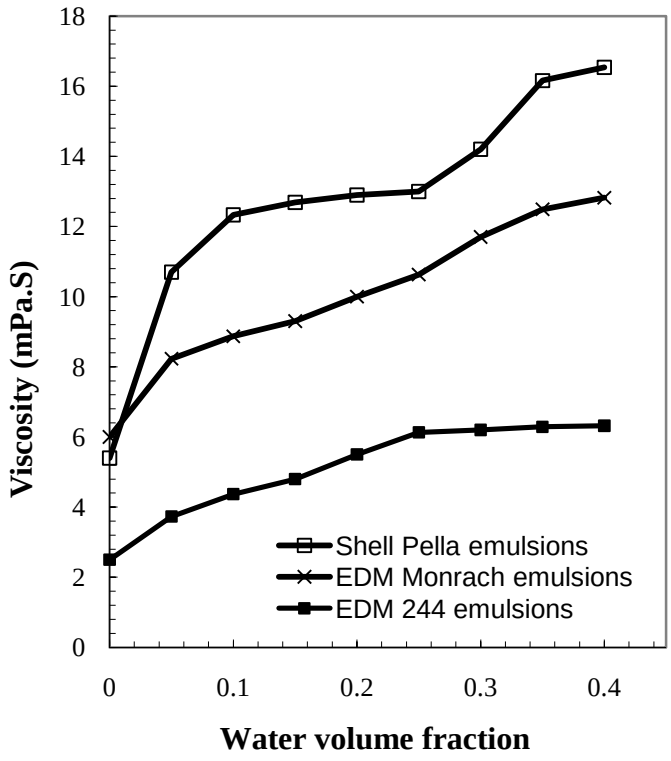

Figure 5.15: Viscosity of Water-in-oil emulsions

The relative viscosities of emulsions were compared with the viscosity model developed by Pal (2003) covering both laminar and turbulent flow regions. In laminar flow, the model gives

$$\eta_{r,0}\left[\frac{2\,\eta_{r,0}+5\lambda}{2+5\lambda}\right]^{3/2} = \exp\left[\frac{2.5\Phi}{1-\frac{\Phi}{\Phi_m}}\right] \qquad (2.32)$$

and in turbulent flow the model gives

$$\eta_{r,\infty}\left[\frac{\lambda-\eta_{r,\infty}}{\lambda-1}\right]^{-2.5}=\exp\left[\frac{2.5\Phi}{1-\frac{\Phi}{\Phi_m}}\right] \tag{2.33}$$

where $\eta_{r,0}$ and $\eta_{r,\infty}$ are the limiting relative viscosities at low and high capillary numbers respectively

The relative viscosities of water-in-oil emulsions obtained from laminar flow data, using equation (2.3), are presented and compared with Pal's Model (equation (2.32)) in figure 5.16 (A, B, and C). The relative viscosities increase with an increase in the dispersed phase volume fraction and they follow the trend predicted by the model. It is should be noted that the viscosity ratio (λ) values are different for each emulsion set.

In turbulent flow, the relative viscosities of EDM-244 and EDM-Monarch emulsions (obtained using Blasius equation) decreased with the increase in the dispersed phase volume fraction, as shown in figure 5.16 (D and E). The predictions of the Pal model fall above the experimental data. The disagreement between the experimental data and model prediction is likely due to the fact that the model does not take into account the suppression of turbulence caused by break-up and coalescence of droplets.

The Shell Pella emulsions exhibited a different behavior as compared with EDM-244 and EDM-Monarch emulsions. As shown in figure 5.16 (F) the relative viscosity of water-in-oil emulsions prepared from Shell Pella oil increased with the increase in the dispersed phase volume fraction. As the droplets of Shell Pella emulsions were small and stable with respect to coalescence, they behaved more like rigid particles and therefore, no reduction in viscosity occurred upon a change in the flow regime from laminar to turbulent. This behavior is consistent with the fact that Shell Pella emulsions did not exhibit any drag reduction. The friction factors of Shell Pella emulsions were in agreement with the Blasius equation.

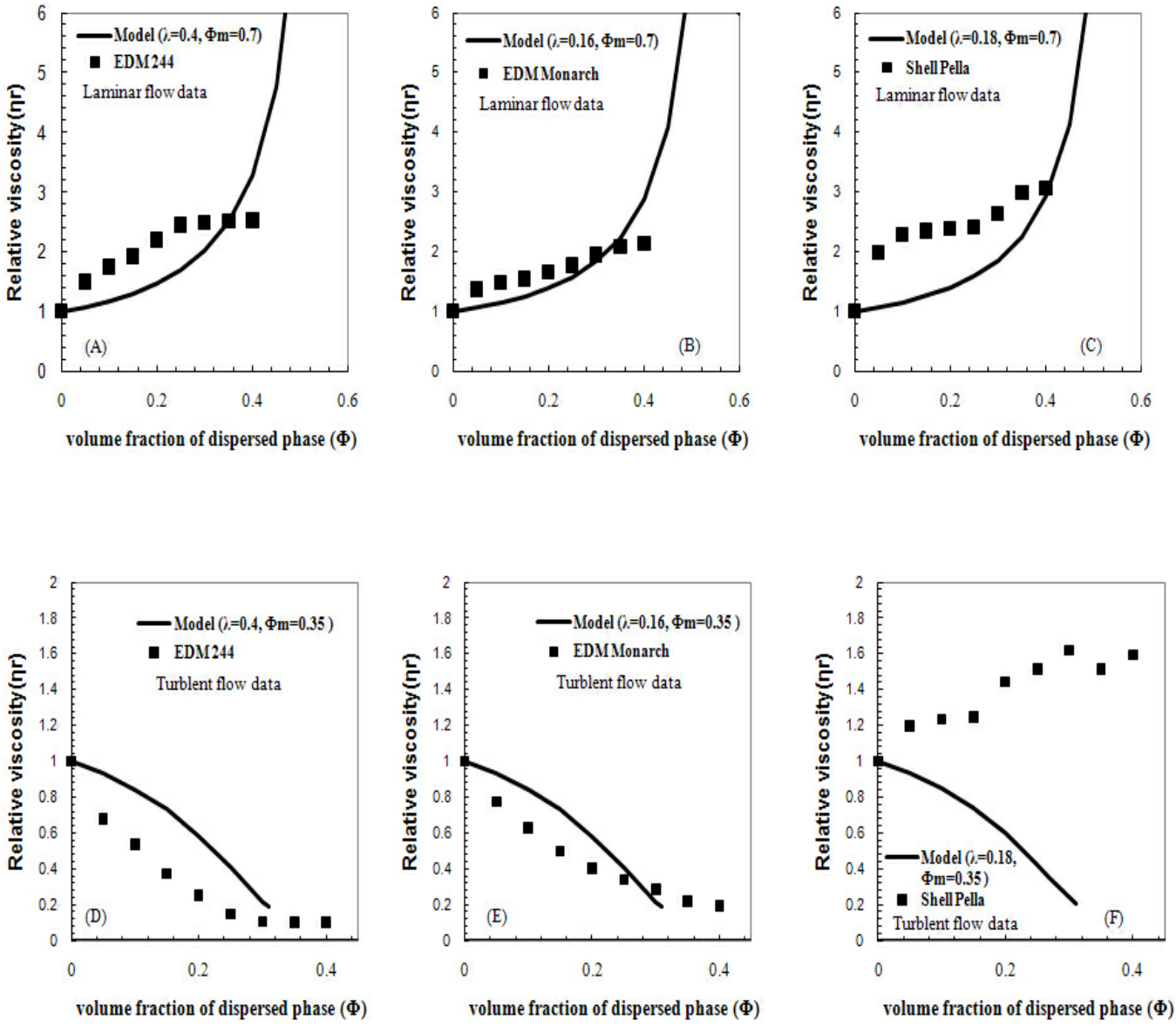

Figure 5.16: Comparison of relative viscosities of water-in-oil emulsions with Pal's Model (A) Laminar data for EDM 244 oil emulsions, (B) Laminar data for EDM Monarch oil emulsions, (C) Laminar data for Shell Pella oil emulsions, (D) Turbulent data for EDM 244 oil emulsions, (E) Turbulent Data for EDM Monarch oil emulsions, (F) Turbulent data for Shell Pella oil emulsions

5.3. Pipeline Flow of Water-in-Oil Emulsions Containing Polymeric Additive

The presence of a polymeric additive in the water droplets of water-in-oil emulsions is found to have a significant effect on the pipeline flow behavior, especially at high Reynolds number. Figures 5.17 (A) and 5.17 (B) show the pipeline data for water-in-EDM 244 oil emulsions containing different amounts of Polyox WSR-303 in the aqueous-phase droplets. The data are shown for two different diameter pipes. The water concentration of the emulsions is fixed at 30% by volume. At high Reynolds numbers, the friction factor of water-in-oil emulsions (with and without polymeric additive) tends to rise resulting in lower drag reduction. The presence of polymeric additive in the water droplets causes the rise in friction factor to occur at a lower Reynolds number. The same behavior is exhibited by other polymers as well (see figure 5.18 (A and B)). Pressure gradient as a function of velocity for 30% water-in-oil emulsion (with and without polymeric additive) is shown in figure 5.19. The pressure gradient increases in the presence of the polymeric additive when comparison is made at the same velocity in the turbulent region. For example, the pressure gradient for a 30% W/O emulsion without polymer additive is 4.5 kPa/m at 5 m/s. At the same velocity (5 m/s), the pressure gradient increases to 8.42 kPa/m when polymer (1% wt POX 303) is added to the dispersed phase.

The lower degree of drag reduction observed in the case of emulsion with polymeric additive could be due to a combination of several factors, namely: increase in droplet viscoelasticity, increase in droplet viscosity, decrease in interfacial tension between oil and aqueous phase, and a decrease in the droplet size. It has been reported in the literature that the presence of viscoelastic polymer in emulsion droplets inhibits the dynamic break-up and coalescence of droplets in turbulent flow (Janssen et al., 1994). The inhibition of break-up/coalescence could result in a decrease in the suppression of turbulence and hence a decrease

in drag reduction. The addition of polymer to the aqueous phase also resulted in an increase in viscosity from 1 mPa.s to 3.6 mPa.s. The interfacial tension between oil and aqueous phase decreased from 40.5 mN/m to 31 mN/m indicating that the polymer was surface active. The addition of polymer also resulted in a decrease in the maximum droplet size (d_{max}) as discussed in section 5.5.

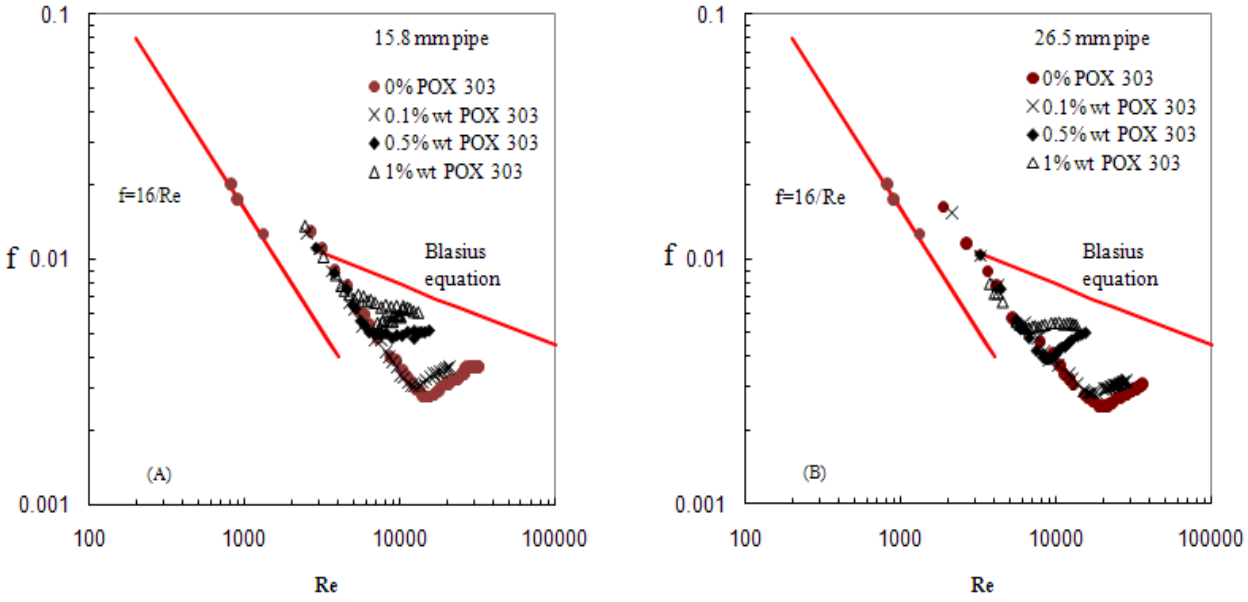

Figure 5.17: The effect of polymer on the pipeline flow behavior of 30% W/O emulsion (the polymer is added to the dispersed aqueous-phase of the emulsion)

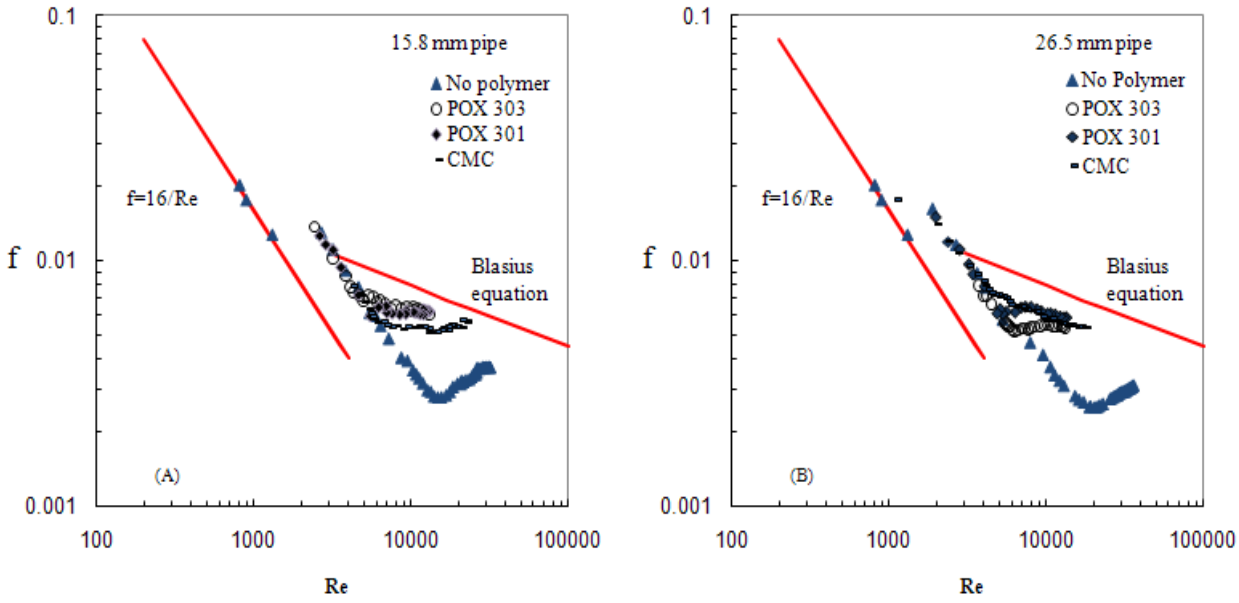

Figure 5.18: The effect of different polymers on the pipeline flow behavior of 30% W/O emulsion (the polymer is added to the dispersed aqueous-phase of the emulsion)

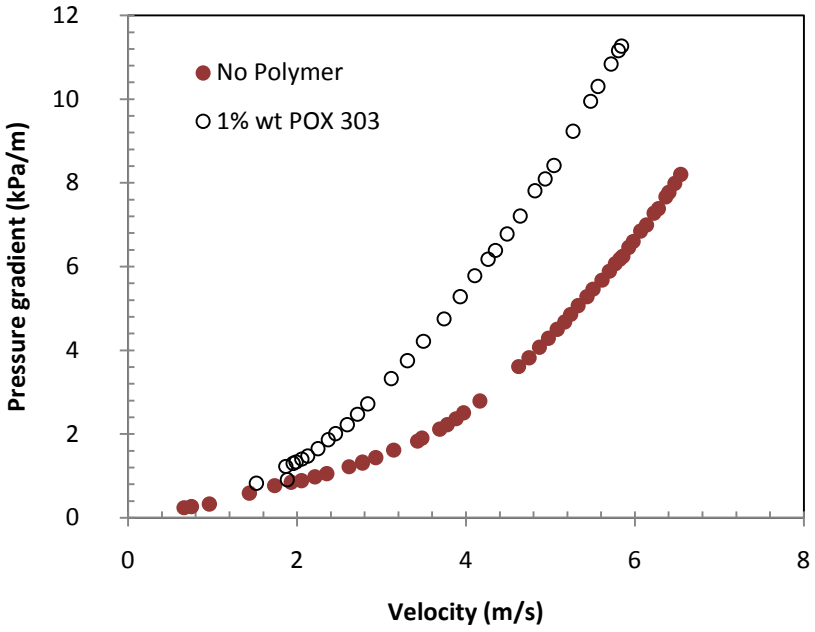

Figure 5.19: Pressure gradient as a function of velocity for 30% water-in-oil emulsion (with and without polymeric additive)

5.4 Pipeline Flow of Emulsions Containing Surfactant

5.4.1 Effect of Surfactant Concentration

The effect of the surfactant on the pipeline flow behavior of water/oil emulsions was studied by adding surfactant (Emsorb-2503) to the oil phase. The interfacial tension between oil and water was reduced from 40.5 mN/m to 5.6 mN/m when surfactant was added at a concentration of 2% wt.

Figure 5.20 shows the pipeline data of 30% by volume water-in-oil emulsions at different surfactant concentrations. In the case where no surfactant is present (figure 5.20-A), the measured friction factor data fall significantly below the Blasius equation for single phase fluids. In the presence of surfactant (surfactant concentration of 0.05% Wt., 0.1% Wt., and 0.5% Wt.), the friction factor increases indicating less drag reduction.

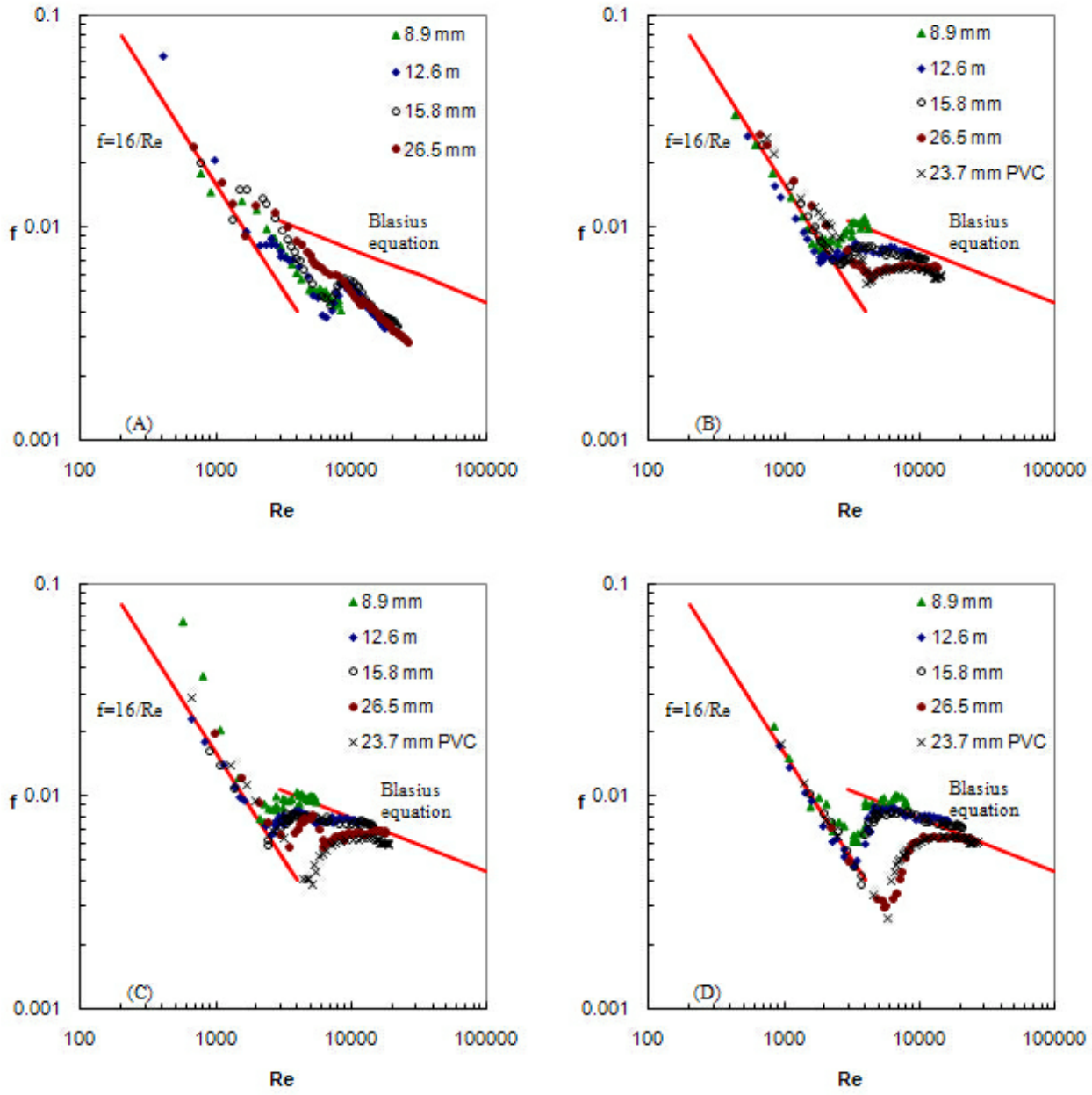

Figure 5.20: Pipeline data for 30% vol. water-in-oil emulsions
(A) No surfactant, (B) 0.05% Wt. surfactant, (C) 0.1% Wt. surfactant, (D) 0.5% Wt. surfactant

At low surfactant concentrations, the measured friction factor is still somewhat less than that expected for single phase fluids. The presence of surfactant at low concentrations does not completely eliminate coalescence and break-up of droplets. At high surfactant concentration, the

friction factor data tend to follow the single phase Blasius equation more closely (see figure 5.21).

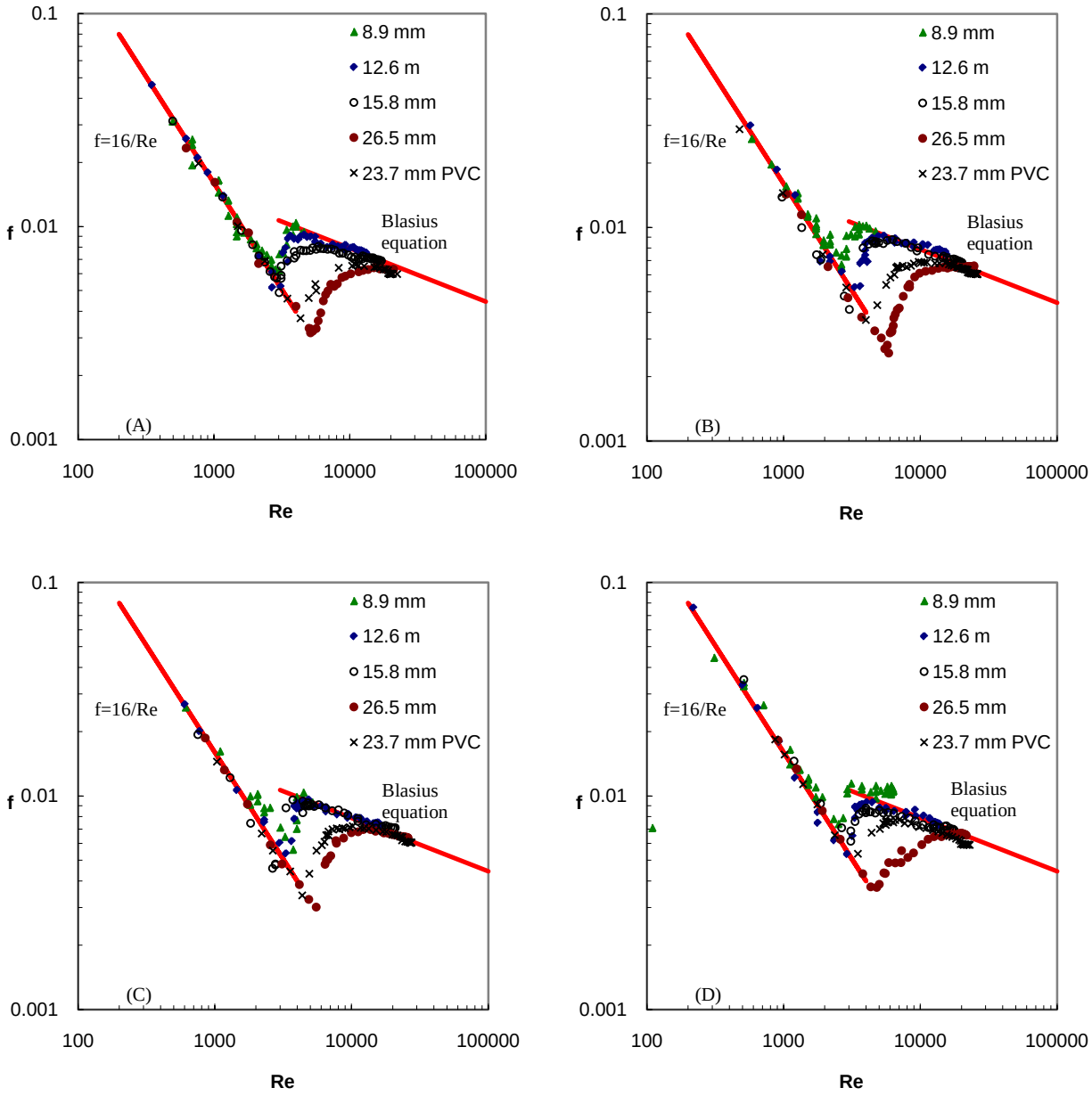

Figure 5.21: Pipeline data for 30% vol. water-in-oil emulsions
(A) 0.75% Wt. surfactant, (B) 1% Wt. surfactant, (C) 1.5% Wt. surfactant, (D) 2% Wt. surfactant

5.4.2 Effect of Dispersed Phase Volume Fraction

The effect of dispersed phase volume fraction on the pipeline flow behavior of emulsions was studied at a fixed surfactant concentration of 2% wt. based on oil phase.

The emulsions were water-in-oil (w/o) type up to a water concentration of 40% by volume. As the water concentration was increased further to 45% by volume, the w/o emulsion inverted to an oil-in-water (o/w) emulsion. This observation was confirmed by measuring the electrical conductance of the emulsions as shown in figure 5.22. Water-in-oil emulsions are expected to have a very low conductance as nonconductive oil forms the continuous phase, whereas oil-in-water emulsions have a high conductance value. As figure 5.22 demonstrates a sudden change in the conductance occurs when inversion of phases takes place.

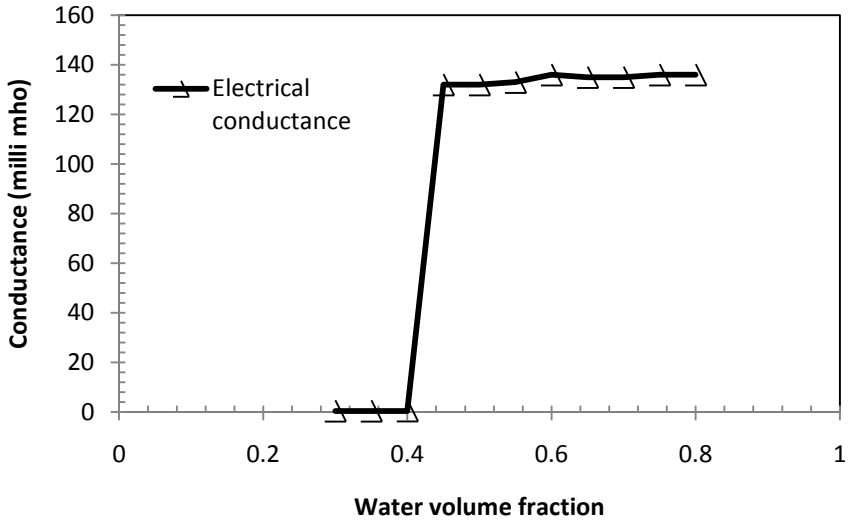

Figure 5.22: Electrical conductance vs. water volume fraction

Figure 5.23 shows the friction factor vs. Reynolds number plots of emulsions before inversion (that is, water-in-oil emulsions). Figures 5.24 and 5.25 show the data for emulsions after inversion (that is, oil-in-water emulsions). From the figures, it can be seen that the

surfactant stabilized emulsions exhibit no drag reduction behavior. In the laminar region the friction factor data from various diameter pipes followed the commonly used equation for single phase flow (Hagen-Poiseuille equation). Also, in turbulent region the friction factor data followed the Blasius equation well. It should be noted that the appearance of all those emulsions was milky (whitish).

The presence of the surfactant in the emulsions makes the dispersed droplets significantly smaller than the scale of turbulence. When the dispersed droplets are significantly smaller than the scale of turbulence, the presence of the dispersed droplets does not affect the turbulence of the continuous phase. Therefore, the stable emulsions show single phase flow behavior, in agreement with the work of Pal (1993).

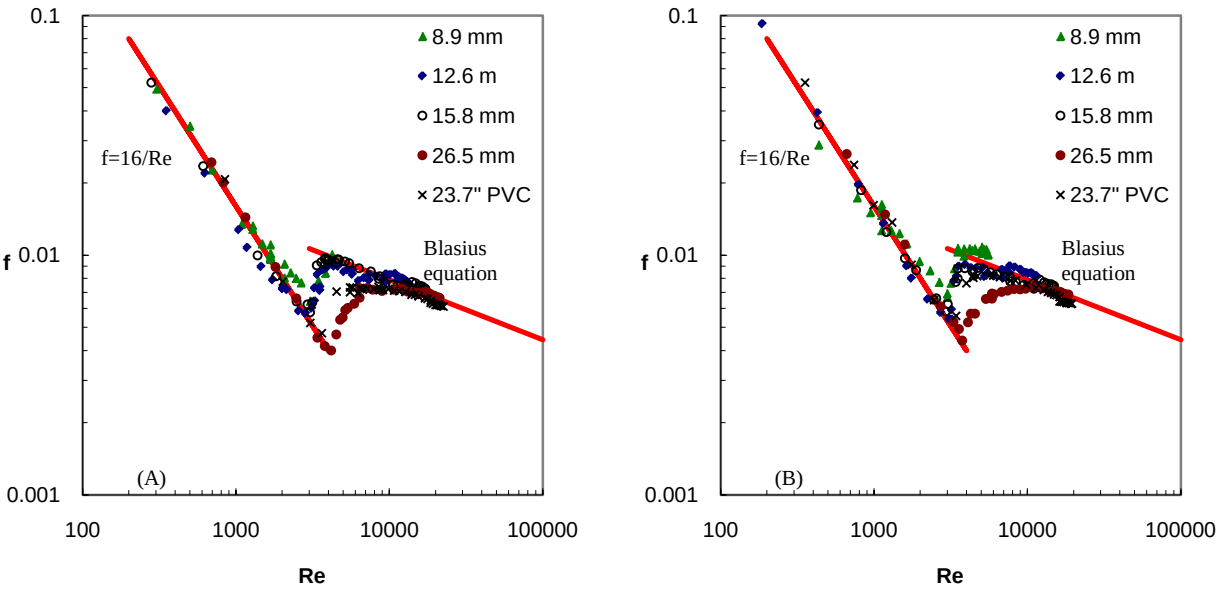

Figure 5.23: Effect of water volume faction on 2% wt surfactant stabilized w/o emulsions (A) 35% vol. water, (B) 40% vol. water,

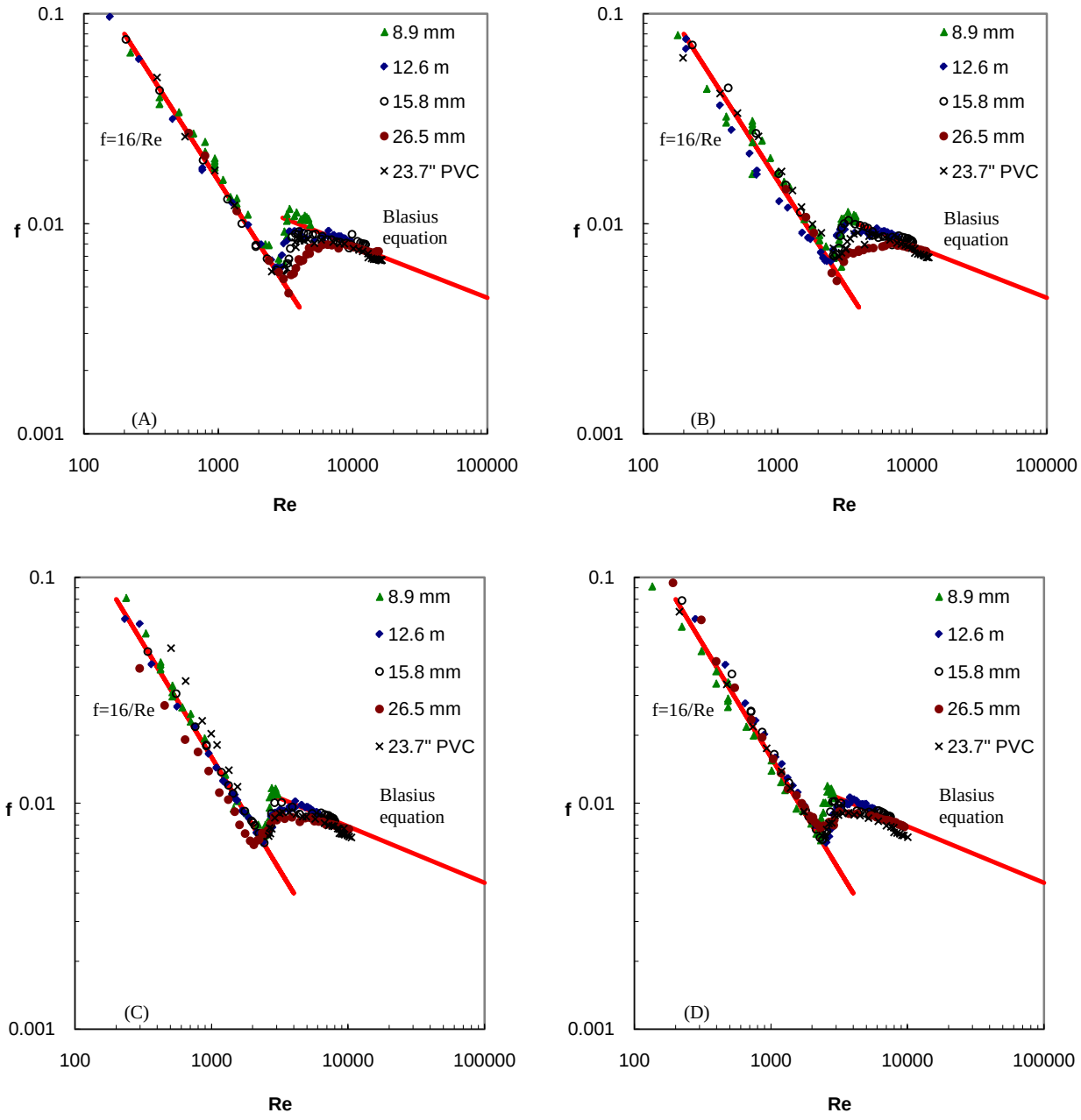

Figure 5.24: Effect of water volume faction on 2% wt surfactant o/w stabilized emulsions (A) 55% vol. oil, (B) 50% vol. oil, (C) 45% vol. oil, (D) 40% vol. oil

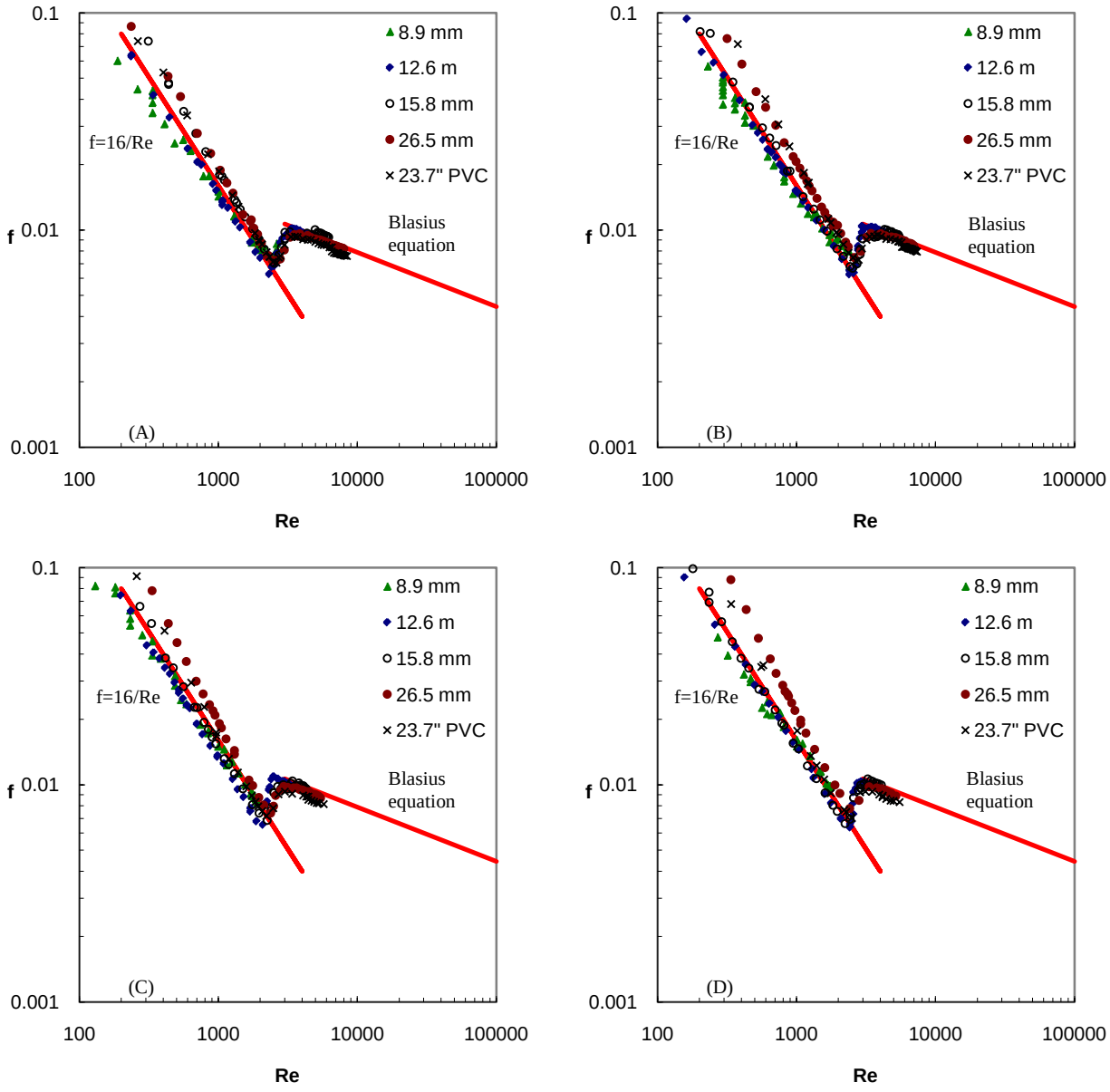

Figure 5.25: Effect of water volume faction on 2% wt surfactant stabilized o/w emulsions (A) 35% vol. oil, (B) 30% vol. oil, (C) 25% vol. oil, (D) 20% vol. oil

5.5. Droplet Size of Emulsions

The droplet size could play an important role. Smaller drops are expected to have lower interaction with the turbulent eddies and hence lower degree of turbulence suppression (less drag reduction). The droplet size also affects the viscosity and rheological behavior of emulsions. In this work, the droplet size was not measured directly. A model developed by Brauner and Ullmann (2002) (equation (3.7)) is used to predict the maximum droplet size (d_{max}) in this work. The model is given as:

$$d_{max} = 2.22 C_H D \left(\frac{\rho_c U_c^2 D}{\sigma}\right)^{-0.6} \left(\frac{\rho_m}{\rho_c (1-\Phi_d)} f\right)^{-0.4} \left(\frac{\Phi_d}{1-\Phi_d}\right)^{0.6} \quad (3.7)$$

The maximum droplet size (d_{max}) is affected by several factors such as: Reynolds number (flow rate), dispersed phase volume fraction, dispersed phase viscosity (in the case of polymeric additives), continuous phase viscosity, and the presence of surface active agents. Figure 5.26 shows the plots of maximum droplet size (d_{max}) against Reynolds number for different systems studied in the present work. The d_{max} decreases with the increase in Reynolds number (flow rate), as shear and turbulence break-up the bigger droplets into smaller ones. At a given Reynolds number, the d_{max} decreases with the increase in the continuous phase viscosity; for instance in the case of EDM-244 emulsions (continuous phase viscosity 2.5 mPa.s), the d_{max} is much larger in comparison with Shell Pella emulsions (continuous phase viscosity 5.4 mPa.s). Although EDM-Monarch emulsions have a higher continuous phase viscosity (6 mPa.s) than the Shell Pella emulsions the data show that the d_{max} in case of Shell Pella emulsions is smaller. This is due to the fact that surface-active additives were present in Shell Pella oil. The presence of surfactant facilitates break-up and reduces coalescence of droplets. Also note that Shell Pella emulsions exhibited negligible drag reduction. The presence of polymeric additive in the

aqueous phase of W/O emulsion also influenced the d_{max} (see figure 5.26 (A)). Lower values of d_{max} are predicted when the polymer is introduced to the dispersed phase. The decrease in the droplet size could be due to factors such as higher viscosity of the dispersed phase and the viscoelastic nature of the polymer or combination of both factors leading to stretching and elongation of the droplets rather than coalescence. The effect of dispersed phase volume fraction on the d_{max} of EDM- 244 emulsions is shown in figure 5.26 (B). As the dispersed phase volume fraction increases the d_{max} increases.

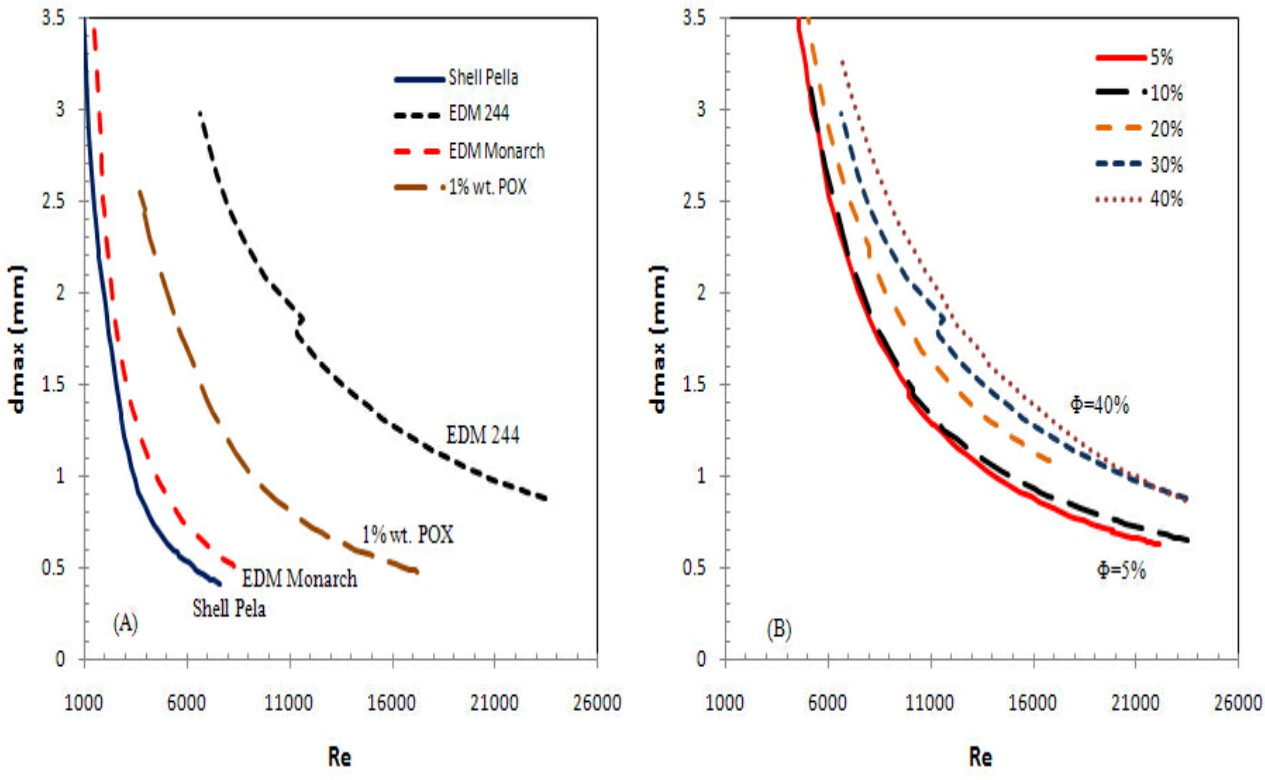

Figure 5.26: Prediction of maximum droplet size for water-in-oil emulsions in 0.0265 m diameter pipe. In figure (A), the volume fraction of water droplets is fixed at 30%. In figure (B), d_{max} is predicted for EDM 244 oil emulsions at different water volume fractions.

The effect of surfactant on the estimated maximum droplet size (d_{max}) is shown in figure 5.27. The figure shows data of estimated (d_{max}) as a function of Reynolds number for 30% water-in-EDM 244 emulsions with and without surfactant in a 0.0265 m diameter pipe. The surfactant concentration is 2% wt. The surfactant is well known for reducing the droplet size; the (d_{max}) was reduced dramatically upon the addition of surfactant. The reduction in (d_{max}) inhibits the dynamic coalescence/break-up processes and therefore, negligible suppression of turbulence.

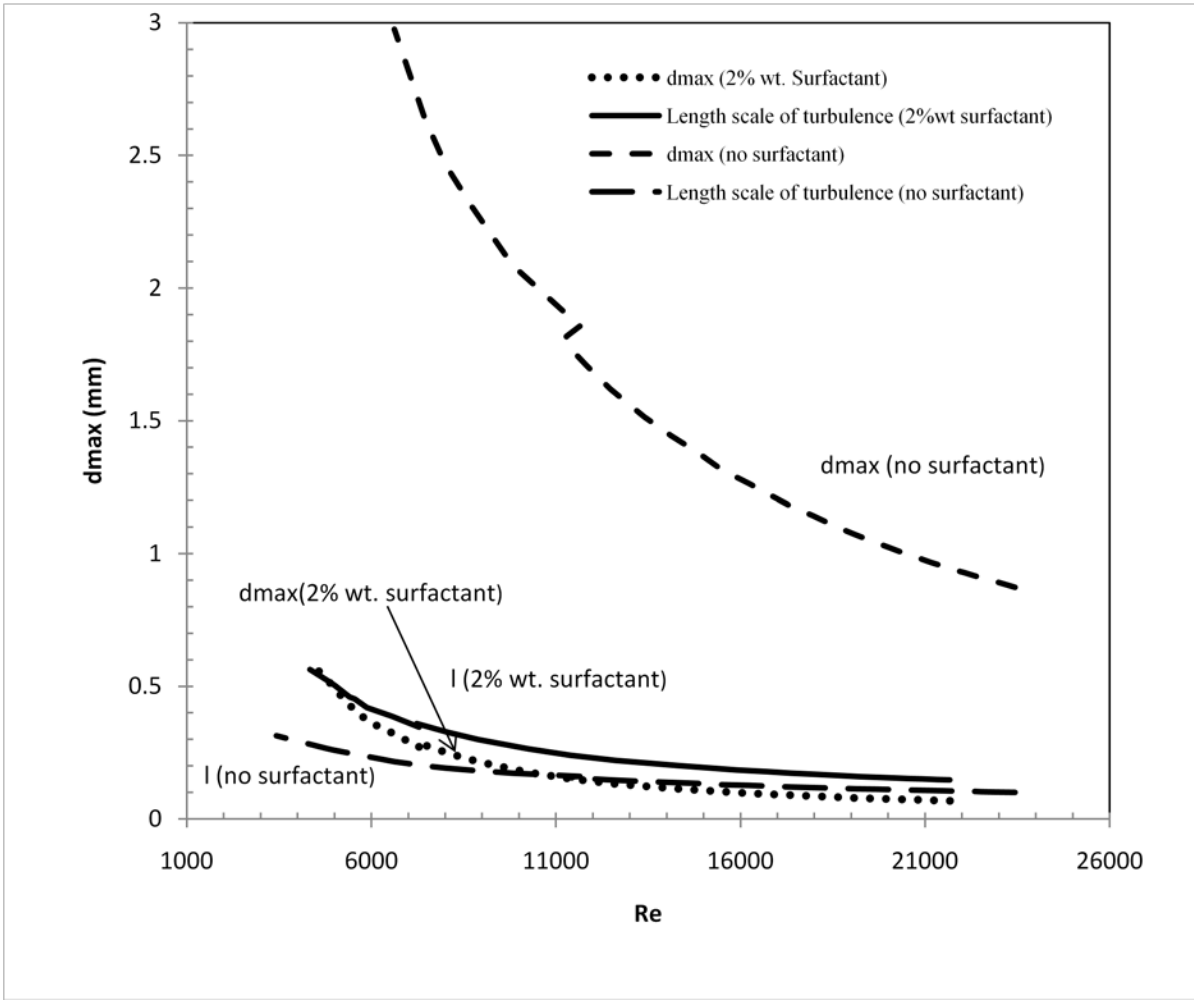

Figure 5.27: The effect of surfactant on estimated d_{max}

The figure also compares d_{max} with the length scale of turbulence (l) evaluated from equation 2.35. In the case of unstable emulsions, d_{max}>>l and therefore, turbulence suppression is

expected. However, the presence of surfactant reduces d_{max} to values lower than the length scale of turbulence; turbulence suppression is expected to be negligible.

Chapter 6 Conclusions and Recommendations

6.1 Conclusions

The main conclusions of this study are as follows:

- The turbulent flow behavior of water-in-oil emulsions in pipelines depends on the stability characteristics of emulsions.
- In the absence of any additives, unstable water-in-oil emulsions exhibit strong drag reduction behavior in turbulent flow. The drag reduction activity of unstable water-in-oil emulsions decreases with the increase in oil viscosity.
- In the presence of surface-active additive in the oil phase, the water-in-oil emulsions produced are stable with respect to coalescence. The stable water-in-oil emulsions exhibit little or no drag reduction.
- The addition of polymer to the dispersed aqueous phase of water-in-oil emulsions has a significant effect on the turbulent drag reduction behavior at high Reynolds number.
- At low surfactant concentrations (less than the critical micelle concentration), the turbulent friction factor of surfactant-stabilized emulsions is still less than that of single phase fluids. A low surfactant concentration does not completely eliminate coalescence of droplets.
- The stable emulsions show no drag reduction and follow the single phase pipeline flow behavior because the dispersed droplets are small, and stable against coalescence, and do not affect the turbulence of the continuous phase.

6.2 Recommendations for Future Work

Based on the results of this study, the following recommendations can be made:

1. The effect of polymer addition to the dispersed phase (aqueous phase) of water-in-oil emulsions on the pipeline flow behavior was studied in this thesis. It was shown that at high Reynolds number the drag reduction decreases when the polymeric additives are presented. It is recommended that further experimental work should be carried out to investigate the behavior of water-in-oil emulsions when polymeric additives are presented in continuous phase (oil phase).
2. It was impossible to study the rheology of unstable water-in-oil emulsions in this thesis due to instability of the emulsion; it is useful to study the rheology of unstable emulsions with and without polymer.
3. Additional experimental measurements are required to quantify the changes in the interfacial shape and the effect of the concentration of the dispersed phase and the polymer during flow.
4. In designing a pipeline system for water/oil emulsions, it is a must to consider the frictional energy loss in pipe elements as well as in straight pipes. Therefore, it is recommended to study the flow behavior of water/oil emulsions (with and without additives) through pipe elements, such as fitting, valves, expansion, and contraction.

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Appendix A Experimental data

1. Single phase experimental data

100% water: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
43757	0.148	3.16	8472.851	0.008256
43119	0.148	3.16	8472.851	0.008136
39833	0.14	2.99	8015.973	0.008397
35452	0.13	2.81	7559.094	0.008404
32010	0.12	2.64	7102.216	0.008596
25282	0.10	2.30	6188.459	0.008942
25381	0.10	2.30	6188.459	0.008977
21909	0.10	2.13	5731.581	0.009034
18872	0.09	1.96	5274.702	0.009188
13665	0.07	1.62	4360.946	0.009733
11322	0.068	1.45	3904.067	0.010062
9065	0.060	1.28	3447.189	0.010334
6635	0.05	1.07	2892.056	0.010746
5420	0.044	0.95	2571.143	0.011107
2556	0.037	0.80	2155.351	0.007455
2531	0.037	0.80	2152.147	0.007404
2049	0.03	0.64	1724.911	0.009331
1883	0.028	0.59	1606.227	0.009887
1808	0.026	0.57	1538.703	0.010346
1750	0.025	0.55	1479.476	0.010831
960	0.014	0.30	813.7288	0.019644

100% water: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
46874	1.11	5.69	100878.4	0.004416
45622	1.106	5.65	100155.5	0.00436
42962	1.04	5.40	95818.02	0.004486
40146	1.02	5.24	92926.39	0.004457
38112	1.00	5.12	90757.66	0.004436
36391	0.97	5.00	88588.93	0.004446
33574	0.93	4.79	84974.39	0.004458
30601	0.89	4.55	80636.94	0.004512
29350	0.86	4.42	78468.21	0.00457
24969	0.79	4.06	71962.03	0.004623
22465	0.75	3.85	68347.48	0.004611
19806	0.69	3.57	63287.12	0.004741
15581	0.61	3.16	56058.03	0.004754
16789	0.61	3.16	56058.03	0.005122
14272	0.55	2.83	50274.76	0.005414
11235	0.48	2.47	43768.58	0.005623
9239	0.43	2.22	39431.13	0.005697
7503	0.39	2.02	35816.59	0.005608
6115	0.34	1.77	31479.13	0.005916
4813	0.30	1.57	27864.59	0.005944
4119	0.27	1.40	24972.95	0.006332
3858	0.264	1.36	24250.04	0.006291
3685	0.25	1.32	23527.13	0.006383
3511	0.25	1.28	22804.23	0.006474
3251	0.24	1.24	22081.32	0.006393
2990	0.23	1.20	21358.41	0.006286
2889	0.22	1.16	20635.5	0.006506
1999	0.18	0.96	17020.95	0.006618
927	0.11	0.59	10514.77	0.008039
345	0.06	0.34	6177.321	0.008668

100% oil: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
63615	0.69	5.55	78453.54	0.004747
61268	0.67	5.42	76640.53	0.004791
58452	0.65	5.29	74827.52	0.004795
51880	0.61	4.97	70294.99	0.004822
48751	0.59	4.78	67575.48	0.004903
45622	0.57	4.59	64855.97	0.004982
39363	0.53	4.26	60323.44	0.004968
36234	0.50	4.07	57603.93	0.005015
31540	0.45	3.69	52164.9	0.005324
31456	0.46	3.75	53071.4	0.005129
27984	0.43	3.49	49445.38	0.005257
20608	0.36	2.92	41286.84	0.005553
15314	0.30	2.47	34941.31	0.005761
11408	0.25	2.08	29502.28	0.00602
9152	0.22	1.83	25876.26	0.006278
5507	0.17	1.38	19530.73	0.006631
5073	0.16	1.31	18624.22	0.006718
4726	0.15	1.25	17717.72	0.006915
2817	0.11	0.93	13185.19	0.007443

100% oil: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
46874	1.11	5.69	100878.4	0.004416
45622	1.10	5.65	100155.5	0.00436
42962	1.05	5.40	95818.02	0.004486
40146	1.02	5.24	92926.39	0.004457
38112	1.00	5.12	90757.66	0.004436
36391	0.97	5.00	88588.93	0.004446
33574	0.93	4.79	84974.39	0.004458
30601	0.89	4.55	80636.94	0.004512
29350	0.86	4.42	78468.21	0.00457
24969	0.79	4.061	71962.03	0.004623
22465	0.75	3.85	68347.48	0.004611
19806	0.69	3.57	63287.12	0.004741
15581	0.61	3.16	56058.03	0.004754
16789	0.61	3.16	56058.03	0.005122
14272	0.55	2.83	50274.76	0.005414
11235	0.48	2.47	43768.58	0.005623
9239	0.43	2.22	39431.13	0.005697
7503	0.39	2.02	35816.59	0.005608
6115	0.34	1.77	31479.13	0.005916
4813	0.30	1.57	27864.59	0.005944
4119	0.27	1.40	24972.95	0.006332
3858	0.26	1.36	24250.04	0.006291
3685	0.25	1.32	23527.13	0.006383
3511	0.25	1.28	22804.23	0.006474
3251	0.24	1.24	22081.32	0.006393
2990	0.23	1.20	21358.41	0.006286
2889	0.22	1.16	20635.5	0.006506
1999	0.18	0.96	17020.95	0.006618
927	0.11	0.59	10514.77	0.008039
345	0.068	0.34	6177.321	0.008668

100% oil: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
13231	1.67	4.02	32153.06	0.005883
12797	1.64	3.95	31539.29	0.005914
12103	1.58	3.81	30465.19	0.005995
11929	1.58	3.81	30465.19	0.005909
11148	1.54	3.72	29697.98	0.005811
10801	1.51	3.64	29084.21	0.00587
10714	1.50	3.62	28930.77	0.005885
10107	1.44	3.49	27856.67	0.005987
10107	1.45	3.50	28010.12	0.005922
9499	1.40	3.37	26936.02	0.006019
8805	1.33	3.22	25708.48	0.006124

8024	1.26	3.04	24327.5	0.006233
8111	1.27	3.06	24480.95	0.006221
7330	1.21	2.93	23406.85	0.00615
6462	1.11	2.68	21412.1	0.006479
5854	1.05	2.54	20338.01	0.006507
5160	0.97	2.35	18803.59	0.006709
4379	0.89	2.14	17115.72	0.006872
3598	0.77	1.87	14967.53	0.007384
2904	0.69	1.68	13433.11	0.007398
2643	0.65	1.58	12665.9	0.007575
2540	0.65	1.56	12512.46	0.007458
2116	0.58	1.41	11284.92	0.007639
2091	0.57	1.39	11131.48	0.007758
1675	0.51	1.24	9903.939	0.007852
1176	0.41	1.01	8062.633	0.00832
993	0.37	0.91	7295.422	0.008582
885	0.35	0.85	6835.096	0.008713
818	0.33	0.81	6528.211	0.008834
652	0.29	0.72	5761.001	0.00904
685	0.30	0.74	5914.443	0.009014
569	0.27	0.66	5300.674	0.009318
141	0.21	0.51	4073.137	0.003915
145	0.21	0.52	4226.579	0.003743
104	0.14	0.35	2845.599	0.005944

2. Emulsions experimental data

5% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
49769	0.164	3.446	6291.292	0.007775
47343	0.164	3.446	6291.292	0.007397
46874	0.156	3.278	5985.073	0.008092
46718	0.164	3.446	6291.292	0.007299
46248	0.156	3.278	5985.073	0.007984
44214	0.156	3.278	5985.073	0.007633
42337	0.148	3.110	5678.855	0.008118
42493	0.156	3.278	5985.073	0.007335
40459	0.156	3.278	5985.073	0.006984
35609	0.148	3.110	5678.855	0.006828
32949	0.140	2.942	5372.636	0.007059
32949	0.132	2.775	5066.417	0.007938
30758	0.132	2.775	5066.417	0.00741
32237	0.132	2.775	5066.417	0.007766
28332	0.124	2.607	4760.198	0.007732
25468	0.116	2.439	4453.98	0.007939
25381	0.116	2.439	4453.98	0.007912
21910	0.108	2.272	4147.761	0.007875
21736	0.108	2.272	4147.761	0.007813
18872	0.100	2.104	3841.542	0.007908
18786	0.100	2.104	3841.542	0.007872
16790	0.084	1.768	3229.105	0.009957
16703	0.084	1.768	3229.105	0.009905
16616	0.092	1.936	3535.323	0.008221
12797	0.084	1.768	3229.105	0.007589
10715	0.068	1.433	2616.667	0.009677
10715	0.076	1.601	2922.886	0.007755
8545	0.068	1.433	2616.667	0.007717
8458	0.068	1.433	2616.667	0.007639
6723	0.060	1.265	2310.448	0.007787
4727	0.043	0.900	1643.279	0.010823
3251	0.038	0.797	1456.15	0.009482
3347	0.038	0.806	1471.76	0.009554
2366	0.030	0.633	1156.72	0.010933
2133	0.027	0.577	1052.819	0.011898
1983	0.025	0.527	962.8402	0.013228

5% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
55677	0.515	5.401	13961	0.005728
55781	0.515	5.401	13961	0.005738
55470	0.507	5.317	13745	0.005887
53289	0.507	5.317	13745	0.005656
51881	0.499	5.233	13528	0.005684
51255	0.491	5.150	13312	0.005799
49534	0.483	5.066	13096	0.005791
48126	0.475	4.982	12879	0.005817
46405	0.459	4.815	12447	0.006006
46405	0.467	4.899	12663	0.005802
44058	0.451	4.731	12231	0.005905
41554	0.435	4.564	11798	0.005986
39051	0.420	4.397	11365	0.006062
36704	0.412	4.313	11149	0.00592
32949	0.388	4.062	10500	0.005992
32237	0.372	3.895	10068	0.006377
29026	0.356	3.727	9635	0.006269
26770	0.332	3.476	8986	0.006647
23212	0.308	3.225	8337	0.006696
26509	0.324	3.393	8770	0.006911
24253	0.308	3.225	8337	0.006996
21389	0.292	3.058	7905	0.006864
19046	0.268	2.807	7256	0.007254
17223	0.260	2.723	7039	0.006969
15054	0.236	2.472	6391	0.007391
13579	0.220	2.305	5958	0.00767
12190	0.212	2.221	5742	0.007414
10888	0.204	2.137	5525	0.007151
10801	0.196	2.054	5309	0.007684
9934	0.188	1.970	5093	0.007679
8719	0.172	1.803	4660	0.00805
7764	0.164	1.719	4444	0.007883
6462	0.148	1.552	4011	0.008053
5421	0.140	1.468	3795	0.007547
4206	0.116	1.217	3146	0.00852
4032	0.108	1.133	2930	0.009419
3338	0.100	1.050	2713	0.00909
2817	0.084	0.882	2281	0.010858
2690	0.092	0.966	2497	0.008649
2690	0.084	0.882	2281	0.010367
2033	0.076	0.799	2065	0.009563
1185	0.068	0.715	1848	0.006954
811	0.060	0.631	1632	0.006103
678	0.027	0.285	737	0.025047
478	0.012	0.127	327	0.089422

5% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
39364	0.803	5.350	17343.05	0.005478
39207	0.795	5.297	17170.56	0.005566
38269	0.779	5.191	16825.58	0.005658
37173	0.771	5.137	16653.09	0.00561
35765	0.747	4.978	16135.62	0.005749
34670	0.739	4.925	15963.13	0.005695
34826	0.747	4.978	16135.62	0.005599
33575	0.723	4.818	15618.15	0.005761
32480	0.715	4.765	15445.66	0.005698
32064	0.691	4.605	14928.19	0.006022
31109	0.675	4.499	14583.21	0.006122
28939	0.651	4.339	14065.74	0.006122
27117	0.627	4.180	13548.27	0.006183
25121	0.603	4.020	13030.8	0.006192

22778	0.571	3.807	12340.84	0.00626
21042	0.547	3.647	11823.36	0.0063
19653	0.523	3.488	11305.89	0.006435
17831	0.499	3.328	10788.42	0.006412
16356	0.467	3.115	10098.46	0.006713
14707	0.443	2.956	9580.99	0.006706
13839	0.435	2.902	9408.5	0.006543
13145	0.412	2.743	8891.029	0.00696
12277	0.396	2.636	8546.048	0.007035
10541	0.364	2.424	7856.087	0.007148
9586	0.348	2.317	7511.107	0.007112
8545	0.316	2.104	6821.145	0.007687
7938	0.308	2.051	6648.655	0.007516
7156	0.284	1.891	6131.184	0.007968
7156	0.292	1.945	6303.674	0.007538
6549	0.276	1.838	5958.694	0.00772
5681	0.252	1.679	5441.223	0.008031
5074	0.236	1.572	5096.242	0.008176
4206	0.212	1.413	4578.771	0.008396
3859	0.196	1.306	4233.79	0.00901
2873	0.164	1.093	3543.829	0.009574
2873	0.172	1.146	3716.32	0.008706
2607	0.164	1.093	3543.829	0.008687
2432	0.156	1.040	3371.339	0.008956
1958	0.140	0.934	3026.358	0.008948
1492	0.116	0.774	2508.887	0.009924
944	0.084	0.561	1818.926	0.011938
638	0.068	0.455	1473.945	0.012287
396	0.036	0.242	783.9841	0.026997
241	0.022	0.150	484.8254	0.042969

5% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
11582	1.721	4.077	22167	0.004947
11409	1.705	4.039	21962	0.004964
11235	1.689	4.002	21756	0.004982
11062	1.673	3.964	21550	0.004999
10801	1.641	3.888	21139	0.005073
10541	1.617	3.831	20830	0.005098
10281	1.593	3.775	20522	0.005123
9847	1.537	3.642	19802	0.00527
9500	1.513	3.585	19493	0.005247
9066	1.465	3.472	18876	0.00534
8719	1.433	3.396	18465	0.005366
8371	1.402	3.321	18054	0.00539
7590	1.322	3.131	17025	0.005496
7156	1.266	2.999	16305	0.005649
6809	1.234	2.923	15894	0.005657
6549	1.194	2.829	15380	0.005811
6115	1.146	2.715	14763	0.005889
5421	1.066	2.526	13734	0.006031
5074	1.026	2.432	13220	0.006093
4727	0.986	2.337	12706	0.006144
4553	0.954	2.261	12294	0.006321
4293	0.923	2.186	11883	0.00638
3859	0.859	2.034	11060	0.00662
3598	0.819	1.940	10546	0.00679
3081	0.771	1.826	9929	0.006558
3089	0.779	1.845	10032	0.006442
2840	0.739	1.751	9518	0.006579
2374	0.659	1.561	8489	0.006913
2116	0.619	1.467	7975	0.006983
1858	0.579	1.372	7461	0.007007
1626	0.539	1.278	6947	0.00707
1293	0.467	1.107	6021	0.007485
1152	0.443	1.051	5712	0.007406
985	0.404	0.956	5198	0.007652
935	0.396	0.937	5095	0.007561
894	0.388	0.918	4993	0.007526
861	0.380	0.899	4890	0.007554
827	0.372	0.880	4787	0.007577
761	0.356	0.843	4581	0.007607
728	0.340	0.805	4375	0.007975
686	0.324	0.767	4170	0.008279
611	0.300	0.710	3861	0.008602
376	0.268	0.635	3450	0.006079
293	0.228	0.540	2936	0.007136

10% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
47903	0.17	3.56	6651.004	0.006914
44997	0.17	3.56	6651.004	0.006495
45935	0.17	3.56	6651.004	0.00663
44371	0.17	3.56	6651.004	0.006404
43275	0.16	3.39	6342.303	0.006869
41867	0.16	3.39	6342.303	0.006646
40929	0.16	3.23	6033.601	0.007178
40459	0.16	3.23	6033.601	0.007096
38269	0.16	3.23	6033.601	0.006712
35296	0.14	2.90	5416.198	0.007682
33105	0.13	2.73	5107.496	0.008103
33888	0.14	2.90	5416.198	0.007376
26534	0.12	2.40	4490.093	0.008403
26690	0.12	2.57	4798.795	0.0074
25752	0.12	2.57	4798.795	0.00714
26377	0.12	2.57	4798.795	0.007314
18711	0.10	2.07	3872.69	0.007966
20261	0.10	2.07	3872.69	0.008626
16442	0.09	1.91	3563.988	0.008265
16008	0.08	1.74	3255.286	0.009646
14360	0.08	1.74	3255.286	0.008652
11149	0.07	1.41	2637.883	0.01023
11062	0.08	1.58	2946.585	0.008135
8979	0.06	1.25	2329.182	0.010568
9066	0.07	1.41	2637.883	0.008319
7070	0.05	1.08	2020.48	0.011057
5594	0.04	0.92	1725.93	0.011991
3425	0.04	0.80	1489.764	0.009853
2383	0.03	0.61	1141.817	0.011672
2291	0.03	0.59	1107.687	0.011921
1883	0.02	0.50	926.3017	0.014014
1709	0.02	0.43	811.944	0.016549
1842	0.02	0.43	797.3979	0.018494

10% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
55574	0.56	5.73	15164.39	0.005003
53446	0.56	5.81	15382.44	0.004676
53289	0.56	5.73	15164.39	0.004798
53133	0.56	5.73	15164.39	0.004783
52194	0.55	5.65	14946.34	0.004837
51412	0.54	5.56	14728.28	0.004907
49847	0.53	5.48	14510.23	0.004901
48595	0.52	5.40	14292.18	0.004925
46874	0.51	5.23	13856.08	0.005055
44527	0.50	5.15	13638.03	0.004956
42493	0.48	4.90	12983.88	0.005218
40929	0.47	4.82	12765.82	0.005199
37956	0.44	4.57	12111.67	0.005357
37643	0.44	4.57	12111.67	0.005313
36235	0.44	4.49	11893.62	0.005303

34044	0.41	4.24	11239.47	0.005579
29976	0.38	3.92	10367.26	0.005774
31283	0.38	3.92	10367.26	0.006026
27811	0.36	3.67	9713.108	0.006103
25728	0.34	3.50	9277.006	0.006189
24253	0.32	3.34	8840.903	0.006424
21997	0.31	3.17	8404.801	0.006447
19827	0.29	3.01	7968.699	0.006464
16876	0.26	2.68	7096.494	0.006938
14533	0.24	2.52	6660.392	0.006783
13058	0.22	2.27	6006.239	0.007494
11149	0.20	2.10	5570.136	0.007439
9847	0.19	1.94	5134.034	0.007734
7677	0.16	1.69	4479.881	0.00792
6723	0.15	1.53	4043.778	0.008511
5594	0.13	1.36	3607.676	0.008899
4553	0.12	1.28	3389.625	0.008204
4119	0.12	1.20	3171.574	0.008478
3685	0.11	1.12	2953.522	0.008746
3598	0.10	1.03	2735.471	0.009956
3512	0.11	1.12	2953.522	0.008334
3425	0.11	1.12	2953.522	0.008128
3338	0.10	1.03	2735.471	0.009235
3022	0.09	0.95	2517.42	0.009874
2382	0.08	0.87	2299.369	0.009328
1609	0.07	0.70	1863.267	0.009594
1567	0.07	0.70	1863.267	0.009346
694	0.02	0.20	537.2659	0.049793
470	0.00	0.05	120.4898	0.669869

10% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
39299	0.84	5.53	18353.12	0.00505
38895	0.83	5.48	18179.23	0.005086
38269	0.82	5.37	17831.45	0.005201
36860	0.80	5.27	17483.67	0.005211
36078	0.79	5.21	17309.79	0.005204
34826	0.78	5.11	16962.01	0.005231
33418	0.76	5.00	16614.23	0.005232
32167	0.75	4.90	16266.45	0.005254
32498	0.73	4.79	15918.67	0.005542
30935	0.71	4.64	15397.01	0.005639
29720	0.69	4.53	15049.23	0.005671
27898	0.66	4.32	14353.67	0.005852
25728	0.64	4.17	13832.01	0.005812
24079	0.61	4.01	13310.34	0.005874
22170	0.59	3.85	12788.67	0.005858
20087	0.55	3.59	11919.23	0.006111
18699	0.53	3.49	11571.45	0.006035
18612	0.52	3.43	11397.56	0.006192
17137	0.50	3.28	10875.9	0.006261
15575	0.48	3.12	10354.23	0.006278
14012	0.44	2.91	9658.674	0.006491
12711	0.42	2.75	9137.007	0.00658
11756	0.40	2.59	8615.341	0.006845
9934	0.36	2.39	7919.785	0.006844
8371	0.32	2.12	7050.341	0.007278
7764	0.32	2.07	6876.452	0.007096
7070	0.30	1.97	6528.674	0.007168
6115	0.28	1.81	6007.007	0.007324
5594	0.26	1.70	5659.23	0.007549
4640	0.24	1.55	5137.563	0.007597
4032	0.21	1.39	4615.896	0.008179
3512	0.20	1.29	4268.118	0.008331
3338	0.19	1.23	4094.23	0.008606
2357	0.17	1.13	3746.452	0.007258
2257	0.16	1.08	3572.563	0.007644
2108	0.15	0.97	3224.785	0.00876
1759	0.14	0.92	3050.896	0.008165
1310	0.12	0.76	2529.23	0.008847
1177	0.11	0.71	2355.341	0.009165
719	0.08	0.50	1659.785	0.011282
678	0.07	0.45	1485.896	0.013264
453	0.04	0.29	964.2296	0.021062
594	0.06	0.40	1312.007	0.014925

10% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
9934	1.81	4.22	23487.55	0.003902
9760	1.78	4.16	23176.52	0.003937
9673	1.76	4.11	22865.49	0.004009
9239	1.73	4.03	22450.78	0.003972
9153	1.69	3.94	21932.39	0.004123
8892	1.67	3.90	21725.04	0.004083
8632	1.64	3.83	21310.33	0.004119
8371	1.61	3.75	20895.62	0.004155
8198	1.58	3.68	20480.91	0.004235
8024	1.55	3.60	20066.2	0.004318
7764	1.51	3.53	19651.49	0.004357
7417	1.45	3.38	18822.08	0.004537
7070	1.41	3.29	18303.69	0.004573
6636	1.34	3.12	17370.6	0.004766
6375	1.29	3.01	16748.53	0.004925
5942	1.23	2.88	16022.79	0.005015
5681	1.19	2.77	15400.73	0.00519
5160	1.11	2.58	14363.96	0.00542
4813	1.05	2.45	13638.22	0.005608
4640	1.03	2.39	13327.19	0.005661
4379	0.99	2.30	12808.8	0.005784
4119	0.95	2.21	12290.42	0.005909
3945	0.90	2.10	11668.35	0.00628
3685	0.87	2.04	11357.32	0.006191
3425	0.83	1.93	10735.26	0.00644
2765	0.75	1.74	9698.488	0.006369
2482	0.70	1.63	9076.425	0.006529
2266	0.67	1.56	8661.717	0.006544
2116	0.64	1.48	8247.008	0.006742
1842	0.60	1.39	7728.622	0.006681
1576	0.54	1.26	7002.882	0.006962
1351	0.50	1.16	6484.497	0.006963
1152	0.45	1.05	5862.434	0.007261
1035	0.43	1.00	5551.402	0.007279
952	0.41	0.96	5344.048	0.007224
885	0.40	0.92	5136.694	0.007272
861	0.39	0.90	5033.017	0.007362
836	0.38	0.89	4929.339	0.007452
777	0.37	0.87	4825.662	0.007234
761	0.36	0.83	4618.308	0.007729
711	0.34	0.79	4410.954	0.007917
644	0.32	0.75	4203.599	0.007902
545	0.30	0.70	3892.568	0.007788
420	0.24	0.57	3166.828	0.009072
224	0.17	0.40	2233.734	0.009732

15% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44684	0.19	3.83	5602.731	0.005486
42337	0.17	3.50	5126.816	0.006207
41867	0.17	3.50	5126.816	0.006138
40929	0.16	3.34	4888.858	0.006599
39833	0.16	3.34	4888.858	0.006422
38582	0.16	3.18	4650.901	0.006873

37173	0.15	3.01	4412.943	0.007356
35922	0.15	3.01	4412.943	0.007108
33262	0.14	2.85	4174.986	0.007354
34320	0.15	3.01	4412.943	0.006791
32324	0.14	2.85	4174.986	0.007146
28679	0.13	2.69	3937.028	0.00713
28679	0.14	2.85	4174.986	0.00634
27030	0.12	2.53	3699.071	0.007613
27117	0.13	2.69	3937.028	0.006742
24427	0.12	2.36	3461.113	0.007858
23298	0.12	2.53	3699.071	0.006562
21736	0.12	2.36	3461.113	0.006992
19480	0.11	2.20	3223.156	0.007226
16616	0.10	2.04	2985.198	0.007185
15488	0.09	1.88	2747.241	0.007908
14620	0.09	1.88	2747.241	0.007465
12450	0.09	1.88	2747.241	0.006357
11062	0.08	1.55	2271.326	0.008263
9847	0.08	1.71	2509.283	0.006026
9066	0.07	1.39	2033.368	0.00845
8719	0.08	1.55	2271.326	0.006513
8632	0.07	1.39	2033.368	0.008045
7590	0.06	1.14	1669.041	0.0105
2210	0.03	0.59	856.6947	0.011603
2091	0.03	0.53	769.9344	0.013594
1692	0.02	0.43	636.5006	0.016095

15% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
54952	0.60	6.04	12529.62	0.004374
52663	0.59	5.96	12361.54	0.004306
51881	0.58	5.88	12193.46	0.00436
51412	0.57	5.80	12025.38	0.004442
50003	0.56	5.72	11857.3	0.004444
49065	0.56	5.64	11689.21	0.004487
48126	0.55	5.56	11521.13	0.00453
46561	0.53	5.40	11184.97	0.00465
45309	0.52	5.31	11016.89	0.004665
44214	0.52	5.23	10848.81	0.004694
42180	0.50	5.07	10512.65	0.004769
40616	0.49	4.99	10344.57	0.004743
39520	0.48	4.91	10176.48	0.004768
38269	0.47	4.75	9840.323	0.004938
36235	0.45	4.58	9504.161	0.005012
32949	0.42	4.26	8831.836	0.005278
31697	0.41	4.18	8663.755	0.005277
33018	0.40	4.10	8495.674	0.005716
31196	0.39	3.94	8159.512	0.005855
29720	0.38	3.85	7991.431	0.005815
26683	0.36	3.61	7487.187	0.005948
25208	0.34	3.45	7151.025	0.006159
22604	0.32	3.21	6646.782	0.006393
20782	0.30	3.04	6310.62	0.00652
18872	0.28	2.88	5974.458	0.006607
16703	0.27	2.72	5638.295	0.006565
14967	0.25	2.56	5302.133	0.006652
12537	0.23	2.31	4797.89	0.006805
10194	0.20	2.07	4293.647	0.006909
7070	0.17	1.75	3621.322	0.006736
5942	0.16	1.67	3453.241	0.006226
5421	0.15	1.50	3117.079	0.006971
4727	0.14	1.42	2948.998	0.006791
4032	0.12	1.26	2612.836	0.00738
3772	0.12	1.18	2444.755	0.007886
3425	0.11	1.10	2276.674	0.008256
3251	0.10	1.02	2108.592	0.009137
2956	0.11	1.10	2276.674	0.007126
2748	0.09	0.94	1940.511	0.009119
2208	0.08	0.85	1772.43	0.008781
1850	0.08	0.77	1604.349	0.008981
1551	0.07	0.69	1436.268	0.009393
1118	0.06	0.61	1268.187	0.008688
1052	0.04	0.41	842.0896	0.018534

15% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
37956	0.90	5.80	15085.47	0.00435
37799	0.89	5.75	14951.43	0.00441
37486	0.88	5.70	14817.39	0.004453
37017	0.87	5.65	14683.35	0.004478
36704	0.87	5.60	14549.31	0.004523
36078	0.86	5.55	14415.27	0.004529
35452	0.84	5.44	14147.2	0.00462
34670	0.83	5.34	13879.12	0.004695
33418	0.81	5.24	13611.04	0.004705
32323	0.79	5.13	13342.96	0.004736
30446	0.76	4.93	12806.8	0.004842
29194	0.74	4.77	12404.68	0.004949
27638	0.69	4.46	11600.45	0.005357
26075	0.67	4.31	11198.33	0.005424
23732	0.63	4.05	10528.13	0.005585
21910	0.60	3.84	9991.976	0.005724
20261	0.57	3.69	9589.858	0.005746
18178	0.53	3.43	8919.661	0.00596
15922	0.49	3.17	8249.464	0.006102
14620	0.47	3.02	7847.346	0.006192
13579	0.44	2.86	7445.228	0.006389
11930	0.41	2.66	6909.071	0.006519
10454	0.38	2.45	6372.913	0.006714
9066	0.36	2.30	5970.795	0.006633
7938	0.33	2.14	5568.677	0.006676
5681	0.28	1.78	4630.402	0.006911
4900	0.26	1.68	4362.323	0.006716
4206	0.24	1.52	3960.205	0.006995
3425	0.21	1.37	3558.087	0.007056
3164	0.20	1.32	3424.047	0.00704
2781	0.20	1.27	3290.008	0.006702
2391	0.17	1.11	2887.89	0.007476
2316	0.16	1.06	2753.851	0.007965
2108	0.15	0.96	2485.772	0.008898
1917	0.14	0.90	2351.733	0.009039
1850	0.12	0.80	2083.654	0.011115
1601	0.11	0.70	1815.575	0.012665
1476	0.09	0.60	1547.496	0.016075
1035	0.08	0.49	1279.418	0.016495
1160	0.08	0.54	1413.457	0.015143
786	0.07	0.44	1145.378	0.015622
511	0.04	0.26	671.5398	0.029574
387	0.03	0.18	471.8407	0.045292

15% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
9239	1.86	4.26	18584.49	0.003499
8892	1.82	4.17	18184.9	0.003517
8805	1.79	4.12	17945.15	0.003576
8545	1.76	4.04	17625.48	0.003597
8111	1.71	3.93	17145.97	0.003608
7938	1.67	3.84	16746.38	0.003702
7677	1.63	3.75	16346.79	0.003757
7417	1.60	3.68	16027.12	0.003776
7156	1.55	3.57	15547.62	0.003872
6723	1.50	3.44	14988.19	0.003914

6462	1.45	3.33	14508.68	0.004015
6115	1.40	3.22	14029.18	0.004063
5855	1.36	3.13	13629.59	0.004122
5594	1.31	3.00	13070.16	0.004283
5247	1.25	2.87	12510.74	0.004385
5074	1.22	2.80	12191.07	0.004465
4553	1.14	2.61	11391.89	0.004588
4379	1.08	2.48	10832.47	0.004881
4119	1.03	2.36	10273.04	0.005105
3772	0.96	2.21	9633.699	0.005315
3512	0.91	2.08	9074.274	0.005577
3251	0.87	1.99	8674.685	0.005651
3078	0.82	1.88	8195.178	0.005993
2817	0.77	1.77	7715.671	0.006189
2557	0.73	1.68	7316.082	0.006248
2383	0.69	1.59	6916.493	0.006516
2210	0.65	1.49	6516.904	0.006805
1833	0.62	1.42	6197.233	0.006243
1626	0.57	1.31	5717.726	0.006503
1310	0.50	1.15	4998.466	0.006855
1143	0.47	1.07	4678.795	0.00683
1010	0.44	1.00	4359.124	0.006953
935	0.43	0.98	4279.206	0.006681
894	0.41	0.94	4119.37	0.006889
869	0.40	0.93	4039.453	0.006964
827	0.40	0.91	3959.535	0.006901
752	0.38	0.87	3799.699	0.006816
711	0.37	0.85	3719.781	0.006719
661	0.36	0.83	3639.864	0.006525
603	0.34	0.78	3400.11	0.006819
553	0.31	0.71	3080.439	0.00762
478	0.28	0.63	2760.768	0.008203
420	0.23	0.52	2281.261	0.010551

20% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
45519	0.20	4.09	5305	0.004821
43275	0.20	3.93	5097.328	0.004964
42180	0.19	3.77	4889.656	0.005259
40929	0.19	3.77	4889.656	0.005102
37643	0.17	3.45	4474.312	0.005605
36548	0.17	3.45	4474.312	0.005441
34983	0.16	3.29	4266.64	0.005728
33418	0.16	3.29	4266.64	0.005472
34233	0.16	3.29	4266.64	0.005605
32931	0.16	3.13	4058.968	0.005958
32150	0.16	3.13	4058.968	0.005817
30501	0.15	2.97	3851.296	0.006129
28158	0.15	2.97	3851.296	0.005659
27377	0.14	2.81	3643.624	0.006147
25989	0.14	2.81	3643.624	0.005835
24513	0.13	2.65	3435.952	0.006189
23212	0.12	2.49	3228.28	0.006639
21823	0.12	2.49	3228.28	0.006241
20261	0.12	2.33	3020.608	0.006619
17657	0.11	2.17	2812.936	0.006651
16529	0.11	2.17	2812.936	0.006226
14446	0.10	2.01	2605.264	0.006344
13492	0.09	1.85	2397.592	0.006996
12711	0.09	1.85	2397.592	0.006591
11235	0.08	1.69	2189.92	0.006983
10801	0.08	1.69	2189.92	0.006713
9760	0.08	1.53	1982.248	0.007404
8892	0.07	1.37	1774.576	0.008416
8198	0.07	1.37	1774.576	0.007759
7070	0.05	1.07	1382.746	0.011021
5855	0.05	0.93	1200.851	0.012101
4553	0.04	0.81	1055.475	0.012182
2191	0.02	0.50	646.8161	0.015609
1759	0.02	0.41	536.7374	0.018195
1260	0.02	0.31	397.0062	0.023822

20% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
51881	0.62	6.19	11375.01	0.003875
51724	0.61	6.11	11228.32	0.003965
51568	0.60	6.03	11081.63	0.004058
51255	0.60	5.95	10934.94	0.004143
50473	0.59	5.87	10788.25	0.004191
49534	0.58	5.79	10641.56	0.004227
48908	0.57	5.71	10494.87	0.004292
47500	0.56	5.63	10348.19	0.004287
46718	0.56	5.55	10201.5	0.004338
44058	0.54	5.39	9908.119	0.004337
42493	0.53	5.31	9761.43	0.00431
41241	0.52	5.23	9614.741	0.004312
39207	0.50	4.99	9174.674	0.004502
37330	0.49	4.91	9027.985	0.004426
35765	0.47	4.67	8587.918	0.004687
34201	0.46	4.59	8441.229	0.004639
33018	0.44	4.35	8001.162	0.004985
30762	0.40	4.04	7414.406	0.005408
29547	0.39	3.88	7121.029	0.005631
28592	0.38	3.80	6974.34	0.005681
26249	0.36	3.64	6680.962	0.005684
24253	0.35	3.48	6387.584	0.005745
21997	0.32	3.24	5947.517	0.00601
19220	0.30	3.00	5507.45	0.006124
18091	0.29	2.92	5360.761	0.006084
16008	0.28	2.76	5067.383	0.006025
14273	0.26	2.60	4774.005	0.006052
12364	0.24	2.44	4480.627	0.005952
10888	0.24	2.36	4333.938	0.005602
9760	0.23	2.28	4187.249	0.00538
8198	0.20	1.96	3600.494	0.006112
7243	0.21	2.12	3893.872	0.004617
5421	0.17	1.72	3160.427	0.005245
4727	0.15	1.48	2720.36	0.006173
4293	0.12	1.24	2280.293	0.007979
3772	0.12	1.16	2133.604	0.008008
3425	0.11	1.08	1986.915	0.008384
3251	0.10	1.00	1840.226	0.009279
3047	0.11	1.08	1986.915	0.00746
2923	0.10	1.00	1840.226	0.008341
2524	0.09	0.92	1693.537	0.008504
2091	0.08	0.84	1546.848	0.008447
1734	0.07	0.68	1253.47	0.010664
686	0.03	0.31	572.3699	0.020235

20% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
37330	0.93	5.92	13633.42	0.004052
37017	0.92	5.87	13516.44	0.004088
36078	0.91	5.77	13282.48	0.004126
35609	0.90	5.71	13165.5	0.004145
34826	0.89	5.66	13048.52	0.004127
34357	0.88	5.61	12931.54	0.004145
33418	0.87	5.51	12697.58	0.004182
32792	0.86	5.46	12580.6	0.00418
32167	0.84	5.36	12346.64	0.004257
31228	0.83	5.31	12229.66	0.004212
30133	0.83	5.26	12112.68	0.004143

29037	0.81	5.16	11878.72	0.004152
30415	0.80	5.11	11761.74	0.004436
29200	0.79	5.00	11527.78	0.004433
27030	0.75	4.75	10942.89	0.004554
25902	0.72	4.60	10591.95	0.004658
24253	0.69	4.39	10124.03	0.004774
22344	0.65	4.14	9539.128	0.004954
20782	0.62	3.94	9071.209	0.005095
19740	0.60	3.78	8720.27	0.005237
18005	0.55	3.48	8018.391	0.00565
16529	0.52	3.28	7550.472	0.005849
14446	0.48	3.07	7082.552	0.00581
12537	0.44	2.82	6497.653	0.005991
11756	0.43	2.72	6263.694	0.006045
10194	0.40	2.52	5795.775	0.006122
8371	0.36	2.26	5210.876	0.00622
7070	0.32	2.06	4742.956	0.00634
5421	0.29	1.86	4275.037	0.005984
4553	0.27	1.70	3924.098	0.005965
3685	0.24	1.50	3456.179	0.006224
3164	0.21	1.35	3105.239	0.006621
2939	0.22	1.40	3222.219	0.005711
2723	0.20	1.25	2871.28	0.006664
2424	0.17	1.09	2520.34	0.007698
2341	0.16	1.04	2403.361	0.008175
2174	0.16	0.99	2286.381	0.008391
1942	0.14	0.89	2052.421	0.009298
1991	0.15	0.94	2169.401	0.008537
1817	0.13	0.84	1935.441	0.009785
1592	0.12	0.74	1701.482	0.011096
1226	0.09	0.59	1350.542	0.013565
794	0.08	0.48	1116.583	0.012849
345	0.03	0.17	389.8106	0.045807

20% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
8892	1.92	4.34	16777.17	0.003196
8805	1.91	4.32	16707.42	0.003191
8632	1.87	4.23	16358.69	0.003263
8458	1.85	4.18	16149.45	0.003281
8111	1.81	4.09	15800.71	0.003286
8024	1.78	4.03	15591.48	0.003339
7417	1.69	3.82	14754.52	0.003446
6983	1.64	3.71	14336.04	0.003437
6809	1.59	3.58	13847.81	0.003592
6462	1.53	3.46	13359.59	0.003663
6115	1.47	3.33	12871.36	0.003734
5768	1.42	3.20	12383.14	0.003805
5421	1.36	3.08	11894.91	0.003876
4900	1.27	2.88	11127.7	0.004003
4640	1.21	2.74	10569.73	0.004201
4293	1.16	2.63	10151.25	0.004214
4119	1.11	2.52	9732.774	0.004399
3859	1.07	2.41	9314.295	0.004499
3598	1.00	2.27	8756.324	0.004747
3338	0.95	2.16	8337.845	0.004857
3164	0.91	2.07	7989.113	0.005015
2781	0.86	1.94	7500.888	0.005001
2565	0.80	1.81	7012.663	0.005277
2349	0.75	1.71	6594.184	0.005465
2091	0.69	1.56	6036.212	0.005806
1908	0.65	1.47	5687.48	0.005968
1675	0.60	1.35	5199.255	0.00627
1501	0.56	1.27	4920.269	0.006271
1318	0.52	1.18	4571.537	0.006379
977	0.44	1.00	3874.073	0.006585
902	0.43	0.97	3734.58	0.006543
877	0.42	0.95	3664.833	0.006607
852	0.41	0.93	3595.087	0.00667
786	0.39	0.88	3385.848	0.006933
744	0.37	0.84	3246.355	0.007143
644	0.34	0.77	2967.369	0.007403
520	0.29	0.66	2548.89	0.008091
387	0.23	0.52	1990.919	0.009866
229	0.17	0.39	1502.693	0.010241
204	0.12	0.26	1014.468	0.020018
207	0.12	0.28	1084.215	0.0178
138	0.07	0.15	595.9897	0.039271
224	0.13	0.30	1153.961	0.017022
431	0.20	0.46	1781.679	0.013732
181	0.10	0.23	874.9755	0.023914
172	0.09	0.21	805.229	0.026892

25% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
40929	0.21	4.18	8284.07	0.004076
42493	0.20	4.03	7971.995	0.004569
40772	0.20	4.03	7971.995	0.004384
37486	0.20	3.87	7659.919	0.004366
35452	0.19	3.71	7347.844	0.004487
33888	0.19	3.71	7347.844	0.004289
31541	0.17	3.40	6723.693	0.004768
30289	0.16	3.24	6411.618	0.005035
31283	0.17	3.40	6723.693	0.004729
28505	0.16	3.24	6411.618	0.004739
27117	0.16	3.08	6099.542	0.004981
25381	0.15	2.92	5787.467	0.005178
21997	0.14	2.77	5475.391	0.005014
19740	0.13	2.61	5163.316	0.00506
17571	0.12	2.45	4851.24	0.005102
14967	0.11	2.13	4227.09	0.005724
13752	0.10	1.98	3915.014	0.006131
12797	0.09	1.82	3602.939	0.006737
11669	0.08	1.66	3290.863	0.007363
10628	0.08	1.50	2978.788	0.008185
9326	0.07	1.35	2666.713	0.008962
8024	0.06	1.19	2354.637	0.009891
6983	0.05	1.00	1982.875	0.012137
4640	0.04	0.78	1541.341	0.013346
1784	0.02	0.46	910.7411	0.014694
1551	0.02	0.39	767.446	0.017992

25% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
47343	0.64	6.33	17754.89	0.003328
46405	0.64	6.26	17534.46	0.003344
45622	0.63	6.18	17314.03	0.003372
44997	0.62	6.10	17093.59	0.003412
44058	0.60	5.94	16652.72	0.00352
43119	0.60	5.86	16432.29	0.003538
42493	0.58	5.70	15991.42	0.003682
41554	0.57	5.63	15770.99	0.003702
40616	0.56	5.55	15550.55	0.003722
39364	0.55	5.39	15109.68	0.00382
38582	0.54	5.31	14889.25	0.003856
37643	0.53	5.23	14668.82	0.003876
35609	0.52	5.08	14227.95	0.003898
33888	0.49	4.84	13566.64	0.00408
32480	0.48	4.68	13125.78	0.004177
31071	0.46	4.53	12684.91	0.004279
29200	0.42	4.13	11582.74	0.004823
31283	0.45	4.45	12464.47	0.004462

30241	0.44	4.29	12023.6	0.004635
27464	0.41	4.05	11362.3	0.004714
26683	0.40	3.90	10921.43	0.004957
24860	0.37	3.66	10260.13	0.005233
22604	0.35	3.42	9598.828	0.005436
20087	0.34	3.35	9378.394	0.005061
18959	0.32	3.19	8937.525	0.005259
13926	0.29	2.87	8055.788	0.004755
12971	0.28	2.72	7614.92	0.004957
9326	0.26	2.56	7174.052	0.004015
7156	0.24	2.32	6512.749	0.003739
6375	0.22	2.17	6071.88	0.003832
6636	0.20	2.01	5631.012	0.004637
5768	0.19	1.85	5190.144	0.004745
5942	0.17	1.69	4749.275	0.005837
4900	0.15	1.46	4087.973	0.006497
4206	0.13	1.30	3647.104	0.007006
3685	0.12	1.22	3426.67	0.006954
3338	0.12	1.14	3206.236	0.007195
3078	0.11	1.07	2985.801	0.007649
2831	0.10	0.99	2765.367	0.008204
2573	0.09	0.91	2544.933	0.008804
2008	0.08	0.83	2324.499	0.008235
1634	0.08	0.75	2104.065	0.008178
1185	0.06	0.59	1663.196	0.009491
877	0.04	0.35	970.5842	0.020633
470	0.01	0.14	403.8993	0.063803

25% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
34983	0.99	6.23	21893.7	0.003376
34357	0.98	6.13	21542.12	0.003424
32792	0.95	5.98	21014.75	0.003435
32323	0.95	5.93	20838.96	0.003443
32010	0.94	5.88	20663.17	0.003468
33105	0.94	5.88	20663.17	0.003586
30675	0.90	5.63	19784.22	0.003625
29807	0.88	5.53	19432.65	0.003651
29286	0.87	5.48	19256.86	0.003653
27638	0.85	5.33	18729.49	0.003644
26857	0.83	5.18	18202.12	0.003749
25642	0.81	5.08	17850.54	0.003722
24253	0.78	4.88	17147.38	0.003815
23125	0.75	4.73	16620.02	0.003872
21823	0.73	4.58	16092.65	0.003898
19653	0.68	4.28	15037.91	0.00402
18872	0.66	4.13	14510.54	0.004146
18005	0.64	3.98	13983.18	0.004259
16876	0.61	3.83	13455.81	0.004311
15922	0.58	3.63	12752.65	0.004528
15401	0.55	3.43	12049.49	0.004906
14446	0.52	3.23	11346.34	0.00519
13752	0.50	3.13	10994.76	0.005262
11496	0.44	2.78	9764.233	0.005577
10194	0.41	2.58	9061.076	0.005743
9153	0.40	2.48	8709.497	0.005581
8198	0.38	2.38	8357.919	0.005428
7330	0.36	2.28	8006.34	0.005289
6202	0.35	2.18	7654.762	0.004896
5334	0.33	2.08	7303.183	0.004626
4466	0.32	1.98	6951.604	0.004275
3164	0.24	1.48	5193.711	0.005426
2898	0.22	1.38	4842.133	0.005717
2723	0.20	1.28	4490.554	0.006246
2299	0.16	1.03	3611.607	0.008153
2249	0.16	0.98	3435.818	0.008813
1975	0.14	0.88	3084.239	0.009602
1792	0.12	0.78	2732.661	0.011099
1576	0.11	0.68	2381.082	0.012855
1443	0.10	0.63	2205.293	0.01372
736	0.07	0.43	1502.136	0.015084
412	0.06	0.38	1326.346	0.01082
262	0.04	0.22	775.3753	0.020147

25% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
8545	2.01	4.47	26364.5	0.002851
8458	1.98	4.42	26050.07	0.002891
8198	1.94	4.33	25526.02	0.002918
8111	1.91	4.26	25106.78	0.002984
7938	1.89	4.21	24792.35	0.002995
7590	1.83	4.08	24058.67	0.003041
7417	1.80	4.01	23639.43	0.003078
6896	1.73	3.85	22696.14	0.003105
6462	1.65	3.67	21648.04	0.003198
5942	1.56	3.48	20495.13	0.003281
5681	1.51	3.35	19761.45	0.003374
5334	1.44	3.21	18922.97	0.003455
5074	1.39	3.10	18294.11	0.003516
4813	1.35	3.00	17665.25	0.003577
4553	1.29	2.87	16931.58	0.003683
4119	1.19	2.66	15673.86	0.003889
3859	1.14	2.53	14940.18	0.004009
3338	1.03	2.29	13472.84	0.004265
3078	0.98	2.18	12843.98	0.004327
2904	0.93	2.07	12215.12	0.004514
2482	0.87	1.93	11376.64	0.004448
2349	0.83	1.84	10852.59	0.004625
2199	0.78	1.73	10223.72	0.00488
2050	0.73	1.63	9594.862	0.005163
1875	0.68	1.50	8861.191	0.005538
1700	0.63	1.40	8232.329	0.005819
1468	0.58	1.29	7603.468	0.005887
1293	0.54	1.20	7079.417	0.005983
1110	0.49	1.09	6450.555	0.006187
1002	0.46	1.02	6031.314	0.006388
919	0.44	0.97	5716.884	0.00652
869	0.42	0.93	5507.263	0.006644
836	0.41	0.92	5402.453	0.00664
811	0.40	0.88	5192.832	0.006972
794	0.38	0.85	4983.212	0.007416
752	0.36	0.81	4773.592	0.007658
669	0.33	0.74	4354.351	0.008187
578	0.30	0.67	3935.11	0.008654
503	0.26	0.58	3411.058	0.010026
387	0.21	0.47	2782.197	0.011583
204	0.15	0.33	1943.715	0.012502
104	0.12	0.28	1629.285	0.009076
97	0.10	0.22	1314.854	0.012949
84	0.08	0.19	1105.233	0.016036
48	0.05	0.12	685.9924	0.023786

30% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
43275	0.20	3.97	6947.024	0.004723
42024	0.20	3.97	6947.024	0.004587
39990	0.20	3.81	6675.072	0.004728
38112	0.20	3.81	6675.072	0.004506
35452	0.19	3.66	6403.121	0.004555
29194	0.17	3.35	5859.218	0.004479
25282	0.16	3.19	5587.267	0.004266
22622	0.16	3.03	5315.315	0.004218

24513	0.16	3.03	5315.315	0.00457
22604	0.15	2.88	5043.364	0.004681
20174	0.14	2.72	4771.412	0.004668
18872	0.13	2.57	4499.461	0.00491
17744	0.12	2.41	4227.51	0.00523
16616	0.12	2.26	3955.558	0.005594
15401	0.11	2.10	3683.607	0.005979
13752	0.10	1.95	3411.655	0.006224
12537	0.09	1.79	3139.704	0.006699
11149	0.08	1.64	2867.752	0.007141
10194	0.08	1.48	2595.801	0.007969
9153	0.07	1.33	2323.85	0.008928
8024	0.06	1.17	2051.898	0.010039
6896	0.05	0.96	1675.853	0.012934
4813	0.04	0.82	1444.265	0.012155
2407	0.03	0.50	872.806	0.016645
1842	0.02	0.40	708.627	0.01932
1426	0.02	0.33	570.3691	0.023089

30% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
50160	0.64	6.24	15472.12	0.003579
45622	0.64	6.16	15280.03	0.003337
44840	0.64	6.24	15472.12	0.003199
44371	0.63	6.09	15087.94	0.003329
43119	0.62	6.01	14895.84	0.003319
41398	0.61	5.93	14703.75	0.00327
40303	0.60	5.85	14511.66	0.003269
39520	0.60	5.78	14319.57	0.003292
37956	0.58	5.62	13935.38	0.003338
37017	0.57	5.54	13743.29	0.003347
35609	0.56	5.39	13359.1	0.003408
32636	0.53	5.16	12782.82	0.003411
31228	0.51	4.92	12206.55	0.00358
33018	0.51	4.92	12206.55	0.003785
30588	0.48	4.61	11438.18	0.003993
29026	0.46	4.46	11053.99	0.004057
26857	0.44	4.23	10477.71	0.004178
25728	0.43	4.15	10285.62	0.004154
23993	0.41	3.99	9901.434	0.00418
22431	0.39	3.76	9325.156	0.004406
19480	0.37	3.61	8940.971	0.004162
17223	0.36	3.45	8556.786	0.004018
14360	0.33	3.22	7980.508	0.003851
12797	0.32	3.06	7596.322	0.003788
10194	0.28	2.68	6635.859	0.003954
9066	0.26	2.52	6251.674	0.003962
8198	0.23	2.21	5483.303	0.004657
7070	0.21	2.06	5099.117	0.004644
5421	0.16	1.59	3946.561	0.005944
4640	0.15	1.44	3562.376	0.006244
4206	0.13	1.28	3178.191	0.007112
3685	0.12	1.13	2794.005	0.008063
3078	0.11	1.05	2601.913	0.007764
2973	0.11	1.05	2601.913	0.007499
2798	0.10	0.97	2409.82	0.008229
2124	0.09	0.89	2217.727	0.007377
1750	0.08	0.74	1833.542	0.008892
1251	0.07	0.66	1641.449	0.007932
1019	0.06	0.58	1449.357	0.008281
661	0.03	0.28	698.3089	0.023151

30% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
35139	1.03	6.38	19844.73	0.003181
34044	1.03	6.33	19691.54	0.00313
33418	1.02	6.28	19538.36	0.003121
32480	1.01	6.23	19385.17	0.003082
32671	0.99	6.14	19078.79	0.0032
31369	0.98	6.04	18772.42	0.003174
30415	0.96	5.94	18466.04	0.00318
29460	0.95	5.84	18159.67	0.003185
28679	0.94	5.79	18006.48	0.003154
27551	0.92	5.69	17700.1	0.003135
26596	0.91	5.59	17393.73	0.003134
23472	0.87	5.35	16627.79	0.003027
22257	0.83	5.15	16015.04	0.003094
20955	0.81	5.00	15555.47	0.003088
20174	0.77	4.76	14789.53	0.003288
19306	0.74	4.56	14176.78	0.003425
18352	0.71	4.36	13564.03	0.003556
17571	0.68	4.21	13104.47	0.003648
16442	0.66	4.07	12644.9	0.003666
15575	0.64	3.92	12185.34	0.00374
14446	0.60	3.67	11419.4	0.00395
12711	0.54	3.33	10347.09	0.004233
11843	0.49	3.03	9427.959	0.00475
10541	0.47	2.88	8968.395	0.004673
9413	0.44	2.69	8355.644	0.004807
7590	0.41	2.54	7896.081	0.004341
6462	0.40	2.44	7589.705	0.004
5594	0.37	2.29	7130.141	0.003923
4813	0.32	2.00	6211.014	0.004449
4206	0.29	1.80	5598.263	0.004785
3772	0.27	1.65	5138.7	0.005093
3078	0.23	1.41	4372.76	0.005739
2904	0.20	1.26	3913.197	0.006761
2840	0.20	1.21	3760.009	0.007161
2349	0.16	1.01	3147.258	0.008455
2282	0.16	0.96	2994.07	0.009078
2191	0.15	0.91	2840.882	0.009679
2041	0.14	0.86	2687.694	0.010075
1825	0.12	0.77	2381.319	0.011475
1526	0.11	0.67	2074.943	0.012635
1293	0.09	0.57	1768.567	0.014738
960	0.08	0.52	1615.38	0.013121
728	0.07	0.42	1309.004	0.015137
345	0.03	0.18	572.4781	0.037533

30% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
8545	2.05	4.49	23431.45	0.002782
8198	2.00	4.39	22883.44	0.002799
8024	1.97	4.32	22518.11	0.002829
7938	1.95	4.28	22335.44	0.002844
7677	1.90	4.18	21787.43	0.002891
7330	1.85	4.06	21148.09	0.00293
7070	1.81	3.97	20691.41	0.002952
6896	1.78	3.90	20326.07	0.002984
6549	1.72	3.78	19686.73	0.003021
6289	1.67	3.67	19138.72	0.003069
6028	1.63	3.56	18590.72	0.003118
5681	1.57	3.44	17951.37	0.003152
5421	1.51	3.32	17312.03	0.003233
4900	1.42	3.11	16216.02	0.003331
4640	1.35	2.97	15485.34	0.003459
4293	1.30	2.85	14846	0.003482
4032	1.23	2.71	14115.32	0.003618
3772	1.17	2.57	13384.64	0.003764
3425	1.09	2.39	12471.3	0.003936
3164	1.03	2.27	11831.95	0.004041
2991	0.99	2.18	11375.28	0.004132

2840	0.99	2.16	11283.95	0.003987
2307	0.86	1.88	9822.591	0.004275
2025	0.76	1.67	8726.576	0.004753
1867	0.70	1.53	7995.899	0.00522
1692	0.65	1.43	7447.891	0.005453
1409	0.58	1.27	6625.879	0.005739
1102	0.50	1.10	5712.533	0.006035
960	0.45	0.99	5164.525	0.006437
902	0.44	0.96	4981.856	0.006498
844	0.42	0.92	4799.186	0.00655
611	0.30	0.66	3429.167	0.00929
802	0.37	0.82	4251.179	0.007937
719	0.35	0.76	3977.175	0.008128
661	0.32	0.69	3611.836	0.009058
520	0.27	0.59	3063.828	0.009896
470	0.24	0.52	2698.49	0.011532
403	0.22	0.48	2515.821	0.011389
312	0.19	0.41	2150.482	0.012051
283	0.17	0.38	1967.813	0.013051
224	0.15	0.32	1693.809	0.013963
198	0.13	0.29	1511.14	0.015518
143	0.12	0.27	1419.805	0.012688
86	0.08	0.17	871.7973	0.020272
91	0.08	0.18	963.1319	0.017606

35% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
47187	0.20	3.76	6596.542	0.005661
44058	0.19	3.60	6327.79	0.005744
37017	0.17	3.30	5790.286	0.005764
34044	0.16	3.14	5521.534	0.00583
31228	0.16	2.99	5252.782	0.005909
27629	0.15	2.84	4984.03	0.005807
29720	0.15	2.84	4984.03	0.006246
26336	0.15	2.84	4984.03	0.005535
24079	0.14	2.68	4715.278	0.005654
22344	0.14	2.68	4715.278	0.005246
19393	0.13	2.53	4446.526	0.005121
17571	0.12	2.38	4177.774	0.005255
16182	0.11	2.07	3640.27	0.006375
14794	0.10	1.92	3371.518	0.006794
13752	0.09	1.77	3102.766	0.007457
12450	0.08	1.61	2834.014	0.008093
11149	0.08	1.46	2565.262	0.008844
10020	0.08	1.46	2565.262	0.007949
8632	0.07	1.31	2296.51	0.008544
7070	0.06	1.15	2027.758	0.008976
6028	0.05	0.92	1618.537	0.012013
2036	0.03	0.48	849.5108	0.01473
1509	0.02	0.37	642.4937	0.019086

35% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
52194	0.64	6.15	15290.1	0.003779
51568	0.64	6.15	15290.1	0.003734
50316	0.64	6.07	15100.26	0.003735
49221	0.63	6.00	14910.43	0.003748
48126	0.62	5.92	14720.6	0.003759
47343	0.62	5.92	14720.6	0.003698
45622	0.61	5.84	14530.77	0.003658
44527	0.60	5.77	14340.93	0.003665
43119	0.60	5.69	14151.1	0.003645
41711	0.60	5.69	14151.1	0.003526
40146	0.59	5.61	13961.27	0.003486
38112	0.57	5.46	13581.6	0.003497
35922	0.56	5.31	13201.94	0.003489
32949	0.54	5.16	12822.27	0.003392
31228	0.52	5.00	12442.61	0.003414
32498	0.52	5.00	12442.61	0.003553
29373	0.50	4.77	11873.11	0.003527
27377	0.48	4.62	11493.44	0.003508
25902	0.47	4.47	11113.78	0.00355
24079	0.45	4.32	10734.11	0.003538
22517	0.44	4.16	10354.45	0.003555
20521	0.41	3.93	9784.947	0.003628
18005	0.39	3.71	9215.449	0.003589
16269	0.36	3.48	8645.95	0.003684
14012	0.32	3.10	7696.787	0.004004
12624	0.30	2.87	7127.288	0.004207
10801	0.25	2.41	5988.292	0.005099
9934	0.24	2.26	5608.626	0.005345
8805	0.22	2.10	5228.961	0.005451
7764	0.20	1.87	4659.462	0.006053
5681	0.16	1.49	3710.298	0.006986
4813	0.14	1.34	3330.633	0.007345
3945	0.12	1.19	2950.967	0.007669
3685	0.12	1.11	2761.135	0.008182
3338	0.11	1.03	2571.302	0.008546
3078	0.10	0.96	2381.469	0.009186
2773	0.09	0.88	2191.636	0.009773
2316	0.08	0.81	2001.804	0.009782
1991	0.08	0.73	1811.971	0.010267
1559	0.07	0.65	1622.138	0.010029
969	0.04	0.41	1013.503	0.015963
910	0.04	0.36	899.8273	0.019034

35% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
39051	1.05	6.39	19914.04	0.00348
37330	1.03	6.29	19611.26	0.00343
36860	1.03	6.24	19459.88	0.003439
35922	1.02	6.19	19308.49	0.003405
34983	1.00	6.10	19005.72	0.003422
33888	0.99	6.05	18854.34	0.003368
32411	0.96	5.85	18248.79	0.003439
31196	0.95	5.76	17946.02	0.003423
27377	0.89	5.42	16886.32	0.003393
24427	0.85	5.17	16129.39	0.003318
22170	0.82	4.98	15523.85	0.003251
20261	0.79	4.78	14918.31	0.003217
17744	0.74	4.49	14010	0.003194
16269	0.71	4.30	13404.45	0.003199
15054	0.68	4.15	12950.3	0.003172
12884	0.64	3.86	12041.98	0.00314
11582	0.60	3.67	11436.44	0.003129
10715	0.57	3.47	10830.9	0.003227
9760	0.54	3.28	10225.36	0.003298
8979	0.52	3.13	9771.199	0.003323
7764	0.47	2.84	8862.885	0.003493
6809	0.42	2.55	7954.571	0.003803
6289	0.38	2.31	7197.643	0.004289
5768	0.34	2.07	6440.715	0.004913
5508	0.31	1.87	5835.172	0.005716
4900	0.28	1.68	5229.63	0.006331
4466	0.26	1.58	4926.859	0.006501
3859	0.23	1.39	4321.316	0.007302
3512	0.20	1.24	3867.159	0.008297
2991	0.19	1.14	3564.388	0.008318
2640	0.17	1.05	3261.617	0.008769
2499	0.16	1.00	3110.231	0.009127
2415	0.16	0.95	2958.846	0.009749
2233	0.15	0.90	2807.46	0.010009

2174	0.14	0.85	2656.074	0.010891
1933	0.13	0.80	2504.689	0.010889
1734	0.12	0.75	2353.303	0.011061
1551	0.12	0.71	2201.918	0.011301
1384	0.11	0.66	2050.532	0.011634
1310	0.10	0.61	1899.146	0.01283
1160	0.09	0.56	1747.761	0.013417
852	0.08	0.46	1444.989	0.014422
719	0.06	0.37	1142.218	0.019479
428	0.04	0.27	831.6349	0.021875

35% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
9760	2.14	4.62	24148.65	0.002965
9500	2.12	4.58	23968.13	0.00293
9153	2.09	4.51	23607.09	0.00291
8545	2.03	4.39	22975.27	0.002868
7590	1.93	4.17	21801.89	0.002829
7417	1.90	4.12	21531.11	0.002835
6809	1.82	3.94	20628.5	0.002835
6375	1.77	3.82	19996.68	0.002825
5681	1.64	3.55	18552.52	0.002924
5334	1.59	3.43	17920.7	0.002943
5074	1.54	3.32	17379.14	0.002976
4900	1.48	3.20	16747.32	0.003095
4293	1.37	2.96	15483.68	0.003172
4119	1.32	2.86	14942.12	0.003269
3685	1.23	2.65	13859	0.003399
3338	1.15	2.48	12956.4	0.003523
3164	1.09	2.36	12324.57	0.003691
2623	1.02	2.20	11512.23	0.003507
2490	0.97	2.10	10970.67	0.003666
2075	0.83	1.80	9436.251	0.004128
1925	0.79	1.70	8894.69	0.004311
1775	0.73	1.58	8262.87	0.004607
1642	0.68	1.46	7631.049	0.004996
1426	0.60	1.30	6818.708	0.005434
1276	0.56	1.22	6367.407	0.005577
1127	0.52	1.11	5825.847	0.005881
994	0.48	1.03	5374.546	0.006094
927	0.45	0.98	5103.766	0.006306
894	0.43	0.92	4832.986	0.00678
877	0.41	0.89	4652.465	0.00718
836	0.38	0.82	4291.425	0.008039
811	0.36	0.79	4110.905	0.008499
777	0.35	0.75	3930.384	0.008916
719	0.32	0.70	3659.604	0.009514
653	0.29	0.63	3298.564	0.010628
594	0.28	0.60	3118.044	0.010834
528	0.25	0.54	2847.263	0.011538
412	0.21	0.46	2395.963	0.012701
204	0.14	0.30	1583.622	0.014388
104	0.11	0.23	1222.581	0.012313
95	0.09	0.20	1042.061	0.015468
107	0.10	0.22	1132.321	0.014768
114	0.11	0.23	1222.581	0.013485
88	0.08	0.18	951.801	0.017193
71	0.07	0.15	771.2808	0.021049

40% water-in-EDM 244 oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
41554	0.16	3.10	5303.168	0.00722
33731	0.15	2.80	4786.922	0.007193
30758	0.14	2.65	4528.798	0.007328
28245	0.13	2.50	4270.675	0.007567
24600	0.12	2.34	4012.551	0.007466
21563	0.12	2.19	3754.428	0.007474
18525	0.11	2.04	3496.305	0.007405
16008	0.10	1.89	3238.181	0.00746
13579	0.09	1.74	2980.058	0.007471
11235	0.08	1.59	2721.934	0.00741
9066	0.08	1.44	2463.811	0.007297
9586	0.07	1.25	2143.097	0.010199
6202	0.05	0.96	1649.772	0.011134
3425	0.04	0.68	1167.084	0.012285
2383	0.03	0.48	822.833	0.0172
2798	0.03	0.56	960.7854	0.01481

40% water-in-EDM 244 oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
55885	0.63	5.91	14320.75	0.004317
53758	0.63	5.91	14320.75	0.004153
53289	0.63	5.91	14320.75	0.004117
50942	0.62	5.83	14138.43	0.004038
50003	0.62	5.83	14138.43	0.003963
47969	0.60	5.68	13773.78	0.004006
46561	0.60	5.61	13591.45	0.003993
45153	0.59	5.53	13409.13	0.003979
43119	0.58	5.46	13226.8	0.003905
41554	0.57	5.38	13044.48	0.003869
38895	0.55	5.16	12497.5	0.003945
36078	0.54	5.08	12315.18	0.003769
34044	0.52	4.93	11950.53	0.003777
31384	1.31	12.31	29818.4	0.000559
32758	0.50	4.71	11403.55	0.003991
29286	0.48	4.56	11038.9	0.003808
28245	0.47	4.41	10674.25	0.003927
27117	0.46	4.33	10491.92	0.003903
24774	0.43	4.03	9762.622	0.004118
23646	0.41	3.88	9397.972	0.004241
21823	0.39	3.65	8850.996	0.004413
20608	0.36	3.43	8304.02	0.004735
18525	0.33	3.13	7574.719	0.005115
16616	0.30	2.82	6845.418	0.005618
15575	0.28	2.67	6480.768	0.005875
13231	0.25	2.37	5751.467	0.006337
11669	0.23	2.15	5204.491	0.006825
9500	0.21	2.00	4839.84	0.006425
8024	0.20	1.85	4475.19	0.006348
6549	0.17	1.62	3928.214	0.006724
5768	0.16	1.47	3563.564	0.007196
5074	0.14	1.32	3198.913	0.007855
4466	0.13	1.24	3016.588	0.007776
3685	0.12	1.17	2834.263	0.007268
3251	0.12	1.09	2651.937	0.007324
2991	0.11	1.02	2469.612	0.007769
2740	0.10	0.94	2287.287	0.008297
2174	0.09	0.87	2104.961	0.007775
2025	0.08	0.79	1922.636	0.008678
1684	0.08	0.72	1740.311	0.008808
1509	0.07	0.64	1557.986	0.00985
969	0.04	0.41	995.0017	0.015501
777	0.03	0.33	792.8774	0.019592

40% water-in-EDM 244 oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
40146	1.04	6.25	18981.08	0.003685
39051	1.03	6.20	18835.68	0.00364
38425	1.03	6.15	18690.28	0.003638
35452	0.99	5.91	17963.29	0.003634
34357	0.98	5.86	17817.89	0.003579
31854	0.94	5.62	17090.89	0.003607

32498	0.93	5.58	16945.5	0.003743
30068	0.89	5.34	16218.5	0.00378
28592	0.87	5.19	15782.31	0.003796
26249	0.84	5.05	15346.11	0.003686
21736	0.77	4.62	14037.52	0.003648
19914	0.74	4.43	13455.93	0.003637
16269	0.67	4.00	12147.34	0.003646
14620	0.64	3.81	11565.75	0.003615
13405	0.60	3.61	10984.15	0.003674
11322	0.56	3.33	10111.76	0.003662
10281	0.52	3.14	9530.166	0.003744
9413	0.49	2.94	8948.571	0.003888
8545	0.46	2.75	8366.977	0.004037
7764	0.41	2.47	7494.585	0.004571
7851	0.36	2.18	6622.193	0.005921
7417	0.33	1.99	6040.599	0.006722
6809	0.30	1.80	5459.004	0.007557
6202	0.28	1.70	5168.207	0.007679
5421	0.27	1.61	4877.41	0.007536
4727	0.24	1.46	4441.214	0.007925
4379	0.23	1.37	4150.417	0.008408
3859	0.20	1.22	3714.221	0.00925
3512	0.19	1.13	3423.424	0.009909
2991	0.17	1.03	3132.626	0.010079
2873	0.17	1.03	3132.626	0.009682
2632	0.16	0.98	2987.228	0.009753
2424	0.16	0.94	2841.829	0.009926
2282	0.15	0.89	2696.431	0.010382
2158	0.14	0.84	2551.032	0.010965
1800	0.13	0.79	2405.633	0.010287
1725	0.12	0.74	2260.235	0.011169
1551	0.12	0.70	2114.836	0.011467
1409	0.11	0.65	1969.437	0.012017
1118	0.10	0.60	1824.039	0.011116
885	0.08	0.50	1533.242	0.012457
636	0.07	0.41	1242.444	0.013627
478	0.06	0.36	1097.046	0.013137
312	0.04	0.22	674.053	0.022692

40% water-in-EDM 244 oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
10888	2.15	4.59	23367	0.003307
10368	2.10	4.48	22846.86	0.003294
10020	2.06	4.40	22413.4	0.003308
9673	2.03	4.33	22066.64	0.003294
9413	2.01	4.28	21806.57	0.003283
8111	1.87	3.99	20332.83	0.003253
7764	1.82	3.89	19812.69	0.00328
6723	1.71	3.65	18599.02	0.003223
6289	1.66	3.53	17992.19	0.003221
5247	1.53	3.26	16605.14	0.003156
4900	1.47	3.14	15998.31	0.003175
4206	1.33	2.83	14437.88	0.003346
3945	1.27	2.71	13831.04	0.00342
3251	1.13	2.41	12270.61	0.003581
2991	1.06	2.25	11490.4	0.003756
2532	0.98	2.08	10623.49	0.00372
2399	0.95	2.02	10276.73	0.003767
2158	0.87	1.85	9409.828	0.004041
2033	0.83	1.76	8976.375	0.004184
1742	0.74	1.57	8022.78	0.004488
1626	0.70	1.49	7589.327	0.00468
1559	0.67	1.42	7242.565	0.004929
1451	0.63	1.34	6809.113	0.005189
1376	0.60	1.29	6549.041	0.00532
1276	0.57	1.22	6202.279	0.005502
1168	0.53	1.13	5768.827	0.005821
1085	0.50	1.06	5422.065	0.00612
1027	0.48	1.01	5161.994	0.00639
994	0.46	0.98	4988.613	0.006621
969	0.44	0.93	4728.541	0.007184
944	0.41	0.88	4468.47	0.007837
927	0.40	0.86	4381.779	0.008007
885	0.37	0.79	4035.017	0.009019
869	0.36	0.76	3861.636	0.009662
844	0.35	0.74	3774.946	0.009821
802	0.33	0.71	3601.565	0.010257
653	0.28	0.59	2994.731	0.012068
578	0.25	0.54	2734.66	0.012813
495	0.23	0.49	2474.588	0.013396
403	0.20	0.42	2127.826	0.014768
302	0.17	0.37	1867.755	0.014339
245	0.15	0.32	1607.683	0.015704
150	0.14	0.30	1520.993	0.010749
107	0.10	0.21	1087.54	0.014984
81	0.08	0.16	827.4686	0.019621
64	0.06	0.13	654.0876	0.02472

5% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
143944	0.24	4.93	3876.498	0.010578287
141484	0.25	5.09	4003.408	0.009748733
140254	0.24	4.93	3876.498	0.010307106
138614	0.24	4.93	3876.498	0.010186582
134104	0.24	4.77	3749.587	0.010533555
126314	0.23	4.60	3622.676	0.010628987
115244	0.21	4.28	3368.855	0.011213781
103763	0.20	4.12	3241.944	0.010902664
91873	0.19	3.80	2988.123	0.011362947
79573	0.17	3.48	2734.302	0.01175361
74025	0.17	3.48	2734.302	0.010934076
55885	0.15	2.99	2353.57	0.01114137
42720	0.12	2.51	1972.838	0.012121396
30800	0.11	2.18	1719.016	0.01151041
29634	0.11	2.18	1719.016	0.011074498
22778	0.09	1.86	1465.195	0.01171703
19306	0.08	1.54	1211.374	0.014529203
19306	0.07	1.48	1162.05	0.015788787
14099	0.06	1.12	881.3647	0.020043954
9760	0.02	0.38	302.4778	0.117804697

5% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
149685	0.75	7.61	8475.329	0.00746169
147635	0.75	7.53	8385.686	0.007517684
145995	0.74	7.45	8296.043	0.0075957
141074	0.72	7.29	8116.756	0.007667546
136564	0.71	7.13	7937.47	0.007761509
127544	0.68	6.88	7668.54	0.00776619
118114	0.65	6.56	7309.967	0.007914856
104583	0.60	6.08	6772.107	0.008165608
77523	0.51	5.11	5696.388	0.00855467
93513	0.56	5.68	6323.891	0.008372926
71018	0.50	5.03	5606.745	0.008089525
53397	0.43	4.31	4799.956	0.008298807
39611	0.36	3.67	4082.81	0.008508802
32251	0.32	3.26	3634.594	0.008741939
32411	0.32	3.26	3634.594	0.008785168
25555	0.29	2.94	3276.021	0.008526124
22257	0.27	2.70	3007.091	0.008813446
17310	0.24	2.38	2648.518	0.008836303
14099	0.20	2.06	2289.945	0.009627608

12364	0.19	1.89	2110.658	0.009937569
10715	0.17	1.73	1931.372	0.010285346
8892	0.16	1.65	1841.729	0.009387059
7156	0.15	1.49	1662.442	0.009272134
6289	0.13	1.33	1483.156	0.010236615
5855	0.12	1.17	1303.869	0.012331364
4293	0.09	0.93	1034.939	0.014350392
3251	0.07	0.69	766.0097	0.019840235

5% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
111554	1.21	7.76	10833.6	0.007104428
110324	1.20	7.70	10762.12	0.007119744
109504	1.19	7.65	10690.63	0.007161651
107454	1.19	7.60	10619.14	0.007122512
105813	1.17	7.50	10476.16	0.007206553
95563	1.11	7.09	9904.264	0.007281782
102943	1.15	7.40	10333.19	0.007206444
89003	1.06	6.78	9475.338	0.007409805
99253	1.13	7.24	10118.73	0.00724577
84079	1.07	6.83	9546.825	0.006895431
80555	1.03	6.63	9260.875	0.007020673
76616	1.00	6.43	8974.924	0.007109656
72677	0.97	6.22	8688.973	0.007195338
66458	0.92	5.91	8260.048	0.007280665
60135	0.87	5.61	7831.122	0.007329392
50942	0.81	5.20	7259.22	0.007225841
43588	0.75	4.79	6687.319	0.007285475
37956	0.69	4.43	6186.906	0.007411764
33262	0.64	4.12	5757.98	0.007498896
34233	0.64	4.07	5686.492	0.007913155
28853	0.58	3.71	5186.078	0.008018579
23732	0.52	3.30	4614.177	0.008331865
20087	0.47	3.00	4185.251	0.008571773
17310	0.43	2.74	3827.813	0.008830657
14707	0.40	2.54	3541.862	0.008762814
11496	0.34	2.18	3041.449	0.009288927
10107	0.32	2.02	2826.986	0.009453064
9066	0.30	1.92	2684.01	0.009406453
8371	0.28	1.82	2541.035	0.009691058
7764	0.28	1.77	2469.547	0.009515693
7243	0.26	1.67	2326.572	0.010002133
6809	0.25	1.61	2255.085	0.010008544
6289	0.24	1.56	2183.597	0.009858321
5942	0.24	1.51	2112.109	0.009955308
5594	0.23	1.46	2040.622	0.010041926
5334	0.22	1.41	1969.134	0.010282404
5421	0.21	1.36	1897.646	0.011251845
4553	0.20	1.26	1754.671	0.011053326
4553	0.19	1.21	1683.183	0.012012172
3685	0.16	1.05	1468.72	0.012769192
3251	0.15	0.95	1325.745	0.013826534
2817	0.13	0.85	1182.77	0.015052852
2210	0.11	0.69	968.3067	0.017616258
1863	0.09	0.59	825.3314	0.020439168
1516	0.07	0.44	610.8685	0.030356545

5% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
28072	2.41	5.49	12852.7	0.00636895
27638	2.39	5.45	12767.46	0.006354514
27204	2.38	5.41	12682.21	0.006339113
26683	2.35	5.36	12554.34	0.006345079
24687	2.25	5.12	12000.25	0.006425066
23472	2.18	4.98	11659.27	0.006471393
19914	2.00	4.56	10678.94	0.006544682
16963	1.82	4.16	9741.238	0.006699901
17657	1.86	4.23	9911.729	0.006736259
15661	1.74	3.96	9272.387	0.006827115
14446	1.67	3.79	8888.782	0.006852758
12711	1.53	3.48	8164.193	0.007147158
11843	1.47	3.36	7865.834	0.007173935
10368	1.37	3.12	7311.737	0.007268157
9586	1.31	2.98	6970.754	0.007394166
8979	1.26	2.87	6715.017	0.007463159
6983	1.09	2.48	5819.938	0.00772665
6375	1.03	2.36	5521.578	0.007837433
5681	0.96	2.19	5137.973	0.008065734
5421	0.93	2.12	4967.481	0.00823345
4900	0.89	2.03	4754.367	0.008124748
4640	0.85	1.94	4541.253	0.008432051
4206	0.80	1.83	4285.516	0.008582924
4032	0.78	1.77	4157.648	0.008742649
3685	0.74	1.68	3944.533	0.008876677
3512	0.71	1.61	3774.042	0.009240076
3251	0.68	1.54	3603.551	0.009383656
2904	0.64	1.45	3390.437	0.009468567
2730	0.61	1.39	3262.568	0.009614162
2644	0.60	1.36	3177.323	0.009814779
2297	0.54	1.23	2878.963	0.010384776
2210	0.52	1.19	2793.717	0.010611451
2036	0.52	1.17	2751.094	0.010083295
2036	0.50	1.14	2665.849	0.010738471
1863	0.48	1.10	2580.603	0.010482809
1776	0.47	1.07	2495.357	0.010688907
1429	0.41	0.94	2196.998	0.011093756
1255	0.37	0.85	1983.883	0.011952379
1082	0.34	0.77	1813.392	0.012327265
995	0.32	0.74	1728.146	0.012484304
648	0.26	0.59	1387.164	0.012614853
518	0.22	0.50	1174.05	0.014086676
340	0.14	0.32	747.8214	0.022798888
411	0.17	0.39	918.3127	0.018281522
269	0.12	0.26	619.9529	0.026234945
233	0.09	0.21	492.0844	0.036134165

10% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
146815	0.26	5.18	3097.739	0.0096311
143124	0.25	5.02	3002.556	0.00999374
139024	0.24	4.86	2907.373	0.010353467
130004	0.24	4.70	2812.19	0.010348186
116884	0.22	4.38	2621.824	0.010703938
98433	0.20	4.07	2431.458	0.010481053
79983	0.19	3.75	2241.092	0.010024756
53289	0.15	2.95	1765.177	0.010766091
42963	0.13	2.63	1574.811	0.010905093
27160	0.11	2.16	1289.262	0.010285858
34927	0.11	2.16	1289.262	0.013227597
26249	0.08	1.68	1003.713	0.016401759
26249	0.08	1.52	908.5303	0.020018473
26249	0.07	1.46	871.5372	0.021753939
6549	0.02	0.38	226.8584	0.080105315
7156	0.02	0.46	274.1995	0.059918748

10% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
152555	0.76	7.59	6423.729	0.00754608
148455	0.75	7.43	6289.264	0.007660625
143124	0.73	7.27	6154.8	0.00771181
138204	0.71	7.11	6020.335	0.007783065
129594	0.69	6.87	5818.637	0.007812913

121804	0.67	6.63	5616.94	0.007880104
103353	0.60	6.00	5079.081	0.008177584
82853	0.54	5.36	4541.221	0.008200357
77756	0.53	5.28	4473.989	0.00792894
63555	0.48	4.73	4003.362	0.00809417
62622	0.47	4.65	3936.129	0.008250137
47074	0.40	3.93	3331.037	0.008659494
39714	0.36	3.54	2994.875	0.009037773
31733	0.32	3.14	2658.713	0.009163006
30675	0.32	3.14	2658.713	0.008857526
25121	0.28	2.82	2389.783	0.008978161
18438	0.24	2.35	1986.388	0.009538195
13492	0.20	1.95	1650.226	0.010112329
12364	0.17	1.71	1448.529	0.012027042
11496	0.16	1.63	1381.296	0.012297924
10628	0.15	1.47	1246.832	0.013954051
9760	0.14	1.39	1179.599	0.01431699
8892	0.13	1.31	1112.367	0.014668374
6289	0.10	1.00	843.437	0.018043537
4553	0.07	0.68	574.5072	0.028156097
1949	0.03	0.28	238.3451	0.07004292

10% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
114014	1.23	7.75	8232.434	0.00716785
113604	1.23	7.75	8232.434	0.007142073
111144	1.21	7.65	8125.202	0.007173061
109094	1.20	7.60	8071.587	0.007134601
106224	1.18	7.45	7910.739	0.007232273
102943	1.15	7.30	7749.892	0.007302904
98433	1.12	7.10	7535.429	0.007386087
94333	1.10	6.95	7374.582	0.007390572
89003	1.07	6.74	7160.119	0.007396952
83768	1.07	6.74	7160.119	0.006961884
75165	1.00	6.34	6731.193	0.007068354
70500	0.96	6.09	6463.114	0.007191096
63555	0.91	5.78	6141.42	0.007179635
63452	0.91	5.73	6087.804	0.007294738
61425	0.90	5.68	6034.188	0.007187812
51099	0.81	5.13	5444.415	0.007345051
39833	0.71	4.47	4747.411	0.007530448
31697	0.62	3.92	4157.637	0.007812972
33192	0.63	3.97	4211.253	0.007974365
27117	2.15	13.61	14451.86	0.000553198
22691	0.50	3.16	3353.401	0.008597426
16703	0.43	2.70	2870.86	0.008634805
11496	0.34	2.15	2281.087	0.009413262
9934	0.32	2.00	2120.239	0.009415087
8892	0.30	1.90	2013.008	0.009349859
8198	0.28	1.80	1905.776	0.009617158
7417	0.28	1.74	1852.161	0.009211909
7330	0.27	1.69	1798.545	0.00965501
6983	0.26	1.64	1744.929	0.009771684
6636	0.26	1.64	1744.929	0.00928591
6028	0.24	1.49	1584.082	0.010235921
5421	0.21	1.34	1423.235	0.011402454
4553	0.16	1.04	1101.54	0.015987507
2817	0.11	0.68	726.23	0.022759769
2557	0.10	0.63	672.6143	0.024080872
1949	0.08	0.48	511.7671	0.031713915

10% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
29547	2.46	5.52	9831.331	0.006530925
29113	2.43	5.47	9735.43	0.006562416
28592	2.40	5.40	9607.561	0.006617741
27724	2.37	5.32	9479.693	0.006591154
26683	2.31	5.20	9255.923	0.006654
25208	2.24	5.04	8968.219	0.006695882
23732	2.17	4.88	8680.515	0.00672879
22083	2.08	4.68	8328.876	0.006801131
21042	2.02	4.55	8105.107	0.00684317
19133	1.92	4.32	7689.534	0.006912975
17484	1.82	4.10	7305.929	0.006997997
15835	1.73	3.89	6922.323	0.007059929
14099	1.61	3.62	6442.816	0.007256583
11756	1.46	3.28	5835.441	0.007375687
10194	1.34	3.01	5355.934	0.007592061
8285	1.15	2.60	4620.69	0.008289919
6896	1.04	2.34	4173.151	0.008459908
5594	0.94	2.11	3757.578	0.008464925
4813	0.86	1.93	3437.907	0.008700488
4032	0.78	1.75	3118.236	0.008859672
3598	0.71	1.61	2862.499	0.009382061
3164	0.66	1.48	2638.729	0.009709364
2817	0.61	1.37	2446.926	0.010052513
2730	0.59	1.32	2351.025	0.010553909
2644	0.58	1.30	2319.058	0.010502124
2557	0.57	1.28	2287.091	0.0104433
2470	0.56	1.27	2255.123	0.010376896
2383	0.55	1.23	2191.189	0.01060512
2297	0.52	1.18	2095.288	0.011175809
2123	0.51	1.14	2031.354	0.010991722
2036	0.48	1.09	1935.452	0.011613032
1949	0.48	1.07	1903.485	0.011494647
1776	0.45	1.02	1807.584	0.011611787
1516	0.40	0.91	1615.781	0.012401663
821	0.25	0.57	1008.406	0.017253664
1082	0.31	0.69	1232.176	0.015219559
1255	0.36	0.80	1423.978	0.013224431
732	0.22	0.49	880.5372	0.020157065
447	0.14	0.31	560.866	0.030352756

15% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
146815	0.26	5.11	2065.16	0.009758312
143124	0.25	4.96	2001.704	0.010125742
139024	0.24	4.80	1938.249	0.01049022
130004	0.24	4.64	1874.794	0.010484869
116884	0.22	4.33	1747.883	0.010845321
98433	0.20	4.01	1620.972	0.010619492
79983	0.19	3.70	1494.062	0.010157168
52284	0.11	2.13	859.5082	0.020062463
40135	0.08	1.66	669.1422	0.025409378
34927	0.08	1.50	605.6869	0.026988796
26249	0.06	1.09	440.6824	0.038315525
12364	0.02	0.37	151.2389	0.15322462
10628	0.02	0.45	182.7997	0.090158681

15% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
155425	0.77	7.57	4327.308	0.007629064
153375	0.76	7.49	4282.486	0.00768685
148455	0.75	7.33	4192.843	0.007761811
143534	0.73	7.18	4103.2	0.007836055
136154	0.71	6.94	3968.735	0.007945362
126314	0.68	6.70	3834.27	0.007897194
118934	0.66	6.47	3699.805	0.007986092
84083	0.54	5.29	3027.481	0.008432021
78689	0.54	5.29	3027.481	0.007891108
62830	0.48	4.67	2668.908	0.008107452
55781	0.44	4.35	2489.621	0.008271935

42099	0.38	3.73	2131.048	0.008520538
35050	0.34	3.33	1906.94	0.008859308
31629	0.32	3.10	1772.475	0.009253709
30241	0.32	3.18	1817.297	0.00841652
26249	0.25	2.47	1413.902	0.012068717
21042	0.22	2.16	1234.616	0.012688475
11496	0.11	1.06	607.113	0.028667046
7156	0.07	0.67	383.0048	0.044841249
8892	0.08	0.83	472.6481	0.0365863

15% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
115244	1.24	7.75	7698.153	0.007153313
110324	1.21	7.55	7500.187	0.007214184
107454	1.19	7.40	7351.712	0.007313186
100483	1.14	7.11	7054.764	0.007426636
96383	1.11	6.91	6856.798	0.007540876
91053	1.07	6.71	6658.832	0.007553733
82317	1.04	6.51	6460.866	0.007253888
71640	0.97	6.06	6015.443	0.00728259
59824	0.87	5.41	5372.054	0.00762527
53293	0.82	5.11	5075.106	0.007611072
44586	0.73	4.56	4530.7	0.007989757
37538	0.67	4.16	4134.768	0.00807659
32251	0.60	3.77	3738.836	0.008486651
24477	0.52	3.22	3194.43	0.008823384
23212	0.52	3.22	3194.43	0.008367212
19567	0.46	2.87	2847.99	0.008873648
15141	0.40	2.52	2501.55	0.008899974
14099	0.37	2.32	2303.584	0.009773499
12364	0.32	1.97	1957.144	0.011872994
11496	0.30	1.87	1858.161	0.012247051
10628	0.28	1.77	1759.178	0.012632487
8458	0.22	1.37	1363.247	0.016741504
6289	0.16	1.02	1016.806	0.022373971
3338	0.09	0.58	571.3833	0.037608899

15% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
31283	2.51	5.57	9281.632	0.006697552
30154	2.46	5.47	9104.583	0.006709536
28419	2.38	5.29	8809.502	0.006754039
26683	2.30	5.11	8514.421	0.0067887
25642	2.26	5.01	8337.372	0.006803756
24513	2.20	4.88	8130.815	0.006839075
23559	2.15	4.78	7953.767	0.006868611
21649	2.05	4.55	7570.161	0.006967867
20521	1.98	4.40	7334.096	0.007036779
19567	1.93	4.28	7127.54	0.007103951
17918	1.84	4.09	6802.95	0.007140877
16703	1.76	3.91	6507.869	0.007274004
15054	1.65	3.66	6094.756	0.007474775
13752	1.56	3.46	5770.166	0.007618246
11496	1.41	3.13	5209.512	0.007812755
10801	1.36	3.02	5032.464	0.007866521
9500	1.26	2.79	4648.858	0.00810734
8719	1.18	2.61	4353.777	0.008483545
7764	1.11	2.45	4088.204	0.008568047
6896	1.03	2.28	3793.123	0.008840454
6375	0.98	2.17	3616.074	0.00899285
5594	0.90	1.99	3320.993	0.009355733
5074	0.84	1.87	3114.436	0.009647734
4727	0.80	1.78	2966.896	0.009903759
4379	0.77	1.71	2848.863	0.009952515
4032	0.73	1.62	2701.323	0.010191947
3598	0.68	1.50	2494.766	0.010663599
3512	0.66	1.46	2435.75	0.010916802
3425	0.65	1.44	2406.242	0.010909737
3251	0.64	1.41	2347.225	0.010884175
3164	0.62	1.37	2288.209	0.01114714
2991	0.57	1.27	2111.161	0.012376932
2644	0.53	1.18	1963.62	0.012646198
2383	0.49	1.09	1816.079	0.013328469
2123	0.44	0.97	1609.523	0.015115316
1863	0.40	0.88	1461.982	0.016073397
1602	0.35	0.77	1284.933	0.017899542

20% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
155015	0.27	5.20	3065.205	0.009824641
153785	0.26	5.05	2973.83	0.01035485
143534	0.25	4.89	2882.454	0.01028713
108684	0.22	4.27	2516.951	0.01021591
93513	0.20	3.81	2242.824	0.011069936
92475	0.19	3.65	2151.449	0.011896695
82110	0.16	3.19	1877.322	0.013873299
71744	0.15	2.88	1694.57	0.014877494
51013	0.10	1.95	1146.316	0.023117148
46209	0.10	1.95	1146.316	0.020940378
40135	0.08	1.64	963.5648	0.025740622
37531	0.08	1.48	872.1891	0.029378629
34927	0.07	1.33	780.8134	0.034114207
28853	0.06	1.17	689.4378	0.036145734

20% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
159115	0.78	7.55	6295.866	0.007750618
157475	0.77	7.47	6231.323	0.007830458
153785	0.76	7.39	6166.78	0.007807875
147635	0.74	7.16	5973.151	0.007989465
142304	0.72	7.01	5844.064	0.008044981
133694	0.70	6.77	5650.435	0.0080851
115654	0.64	6.23	5198.633	0.008262624
102943	0.61	5.92	4940.46	0.008143298
89003	0.56	5.38	4488.658	0.008529202
81213	0.53	5.15	4295.029	0.008500201
75476	0.53	5.15	4295.029	0.007899716
63452	0.48	4.68	3907.77	0.008022714
60956	0.48	4.61	3843.227	0.007968181
52976	0.45	4.37	3649.598	0.007679395
44527	0.41	3.99	3326.882	0.007767599
33105	0.32	3.06	2552.364	0.009811827
34927	0.32	3.06	2552.364	0.010351858
28853	0.28	2.67	2229.649	0.011205935
26249	0.24	2.36	1971.476	0.013039677
24513	0.22	2.13	1777.847	0.014974439
21910	0.20	1.90	1584.217	0.016855663
21042	0.19	1.82	1519.674	0.01759228
15835	0.14	1.36	1132.415	0.023841901
8892	0.08	0.82	680.6132	0.037063249

20% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
117704	1.24	7.65	8006.079	0.007401255
117294	1.23	7.60	7954.608	0.00747123
115244	1.23	7.60	7954.608	0.007340648
114014	1.22	7.51	7851.665	0.007453978
111554	1.21	7.46	7800.194	0.007389712
108274	1.18	7.26	7594.31	0.007566593
104583	1.15	7.11	7439.896	0.007615244
100073	1.13	6.96	7285.483	0.007598998
95153	1.10	6.77	7079.599	0.007651751

88183	1.04	6.42	6719.301	0.007872116
83146	1.04	6.42	6719.301	0.007422478
78896	1.02	6.28	6564.888	0.007378309
73817	0.98	6.03	6307.532	0.007478134
67183	0.93	5.73	5998.705	0.007524895
60964	0.87	5.39	5638.408	0.00772884
58765	0.87	5.39	5638.408	0.007450105
50473	0.81	5.00	5226.639	0.007446747
41711	0.73	4.50	4711.928	0.007571924
35922	0.68	4.16	4351.63	0.007645533
29976	0.61	3.77	3939.861	0.007783383
31803	0.61	3.77	3939.861	0.008257793
25034	0.54	3.32	3476.621	0.008347781
20261	0.48	2.93	3064.852	0.008693499
17223	0.44	2.73	2858.968	0.008492912
15835	0.40	2.49	2601.612	0.009429426
14099	0.34	2.09	2189.843	0.011850152
13231	0.32	1.99	2086.901	0.012244928
12364	0.29	1.80	1881.016	0.014083555
12364	0.28	1.75	1829.545	0.014887135
11496	0.28	1.70	1778.074	0.014655147
10628	0.25	1.55	1623.661	0.016248361
8892	0.21	1.31	1366.305	0.019198477
8892	0.20	1.26	1314.834	0.020731003
6289	0.15	0.91	954.5364	0.027818025
2817	0.07	0.42	439.8253	0.058697848

20% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
31543	2.56	5.61	9837.028	0.006587614
31283	2.55	5.59	9806.339	0.006574195
30241	2.50	5.48	9622.209	0.006600895
28853	2.44	5.34	9376.701	0.006631914
27117	2.36	5.17	9069.817	0.006661887
24774	2.24	4.91	8609.49	0.00675446
22604	2.13	4.66	8179.852	0.006827328
21129	2.04	4.47	7842.279	0.006942949
19046	1.93	4.22	7412.641	0.007005046
18005	1.87	4.10	7197.822	0.007023184
16790	1.81	3.96	6952.315	0.00701996
15314	1.71	3.75	6584.053	0.007139413
14707	1.67	3.65	6399.923	0.007256396
13926	1.61	3.53	6185.104	0.007356588
13492	1.57	3.44	6031.661	0.007494603
12364	1.50	3.28	5755.466	0.00754287
11149	1.41	3.09	5417.893	0.007675606
10194	1.34	2.93	5141.697	0.00779262
9326	1.26	2.76	4834.812	0.008062969
8111	1.15	2.53	4435.863	0.008330647
7243	1.08	2.37	4159.667	0.008460033
6549	1.02	2.23	3914.159	0.008638774
6115	0.99	2.16	3791.406	0.008597173
5594	0.93	2.04	3576.587	0.008838284
4987	0.88	1.93	3392.456	0.008756987
4553	0.83	1.83	3208.325	0.008939043
4379	0.79	1.74	3054.883	0.009483716
4119	0.76	1.67	2932.129	0.009682411
3859	0.72	1.58	2778.687	0.010099827
3512	0.69	1.51	2655.933	0.010060465
3251	0.66	1.44	2533.18	0.010239171
3164	0.64	1.41	2471.803	0.010466921
2991	0.62	1.36	2379.738	0.010673063
2904	0.60	1.32	2318.361	0.010919353
2817	0.60	1.30	2287.672	0.010879152
2730	0.59	1.29	2256.984	0.010832712
2644	0.58	1.27	2226.295	0.010779559
2730	0.57	1.25	2195.607	0.011446821
2817	0.56	1.23	2164.919	0.012147853
2644	0.55	1.20	2103.542	0.012074366
2644	0.52	1.13	1980.788	0.013617287
1689	0.34	0.74	1305.642	0.02002415
1255	0.26	0.57	998.7579	0.025429016

25% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
156245	0.26	4.98	2926.998	0.010655878
155015	0.25	4.83	2837.061	0.011252892
151735	0.25	4.83	2837.061	0.011014783
145175	0.24	4.68	2747.124	0.011239893
131234	0.23	4.37	2567.251	0.011634257
116474	0.22	4.22	2477.314	0.011089051
102841	0.21	4.06	2387.378	0.010542698
92061	0.20	3.91	2297.441	0.010190926
89432	0.17	3.30	1937.694	0.013917165
78480	0.16	3.15	1847.757	0.013430593
62833	0.13	2.53	1488.011	0.016580829
55010	0.12	2.23	1308.137	0.018782992
45342	0.09	1.77	1038.327	0.024572912
52284	0.11	2.07	1218.201	0.020585543
43606	0.08	1.46	858.4539	0.034573214
34927	0.07	1.31	768.5172	0.034553207
34927	0.06	1.16	678.5805	0.04431929

25% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
158295	0.78	7.45	6196.719	0.007809899
155425	0.76	7.30	6069.665	0.00799269
150095	0.75	7.15	5942.612	0.008052165
141484	0.72	6.92	5752.032	0.008101553
126314	0.68	6.46	5370.872	0.008295914
116474	0.64	6.15	5116.765	0.00842829
104583	0.61	5.85	4862.658	0.008379495
90233	0.56	5.31	4417.971	0.008758352
70553	0.49	4.70	3909.757	0.00874411
64711	0.48	4.62	3846.231	0.008287218
53602	0.44	4.17	3465.07	0.008457834
39364	0.35	3.33	2766.276	0.009745613
29976	0.27	2.56	2131.009	0.012505674
28853	0.26	2.49	2067.483	0.012788007
23646	0.22	2.10	1749.849	0.014630178
22778	0.20	1.95	1622.796	0.016386405
20174	0.17	1.65	1368.689	0.0204027
19306	0.17	1.65	1368.689	0.019525024
17571	0.16	1.49	1241.635	0.02159239
14099	0.12	1.19	987.5285	0.027390395
10628	0.09	0.88	733.4216	0.037431776
5855	0.05	0.50	415.7881	0.064159973

25% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
118524	1.23	7.46	7778.678	0.007746658
113604	1.19	7.26	7576.035	0.007827602
107454	1.16	7.07	7373.393	0.007816389
103353	1.13	6.88	7170.751	0.007949062
97613	1.10	6.68	6968.109	0.00795059
84903	1.01	6.15	6410.843	0.008169826
81073	1.01	6.15	6410.843	0.007801297
69775	0.93	5.66	5904.238	0.007915715
56403	0.83	5.03	5245.65	0.008106325
53915	0.83	5.03	5245.65	0.007748731
44684	0.75	4.54	4739.045	0.00786841
34514	0.64	3.91	4080.458	0.008197701

36056	0.64	3.91	4080.458	0.008563984
29373	0.57	3.48	3624.513	0.008842461
22864	0.50	3.04	3168.568	0.009006473
17571	0.43	2.60	2712.623	0.009443389
14967	0.36	2.16	2256.678	0.011622986
12364	0.31	1.87	1952.715	0.012822873
11930	0.28	1.73	1800.734	0.014549495
11496	0.28	1.68	1750.073	0.014843737
10628	0.26	1.58	1648.752	0.015461629
9760	0.23	1.39	1446.11	0.018457296
5421	0.13	0.80	838.1832	0.030514438
2383	0.06	0.37	382.2384	0.064511728

25% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
33279	2.54	5.50	9621.703	0.007128217
32584	2.52	5.45	9531.088	0.007112849
31022	2.45	5.29	9259.242	0.007175326
29894	2.40	5.19	9078.011	0.007193207
28419	2.33	5.03	8806.164	0.007266914
26509	2.24	4.84	8473.908	0.007320698
24513	2.14	4.64	8111.446	0.007387991
22431	2.04	4.41	7718.779	0.007465562
20174	1.92	4.15	7265.701	0.007578095
19133	1.86	4.03	7054.265	0.007624185
17137	1.74	3.77	6601.188	0.007798351
16095	1.68	3.64	6359.547	0.00789162
14273	1.55	3.36	5876.264	0.008196468
12190	1.42	3.07	5362.777	0.008405114
10281	1.28	2.77	4849.289	0.008669371
8458	1.11	2.41	4214.981	0.009440815
7504	1.03	2.24	3912.929	0.009718229
6723	0.96	2.08	3641.083	0.010055274
5421	0.84	1.82	3188.006	0.010576579
5074	0.79	1.72	3006.775	0.011128581
4640	0.76	1.65	2885.954	0.011046759
4032	0.69	1.49	2614.108	0.011700933
3685	0.65	1.41	2463.082	0.012045173
3512	0.62	1.34	2342.261	0.012692507
3338	0.60	1.29	2251.646	0.013055783
3251	0.59	1.27	2221.441	0.013064506
2817	0.53	1.15	2010.005	0.013827835
2036	0.44	0.96	1677.748	0.014344619
1342	0.34	0.73	1285.081	0.016113517
1168	0.25	0.54	952.8243	0.02551956
995	0.17	0.37	650.7728	0.046579599

30% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
160755	0.28	5.37	3247.957	0.009307705
162395	0.28	5.22	3156.581	0.009954913
142304	0.26	4.92	2973.83	0.009828451
126314	0.24	4.62	2791.078	0.009903903
106634	0.23	4.32	2608.327	0.009573451
79983	0.20	3.86	2334.2	0.008966429
62833	0.17	3.26	1968.697	0.009902181
47187	0.12	2.35	1420.443	0.014284787
47945	0.12	2.35	1420.443	0.014514278
47077	0.13	2.50	1511.819	0.012580867
34927	0.10	1.90	1146.316	0.016235178
30588	0.08	1.59	963.5648	0.020122948
27985	0.08	1.44	872.1891	0.022469761
25381	0.07	1.29	780.8134	0.025428237

30% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
161575	0.79	7.43	6360.41	0.007909999
160345	0.79	7.43	6360.41	0.007849782
156655	0.77	7.28	6231.323	0.007990166
151325	0.75	7.13	6102.237	0.008048301
139844	0.72	6.83	5844.064	0.00810938
129594	0.70	6.60	5650.435	0.008038854
107454	0.63	5.92	5069.547	0.008280472
101286	0.62	5.85	5005.004	0.0080078
79726	0.55	5.17	4424.115	0.0080671
67287	0.50	4.72	4036.857	0.008177423
47385	0.41	3.89	3326.882	0.008478881
44840	0.41	3.89	3326.882	0.008023508
32636	0.36	3.36	2875.08	0.007819332
33886	0.36	3.36	2875.08	0.008118835
21910	0.29	2.76	2358.735	0.007799254
19306	0.27	2.53	2165.105	0.008156677
17571	0.24	2.23	1906.933	0.009569481
16703	0.21	2.00	1713.303	0.011269177
15835	0.20	1.85	1584.217	0.012495651
14967	0.20	1.85	1584.217	0.011810818
13231	0.17	1.63	1390.588	0.013551304
10628	0.14	1.32	1132.415	0.016413714
8024	0.11	1.02	874.2426	0.020793002
5421	0.07	0.64	551.527	0.035294109
4032	0.05	0.49	422.4407	0.044749514

30% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
121394	1.26	7.56	8109.021	0.007632216
120574	1.25	7.51	8057.55	0.007677819
118114	1.23	7.37	7903.136	0.007817941
113604	1.20	7.22	7748.723	0.00782209
98798	1.15	6.89	7388.425	0.007482317
89055	1.08	6.50	6976.656	0.007564014
70500	0.95	5.73	6153.119	0.007698224
65806	0.95	5.73	6153.119	0.007185652
60643	0.90	5.40	5792.821	0.007471192
50629	0.80	4.82	5175.168	0.007815252
44840	0.75	4.54	4866.341	0.007828022
36229	0.66	3.96	4248.688	0.008297364
35296	0.67	4.01	4300.159	0.007891244
27985	0.58	3.48	3733.976	0.008297904
20868	0.49	2.95	3167.794	0.008597377
20608	0.49	2.95	3167.794	0.008490116
16356	0.43	2.57	2756.025	0.008902075
12624	0.38	2.28	2447.199	0.008714562
10194	0.31	1.85	1983.959	0.010706985
9760	0.31	1.85	1983.959	0.010251225
9760	0.30	1.80	1932.488	0.010804573
8892	0.28	1.71	1829.545	0.010982773
8024	0.27	1.61	1726.603	0.011127924
7156	0.24	1.42	1520.719	0.012793593
5421	0.19	1.13	1211.892	0.015258994
4987	0.16	0.99	1057.479	0.01843639
3164	0.11	0.65	697.1808	0.026914833

30% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
33539	2.59	5.53	9959.781	0.007008742
33018	2.57	5.48	9867.716	0.007029281
31716	2.50	5.35	9622.209	0.007101101
28505	2.36	5.04	9069.817	0.007183253
25728	2.22	4.75	8548.113	0.007298972
22604	2.06	4.41	7934.345	0.007443131
19567	1.90	4.05	7289.887	0.007632474
17744	1.80	3.85	6921.626	0.007677682

15488	1.67	3.56	6399.923	0.007838452
13752	1.55	3.32	5970.285	0.007997778
12277	1.45	3.10	5571.335	0.008198905
10628	1.31	2.81	5049.632	0.008640064
8719	1.17	2.50	4497.24	0.008936046
7851	1.10	2.35	4221.044	0.009134032
6896	1.03	2.19	3944.848	0.009186194
5768	0.91	1.95	3515.21	0.009676281
4987	0.83	1.78	3208.325	0.010042975
4379	0.76	1.63	2932.129	0.010559358
3859	0.71	1.53	2747.999	0.010592446
3425	0.68	1.44	2594.557	0.010546156
3078	0.64	1.37	2471.803	0.010441864
2817	0.62	1.32	2379.738	0.010312419
2730	0.60	1.27	2287.672	0.010815398
2557	0.59	1.25	2256.984	0.010405188
2383	0.58	1.24	2226.295	0.009968094
2123	0.57	1.22	2195.607	0.009129142
2036	0.56	1.19	2134.23	0.009266813
1776	0.51	1.08	1950.099	0.009680209
1516	0.43	0.91	1643.215	0.011634787
1255	0.34	0.73	1305.642	0.015262921
995	0.26	0.55	998.7579	0.020673042
474	0.11	0.23	415.6776	0.056877248

35% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
168955	0.31	5.76	3522.084	0.008423362
146405	0.30	5.61	3430.708	0.007693084
126724	0.29	5.46	3339.333	0.007028346
93513	0.26	4.86	2973.83	0.006539644
78480	0.20	3.66	2242.824	0.00964894
70656	0.16	3.07	1877.322	0.012399034
69153	0.22	4.11	2516.951	0.006751075
62833	0.14	2.62	1603.195	0.015119273
55010	0.12	2.32	1420.443	0.016861985
52284	0.12	2.17	1329.068	0.018305892
47945	0.11	2.02	1237.692	0.019356763
43606	0.10	1.87	1146.316	0.020523425
39267	0.09	1.72	1054.94	0.021821355
34927	0.08	1.57	963.5648	0.023265836
28853	0.07	1.28	780.8134	0.029268689

35% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
163625	0.80	7.49	6489.496	0.00779139
161575	0.79	7.34	6360.41	0.008009235
156655	0.78	7.27	6295.866	0.007925377
149275	0.75	6.97	6037.694	0.008211661
139434	0.71	6.67	5779.521	0.008370922
125084	0.68	6.30	5456.806	0.008423877
115654	0.64	6.00	5198.633	0.008581607
97203	0.59	5.48	4746.831	0.008650886
81213	0.54	5.03	4359.572	0.008568885
76616	0.53	4.96	4295.029	0.008328638
59927	0.47	4.36	3778.684	0.00841649
46348	0.41	3.84	3326.882	0.008397449
44058	0.41	3.84	3326.882	0.007982428
36235	0.38	3.54	3068.709	0.007716132
31541	0.35	3.24	2810.537	0.008007202
29720	0.35	3.24	2810.537	0.007545072
28853	0.31	2.87	2487.821	0.009348314
25381	0.28	2.65	2294.192	0.009670296
22778	0.26	2.42	2100.562	0.010352022
20608	0.24	2.20	1906.933	0.011364579
19306	0.22	2.05	1777.847	0.012248909

18438	0.20	1.90	1648.76	0.013601801
17571	0.20	1.83	1584.217	0.014039265
14099	0.16	1.46	1261.501	0.01776671
10628	0.12	1.08	938.7858	0.024182424
8892	0.10	0.93	809.6995	0.027198639

35% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
121804	1.26	7.46	8109.021	0.007754069
122214	1.27	7.51	8160.492	0.007682335
119754	1.25	7.42	8057.55	0.00772127
114424	1.21	7.18	7800.194	0.00787246
111554	1.19	7.08	7697.252	0.007881658
105813	1.15	6.85	7439.896	0.008002258
100042	1.15	6.85	7439.896	0.007565791
96621	1.14	6.75	7336.954	0.007513587
91231	1.11	6.56	7131.07	0.007510003
80348	1.02	6.04	6564.888	0.007804106
74335	0.98	5.81	6307.532	0.007821364
68323	0.94	5.57	6050.176	0.00781338
65806	0.94	5.57	6050.176	0.007525499
56888	0.87	5.14	5586.936	0.007629153
45622	0.78	4.62	5020.754	0.007576096
38425	0.71	4.24	4608.985	0.007571986
31697	0.64	3.82	4145.745	0.007720069
32498	0.63	3.72	4042.803	0.008323195
26596	0.57	3.39	3682.505	0.008209894
22604	0.52	3.11	3373.679	0.008313518
18178	0.47	2.77	3013.381	0.008380028
16182	0.44	2.63	2858.968	0.00828744
14099	0.40	2.39	2601.612	0.008719981
13231	0.37	2.21	2395.728	0.009650186
12364	0.36	2.16	2344.256	0.009417549
11496	0.32	1.92	2086.901	0.011049356
11062	0.31	1.83	1983.959	0.011764268
10628	0.29	1.73	1881.016	0.012573776
8892	0.26	1.54	1675.132	0.013265233
8024	0.23	1.35	1469.248	0.015560511
6375	0.19	1.12	1211.892	0.018171321
5421	0.16	0.93	1006.008	0.022421563
4987	0.14	0.83	903.0653	0.025597373
4206	0.12	0.69	748.652	0.031411999
2991	0.08	0.50	542.7675	0.042498156

35% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
33799	2.62	5.52	10051.85	0.007021354
32150	2.54	5.35	9744.962	0.007106093
31196	2.50	5.26	9591.52	0.007117471
30415	2.46	5.18	9438.078	0.007166736
29286	2.40	5.06	9223.259	0.007226096
27985	2.34	4.94	9008.44	0.007238142
26683	2.29	4.83	8793.621	0.007242754
25815	2.24	4.72	8609.49	0.007310119
23906	2.15	4.54	8271.917	0.007333263
23125	2.11	4.46	8118.475	0.007364348
21389	2.02	4.27	7780.902	0.00741546
19827	1.94	4.10	7474.018	0.007449959
18525	1.86	3.93	7167.134	0.007569686
17223	1.78	3.76	6860.249	0.007681499
15227	1.67	3.51	6399.923	0.007803372
13058	1.52	3.21	5847.531	0.008015504
11496	1.41	2.97	5417.893	0.008220152
10107	1.30	2.74	4988.255	0.008525832
10020	1.29	2.72	4957.566	0.008557597
8545	1.16	2.45	4466.551	0.008990304

7764	1.11	2.33	4251.732	0.00901483
6723	1.01	2.13	3883.471	0.00935621
6115	0.96	2.03	3699.34	0.009379037
5681	0.93	1.96	3576.587	0.009321891
5074	0.87	1.84	3361.768	0.009423045
4640	0.82	1.73	3146.948	0.009833757
3772	0.73	1.54	2809.376	0.010031023
3425	0.68	1.42	2594.557	0.010678464
3078	0.64	1.36	2471.803	0.010572864
2730	0.60	1.27	2318.361	0.010663081
2036	0.55	1.15	2103.542	0.009658846
1949	0.51	1.07	1950.099	0.010759648
1602	0.39	0.82	1489.773	0.015153235
1516	0.30	0.63	1152.2	0.023961062
1168	0.23	0.48	876.0042	0.031957403

40% water-in-EDM Monarch oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
168955	0.31	5.68	3668.837	0.008527729
146405	0.30	5.54	3573.654	0.007788403
126724	0.29	5.39	3478.471	0.007115429
93513	0.26	4.80	3097.739	0.006620671
97658	0.26	4.80	3097.739	0.006914124
87292	0.23	4.21	2717.007	0.008033671
82110	0.20	3.77	2431.458	0.009435818
78480	0.20	3.62	2336.275	0.009768492
62833	0.16	2.88	1860.36	0.012334305
51881	0.13	2.44	1574.811	0.014212467
47945	0.12	2.29	1479.628	0.01487846
34927	0.08	1.56	1003.713	0.023554104
29720	0.07	1.26	813.3473	0.030522602
28853	0.07	1.35	871.5372	0.025806637
21910	0.06	1.02	661.0235	0.03406621

40% water-in-EDM Monarch oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
164855	0.81	7.47	6827.124	0.007791468
163215	0.80	7.40	6759.891	0.007868161
157065	0.79	7.25	6625.427	0.007882136
148865	0.76	7.03	6423.729	0.007947119
148455	0.75	6.96	6356.497	0.008093767
140664	0.73	6.74	6154.8	0.00817992
130004	0.70	6.44	5885.87	0.00826663
119754	0.68	6.22	5684.172	0.008164841
104583	0.62	5.71	5213.545	0.00847597
64695	0.49	4.53	4137.826	0.008323811
62051	0.49	4.53	4137.826	0.007983565
47813	0.44	4.09	3734.432	0.007552462
34927	0.40	3.65	3331.037	0.00693427
29720	0.33	3.06	2793.178	0.008391706
24513	0.27	2.47	2255.318	0.010616458
20174	0.24	2.17	1986.388	0.011263131
19306	0.22	2.03	1851.924	0.012400675
17571	0.20	1.88	1717.459	0.013122201
18438	0.21	1.95	1784.691	0.012752368
17571	0.20	1.81	1650.226	0.014213215
14099	0.15	1.36	1246.832	0.019978938
9760	0.11	1.00	910.6694	0.025925165
6723	0.08	0.70	641.7397	0.03595917
8892	0.04	0.33	305.5775	0.209776906

40% water-in-EDM Monarch oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
122624	1.27	7.42	8500.513	0.007803613
120984	1.25	7.33	8393.281	0.007897229
114834	1.22	7.14	8178.818	0.007894036
106634	1.17	6.86	7857.124	0.007942867
95563	1.11	6.48	7428.198	0.007964062
90091	1.10	6.44	7374.582	0.007617599
80037	1.03	6.02	6892.04	0.007748247
66147	0.93	5.45	6248.651	0.007790156
64085	0.93	5.45	6248.651	0.007547351
42337	0.75	4.42	5069.105	0.007576437
33105	0.67	3.91	4479.332	0.007587223
35101	0.67	3.91	4479.332	0.008044593
35882	0.68	3.96	4532.948	0.008030213
27030	0.58	3.39	3889.559	0.008215945
23038	0.54	3.16	3621.48	0.008077622
20001	0.51	2.97	3407.017	0.007923267
16963	0.48	2.83	3246.17	0.00740242
15835	0.46	2.69	3085.323	0.007649363
14967	0.44	2.55	2924.475	0.008047326
14099	0.39	2.27	2602.781	0.009570415
13231	0.36	2.13	2441.934	0.010203478
12364	0.34	1.99	2281.087	0.010926223
11930	0.33	1.94	2227.471	0.011056388
11496	0.32	1.90	2173.855	0.01118626
11496	0.32	1.90	2173.855	0.01118626
11062	0.32	1.85	2120.239	0.011315294
10628	0.30	1.76	2013.008	0.012060503
9760	0.26	1.52	1744.929	0.014740271
7590	0.21	1.24	1423.235	0.01723148
4987	0.15	0.87	994.3088	0.023195121
3425	0.10	0.59	672.6143	0.034810342
1776	0.05	0.31	350.9199	0.066313561

40% water-in-EDM Monarch oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
34233	2.62	5.45	10470.67	0.007199609
33799	2.60	5.42	10406.74	0.00719596
32845	2.56	5.33	10246.9	0.007212569
31977	2.53	5.27	10119.04	0.007200581
30328	2.45	5.10	9799.364	0.00728211
29200	2.40	5.00	9607.561	0.007293951
27985	2.34	4.88	9383.791	0.007327824
26336	2.26	4.72	9064.12	0.007391052
24166	2.16	4.50	8648.548	0.0074496
25121	2.20	4.58	8808.383	0.007465389
22604	2.06	4.30	8264.942	0.007629888
21216	1.99	4.15	7977.238	0.007687052
19740	1.91	3.98	7657.567	0.00776213
18091	1.82	3.79	7273.961	0.007883857
16008	1.69	3.52	6762.488	0.008071384
14186	1.61	3.35	6442.816	0.00787988
12016	1.42	2.95	5675.605	0.008601237
10281	1.30	2.70	5196.099	0.008779696
8458	1.16	2.42	4652.658	0.009009257
7330	1.08	2.25	4332.986	0.009002086
5942	0.97	2.02	3885.447	0.009074551
4987	0.90	1.87	3597.743	0.008883397
4206	0.84	1.76	3373.973	0.00851879
3512	0.79	1.64	3150.203	0.008158899
2817	0.71	1.49	2862.499	0.007927718
2644	0.67	1.39	2670.696	0.008546214
2557	0.64	1.32	2542.828	0.009117864
2470	0.61	1.27	2446.926	0.009512372
2297	0.60	1.24	2382.992	0.009324888
2210	0.59	1.22	2351.025	0.009218171
2210	0.58	1.21	2319.058	0.009474059
2123	0.57	1.19	2287.091	0.009358204
2036	0.54	1.12	2159.222	0.010070205
1776	0.47	0.97	1871.518	0.011690425

1429	0.36	0.74	1423.978	0.016246153
1168	0.28	0.57	1104.307	0.022090706
908	0.16	0.34	656.7674	0.048537703

5% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
50629	0.14	2.70	2414.45	0.011825
49690	0.13	2.55	2276.836	0.013051
48752	0.13	2.55	2276.836	0.012804
44997	0.13	2.55	2276.836	0.011818
42024	0.12	2.39	2139.222	0.012503
39520	0.12	2.39	2139.222	0.011758
35139	0.12	2.24	2001.608	0.011942
31697	0.11	2.08	1863.994	0.012421
28568	0.10	1.93	1726.38	0.013051
24500	0.09	1.78	1588.766	0.013215
25642	0.09	1.78	1588.766	0.013831
19133	0.08	1.62	1451.152	0.01237
12450	0.08	1.47	1313.538	0.009825
12103	0.07	1.41	1260.054	0.010379
8545	0.06	1.07	955.6967	0.012738
6289	0.04	0.77	689.4488	0.018013
5855	0.04	0.73	654.9763	0.018581
2817	0.02	0.35	310.252	0.039849
3078	0.02	0.39	344.7244	0.035261
4119	0.03	0.52	465.3779	0.025894

5% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
56888	0.44	4.26	5399.178	0.008615
55949	0.44	4.19	5301.975	0.008786
54697	0.44	4.19	5301.975	0.00859
52820	0.43	4.11	5204.771	0.008608
50473	0.41	3.96	5010.364	0.008876
48595	0.40	3.88	4913.161	0.008887
46718	0.40	3.80	4815.957	0.008892
44058	0.39	3.73	4718.754	0.008735
41867	0.38	3.65	4621.55	0.008654
38269	0.36	3.42	4329.94	0.009011
35609	0.35	3.34	4232.736	0.008774
32792	0.32	3.11	3941.126	0.00932
29350	0.31	2.96	3746.719	0.00923
27316	0.29	2.80	3552.312	0.009556
24969	0.28	2.65	3357.904	0.009776
26162	0.28	2.65	3357.904	0.010243
21736	0.24	2.34	2969.09	0.010885
18265	0.23	2.19	2774.683	0.010473
14794	0.20	1.88	2385.869	0.011473
10975	0.16	1.58	1997.055	0.012148
9153	0.16	1.50	1899.852	0.011194
7764	0.14	1.35	1705.445	0.011784
5768	0.12	1.19	1511.038	0.011152
4900	0.12	1.12	1413.834	0.010822
3685	0.10	0.96	1219.427	0.01094
2817	0.08	0.81	1025.02	0.011838
2644	0.07	0.06	852.2353	0.016069
2036	0.06	0.58	739.2776	0.016448
2091	0.06	0.54	681.7882	0.01986
1759	0.05	0.43	547.8656	0.025865
1177	0.03	0.29	365.2437	0.038934
861	0.02	0.20	255.6706	0.058118

5% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
43588	0.72	4.42	7018.76	0.008154
42493	0.71	4.32	6863.726	0.008312
41241	0.70	4.27	6786.209	0.008253
40459	0.69	4.22	6708.693	0.008284
39364	0.68	4.13	6553.659	0.008446
37799	0.67	4.08	6476.143	0.008305
36548	0.65	3.98	6321.109	0.008429
34983	0.64	3.88	6166.076	0.008479
33262	0.62	3.78	6011.042	0.008483
31854	0.60	3.69	5856.009	0.00856
29663	0.58	3.54	5623.458	0.008644
30762	0.58	3.54	5623.458	0.008964
29113	0.56	3.39	5390.908	0.009232
27377	0.54	3.30	5235.875	0.009203
25208	0.52	3.15	5003.325	0.00928
22778	0.49	3.00	4770.774	0.009222
20608	0.46	2.81	4460.707	0.009544
17744	0.42	2.56	4073.124	0.009856
14794	0.37	2.27	3608.023	0.010472
13058	0.35	2.13	3375.473	0.010561
11149	0.32	1.93	3065.406	0.010933
8805	0.28	1.69	2677.823	0.011316
6809	0.24	1.44	2290.239	0.011964
5681	0.21	1.30	2057.689	0.012365
4813	0.20	1.20	1902.655	0.012253
4119	0.18	1.10	1747.622	0.012428
3512	0.16	1.00	1592.588	0.012759
3164	0.16	0.95	1515.072	0.012704
2904	0.15	0.91	1437.555	0.01295
2781	0.16	0.95	1515.072	0.011166
2657	0.16	1.00	1592.588	0.009652
2573	0.15	0.91	1437.555	0.011476
2116	0.14	0.86	1360.038	0.010543
1784	0.12	0.71	1127.488	0.012929
1551	0.11	0.66	1049.971	0.012962
1351	0.09	0.56	894.9377	0.015546
910	0.06	0.37	584.8708	0.024527
1093	0.08	0.47	739.9042	0.018405

5% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
15227	1.67	3.62	9638.438	0.007574
15054	1.64	3.57	9499.785	0.007708
14446	1.61	3.50	9314.915	0.007693
14012	1.58	3.43	9130.045	0.007768
13665	1.55	3.38	8991.392	0.007811
13145	1.52	3.31	8806.522	0.007832
12624	1.48	3.22	8575.435	0.007932
12103	1.44	3.13	8344.347	0.008032
11409	1.39	3.03	8067.042	0.008101
10888	1.35	2.94	7835.954	0.008194
10281	1.31	2.84	7558.649	0.008315
9760	1.27	2.75	7327.562	0.008399
9153	1.23	2.66	7096.474	0.008398
8545	1.17	2.54	6772.951	0.008607
7764	1.11	2.40	6403.211	0.00875
7417	1.07	2.33	6218.341	0.008863
6896	1.03	2.23	5941.036	0.009028
6462	0.99	2.14	5709.948	0.009159
5768	0.92	2.00	5340.208	0.009346
5247	0.87	1.90	5062.903	0.009459
4727	0.82	1.78	4739.38	0.009723
4466	0.79	1.71	4554.51	0.009949
4119	0.75	1.64	4369.64	0.009968
3338	0.67	1.45	3861.247	0.010345
2991	0.61	1.33	3537.725	0.011042
2831	0.61	1.33	3537.725	0.010453
2415	0.55	1.19	3167.984	0.011121

2116	0.52	1.12	2983.114	0.010988
1950	0.48	1.05	2798.244	0.011506
1750	0.44	0.96	2567.157	0.012272
1509	0.40	0.88	2336.069	0.012778
1243	0.36	0.79	2104.981	0.012963
1160	0.34	0.74	1966.329	0.013862
1093	0.33	0.72	1920.111	0.013703
1019	0.32	0.70	1873.894	0.013403
927	0.32	0.69	1827.676	0.012824
827	0.30	0.65	1735.241	0.012696
653	0.29	0.63	1689.024	0.010572
594	0.28	0.60	1596.589	0.010776
517	0.26	0.56	1504.154	0.010561
483	0.24	0.51	1365.501	0.01196
424	0.20	0.44	1180.631	0.014057
379	0.16	0.36	949.5432	0.019434
359	0.12	0.27	718.4556	0.032095
371	0.13	0.29	764.6731	0.029286
302	0.10	0.22	579.803	0.041462

5% water-in-Shell Pella-oil emulsions: 0.023735 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
22431	1.54	4.16	9935.638	0.007544
20955	1.48	4.01	9574.427	0.007589
20174	1.45	3.93	9368.02	0.007632
19306	1.40	3.80	9058.411	0.007812
17571	1.33	3.60	8593.996	0.007898
16529	1.28	3.47	8284.386	0.007996
15314	1.23	3.32	7923.175	0.008099
14273	1.18	3.19	7613.565	0.008175
12971	1.11	3.00	7149.151	0.008426
11843	1.05	2.85	6787.939	0.008533
10715	0.99	2.67	6375.127	0.008753
10020	0.95	2.59	6168.72	0.008743
9586	0.92	2.50	5962.314	0.008953
8719	0.88	2.39	5704.306	0.008896
7938	0.83	2.24	5343.094	0.009231
6896	0.76	2.07	4930.281	0.009419
6289	0.72	1.96	4672.273	0.009564
5247	0.65	1.76	4207.859	0.009839
4466	0.58	1.57	3743.444	0.010581
4032	0.55	1.48	3537.038	0.010701
3425	0.49	1.33	3175.826	0.011274
3164	0.47	1.27	3021.021	0.011511
2730	0.42	1.14	2711.412	0.012331
2582	0.43	1.16	2763.013	0.011228
2349	0.40	1.07	2556.607	0.011931
2025	0.36	0.99	2350.2	0.01217
1833	0.33	0.90	2143.794	0.013245
1692	0.32	0.88	2092.192	0.012834
1617	0.32	0.88	2092.192	0.012266
1517	0.30	0.81	1937.387	0.013422
1251	0.28	0.75	1782.583	0.013075
1068	0.26	0.70	1679.379	0.012577
769	0.20	0.53	1266.566	0.015917
578	0.15	0.40	956.9567	0.020949
511	0.12	0.34	802.1518	0.026383
428	0.10	0.27	647.3469	0.033922
345	0.08	0.21	492.5421	0.047217

10% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
50629	0.14	2.70	2154.831	0.011825
49690	0.13	2.55	2032.015	0.013051
48752	0.13	2.55	2032.015	0.012804
44997	0.13	2.55	2032.015	0.011818
42024	0.12	2.39	1909.198	0.012503
39520	0.12	2.39	1909.198	0.011758
35139	0.12	2.24	1786.381	0.011942
31697	0.11	2.08	1663.564	0.012421
28568	0.10	1.93	1540.748	0.013051
24500	0.09	1.78	1417.931	0.013215
25642	0.09	1.78	1417.931	0.013831
19133	0.08	1.62	1295.114	0.01237
12450	0.08	1.47	1172.297	0.009825
12103	0.07	1.41	1124.564	0.010379
8545	0.06	1.07	852.9336	0.012738
7243	0.04	0.85	676.846	0.017146
6289	0.04	0.73	584.5488	0.019959
4813	0.03	0.56	446.103	0.026229
3685	0.02	0.44	353.8058	0.031925
3078	0.02	0.37	292.7205	0.038951

10% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
56888	0.44	4.26	4818.622	0.008615
55949	0.44	4.19	4731.87	0.008786
54697	0.44	4.19	4731.87	0.00859
52820	0.43	4.11	4645.119	0.008608
50473	0.41	3.96	4471.616	0.008876
48595	0.40	3.88	4384.864	0.008887
46718	0.40	3.80	4298.112	0.008892
44058	0.39	3.73	4211.361	0.008735
41867	0.38	3.65	4124.609	0.008654
38269	0.36	3.42	3864.355	0.009011
35609	0.35	3.34	3777.603	0.008774
32792	0.32	3.11	3517.349	0.00932
29350	0.31	2.96	3343.846	0.00923
27316	0.29	2.80	3170.343	0.009556
24969	0.28	2.65	2996.839	0.009776
26162	0.28	2.65	2996.839	0.010243
21736	0.24	2.34	2649.833	0.010885
18265	0.23	2.19	2476.33	0.010473
14794	0.20	1.88	2129.324	0.011473
10975	0.16	1.58	1782.318	0.012148
9153	0.16	1.50	1695.567	0.011194
7764	0.14	1.35	1522.063	0.011784
5768	0.12	1.19	1348.56	0.011152
4900	0.12	1.12	1261.809	0.010822
4032	0.10	0.96	1088.306	0.011971
3685	0.08	0.81	914.8027	0.015484
2257	0.06	0.54	608.4777	0.02144
2008	0.05	0.48	543.2836	0.023922
861	0.02	0.20	226.2559	0.05911
1343	0.03	0.32	358.5672	0.036725

10% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
43588	0.72	4.42	6264.054	0.008154
42493	0.71	4.32	6125.691	0.008312
41241	0.70	4.27	6056.51	0.008253
40459	0.69	4.22	5987.328	0.008284
39364	0.68	4.13	5848.965	0.008446
37799	0.67	4.08	5779.783	0.008305
36548	0.65	3.98	5641.42	0.008429
34983	0.64	3.88	5503.057	0.008479
33262	0.62	3.78	5364.694	0.008483
31854	0.60	3.69	5226.33	0.00856
29663	0.58	3.54	5018.786	0.008644
30762	0.58	3.54	5018.786	0.008964
29113	0.56	3.39	4811.241	0.009232
27377	0.54	3.30	4672.878	0.009203

25208	0.52	3.15	4465.333	0.00928
22778	0.49	3.00	4257.788	0.009222
20608	0.46	2.81	3981.061	0.009544
17744	0.42	2.56	3635.153	0.009856
14794	0.37	2.27	3220.064	0.010472
13058	0.35	2.13	3012.519	0.010561
11149	0.32	1.93	2735.793	0.010933
8805	0.28	1.69	2389.885	0.011316
6809	0.24	1.44	2043.977	0.011964
5681	0.21	1.30	1836.432	0.012365
4813	0.20	1.20	1698.069	0.012253
3512	0.16	1.00	1421.342	0.012759
3164	0.16	0.95	1352.161	0.012704
2904	0.15	0.91	1282.979	0.01295
2781	0.16	0.95	1352.161	0.011166
2657	0.16	1.00	1421.342	0.009652
2573	0.15	0.91	1282.979	0.011476
2116	0.14	0.86	1213.797	0.010543
1784	0.12	0.71	1006.253	0.012929
1551	0.11	0.66	937.071	0.012962
1351	0.09	0.56	798.7078	0.015546
910	0.06	0.37	521.9814	0.024527
1093	0.08	0.47	660.3446	0.018405

10% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
15227	1.67	3.62	8602.047	0.007574
15054	1.64	3.57	8478.303	0.007708
14446	1.61	3.50	8313.311	0.007693
14012	1.58	3.43	8148.32	0.007768
13665	1.55	3.38	8024.576	0.007811
13145	1.52	3.31	7859.584	0.007832
12624	1.48	3.22	7653.345	0.007932
12103	1.44	3.13	7447.106	0.008032
11409	1.39	3.03	7199.618	0.008101
10888	1.35	2.94	6993.379	0.008194
10281	1.31	2.84	6745.891	0.008315
9760	1.27	2.75	6539.652	0.008399
9153	1.23	2.66	6333.412	0.008398
8545	1.17	2.54	6044.677	0.008607
7764	1.11	2.40	5714.694	0.00875
7417	1.07	2.33	5549.702	0.008863
6896	1.03	2.23	5302.215	0.009028
6462	0.99	2.14	5095.975	0.009159
5768	0.92	2.00	4765.992	0.009346
5247	0.87	1.90	4518.505	0.009459
4727	0.82	1.78	4229.769	0.009723
4466	0.79	1.71	4064.778	0.009949
4119	0.75	1.64	3899.786	0.009968
3338	0.67	1.45	3446.059	0.010345
2991	0.61	1.33	3157.324	0.011042
2415	0.55	1.19	2827.341	0.011121
2116	0.52	1.12	2662.349	0.010988
1950	0.48	1.05	2497.358	0.011506
1750	0.44	0.96	2291.118	0.012272
1509	0.40	0.88	2084.879	0.012778
1243	0.36	0.79	1878.639	0.012963
1160	0.34	0.74	1754.896	0.013862
1093	0.33	0.72	1713.648	0.013703
1019	0.32	0.70	1672.4	0.013403
927	0.32	0.69	1631.152	0.012824
827	0.30	0.65	1548.656	0.012696
653	0.29	0.63	1507.408	0.010572
594	0.28	0.60	1424.912	0.010776
593	0.27	0.58	1383.664	0.011399
564	0.24	0.53	1259.921	0.013068
493	0.21	0.46	1094.929	0.015134
448	0.17	0.37	888.6897	0.020885
427	0.13	0.29	682.4502	0.033781
440	0.14	0.30	723.6981	0.030888
388	0.11	0.24	558.7065	0.045728
357	0.09	0.20	476.2107	0.057908

10% water-in-Shell Pella-oil emulsions: 0.023735 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
22431	1.54	4.16	8867.29	0.007544
20955	1.48	4.01	8544.919	0.007589
20174	1.45	3.93	8360.706	0.007632
19306	1.40	3.80	8084.388	0.007812
17571	1.33	3.60	7669.911	0.007898
16529	1.28	3.47	7393.592	0.007996
15314	1.23	3.32	7071.221	0.008099
14273	1.18	3.19	6794.902	0.008175
12971	1.11	3.00	6380.425	0.008426
11843	1.05	2.85	6058.054	0.008533
10715	0.99	2.67	5689.629	0.008753
10020	0.95	2.59	5505.417	0.008743
9586	0.92	2.50	5321.205	0.008953
8719	0.88	2.39	5090.939	0.008896
7938	0.83	2.24	4768.568	0.009231
6896	0.76	2.07	4400.143	0.009419
6289	0.72	1.96	4169.878	0.009564
5247	0.65	1.76	3755.401	0.009839
4466	0.58	1.57	3340.923	0.010581
4032	0.55	1.48	3156.711	0.010701
3425	0.49	1.33	2834.34	0.011274
3164	0.47	1.27	2696.18	0.011511
2730	0.42	1.14	2419.862	0.012331
2582	0.43	1.16	2465.915	0.011228
2349	0.40	1.07	2281.703	0.011931
2025	0.36	0.99	2097.491	0.01217
1833	0.33	0.90	1913.278	0.013245
1692	0.32	0.88	1867.225	0.012834
1617	0.32	0.88	1867.225	0.012266
1517	0.30	0.81	1729.066	0.013422
1251	0.28	0.75	1590.907	0.013075
1068	0.26	0.70	1498.801	0.012577
769	0.20	0.53	1130.376	0.015917
661	0.15	0.40	854.0581	0.023964
594	0.12	0.34	715.8989	0.030673
511	0.10	0.27	577.7398	0.04051
412	0.08	0.21	439.5806	0.05632

15% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
55167	0.16	3.13	2607.391	0.009499
54697	0.16	2.97	2480.48	0.010406
53602	0.16	2.97	2480.48	0.010198
52507	0.16	2.97	2480.48	0.00999
51255	0.16	2.97	2480.48	0.009751
49221	0.15	2.82	2353.57	0.010402
46874	0.15	2.82	2353.57	0.009906
44997	0.14	2.67	2226.659	0.010624
42337	0.14	2.67	2226.659	0.009996
38425	0.13	2.52	2099.748	0.010202
34514	0.13	2.52	2099.748	0.009163
30915	0.12	2.37	1972.838	0.009298
28255	0.12	2.21	1845.927	0.009707
24813	0.11	2.06	1719.016	0.009829

23212	0.11	2.06	1719.016	0.009195
20348	0.10	1.91	1592.106	0.009397
16356	0.08	1.60	1338.284	0.01069
6809	0.04	0.82	685.9916	0.016938
3512	0.02	0.43	358.5894	0.031967
4727	0.03	0.57	476.8687	0.02433
2644	0.02	0.30	254.33	0.047843

15% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
57514	0.44	4.22	4979.242	0.008805
55010	0.44	4.14	4889.599	0.008733
53446	0.43	4.07	4799.956	0.008805
51724	0.42	3.99	4710.313	0.008849
47500	0.40	3.84	4531.026	0.008782
45466	0.39	3.69	4351.74	0.009112
43432	0.38	3.61	4262.096	0.009075
41867	0.37	3.53	4172.453	0.009128
37017	0.35	3.31	3903.523	0.009221
33418	0.33	3.15	3724.237	0.009145
30915	0.32	3.00	3544.95	0.009337
28412	0.31	2.93	3455.307	0.009032
29807	0.32	3.00	3544.95	0.009003
25468	0.28	2.62	3096.734	0.01008
22257	0.26	2.47	2917.448	0.009925
19653	0.24	2.32	2738.161	0.009949
17831	0.24	2.24	2648.518	0.009648
15922	0.22	2.09	2469.231	0.009912
13579	0.20	1.94	2289.945	0.009828
9847	0.17	1.64	1931.372	0.010019
8111	0.16	1.48	1752.085	0.010029
7070	0.15	1.41	1662.442	0.009709
5942	0.13	1.26	1483.156	0.010252
5160	0.12	1.10	1303.869	0.011521
4553	0.10	0.95	1124.583	0.013664
4379	0.09	0.88	1034.939	0.015519
3598	0.08	0.80	945.2962	0.015284
2008	0.05	0.48	561.3931	0.024183
1177	0.03	0.27	314.3801	0.045182

15% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44527	0.73	4.42	6544.344	0.008237
44371	0.72	4.37	6472.856	0.008391
43275	0.71	4.32	6401.369	0.008367
42337	0.71	4.28	6329.881	0.008372
41241	0.70	4.23	6258.393	0.008343
40146	0.68	4.13	6115.418	0.008505
37956	0.67	4.03	5972.443	0.008431
34670	0.64	3.84	5686.492	0.008495
33262	0.62	3.74	5543.517	0.008576
31854	0.60	3.60	5329.054	0.008887
30758	0.59	3.55	5257.566	0.008816
29507	0.58	3.50	5186.078	0.008692
27003	0.55	3.31	4900.128	0.00891
26221	0.54	3.26	4828.64	0.00891
27551	0.55	3.31	4900.128	0.009091
25294	0.52	3.12	4614.177	0.009413
22604	0.48	2.92	4328.227	0.00956
21216	0.47	2.83	4185.251	0.009596
19740	0.44	2.68	3970.788	0.00992
17571	0.42	2.54	3756.325	0.009866
13231	0.36	2.15	3184.424	0.010338
12190	0.34	2.05	3041.449	0.010441
10541	0.32	1.91	2826.986	0.01045
9586	0.30	1.81	2684.01	0.010543
8805	0.29	1.76	2612.523	0.010222
8371	0.28	1.67	2469.547	0.010876
7677	0.27	1.62	2398.06	0.010577
7156	0.26	1.57	2326.572	0.010475
6723	0.24	1.47	2183.597	0.011171
6202	0.24	1.43	2112.109	0.011015
5681	0.23	1.38	2040.622	0.01081
5160	0.21	1.28	1897.646	0.011354
4553	0.20	1.23	1826.159	0.010817
4032	0.19	1.14	1683.183	0.011277
3338	0.17	1.04	1540.208	0.011149
3251	0.16	0.99	1468.72	0.011942
2698	0.16	0.94	1397.233	0.01095
1842	0.13	0.80	1182.77	0.010431
1675	0.12	0.75	1111.282	0.010749
1343	0.10	0.61	896.8191	0.013228
1010	0.07	0.41	610.8685	0.021449
1177	0.09	0.56	825.3314	0.013685
1093	0.08	0.46	682.3561	0.018605
927	0.06	0.36	537.2319	0.02545
678	0.05	0.27	402.9239	0.03307

15% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
15922	1.66	3.56	6457.05	0.008083
15227	1.62	3.48	6301.492	0.008117
14880	1.60	3.44	6239.269	0.008091
14273	1.58	3.39	6145.935	0.007998
13665	1.54	3.30	5990.377	0.008061
12277	1.44	3.10	5617.038	0.008236
11669	1.39	3.00	5430.369	0.008376
10801	1.35	2.89	5243.7	0.008315
9934	1.27	2.74	4963.696	0.008534
9500	1.23	2.65	4808.138	0.008698
8805	1.19	2.57	4652.58	0.00861
8371	1.15	2.48	4497.022	0.008762
7851	1.11	2.38	4310.353	0.008944
6636	0.99	2.14	3874.791	0.009355
5942	0.94	2.02	3657.01	0.009404
5421	0.87	1.88	3408.118	0.009878
4900	0.83	1.78	3221.449	0.009994
3685	0.70	1.50	2723.664	0.010515
3251	0.65	1.40	2536.994	0.010692
3078	0.62	1.33	2412.548	0.011192
2730	0.59	1.26	2288.102	0.011039
2623	0.59	1.26	2288.102	0.010606
2266	0.53	1.14	2070.321	0.011189
2091	0.50	1.07	1945.875	0.01169
1759	0.47	1.00	1821.429	0.01122
1526	0.43	0.92	1665.871	0.011637
1359	0.40	0.87	1572.536	0.011636
1210	0.38	0.82	1479.202	0.011703
1177	0.37	0.80	1448.09	0.011876
1052	0.36	0.78	1416.979	0.011088
977	0.36	0.76	1385.867	0.010767
935	0.35	0.75	1354.755	0.010788
844	0.34	0.73	1323.644	0.010196
703	0.32	0.68	1230.309	0.009824
619	0.29	0.63	1136.975	0.010142
653	0.27	0.58	1043.64	0.012684
578	0.25	0.54	981.4168	0.012698
534	0.24	0.52	950.3052	0.012524
483	0.21	0.46	825.859	0.014978

500	0.19	0.40	732.5243	0.019718
498	0.17	0.37	670.3012	0.023468
431	0.15	0.32	576.9666	0.0274
345	0.12	0.25	452.5204	0.035634
328	0.10	0.22	390.2972	0.045507

15% water-in-Shell Pella-oil emulsions: 0.023535 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
23038	1.55	3.34	6757.695	0.007672
22864	1.55	3.32	6722.959	0.007693
22344	1.52	3.27	6618.752	0.007757
21476	1.48	3.18	6445.072	0.007863
20521	1.45	3.12	6306.129	0.007848
19567	1.41	3.03	6132.449	0.007913
18438	1.36	2.93	5924.034	0.00799
17571	1.32	2.84	5750.355	0.008081
16703	1.28	2.76	5576.675	0.008168
15575	1.23	2.65	5368.26	0.008219
14446	1.18	2.53	5125.109	0.008364
13579	1.13	2.43	4916.694	0.008543
12797	1.10	2.36	4777.75	0.008526
11062	1.00	2.15	4360.919	0.008846
10281	0.96	2.07	4187.24	0.008918
8632	0.87	1.86	3770.409	0.009234
7851	0.82	1.76	3561.994	0.00941
6636	0.74	1.59	3214.635	0.009766
5594	0.67	1.43	2902.012	0.010103
4727	0.61	1.31	2658.861	0.010168
4119	0.56	1.21	2450.446	0.010433
3425	0.52	1.11	2242.031	0.010362
2904	0.48	1.02	2068.351	0.010324
2906	0.48	1.02	2068.351	0.010331
2391	0.44	0.94	1894.672	0.010128
2083	0.40	0.85	1720.992	0.010695
1908	0.37	0.80	1616.785	0.011102
1800	0.36	0.76	1547.313	0.011435
1675	0.33	0.71	1443.105	0.012235
1551	0.32	0.70	1408.369	0.01189
1368	0.29	0.63	1269.426	0.012909
1077	0.25	0.54	1095.747	0.013639
927	0.21	0.46	922.0671	0.016583
678	0.17	0.37	748.3877	0.0184
636	0.16	0.33	674.3564	0.021271
594	0.13	0.28	574.7083	0.027373
511	0.10	0.21	435.0687	0.041083
428	0.08	0.18	366.293	0.048533
378	0.08	0.17	335.0029	0.051262

20% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
55167	0.16	3.09	1661.935	0.009601
54697	0.16	2.94	1581.043	0.010519
53602	0.16	2.94	1581.043	0.010308
52507	0.16	2.94	1581.043	0.010097
51255	0.16	2.94	1581.043	0.009857
49221	0.15	2.79	1500.151	0.010514
46874	0.15	2.79	1500.151	0.010012
44997	0.14	2.64	1419.259	0.010738
42337	0.14	2.64	1419.259	0.010103
38425	0.13	2.49	1338.367	0.010312
34514	0.13	2.49	1338.367	0.009262
30915	0.12	2.34	1257.475	0.009398
28255	0.12	2.19	1176.582	0.009811
24813	0.11	2.04	1095.69	0.009935
21997	0.11	2.04	1095.69	0.008808
23212	0.11	2.04	1095.69	0.009294
20348	0.10	1.89	1014.798	0.009498
16356	0.08	1.59	853.0142	0.010805
12277	0.06	1.14	613.5801	0.015675
6809	0.04	0.81	437.2468	0.017121
3512	0.02	0.43	228.5626	0.032312
4727	0.03	0.57	303.9532	0.024593
2644	0.02	0.30	162.1084	0.048359

20% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
57670	0.44	4.17	3173.738	0.008924
57514	0.44	4.17	3173.738	0.0089
55010	0.44	4.10	3116.6	0.008827
53446	0.43	4.02	3059.462	0.0089
51724	0.42	3.95	3002.324	0.008944
49847	0.41	3.87	2945.186	0.008957
47500	0.40	3.80	2888.048	0.008876
45466	0.39	3.65	2773.772	0.009211
43432	0.38	3.57	2716.634	0.009173
41867	0.37	3.50	2659.496	0.009226
39364	0.36	3.35	2545.22	0.009471
37017	0.35	3.27	2488.081	0.00932
33418	0.33	3.12	2373.805	0.009244
30915	0.32	2.97	2259.529	0.009438
28412	0.31	2.90	2202.391	0.00913
29807	0.32	2.97	2259.529	0.0091
25468	0.28	2.59	1973.839	0.010189
22257	0.26	2.44	1859.563	0.010032
19653	0.24	2.29	1745.287	0.010057
17831	0.24	2.22	1688.149	0.009752
15922	0.22	2.07	1573.873	0.010018
13579	0.20	1.92	1459.597	0.009934
9847	0.17	1.62	1231.044	0.010127
8111	0.16	1.47	1116.768	0.010137
7070	0.15	1.39	1059.63	0.009814
5942	0.13	1.24	945.3542	0.010362
5160	0.12	1.09	831.0781	0.011645
4553	0.10	0.94	716.802	0.013812
4379	0.09	0.87	659.6639	0.015686
4032	0.09	0.87	659.6639	0.014443
3598	0.08	0.79	602.5259	0.015449

20% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44527	0.73	4.37	4171.324	0.008326
44371	0.72	4.33	4125.758	0.008481
43901	0.72	4.33	4125.758	0.008391
43275	0.71	4.28	4080.192	0.008458
42337	0.71	4.23	4034.627	0.008462
41241	0.70	4.18	3989.061	0.008433
40146	0.68	4.09	3897.929	0.008597
37956	0.67	3.99	3806.798	0.008522
36391	0.65	3.90	3715.666	0.008576
34670	0.64	3.80	3624.535	0.008587
33262	0.62	3.70	3533.403	0.008668
31854	0.60	3.56	3396.706	0.008983
30758	0.59	3.51	3351.14	0.008911
29507	0.58	3.47	3305.574	0.008786
27003	0.55	3.27	3123.311	0.009006
26221	0.54	3.23	3077.745	0.009006
27551	0.55	3.27	3123.311	0.009189
25294	0.52	3.08	2941.048	0.009515

22604	0.48	2.89	2758.785	0.009663
21216	0.47	2.80	2667.653	0.0097
19740	0.44	2.65	2530.956	0.010027
17571	0.42	2.51	2394.258	0.009973
14620	0.38	2.27	2166.429	0.010135
13231	0.36	2.13	2029.732	0.01045
12190	0.34	2.03	1938.6	0.010553
10541	0.32	1.89	1801.903	0.010563
9586	0.30	1.79	1710.772	0.010657
8805	0.29	1.75	1665.206	0.010332
8371	0.28	1.65	1574.074	0.010993
7677	0.27	1.60	1528.508	0.010691
7156	0.26	1.55	1482.943	0.010588
6723	0.24	1.46	1391.811	0.011291
6202	0.24	1.41	1346.245	0.011134
5681	0.23	1.36	1300.679	0.010926
5160	0.21	1.27	1209.548	0.011477
4553	0.20	1.22	1163.982	0.010934
4032	0.19	1.12	1072.851	0.011398
3338	0.17	1.03	981.719	0.011269
3251	0.16	0.98	936.1532	0.01207
3078	0.16	0.93	890.5874	0.012625
2257	0.13	0.79	753.89	0.012923
2066	0.12	0.74	708.3242	0.013399
1675	0.10	0.60	571.6269	0.016683
1260	0.07	0.41	389.3637	0.027034
1468	0.09	0.55	526.0611	0.017254
1351	0.08	0.46	434.9295	0.02324

20% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
15922	1.66	3.52	5638.486	0.00817
15748	1.64	3.49	5584.151	0.008239
15227	1.62	3.44	5502.649	0.008204
14880	1.60	3.41	5448.314	0.008178
14273	1.58	3.35	5366.811	0.008084
13665	1.54	3.27	5230.974	0.008147
13058	1.50	3.18	5095.136	0.008206
12277	1.44	3.07	4904.963	0.008325
11669	1.39	2.96	4741.958	0.008466
10801	1.35	2.86	4578.953	0.008405
9934	1.27	2.71	4334.445	0.008626
9500	1.23	2.62	4198.608	0.008792
8805	1.19	2.54	4062.77	0.008703
8371	1.15	2.45	3926.932	0.008857
7851	1.11	2.35	3763.927	0.009041
7156	1.05	2.23	3573.755	0.009142
6636	0.99	2.11	3383.582	0.009456
5942	0.94	2.00	3193.409	0.009505
5421	0.87	1.86	2976.069	0.009985
4900	0.83	1.76	2813.064	0.010102
4119	0.75	1.59	2541.389	0.010405
3685	0.70	1.49	2378.383	0.010628
3251	0.65	1.38	2215.378	0.010807
3078	0.62	1.32	2106.708	0.011313
2730	0.59	1.25	1998.038	0.011158
2266	0.53	1.13	1807.865	0.01131
2091	0.50	1.06	1699.195	0.011816
1759	0.47	0.99	1590.525	0.011341
1526	0.43	0.91	1454.688	0.011763
1359	0.40	0.86	1373.185	0.011762
1210	0.38	0.81	1291.682	0.011829
1177	0.37	0.79	1264.515	0.012004
1052	0.36	0.77	1237.347	0.011208
977	0.36	0.76	1210.18	0.010883
935	0.35	0.74	1183.012	0.010904
844	0.34	0.72	1155.845	0.010306
703	0.32	0.67	1074.342	0.00993
619	0.29	0.62	992.8397	0.010252
653	0.27	0.57	911.3371	0.012821
578	0.25	0.54	857.002	0.012835
590	0.24	0.52	829.8345	0.013966
533	0.21	0.45	721.1644	0.016708
538	0.17	0.37	585.3268	0.025609
483	0.15	0.31	503.8242	0.031019
396	0.12	0.25	395.1541	0.041421
355	0.10	0.21	340.8191	0.049871

20% water-in-Shell Pella-oil emulsions: 0.023535 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
23038	1.55	3.30	5901.019	0.007755
22864	1.55	3.29	5870.686	0.007776
22344	1.52	3.24	5779.689	0.007841
21476	1.48	3.15	5628.027	0.007948
20521	1.45	3.08	5506.698	0.007933
19567	1.41	3.00	5355.036	0.007998
18438	1.36	2.90	5173.041	0.008077
17571	1.32	2.81	5021.379	0.008168
16703	1.28	2.73	4869.717	0.008256
15575	1.23	2.62	4687.723	0.008308
14446	1.18	2.51	4475.396	0.008455
13579	1.13	2.40	4293.402	0.008635
12797	1.10	2.34	4172.072	0.008618
11062	1.00	2.13	3808.083	0.008942
10281	0.96	2.05	3656.421	0.009014
8632	0.87	1.84	3292.433	0.009334
7851	0.82	1.74	3110.438	0.009512
6636	0.74	1.57	2807.114	0.009871
5594	0.67	1.42	2534.123	0.010212
4727	0.61	1.30	2321.796	0.010278
4119	0.56	1.20	2139.802	0.010545
3425	0.52	1.10	1957.807	0.010473
2904	0.48	1.01	1806.145	0.010435
2906	0.48	1.01	1806.145	0.010442
2391	0.44	0.93	1654.483	0.010237
2083	0.40	0.84	1502.821	0.01081
1908	0.37	0.79	1411.824	0.011222
1800	0.36	0.76	1351.159	0.011558
1675	0.33	0.71	1260.162	0.012367
1551	0.32	0.69	1229.83	0.012018
1368	0.29	0.62	1108.5	0.013048
1077	0.25	0.54	956.8382	0.013786
927	0.21	0.45	805.1762	0.016762
827	0.17	0.37	653.5142	0.022706
736	0.13	0.28	501.8522	0.034247
495	0.08	0.18	319.8578	0.056678

25% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
52820	0.16	3.06	1819.11	0.009291
51724	0.16	3.06	1819.11	0.009098
50316	0.16	3.06	1819.11	0.00885
47187	0.16	2.91	1730.568	0.009171
43745	0.16	2.91	1730.568	0.008502
42337	0.15	2.76	1642.025	0.00914
38425	0.15	2.76	1642.025	0.008295
33105	0.14	2.61	1553.483	0.007985
29663	0.13	2.46	1464.941	0.008046
28255	0.13	2.46	1464.941	0.007664

29807	0.13	2.46	1464.941	0.008085
27464	0.12	2.32	1376.398	0.008438
25294	0.12	2.17	1287.856	0.008877
23125	0.11	2.02	1199.314	0.009358
19306	0.09	1.72	1022.229	0.010754
16963	0.08	1.57	933.6868	0.011326
14099	0.08	1.42	845.1445	0.01149
12971	0.06	1.17	692.7905	0.015731
10020	0.05	0.93	554.2213	0.018989
6289	0.03	0.62	369.8505	0.02676
3685	0.02	0.44	260.082	0.031711

25% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
58139	0.46	4.28	3598.974	0.008472
57201	0.44	4.13	3473.89	0.008946
54541	0.44	4.05	3411.348	0.008845
52663	0.43	3.98	3348.806	0.008863
50629	0.42	3.91	3286.265	0.008848
48282	0.41	3.83	3223.723	0.008768
46248	0.40	3.68	3098.639	0.009091
45153	0.39	3.61	3036.097	0.009245
43432	0.38	3.53	2973.556	0.009271
40146	0.37	3.46	2911.014	0.008941
37486	0.36	3.31	2785.93	0.009116
34357	0.34	3.16	2660.847	0.009159
28881	0.31	2.86	2410.679	0.00938
26065	0.29	2.72	2285.596	0.009417
30758	0.32	2.94	2473.221	0.00949
27377	0.29	2.72	2285.596	0.009891
24166	0.27	2.49	2097.97	0.010362
20695	0.25	2.34	1972.887	0.010035
18005	0.24	2.20	1847.803	0.009952
14360	0.22	2.05	1722.72	0.009132
12190	0.20	1.90	1597.636	0.009014
8111	0.16	1.53	1284.927	0.009272
6115	0.13	1.23	1034.76	0.010779
5074	0.12	1.08	909.6762	0.011572
4640	0.10	0.93	784.5925	0.014225
4206	0.09	0.86	722.0507	0.015225
3685	0.08	0.78	659.5089	0.01599
2644	0.07	0.64	534.4253	0.01747
1900	0.05	0.45	381.0475	0.024696
969	0.03	0.24	201.1223	0.045195

25% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44684	0.73	4.33	4565.821	0.008445
44527	0.72	4.28	4515.946	0.008602
43432	0.71	4.23	4466.071	0.008579
42493	0.71	4.18	4416.196	0.008584
40929	0.69	4.09	4316.446	0.008654
39833	0.68	4.00	4216.696	0.008826
38269	0.66	3.90	4116.945	0.008895
37017	0.65	3.85	4067.07	0.008817
35609	0.64	3.76	3967.32	0.008913
33575	0.62	3.67	3867.57	0.008843
32323	0.60	3.57	3767.82	0.00897
30133	0.59	3.48	3668.069	0.008823
28099	0.57	3.38	3568.319	0.008694
26065	0.55	3.24	3418.694	0.008786
27551	0.55	3.24	3418.694	0.009287
26336	0.53	3.15	3318.944	0.009419
25208	0.52	3.05	3219.193	0.009583
24166	0.50	2.96	3119.443	0.009784
22778	0.48	2.86	3019.693	0.009841
21216	0.47	2.77	2919.943	0.009803
19480	0.45	2.67	2820.192	0.009649
16790	0.41	2.44	2570.817	0.010008
14967	0.39	2.29	2421.192	0.010059
13145	0.36	2.11	2221.691	0.010492
11062	0.33	1.96	2072.066	0.01015
9500	0.31	1.82	1922.441	0.010127
8458	0.29	1.73	1822.69	0.01003
7417	0.27	1.59	1673.065	0.010439
6462	0.25	1.49	1573.315	0.010285
4987	0.23	1.35	1423.689	0.009693
4119	0.20	1.21	1274.064	0.009997
3685	0.18	1.07	1124.439	0.011483
3425	0.17	1.02	1074.564	0.011685
3251	0.16	0.97	1024.689	0.012199
3078	0.16	0.92	974.8135	0.01276
2817	0.15	0.88	924.9384	0.012974
2840	0.16	0.92	974.8135	0.011773
2507	0.15	0.88	924.9384	0.011545
2008	0.12	0.73	775.3131	0.013161
1592	0.10	0.59	625.6877	0.016024
1260	0.08	0.50	525.9375	0.017941
1010	0.06	0.36	376.3122	0.028105

25% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
16269	1.67	3.50	6201.476	0.008357
16182	1.66	3.49	6171.739	0.008392
15661	1.63	3.44	6082.528	0.008362
15054	1.60	3.37	5963.581	0.008362
14533	1.58	3.32	5874.37	0.00832
14012	1.54	3.24	5725.686	0.008444
13665	1.52	3.20	5666.212	0.008408
12971	1.47	3.10	5487.791	0.008508
12277	1.43	3.02	5339.107	0.008508
11496	1.39	2.92	5160.686	0.008527
10801	1.34	2.81	4982.264	0.008596
10368	1.30	2.73	4833.58	0.008766
9500	1.23	2.60	4595.685	0.008885
9326	1.22	2.56	4536.212	0.008953
8892	1.19	2.50	4417.264	0.009003
8545	1.16	2.45	4328.054	0.009011
8198	1.14	2.39	4238.843	0.009013
7851	1.11	2.34	4149.632	0.009007
7330	1.07	2.26	4000.948	0.009046
6983	1.03	2.18	3852.264	0.009295
6289	0.97	2.04	3614.369	0.00951
5508	0.91	1.91	3376.474	0.009543
5160	0.88	1.86	3287.264	0.009434
4727	0.83	1.76	3108.842	0.009661
3945	0.75	1.59	2811.474	0.00986
3425	0.70	1.47	2603.316	0.009983
2904	0.64	1.35	2395.158	0.01
2507	0.60	1.25	2216.737	0.010078
2257	0.56	1.19	2097.789	0.010134
1975	0.52	1.10	1949.105	0.010269
1817	0.50	1.05	1859.894	0.010375
1642	0.47	0.98	1740.947	0.010703
1401	0.44	0.92	1622	0.01052
1210	0.41	0.87	1532.789	0.010172
1177	0.40	0.83	1473.315	0.010707
1002	0.39	0.82	1443.578	0.009498
786	0.36	0.75	1324.631	0.008846

728	0.35	0.73	1294.894	0.008571
719	0.33	0.70	1235.42	0.009309
603	0.31	0.65	1146.21	0.009071
586	0.29	0.61	1086.736	0.009803
571	0.25	0.53	938.0518	0.012809
546	0.20	0.41	729.8938	0.020261
502	0.17	0.36	640.6833	0.02414
395	0.12	0.24	432.5253	0.041681
317	0.09	0.19	343.3147	0.053157

25% water-in-Shell Pella-oil emulsions: 0.023535 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
23125	1.56	4.10	6492.301	0.007787
22864	1.55	4.07	6459.1	0.007779
22083	1.52	3.99	6326.295	0.007832
21302	1.48	3.89	6160.29	0.007968
20695	1.46	3.82	6060.687	0.007997
19827	1.43	3.74	5927.883	0.008009
18872	1.39	3.63	5761.878	0.008069
18265	1.35	3.55	5629.073	0.008182
17137	1.31	3.43	5429.867	0.00825
16529	1.28	3.36	5330.264	0.008258
15835	1.26	3.30	5230.661	0.008215
14967	1.21	3.17	5031.455	0.008392
14099	1.15	3.03	4799.047	0.008689
13405	1.13	2.96	4699.444	0.008615
12364	1.07	2.82	4467.037	0.008794
11582	1.03	2.71	4301.032	0.008887
11062	0.99	2.61	4135.027	0.009183
10020	0.95	2.50	3969.021	0.009028
9066	0.89	2.34	3703.413	0.009382
8285	0.86	2.25	3570.609	0.009223
7243	0.79	2.08	3305.001	0.009412
6723	0.75	1.98	3138.995	0.009684
5768	0.70	1.83	2906.588	0.009691
4379	0.60	1.56	2474.975	0.010148
3685	0.55	1.44	2275.768	0.010099
3338	0.52	1.35	2142.964	0.010317
4813	0.64	1.67	2640.98	0.009795
2881	0.52	1.35	2142.964	0.008905
2507	0.47	1.23	1943.758	0.009418
2257	0.44	1.14	1810.954	0.00977
1975	0.39	1.02	1611.748	0.01079
1817	0.37	0.97	1545.345	0.010798
1642	0.36	0.93	1478.943	0.010656
1401	0.32	0.83	1312.938	0.011536
1210	0.29	0.77	1213.335	0.011664
1177	0.25	0.66	1047.33	0.015224
1002	0.23	0.60	947.7267	0.015833
944	0.20	0.51	814.9225	0.02017
786	0.16	0.43	682.1184	0.023969
728	0.12	0.30	482.9121	0.044279

30% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
48752	0.20	3.32	2029.229	0.007196
47187	0.20	3.32	2029.229	0.006966
44997	0.17	3.18	1939.221	0.007273
43275	0.17	3.18	1939.221	0.006995
40929	0.16	3.03	1849.214	0.007275
37799	0.16	2.88	1759.206	0.007424
35452	0.15	2.73	1669.198	0.007734
33262	0.14	2.59	1579.191	0.008107
29820	0.12	2.29	1399.176	0.009259
31716	0.13	2.44	1489.183	0.008693
27290	0.12	2.29	1399.176	0.008473
23038	0.11	2.00	1219.161	0.009421
20174	0.09	1.70	1039.145	0.011356
17137	0.08	1.55	949.1379	0.011563
17050	0.07	1.33	809.9779	0.015797
10541	0.06	1.04	632.6797	0.016007
6549	0.03	0.56	338.9601	0.034647

30% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
59235	0.47	4.31	3722.108	0.008427
58296	0.46	4.23	3658.531	0.008584
56262	0.44	4.08	3531.378	0.008892
55010	0.44	4.01	3467.801	0.009016
53133	0.43	3.94	3404.224	0.009036
51099	0.43	3.94	3404.224	0.00869
48752	0.41	3.79	3277.07	0.008947
46561	0.40	3.72	3213.494	0.008887
43275	0.39	3.57	3086.34	0.008954
39833	0.37	3.42	2959.187	0.008965
37017	0.36	3.28	2832.033	0.009096
33575	0.34	3.13	2704.88	0.009044
29663	0.32	2.98	2577.726	0.008799
26065	0.31	2.83	2450.572	0.008554
27811	0.31	2.83	2450.572	0.009127
19740	0.29	2.69	2323.419	0.007207
16876	0.28	2.54	2196.265	0.006896
13492	0.26	2.39	2069.112	0.006211
11409	0.23	2.10	1814.805	0.006827
9673	0.20	1.81	1560.498	0.007829
7677	0.16	1.44	1242.614	0.009799
5942	0.12	1.14	988.3067	0.011989
4987	0.11	1.00	861.1531	0.013254
4640	0.10	0.92	797.5763	0.014375
4379	0.09	0.85	733.9996	0.016021
3164	0.07	0.62	539.1205	0.021458
2257	0.05	0.42	364.6109	0.033468
1675	0.03	0.30	262.7797	0.04782

30% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44684	0.75	4.38	4742.78	0.008173
44058	0.73	4.28	4641.379	0.008414
42493	0.71	4.19	4539.978	0.008482
41398	0.70	4.09	4438.577	0.008645
40616	0.68	4.00	4337.176	0.008883
39364	0.68	3.95	4286.475	0.008814
37486	0.66	3.86	4185.074	0.008805
35296	0.64	3.77	4083.673	0.008708
33105	0.62	3.63	3931.572	0.008812
31384	0.60	3.53	3830.171	0.008802
27786	0.57	3.35	3627.369	0.008688
26221	0.56	3.25	3525.968	0.008677
23561	0.52	3.07	3323.167	0.008778
21058	0.49	2.88	3120.365	0.008898
18554	0.46	2.69	2917.563	0.008968
19914	0.46	2.69	2917.563	0.009625
17310	0.43	2.50	2714.761	0.009663
15488	0.40	2.36	2562.66	0.009703
12971	0.39	2.27	2461.259	0.008809
10628	0.36	2.13	2309.157	0.0082
7590	0.34	1.99	2157.056	0.006712
6462	0.31	1.80	1954.254	0.006962

5594	0.27	1.57	1700.752	0.007957
5074	0.24	1.43	1548.65	0.008704
4206	0.22	1.29	1396.549	0.008872
3598	0.20	1.15	1244.447	0.009559
3164	0.17	1.01	1092.346	0.010911
2991	0.16	0.96	1041.646	0.011341
2765	0.16	0.96	1041.646	0.010483
2573	0.16	0.91	990.9452	0.010782
2249	0.14	0.82	889.5442	0.011694
1925	0.13	0.77	838.8438	0.011254
1759	0.12	0.68	737.4428	0.013304
1509	0.09	0.54	585.3414	0.018121
1343	0.08	0.45	483.9405	0.02359

30% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
16095	1.67	3.48	6334.329	0.008275
15488	1.65	3.43	6243.642	0.008196
14880	1.62	3.37	6122.727	0.008189
14446	1.58	3.28	5971.582	0.008357
14099	1.56	3.25	5911.124	0.008324
13665	1.53	3.18	5790.208	0.008408
13231	1.50	3.12	5669.292	0.008492
12624	1.45	3.02	5487.919	0.008647
12016	1.43	2.97	5397.232	0.00851
11496	1.39	2.89	5246.087	0.008617
10715	1.34	2.79	5064.713	0.008617
10368	1.30	2.70	4913.568	0.008859
9673	1.24	2.59	4701.966	0.009026
9239	1.22	2.54	4611.279	0.008964
8805	1.18	2.45	4460.134	0.009131
8111	1.12	2.34	4248.531	0.00927
7590	1.07	2.22	4036.929	0.009608
6983	1.03	2.14	3885.784	0.00954
6289	0.97	2.02	3674.181	0.00961
5768	0.92	1.92	3492.807	0.009753
5247	0.87	1.82	3311.434	0.009871
4553	0.80	1.67	3039.373	0.010167
4032	0.76	1.59	2888.228	0.009972
3598	0.71	1.49	2706.855	0.010131
3078	0.69	1.44	2616.168	0.009276
2730	0.65	1.36	2465.023	0.00927
2383	0.61	1.27	2313.878	0.009183
2307	0.61	1.27	2313.878	0.00889
1925	0.57	1.19	2162.733	0.008489
1501	0.52	1.07	1951.131	0.008133
1418	0.48	1.01	1830.215	0.008731
1251	0.44	0.92	1679.07	0.009156
1143	0.40	0.84	1527.925	0.010102
1077	0.38	0.79	1437.238	0.010753
1052	0.37	0.77	1407.009	0.01096
1019	0.36	0.74	1346.552	0.011588
969	0.34	0.71	1286.094	0.012081
952	0.32	0.67	1225.636	0.013074
844	0.30	0.62	1134.949	0.013516
761	0.28	0.57	1044.262	0.014392
661	0.24	0.49	893.1172	0.017095
570	0.21	0.44	802.4304	0.018246
596	0.21	0.44	802.4304	0.019108
476	0.16	0.32	590.8277	0.028115
346	0.11	0.23	409.4539	0.042631

30% water-in-Shell Pella-oil emulsions: 0.023535 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
23298	1.55	4.03	6565.988	0.00801
22864	1.53	3.97	6464.736	0.008109
21736	1.50	3.89	6329.734	0.008041
21042	1.47	3.80	6194.733	0.008127
20087	1.43	3.70	6025.98	0.008199
18699	1.36	3.53	5755.976	0.008365
17137	1.29	3.35	5452.222	0.008545
16269	1.25	3.24	5283.47	0.008638
15227	1.19	3.10	5047.217	0.00886
14099	1.14	2.95	4810.963	0.009029
12711	1.08	2.81	4574.71	0.009002
10975	0.99	2.58	4203.455	0.009207
9586	0.91	2.37	3865.95	0.009507
8371	0.86	2.23	3629.697	0.009418
6983	0.77	2.00	3258.442	0.009748
5334	0.67	1.73	2819.686	0.009944
4379	0.62	1.61	2617.183	0.009477
3945	0.57	1.48	2414.68	0.01003
3338	0.52	1.36	2212.177	0.01011
2817	0.48	1.23	2009.675	0.010339
2590	0.48	1.23	2009.675	0.009506
2216	0.43	1.11	1807.172	0.010057
1883	0.38	0.99	1604.669	0.010841
1800	0.36	0.94	1537.168	0.011292
1734	0.35	0.90	1469.667	0.011897
1675	0.34	0.88	1435.917	0.012044
1626	0.33	0.86	1402.166	0.012255
1509	0.31	0.80	1300.915	0.013217
1310	0.27	0.70	1132.162	0.015143
1093	0.22	0.57	929.6597	0.018751
619	0.12	0.32	524.6541	0.033354
428	0.08	0.22	355.9017	0.050103
594	0.12	0.30	490.9036	0.036564
553	0.10	0.26	423.4027	0.045714
678	0.14	0.36	592.155	0.028644

35% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
49065	0.20	3.58	1695	0.006174
48282	0.19	3.43	1625.944	0.006603
44997	0.18	3.29	1556.887	0.006712
43745	0.17	3.14	1487.83	0.007145
40929	0.17	3.14	1487.83	0.006685
37173	0.16	2.85	1349.717	0.007377
35139	0.15	2.71	1280.661	0.007746
33731	0.14	2.56	1211.604	0.008307
31541	0.13	2.41	1142.548	0.008735
29507	0.13	2.41	1142.548	0.008172
28412	0.12	2.27	1073.491	0.008914
30154	0.12	2.27	1073.491	0.00946
24947	0.12	2.12	1004.434	0.00894
21389	0.11	1.98	935.3778	0.008838
17137	0.09	1.68	797.2646	0.009747
14360	0.08	1.54	728.208	0.00979
11149	0.05	0.87	411.1998	0.023838
8285	0.03	0.52	246.2217	0.049406

35% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
60017	0.48	4.33	2904.494	0.00834
59235	0.47	4.26	2855.716	0.008515
58139	0.46	4.19	2806.938	0.00865
52194	0.44	4.04	2709.382	0.008335
50003	0.44	3.97	2660.604	0.008281

46405	0.42	3.82	2563.048	0.008281
43901	0.41	3.75	2514.27	0.008141
40459	0.40	3.61	2416.714	0.008121
36548	0.37	3.39	2270.38	0.008312
32949	0.36	3.31	2221.602	0.007826
29976	0.35	3.17	2124.045	0.007789
25908	0.34	3.10	2075.267	0.007052
27204	0.34	3.10	2075.267	0.007405
20955	0.33	3.02	2026.489	0.005982
16442	0.31	2.81	1880.155	0.005453
13492	0.26	2.37	1587.487	0.006276
11322	0.23	2.08	1392.374	0.006846
6809	0.16	1.42	953.3717	0.008782
5594	0.13	1.20	807.0375	0.010069
4987	0.12	1.13	758.2595	0.010168
4553	0.12	1.06	709.4814	0.010603
4293	0.11	0.99	660.7033	0.011528
4032	0.10	0.91	611.9253	0.012624
3598	0.09	0.84	563.1472	0.013301
3164	0.08	0.77	514.3691	0.014021
2817	0.06	0.54	360.8074	0.025369
1842	0.04	0.34	226.35	0.04214

35% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44684	0.75	4.33	3638.807	0.008258
44058	0.74	4.28	3599.908	0.008319
42963	0.73	4.24	3561.009	0.008291
41241	0.71	4.14	3483.211	0.008318
39677	0.71	4.10	3444.312	0.008184
37799	0.69	4.01	3366.515	0.008162
35922	0.67	3.87	3249.818	0.008323
33888	0.65	3.77	3172.02	0.008242
31228	0.62	3.59	3016.424	0.008399
28255	0.60	3.45	2899.727	0.008223
25908	0.56	3.27	2744.131	0.008419
27117	0.56	3.27	2744.131	0.008812
24600	0.54	3.13	2627.434	0.00872
22691	0.52	2.99	2510.737	0.008808
20782	0.49	2.85	2394.04	0.008873
19133	0.47	2.71	2277.343	0.009028
16876	0.45	2.62	2199.546	0.008536
14099	0.44	2.52	2121.748	0.007664
11235	0.41	2.39	2005.051	0.006839
7851	0.36	2.11	1771.657	0.006121
6723	0.32	1.88	1577.162	0.006614
5855	0.29	1.69	1421.566	0.00709
4813	0.25	1.46	1227.071	0.007823
4206	0.23	1.32	1110.374	0.008348
3598	0.20	1.14	954.7786	0.009659
3425	0.19	1.09	915.8797	0.009991
3338	0.16	0.95	799.1828	0.012791
3089	0.15	0.86	721.3848	0.014526
2673	0.12	0.72	604.6879	0.017891
2424	0.10	0.58	487.991	0.024907
2091	0.08	0.49	410.1931	0.030413

35% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
16182	1.70	3.50	4929.471	0.008171
15922	1.69	3.48	4906.279	0.008116
15575	1.67	3.45	4859.894	0.008091
15054	1.65	3.40	4790.316	0.00805
14533	1.63	3.37	4743.931	0.007924
14099	1.59	3.28	4627.968	0.008077
13492	1.55	3.20	4512.005	0.008132
13058	1.53	3.15	4442.427	0.008119
12364	1.47	3.04	4280.079	0.008281
11669	1.43	2.94	4140.923	0.00835
10888	1.37	2.82	3978.575	0.00844
10194	1.32	2.72	3839.42	0.008485
9326	1.26	2.59	3653.879	0.008571
8632	1.19	2.46	3468.338	0.008805
7677	1.12	2.31	3259.605	0.008866
6549	1.03	2.13	3004.486	0.008902
5768	0.95	1.97	2772.56	0.009207
4813	0.87	1.79	2517.442	0.009319
4119	0.80	1.65	2331.901	0.009294
3598	0.75	1.56	2192.746	0.009183
3164	0.72	1.49	2099.975	0.008805
2817	0.69	1.42	2007.205	0.00858
2025	0.64	1.33	1868.049	0.007119
1867	0.60	1.23	1728.894	0.007663
1800	0.56	1.16	1636.123	0.008251
1684	0.52	1.08	1520.16	0.00894
1626	0.50	1.03	1450.583	0.009479
1409	0.44	0.90	1265.042	0.010806
1268	0.40	0.82	1149.079	0.011783
1243	0.38	0.78	1102.694	0.012544
1210	0.37	0.77	1079.501	0.012738
1177	0.36	0.75	1056.309	0.012938
1168	0.35	0.72	1009.923	0.014054
1077	0.34	0.70	986.7309	0.013569
1177	0.32	0.67	940.3457	0.016326
1035	0.30	0.62	870.7679	0.016752
1093	0.28	0.57	801.1901	0.0209
1010	0.27	0.55	777.9976	0.020479
927	0.24	0.49	685.2272	0.024227
844	0.21	0.44	615.6494	0.02732
594	0.15	0.31	430.1087	0.039429
517	0.12	0.24	337.3383	0.055757
465	0.09	0.19	267.7606	0.079649

35% water-in-Shell Pella-oil emulsions: 0.023535 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
23906	1.56	4.01	5063.523	0.00822
23212	1.53	3.93	4959.946	0.008318
22344	1.50	3.85	4856.368	0.008352
21649	1.47	3.76	4752.791	0.008449
20434	1.42	3.64	4597.424	0.008523
19306	1.38	3.54	4467.952	0.008526
18005	1.31	3.37	4260.797	0.008743
16790	1.27	3.27	4131.325	0.008672
15748	1.23	3.15	3975.958	0.008783
14273	1.15	2.96	3742.909	0.008982
12884	1.09	2.80	3535.754	0.009086
11930	1.04	2.68	3380.387	0.009204
10541	0.96	2.47	3121.443	0.009538
9239	0.90	2.31	2914.288	0.009591
7590	0.81	2.08	2629.45	0.009679
6809	0.75	1.94	2448.189	0.010016
5855	0.71	1.84	2318.717	0.0096
4813	0.64	1.65	2085.667	0.009755
4119	0.60	1.55	1956.195	0.00949
2991	0.54	1.39	1749.04	0.008619
2840	0.54	1.39	1749.04	0.008183
2332	0.46	1.18	1490.096	0.009261
2099	0.42	1.08	1360.624	0.009998
1933	0.38	0.98	1231.152	0.011244

1759	0.36	0.93	1179.363	0.011147
1659	0.33	0.85	1075.785	0.012636
1609	0.32	0.83	1049.891	0.012868
1509	0.28	0.73	920.4189	0.015705
1376	0.24	0.61	765.0525	0.020727
927	0.13	0.34	428.4252	0.044529
761	0.09	0.24	298.9532	0.075046
802	0.12	0.30	376.6364	0.049865

40% water-in-Shell Pella-oil emulsions: 0.0089 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
53289	0.20	3.69	1805.538	0.006255
53446	0.20	3.54	1734.858	0.006795
52350	0.20	3.54	1734.858	0.006656
51099	0.19	3.40	1664.177	0.00706
49690	0.19	3.40	1664.177	0.006866
43901	0.17	3.11	1522.817	0.007244
42024	0.16	2.97	1452.136	0.007626
39990	0.16	2.82	1381.456	0.008018
37956	0.15	2.68	1310.775	0.008453
35296	0.14	2.53	1240.095	0.008783
32480	0.13	2.39	1169.414	0.009088
30758	0.12	2.24	1098.734	0.00975
37956	0.16	2.82	1381.456	0.007611
33105	0.12	2.24	1098.734	0.010494
29113	0.12	2.10	1028.053	0.010541
24687	0.11	1.96	957.373	0.010307
20001	0.10	1.81	886.6926	0.009734
17397	0.08	1.52	745.3317	0.011984
15835	0.05	0.82	403.2521	0.037263
10541	0.06	1.16	568.8607	0.012465
7417	0.05	0.86	421.9846	0.015938
6289	0.04	0.68	334.6078	0.021493

40% water-in-Shell Pella-oil emulsions: 0.0126 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
60799	0.50	4.51	3122.568	0.007737
60330	0.49	4.43	3072.643	0.007929
59235	0.48	4.36	3022.718	0.008044
56575	0.48	4.29	2972.793	0.007943
54697	0.48	4.29	2972.793	0.007679
53133	0.47	4.22	2922.868	0.007717
50316	0.46	4.15	2872.943	0.007564
47031	0.45	4.07	2823.018	0.007322
44840	0.45	4.07	2823.018	0.006981
40929	0.44	4.00	2773.093	0.006604
36235	0.44	3.93	2723.168	0.006063
31697	0.43	3.86	2673.243	0.005503
26377	0.41	3.71	2573.393	0.004942
28072	0.42	3.79	2623.318	0.005061
26336	0.40	3.57	2473.542	0.005341
23212	0.36	3.28	2273.842	0.00557
21389	0.34	3.06	2124.067	0.005882
18699	0.31	2.78	1924.367	0.006265
16876	0.28	2.49	1724.666	0.00704
14620	0.25	2.27	1574.891	0.007314
13492	0.24	2.13	1475.041	0.007694
12103	0.21	1.91	1325.266	0.00855
11149	0.20	1.84	1275.341	0.008505
8111	0.17	1.55	1075.64	0.008698
6636	0.15	1.34	925.8651	0.009605
5594	0.13	1.19	826.0149	0.010173
4900	0.12	1.12	776.0898	0.010094
4727	0.12	1.05	726.1648	0.011121
4119	0.11	0.98	676.2397	0.011176
3685	0.10	0.90	626.3146	0.011656
3598	0.09	0.83	576.3895	0.013439
3089	0.08	0.76	526.4644	0.013828
2257	0.05	0.46	320.3547	0.027293
1925	0.03	0.27	188.1257	0.067483

40% water-in-Shell Pella-oil emulsions: 0.0158 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
43901	0.75	4.29	3724.373	0.008197
43588	0.74	4.24	3684.56	0.008316
42337	0.73	4.19	3644.746	0.008254
41398	0.72	4.15	3604.932	0.008251
39833	0.71	4.06	3525.305	0.008302
38738	0.69	3.96	3445.678	0.008451
36235	0.68	3.87	3366.05	0.008283
34670	0.66	3.78	3286.423	0.008314
31854	0.64	3.64	3166.982	0.008226
28881	0.61	3.51	3047.541	0.008054
26065	0.59	3.37	2928.1	0.007874
23718	0.57	3.28	2848.473	0.007571
24947	0.57	3.28	2848.473	0.007963
22691	0.56	3.23	2808.659	0.00745
17831	0.54	3.09	2689.218	0.006386
16269	0.52	2.96	2569.777	0.006381
13405	0.50	2.87	2490.15	0.005599
11930	0.45	2.59	2251.268	0.006096
10020	0.40	2.27	1972.572	0.00667
8979	0.36	2.09	1813.317	0.007073
8024	0.33	1.90	1654.062	0.007596
7156	0.31	1.77	1534.621	0.00787
6375	0.28	1.58	1375.367	0.008729
5681	0.25	1.45	1255.926	0.009329
5074	0.24	1.35	1176.298	0.009497
4553	0.21	1.22	1056.857	0.010558
4032	0.20	1.17	1017.044	0.010097
3598	0.19	1.08	937.4164	0.010606
3251	0.17	0.99	857.7891	0.011444
2817	0.16	0.90	778.1618	0.01205
3089	0.16	0.94	817.9754	0.011958
2590	0.15	0.85	738.3481	0.012305
2424	0.14	0.80	698.5344	0.012865
2091	0.12	0.71	618.9071	0.01414
1842	0.11	0.62	539.2797	0.016402
1509	0.08	0.48	419.8387	0.022175
1260	0.07	0.38	329.121	0.03012

40% water-in-Shell Pella-oil emulsions: 0.0265 m pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
16269	1.68	3.43	4997.911	0.008458
15227	1.61	3.28	4784.27	0.00864
14533	1.57	3.20	4665.58	0.008671
14012	1.53	3.12	4546.89	0.008802
13405	1.51	3.07	4475.676	0.008691
12624	1.44	2.94	4285.772	0.008926
11756	1.39	2.83	4119.607	0.008996
10975	1.34	2.73	3977.179	0.009011
10020	1.27	2.60	3787.275	0.009073
8979	1.20	2.45	3573.634	0.009131
7677	1.11	2.26	3288.778	0.009218
6115	1.01	2.06	3003.922	0.008801
5334	0.96	1.96	2861.495	0.00846
4119	0.87	1.78	2600.377	0.007911
3425	0.79	1.62	2362.997	0.007965

3164	0.73	1.49	2173.094	0.008702
2991	0.69	1.41	2054.404	0.009203
2773	0.70	1.43	2078.142	0.008339
2490	0.64	1.30	1888.238	0.009071
2183	0.57	1.17	1698.335	0.009827
2008	0.53	1.08	1579.645	0.010451
1759	0.47	0.95	1389.741	0.011825
1509	0.42	0.86	1247.313	0.012597
1409	0.40	0.82	1199.837	0.012714
1326	0.38	0.77	1128.624	0.013521
1243	0.36	0.74	1081.148	0.013811
1135	0.34	0.69	1009.934	0.014451
1093	0.32	0.66	962.4578	0.015329
1027	0.30	0.61	891.2439	0.016789
994	0.28	0.58	843.768	0.018124
902	0.27	0.55	796.2921	0.018477
844	0.24	0.50	725.0782	0.020847
744	0.21	0.43	630.1263	0.024339
636	0.19	0.38	558.9124	0.026443
545	0.15	0.30	440.2226	0.036494

40% water-in-Shell Pella-oil emulsions: 0.023535 m PVC pipe

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
23646	1.55	3.93	5129.585	0.008385
23385	1.54	3.91	5103.081	0.008379
22431	1.50	3.81	4970.565	0.008472
21563	1.47	3.75	4891.055	0.008411
20868	1.43	3.64	4758.539	0.0086
20174	1.40	3.56	4652.525	0.008697
19306	1.37	3.48	4546.512	0.008715
18178	1.32	3.36	4387.492	0.008812
16963	1.27	3.22	4201.969	0.008965
15835	1.22	3.10	4042.949	0.00904
14794	1.17	2.98	3883.929	0.009151
13579	1.11	2.83	3698.406	0.009263
12277	1.05	2.67	3486.38	0.009425
10715	0.98	2.49	3247.85	0.009478
9760	0.92	2.35	3062.327	0.009711
8632	0.87	2.22	2903.307	0.009555
7070	0.81	2.06	2691.281	0.009108
5508	0.75	1.92	2505.757	0.008185
4640	0.70	1.78	2320.234	0.008042
4119	0.65	1.66	2161.214	0.008229
3859	0.60	1.53	2002.195	0.008982
3512	0.56	1.43	1869.678	0.009373
3338	0.52	1.33	1737.162	0.010321
3078	0.49	1.25	1631.148	0.010794
2740	0.48	1.23	1604.645	0.009929
2374	0.43	1.09	1419.122	0.010999
2149	0.38	0.97	1260.102	0.012631
1958	0.35	0.88	1154.089	0.013718
1933	0.33	0.84	1101.082	0.014879
1817	0.32	0.80	1048.076	0.015433
1767	0.31	0.78	1021.572	0.015798
1675	0.28	0.72	942.0624	0.017616
1534	0.26	0.66	862.5525	0.01924
1418	0.23	0.58	756.5393	0.023112
1260	0.20	0.52	677.0293	0.025644
985	0.16	0.42	544.5128	0.031008
786	0.12	0.30	385.493	0.049336
719	0.11	0.27	358.9897	0.052073
611	0.08	0.21	279.4798	0.073004
636	0.09	0.23	305.9831	0.063391

30% vol. water-in-EDM 244 oil emulsions with 0.1% wt. POX 303 polymer (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
97140	1.59	9.83	25548.34	0.003723856
95585	1.57	9.74	25290.99	0.003739204
94756	1.56	9.69	25162.31	0.003744774
90817	1.53	9.49	24647.6	0.003740573
85530	1.48	9.19	23875.53	0.003754355
81591	1.45	8.99	23360.82	0.003741016
79311	1.43	8.84	22974.79	0.003759686
75061	1.39	8.65	22460.07	0.003723177
70604	1.35	8.40	21816.69	0.003711695
67702	1.32	8.20	21301.97	0.003733189
63772	1.30	8.05	20915.94	0.003647515
60486	1.27	7.90	20529.91	0.003590912
57044	1.23	7.66	19886.52	0.003609235
53133	1.20	7.46	19371.81	0.003542764
48752	1.16	7.21	18728.42	0.003477831
44214	1.11	6.86	17827.67	0.00348092
40616	1.07	6.62	17184.29	0.003441527
37173	1.03	6.37	16540.9	0.003399662
32845	0.98	6.07	15768.83	0.003305117
28072	0.91	5.67	14739.41	0.003233158
24774	0.87	5.43	14096.02	0.003119746
21649	0.83	5.13	13323.95	0.003051422
18699	0.77	4.78	12423.21	0.003031569
16963	0.73	4.53	11779.82	0.003058789
15488	0.69	4.29	11136.43	0.003124773
14794	0.66	4.09	10621.72	0.003280973
13752	0.63	3.89	10107.01	0.003368564
12971	0.59	3.64	9463.619	0.003623943
12277	0.56	3.44	8948.908	0.003835879
11756	0.53	3.30	8562.874	0.00401184
11235	0.51	3.15	8176.841	0.004204716
10541	0.47	2.90	7533.452	0.004647485
8892	0.43	2.65	6890.063	0.004686867
6983	0.36	2.21	5731.963	0.005318035
6462	0.32	1.96	5088.574	0.006244677
5855	0.29	1.81	4702.541	0.006624637
5855	0.27	1.66	4316.508	0.007862529
4813	0.23	1.41	3673.119	0.00892678
4032	0.19	1.17	3029.73	0.010991593
3251	0.16	0.97	2515.019	0.012861185
272	0.13	0.82	2128.985	0.000110381
152	0.12	0.72	1871.63	0.000142823
127	0.09	0.57	1485.597	0.000226692
8	0.07	0.42	1099.563	0.000413807
66	0.05	0.34	870.3156	0.000660518

30% vol. water-in-EDM 244 oil emulsions with 0.1% wt. POX 303 polymer (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
20695	2.97	6.54	28505.34	0.003195441
20174	2.93	6.47	28198.46	0.003183211
19653	2.90	6.40	27891.58	0.003169666
18699	2.85	6.28	27354.53	0.003135282
18438	2.82	6.23	27124.36	0.003144318
17744	2.78	6.14	26740.76	0.003113362
17397	2.75	6.07	26433.88	0.00312374
16790	2.71	5.98	26050.27	0.003104101
16442	2.69	5.93	25820.11	0.003094359
15922	2.66	5.86	25513.22	0.003068882
15748	2.64	5.82	25359.78	0.00307227
15488	2.62	5.77	25129.62	0.00307708
15054	2.58	5.70	24822.73	0.003065279
14533	2.54	5.61	24439.13	0.00305288

14012	2.50	5.50	23978.8	0.003057598
13579	2.46	5.43	23671.92	0.003040234
13058	2.42	5.33	23211.59	0.00304076
12537	2.38	5.24	22827.98	0.003018448
12103	2.34	5.17	22521.1	0.002993933
11669	2.30	5.08	22137.49	0.002987501
11149	2.26	4.98	21677.17	0.0029767
10628	2.21	4.87	21216.84	0.00296214
10020	2.15	4.75	20679.79	0.002939765
9500	2.10	4.62	20142.75	0.002937596
7504	1.89	4.17	18148	0.002858478
6809	1.80	3.97	17304.07	0.002853188
6462	1.76	3.88	16920.46	0.002831901
6115	1.71	3.78	16460.13	0.002831758
5855	1.67	3.69	16076.53	0.002842123
5334	1.58	3.48	15155.87	0.002913489
5160	1.55	3.43	14925.71	0.002906286
4640	1.43	3.14	13698.17	0.00310234
4206	1.33	2.93	12777.52	0.003232053
3945	1.26	2.77	12087.03	0.003388286
1059	1.33	2.93	12777.52	0.00081369
1037	1.26	2.77	12087.03	0.000890981
3072	1.07	2.35	10245.72	0.00367221
2887	1.00	2.21	9631.956	0.003904936
2453	0.93	2.05	8941.466	0.003850193
2354	0.87	1.93	8404.419	0.004181032
2162	0.79	1.74	7560.487	0.004744853
1728	0.65	1.44	6256.228	0.005538111
1087	0.44	0.96	4184.759	0.007789888
874	0.34	0.75	3264.106	0.010290244
552	0.22	0.49	2113.289	0.015495744
396	0.16	0.34	1499.521	0.022120928

30% vol. water-in-EDM 244 oil emulsions with 0.5% wt. POX 303 polymer (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
106634	1.36	8.33	21945.36	0.005622021
104173	1.34	8.18	21559.33	0.005690768
101303	1.32	8.08	21301.97	0.005668505
98433	1.31	7.98	21044.62	0.005643445
95153	1.28	7.84	20658.59	0.005661176
89003	1.24	7.59	20015.2	0.005641175
84083	1.21	7.40	19500.49	0.005614374
82835	1.21	7.40	19500.49	0.005531064
79415	1.19	7.25	19114.45	0.005519008
74335	1.15	7.01	18471.06	0.005532185
69464	1.11	6.76	17827.67	0.005549484
62830	1.05	6.42	16926.93	0.005567918
59927	1.03	6.32	16669.57	0.005475959
51117	0.96	5.88	15511.47	0.005394361
48282	0.96	5.88	15511.47	0.005095254
41398	0.90	5.49	14482.05	0.005011901
37173	0.85	5.20	13709.99	0.005021608
34201	0.82	5.01	13195.27	0.004987484
28724	0.77	4.71	12423.21	0.004725722
30849	0.77	4.71	12423.21	0.00507519
25121	0.70	4.27	11265.11	0.005026292
20521	0.64	3.93	10364.36	0.004850687
17657	0.60	3.64	9592.297	0.004872653
14967	0.56	3.39	8948.908	0.00474549
13058	0.51	3.10	8176.841	0.004958882
11409	0.48	2.91	7662.13	0.004934346
10281	0.45	2.76	7276.097	0.004930726
9239	0.43	2.61	6890.063	0.00494171
8024	0.40	2.42	6375.352	0.005012848
7504	0.37	2.27	5989.319	0.005311293
6896	0.35	2.13	5603.285	0.005577046
6723	0.32	1.98	5217.252	0.00627098
6289	0.31	1.88	4959.897	0.006490763
6202	0.28	1.74	4573.863	0.007527306
4987	0.24	1.44	3801.797	0.008760623
3685	0.18	1.10	2901.052	0.011117924

30% vol. water-in-EDM 244 oil emulsions with 0.5% wt. POX 303 polymer (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
26596	2.69	5.84	25820.11	0.005079107
26336	2.67	5.81	25666.66	0.005089701
25555	2.63	5.72	25283.06	0.005089755
24253	2.56	5.56	24592.57	0.005105543
23385	2.52	5.48	24208.96	0.005080098
21649	2.42	5.27	23288.31	0.005082244
19653	2.32	5.04	22290.94	0.005035771
18872	2.27	4.94	21830.61	0.005041723
18178	2.22	4.82	21293.56	0.005104298
16703	2.14	4.64	20526.35	0.005047183
15661	2.06	4.49	19835.86	0.005067705
14707	2.00	4.35	19222.09	0.005067559
14186	1.96	4.26	18838.49	0.005089237
13231	1.89	4.10	18148	0.005114842
12016	1.81	3.93	17380.79	0.005064307
10715	1.72	3.74	16536.85	0.004988341
9413	1.61	3.50	15462.76	0.005012249
8285	1.52	3.31	14618.83	0.004935543
7243	1.43	3.12	13774.9	0.004860067
5768	1.31	2.84	12547.36	0.004664446
5160	1.25	2.72	12010.31	0.004554733
4553	1.19	2.60	11473.26	0.004403558
4032	1.13	2.46	10859.49	0.004353238
3685	1.09	2.37	10475.89	0.004275167
3164	1.03	2.25	9938.841	0.004078541
2730	0.98	2.13	9401.793	0.003932805
2557	0.95	2.06	9094.909	0.003935535
2383	0.91	1.99	8788.024	0.003929062
2297	0.90	1.95	8634.582	0.003921748
2123	0.86	1.87	8250.977	0.003970289
1863	0.78	1.69	7483.766	0.004234214
2226	0.87	1.88	8327.698	0.004086146
1692	0.70	1.52	6716.555	0.004775515
1585	0.65	1.42	6256.228	0.005156948
1372	0.58	1.26	5565.738	0.005638547
1443	0.62	1.35	5949.344	0.005190802
1158	0.46	1.00	4414.922	0.007566905
874	0.34	0.74	3264.106	0.010442119

30% vol. water-in-EDM 244 oil emulsions with 1% wt. POX 303 polymer (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
110734	1.36	8.33	18287.8	0.005838191
108274	1.34	8.18	17966.11	0.005914748
105403	1.32	8.08	17751.65	0.005897929
102533	1.31	7.98	17537.18	0.005878515
99253	1.28	7.84	17215.49	0.005905113
93103	1.24	7.59	16679.33	0.005901047
88183	1.21	7.40	16250.4	0.005888146
83872	1.21	7.40	16250.4	0.005600277
80451	1.19	7.25	15928.71	0.005591045
75372	1.15	7.01	15392.55	0.005609327
70500	1.11	6.76	14856.4	0.005632295
63866	1.05	6.42	14105.78	0.005659777

60964	1.03	6.32	13891.31	0.005570676
52153	0.96	5.88	12926.23	0.005503749
57670	0.96	5.88	12926.23	0.00608595
50786	0.90	5.49	12068.38	0.006148445
46561	0.85	5.20	11424.99	0.006289763
43588	0.82	5.01	10996.06	0.006356503
38112	0.77	4.71	10352.67	0.006270191
39267	0.77	4.71	10352.67	0.006460126
32324	0.70	4.27	9387.59	0.00646752
27117	0.64	3.93	8636.969	0.006409714
23646	0.60	3.64	7993.581	0.006525107
20174	0.56	3.39	7457.423	0.006396451
17571	0.51	3.10	6814.034	0.006672672
15835	0.48	2.91	6385.108	0.006848587
14099	0.45	2.76	6063.414	0.006762118
13231	0.43	2.61	5741.719	0.007076902
11496	0.40	2.42	5312.793	0.007181436
9760	0.37	2.27	4991.099	0.006908437
8892	0.35	2.13	4669.405	0.007191285
8024	0.32	1.98	4347.71	0.0074853
7590	0.31	1.88	4133.247	0.007834368
7156	0.28	1.74	3811.553	0.008685955
5855	0.24	1.44	3168.164	0.010285195

30% vol. water-in-EDM 244 oil emulsions with 1% wt. POX 303 polymer (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
27464	2.69	5.84	21516.76	0.005244841
27204	2.67	5.81	21388.89	0.005257422
26423	2.63	5.72	21069.22	0.005262604
25121	2.56	5.56	20493.81	0.005288234
24253	2.52	5.48	20174.14	0.005268625
22517	2.42	5.27	19406.93	0.005285972
20521	2.32	5.04	18575.78	0.005258137
19740	2.27	4.94	18192.17	0.005273566
19046	2.22	4.82	17744.64	0.005347983
17571	2.14	4.64	17105.29	0.005309425
16529	2.06	4.49	16529.88	0.005348522
15575	2.00	4.35	16018.41	0.005366596
15054	1.96	4.26	15698.74	0.005400576
14099	1.89	4.10	15123.33	0.005450324
12884	1.81	3.93	14483.99	0.005430059
11582	1.72	3.74	13780.71	0.005392377
10281	1.61	3.50	12885.63	0.005474366
9153	1.52	3.31	12182.36	0.005452555
8111	1.43	3.12	11479.08	0.00544237
6636	1.31	2.84	10456.13	0.005366258
6028	1.25	2.72	10008.59	0.005320713
5421	1.19	2.60	9561.052	0.005242925
4900	1.13	2.46	9049.578	0.005290166
4553	1.09	2.37	8729.907	0.005281969
4032	1.03	2.25	8282.367	0.005197088
3598	0.98	2.13	7834.827	0.005182788
3425	0.95	2.06	7579.091	0.005271297
3251	0.91	1.99	7323.354	0.005359744
3164	0.90	1.95	7195.485	0.00540373
2991	0.86	1.87	6875.814	0.005593275
3008	0.87	1.88	6939.748	0.005523044
2368	0.70	1.52	5597.129	0.00668323
2226	0.65	1.42	5213.524	0.007240001
1941	0.58	1.26	4638.115	0.007978071
2012	0.62	1.35	4957.787	0.007238354

30% vol. water-in-EDM 244 oil emulsions with 1% wt. POX 301 polymer (0.0158 m pipe)

ΔP (Pa)	Flow rate	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
	(kg/s)			
109094	1.30	8.05	13072.46	0.006239729
109504	1.31	8.10	13152.89	0.006186821
106224	1.28	7.95	12911.62	0.006227888
99253	1.23	7.66	12429.07	0.006279844
93513	1.19	7.41	12026.96	0.006318918
88951	1.19	7.41	12026.96	0.006010637
80140	1.13	7.01	11383.57	0.006044704
73299	1.07	6.66	10820.6	0.006118939
68427	1.03	6.42	10418.48	0.006161699
56196	0.93	5.77	9372.977	0.006252152
53446	0.92	5.72	9292.553	0.006049545
44371	0.84	5.23	8488.317	0.00601914
35922	0.75	4.68	7603.658	0.00607286
31071	0.70	4.34	7040.692	0.00612648
32324	0.69	4.29	6960.269	0.006521591
25642	0.62	3.84	6236.456	0.006443914
18438	0.55	3.40	5512.644	0.005930424
15835	0.46	2.85	4627.984	0.007226256
12364	0.36	2.21	3582.477	0.009415804
11496	0.32	1.96	3180.359	0.01110873
9760	0.28	1.76	2858.665	0.011673614
8892	0.26	1.61	2617.394	0.012686767
8371	0.24	1.51	2456.546	0.013559159
7851	0.22	1.36	2215.276	0.015636421
7156	0.20	1.27	2054.428	0.016572917
4293	0.13	0.82	1330.616	0.023697164
2036	0.05	0.32	526.3798	0.071829872
2557	0.08	0.47	767.6506	0.042410193

30% vol. water-in-EDM 244 oil emulsions with 1% wt. POX 301 polymer (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
27464	2.69	5.84	17213.4	0.005244841
27204	2.67	5.81	17111.11	0.005257422
26423	2.63	5.72	16855.37	0.005262604
25121	2.56	5.56	16395.05	0.005288234
24253	2.52	5.48	16139.31	0.005268625
22517	2.42	5.27	15525.54	0.005285972
20521	2.32	5.04	14860.62	0.005258137
19740	2.27	4.94	14553.74	0.005273566
19046	2.22	4.82	14195.71	0.005347983
17571	2.14	4.64	13684.23	0.005309425
16529	2.06	4.49	13223.91	0.005348522
15575	2.00	4.35	12814.73	0.005366596
15054	1.96	4.26	12558.99	0.005400576
14099	1.89	4.10	12098.66	0.005450324
12884	1.81	3.93	11587.19	0.005430059
11582	1.72	3.74	11024.57	0.005392377
10281	1.61	3.50	10308.51	0.005474366
9153	1.52	3.31	9745.885	0.005452555
8111	1.43	3.12	9183.263	0.00544237
6636	1.31	2.84	8364.905	0.005366258
6028	1.25	2.72	8006.873	0.005320713
5421	1.19	2.60	7648.842	0.005242925
4900	1.13	2.46	7239.662	0.005290166
4553	1.09	2.37	6983.926	0.005281969
4032	1.03	2.25	6625.894	0.005197088
3598	0.98	2.13	6267.862	0.005182788
3425	0.95	2.06	6063.272	0.005271297
3251	0.91	1.99	5858.683	0.005359744
3164	0.90	1.95	5756.388	0.00540373
2991	0.86	1.87	5500.651	0.005593275
3008	0.87	1.88	5551.798	0.005523044
2368	0.70	1.52	4477.703	0.00668323

2226	0.65	1.42	4170.819	0.007240001
1941	0.58	1.26	3710.492	0.007978071
2012	0.62	1.35	3966.229	0.007238354
1863	0.46	1.01	2759.326	0.011989584
1602	0.38	0.84	2279.819	0.015108477

30% vol. water-in-EDM 244 oil emulsions with 1% wt. CMC polymer (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
109914	1.37	8.50	14716.03	0.005644287
105813	1.34	8.30	14372.89	0.005696287
100483	1.31	8.10	14029.75	0.005677189
96383	1.27	7.90	13686.61	0.005722014
90817	1.28	7.95	13772.39	0.005324589
85530	1.24	7.70	13343.46	0.005342218
81280	1.20	7.46	12914.54	0.005419597
75268	1.16	7.21	12485.61	0.005369473
68116	1.10	6.81	11799.33	0.005440941
65214	1.07	6.66	11541.98	0.005443997
60860	1.04	6.47	11198.83	0.005396681
58452	1.04	6.47	11198.83	0.005183166
51568	0.97	6.02	10426.77	0.005274965
47500	0.94	5.82	10083.63	0.005195154
41554	0.88	5.48	9483.131	0.005138685
35452	0.82	5.08	8796.85	0.005094824
32010	0.78	4.83	8367.924	0.00508383
33279	0.78	4.83	8367.924	0.005285279
29807	0.73	4.53	7853.213	0.005374835
26249	0.68	4.24	7338.501	0.005420475
22864	0.64	3.99	6909.576	0.005325945
20087	0.60	3.74	6480.65	0.00531893
18178	0.57	3.54	6137.509	0.005366644
15401	0.53	3.30	5708.583	0.005255704
13145	0.48	3.00	5193.872	0.005418808
11756	0.46	2.85	4936.516	0.005364869
10368	0.43	2.65	4593.376	0.005464482
9500	0.40	2.50	4336.02	0.005619068
8024	0.37	2.31	3992.879	0.005597254
7243	0.35	2.16	3735.524	0.005772585
7070	0.34	2.11	3649.738	0.005902231
6983	0.33	2.06	3563.953	0.006113804
6896	0.32	2.01	3478.168	0.006339326
6636	0.31	1.91	3306.598	0.006749442
6375	0.29	1.81	3135.027	0.007213818
6115	0.28	1.76	3049.242	0.007314025
5508	0.26	1.61	2791.887	0.007857857
4553	0.22	1.36	2362.961	0.009068156
3251	0.16	1.02	1762.464	0.011639659
2817	0.14	0.87	1505.109	0.013830281

30% vol. water-in-EDM 244 oil emulsions with 1% wt. CMC polymer (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
28592	2.70	5.96	17315.7	0.005317488
28072	2.68	5.91	17162.26	0.005314418
27464	2.65	5.84	16957.67	0.005325626
26509	2.60	5.73	16650.78	0.005331743
23472	2.44	5.38	15627.84	0.005359078
21563	2.33	5.13	14911.77	0.005407333
20174	2.25	4.96	14400.3	0.005424888
19220	2.19	4.83	14042.27	0.005435089
18612	2.16	4.76	13837.68	0.005420082
18005	2.11	4.66	13530.79	0.005483704
17223	2.07	4.57	13275.05	0.005449877
16616	2.02	4.46	12968.17	0.005509437
15227	1.93	4.25	12354.4	0.005563164
13926	1.84	4.06	11791.78	0.005584649
13058	1.77	3.90	11331.45	0.005670719
11756	1.66	3.65	10615.39	0.005817393
10541	1.59	3.50	10155.06	0.005699782
9760	1.52	3.36	9745.885	0.005729895
9153	1.45	3.20	9285.558	0.005919208
8458	1.38	3.04	8825.232	0.006055737
7851	1.31	2.90	8416.053	0.006180641
6896	1.23	2.70	7853.431	0.006234841
6375	1.18	2.60	7546.547	0.006242397
6115	1.15	2.53	7341.957	0.006325818
5681	1.10	2.42	7035.073	0.006400853
5421	1.07	2.35	6830.483	0.006478867
4727	0.99	2.19	6370.157	0.006495017
4466	0.96	2.12	6165.567	0.006551307
3945	0.90	1.98	5756.388	0.006639521
3859	0.87	1.93	5602.946	0.006854008
3598	0.83	1.84	5347.209	0.007017542
3338	0.79	1.75	5091.472	0.007180174
3078	0.76	1.68	4886.882	0.007186047
2991	0.75	1.65	4784.588	0.007285215
2730	0.71	1.58	4579.998	0.007258514
2557	0.68	1.51	4375.408	0.007447625
2470	0.68	1.49	4324.261	0.007366053
2383	0.65	1.44	4170.819	0.007639821
2297	0.63	1.38	4017.377	0.007934723
2210	0.60	1.33	3863.934	0.008253302
1949	0.55	1.21	3505.903	0.008843932
1689	0.49	1.08	3147.871	0.009505017
1342	0.41	0.91	2636.397	0.010765848
1166	0.36	0.80	2329.513	0.011977
981	0.31	0.68	1971.481	0.014068034
831	0.25	0.56	1613.449	0.017803579

30% vol. water-in-EDM 244 oil emulsion with 0.05% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
147635	0.25	4.92	4048.391	0.010510244
147225	0.26	5.08	4176.727	0.009846856
145585	0.24	4.77	3920.054	0.01105403
138614	0.24	4.77	3920.054	0.010524794
132054	0.24	4.61	3791.717	0.010716914
121394	0.23	4.46	3663.381	0.010554126
114014	0.23	4.46	3663.381	0.009912484
104173	0.21	4.14	3406.707	0.010473141
97203	0.20	3.99	3278.371	0.010552474
89413	0.20	3.83	3150.034	0.010513808
82033	0.20	3.83	3150.034	0.009645994
76927	0.20	3.83	3150.034	0.009045594
61379	0.17	3.36	2765.024	0.009367161
60643	0.17	3.36	2765.024	0.009254886
52820	0.16	3.21	2636.688	0.008864781
44997	0.16	3.05	2508.351	0.008344343
37643	0.14	2.74	2251.678	0.008662815
33105	0.13	2.58	2123.341	0.008567392
28568	0.12	2.43	1995.004	0.008374928
29894	0.12	2.43	1995.004	0.008763658
26162	0.12	2.27	1866.668	0.008760532
23298	0.12	2.27	1866.668	0.00780155
20695	0.11	2.11	1738.331	0.00799073
18612	0.10	1.96	1609.995	0.008377878
18438	0.09	1.80	1481.658	0.009799815
17571	0.08	1.65	1353.321	0.011193716
14967	0.07	1.37	1125.196	0.013793359
10281	0.05	1.00	819.7856	0.017848939
7764	0.04	0.74	610.8206	0.024279857

5421	0.03	0.53	434.0041	0.033578777

30% vol. water-in-EDM 244 oil emulsion with 0.05% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
150095	0.76	7.44	8661.208	0.007569576
149275	0.76	7.44	8661.208	0.00752822
148455	0.75	7.36	8570.558	0.007646079
146405	0.75	7.36	8570.558	0.007540492
144764	0.75	7.29	8479.907	0.007616285
140664	0.74	7.21	8389.257	0.007561371
138614	0.73	7.13	8298.606	0.007614847
131234	0.71	6.90	8026.655	0.007706213
123444	0.68	6.66	7754.703	0.007766096
107044	0.64	6.20	7210.8	0.007788553
91873	0.58	5.65	6576.247	0.008037031
80393	0.54	5.26	6122.995	0.008112467
78274	0.54	5.26	6122.995	0.007898694
67598	0.50	4.87	5669.742	0.007955539
59513	0.47	4.56	5307.14	0.007993774
56888	0.47	4.56	5307.14	0.007641184
50786	0.44	4.33	5035.189	0.007578321
42337	0.40	3.94	4581.937	0.007629253
33418	0.36	3.47	4038.034	0.007753681
28099	0.32	3.16	3675.432	0.007869206
29981	0.33	3.24	3766.082	0.007996985
25815	0.30	2.92	3403.48	0.008431227
22083	0.28	2.77	3222.179	0.008046917
19480	0.27	2.61	3040.878	0.007969864
17571	0.26	2.53	2950.228	0.007637281
16269	0.25	2.46	2859.577	0.007526898
14967	0.24	2.38	2768.927	0.007385452
13752	0.24	2.30	2678.277	0.007253059
12711	0.22	2.15	2496.976	0.007712647
11843	0.22	2.15	2496.976	0.007186053
11235	0.21	2.07	2406.325	0.007340762
10107	0.20	1.99	2315.675	0.007130778
9413	0.20	1.91	2225.024	0.0071931
7504	0.17	1.68	1953.073	0.007442131
7070	0.17	1.68	1953.073	0.007011765
6289	0.16	1.60	1862.422	0.006859046
5768	0.15	1.44	1681.121	0.007721212
5247	0.13	1.29	1499.82	0.008825
4987	0.12	1.21	1409.17	0.009500907
4379	0.11	1.06	1227.869	0.01098936
3338	0.08	0.82	955.9175	0.013819913
3089	0.08	0.74	865.267	0.015609157
2091	0.05	0.47	544.9928	0.026636251

30% vol. water-in-EDM 244 oil emulsion with 0.05% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
109914	1.23	7.61	11099.91	0.007045208
108684	1.22	7.56	11027.62	0.007058
104173	1.19	7.36	10738.46	0.007134354
101303	1.17	7.26	10593.87	0.007128458
98023	1.15	7.16	10449.29	0.007089847
93923	1.13	7.01	10232.42	0.007084308
89823	1.10	6.81	9943.257	0.007174836
86133	1.07	6.66	9726.384	0.007190317
85530	1.08	6.71	9798.675	0.007035042
78585	1.03	6.37	9292.639	0.007186955
71329	0.97	6.02	8786.602	0.007296395
66769	0.94	5.82	8497.439	0.007302601
59513	0.88	5.48	7991.403	0.007359444
51412	0.83	5.13	7485.366	0.007246289
42806	0.75	4.63	6762.458	0.007392267
37956	0.70	4.34	6328.712	0.0074839
33888	0.65	4.04	5894.967	0.00770124
29507	0.62	3.84	5605.803	0.007415268
30241	0.61	3.79	5533.512	0.007799688
24340	0.55	3.40	4955.185	0.007828492
20782	0.50	3.10	4521.44	0.008027996
17744	0.46	2.85	4159.986	0.008097544
16703	0.45	2.80	4087.695	0.007894281
14794	0.42	2.60	3798.531	0.00809694
13231	0.40	2.45	3581.659	0.008145509
11930	0.38	2.36	3437.077	0.007974977
10454	0.36	2.26	3292.495	0.007615974
9239	0.34	2.11	3075.622	0.007713557
8198	0.33	2.06	3003.331	0.007177565
7677	0.32	2.01	2931.041	0.007057321
7156	0.32	1.96	2858.75	0.006915581
6636	0.31	1.91	2786.459	0.006749442
6462	0.30	1.86	2714.168	0.006927696
5942	0.29	1.81	2641.877	0.006722834
5594	0.28	1.76	2569.586	0.006691227
4553	0.25	1.56	2280.423	0.00691423
3685	0.19	1.17	1702.095	0.010045324
4466	0.24	1.46	2135.841	0.007731766
4293	0.23	1.41	2063.55	0.007961077
3945	0.21	1.31	1918.968	0.00846143
3685	0.20	1.27	1846.677	0.008533944
3598	0.20	1.22	1774.386	0.009025794
3164	0.16	1.02	1485.223	0.01132896
2923	0.15	0.92	1340.641	0.012842179
2482	0.12	0.77	1123.768	0.015521279
1476	0.08	0.47	690.023	0.024479387

30% vol. water-in-EDM 244 oil emulsion with 0.05% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
30675	2.54	5.61	13729.85	0.006443696
28245	2.43	5.36	13126.42	0.006491295
27117	2.38	5.26	12867.81	0.006485025
26423	2.35	5.19	12695.4	0.006491781
25294	2.30	5.08	12436.79	0.006475733
23906	2.25	4.96	12135.08	0.00642836
22951	2.20	4.85	11876.47	0.00644336
22083	2.16	4.76	11660.96	0.006430995
20695	2.10	4.62	11316.15	0.0063995
19740	2.05	4.52	11057.54	0.006393169
18091	1.95	4.31	10540.32	0.00644828
16269	1.85	4.08	9979.995	0.006468107
14360	1.73	3.81	9333.469	0.00652735
11930	1.56	3.44	8428.333	0.006650046
9760	1.43	3.14	7695.603	0.00652599
8371	1.32	2.92	7135.281	0.006511194
6896	1.21	2.67	6531.857	0.006400495
6028	1.14	2.51	6143.941	0.006323845
5421	1.07	2.35	5756.025	0.006478867
4900	1.03	2.26	5540.517	0.006320988
4293	0.97	2.14	5238.804	0.006193519
3772	0.91	2.02	4937.092	0.006127713
3164	0.85	1.88	4592.278	0.005941785
3165	0.86	1.89	4635.38	0.005832588
2832	0.82	1.81	4419.871	0.00573992
2665	0.78	1.72	4204.363	0.005970277
2582	0.75	1.66	4075.058	0.006156563
2415	0.73	1.61	3945.752	0.006143005
2332	0.71	1.56	3816.447	0.006339882
2249	0.68	1.51	3687.142	0.00654975

2165	0.67	1.47	3600.938	0.006612743
2082	0.66	1.45	3557.837	0.006513382
1999	0.64	1.40	3428.532	0.006733367
1916	0.62	1.37	3342.328	0.006789937
1832	0.61	1.35	3299.226	0.006665506
1674	0.54	1.19	2911.311	0.007820788
833	0.30	0.66	1618.259	0.012592141
1083	0.38	0.84	2049.276	0.010208325
2499	0.74	1.63	3988.854	0.006218252
583	0.22	0.49	1187.241	0.016375128
350	0.14	0.31	756.2239	0.024212779
308	0.12	0.27	670.0204	0.027170564

30% vol. water-in-EDM 244 oil emulsion with 0.05% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44527	2.43	6.68	14655.58	0.00589835
43901	2.43	6.68	14655.58	0.005815445
42963	2.41	6.62	14511.21	0.005804891
41554	2.37	6.51	14270.6	0.005805557
39677	2.32	6.38	13981.86	0.005774554
38112	2.28	6.27	13741.25	0.005742794
36235	2.22	6.09	13356.26	0.005779171
34670	2.18	5.98	13115.65	0.005734373
33105	2.12	5.83	12778.79	0.005768073
35361	2.13	5.85	12826.91	0.006115001
32671	2.04	5.61	12297.56	0.006146628
30068	1.96	5.39	11816.33	0.006126946
27985	1.89	5.19	11383.23	0.006144715
25381	1.78	4.91	10757.63	0.006240083
23472	1.70	4.69	10276.4	0.006323803
19046	1.53	4.20	9217.697	0.00637777
16616	1.43	3.94	8640.223	0.006332677
14012	1.31	3.61	7918.38	0.006358471
12537	1.25	3.44	7533.397	0.006285317
10888	1.16	3.19	7004.046	0.006314951
9239	1.07	2.93	6426.571	0.006364909
8371	1.02	2.80	6137.834	0.006322408
7243	0.95	2.62	5752.851	0.006227011
6115	0.88	2.43	5319.746	0.006147963
5334	0.83	2.29	5031.008	0.005995914
4466	0.77	2.12	4646.026	0.005886856
3945	0.74	2.03	4453.534	0.005659784
3512	0.71	1.94	4261.043	0.005502721
3078	0.67	1.83	4020.428	0.005417286
3480	0.67	1.83	4020.428	0.006125208
3480	0.63	1.72	3779.814	0.006929862
3480	0.62	1.70	3731.691	0.007109746
3480	0.60	1.66	3635.446	0.00749118
2507	0.53	1.46	3202.34	0.006955358
2091	0.43	1.18	2576.743	0.008961089
1675	0.38	1.04	2288.006	0.009105894
1675	0.36	1.00	2191.76	0.009923179
1675	0.36	0.98	2143.637	0.010373714
1542	0.34	0.93	2047.391	0.010468935
1426	0.32	0.87	1903.023	0.011203019
1343	0.30	0.82	1806.777	0.011703645
1260	0.28	0.78	1710.531	0.012249179
844	0.22	0.60	1325.548	0.013665348
553	0.14	0.39	844.3199	0.022066663
511	0.12	0.34	748.0742	0.025996261

30% vol. water-in-EDM 244 oil emulsion with 0.1% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
141074	0.26	5.08	5471.588	0.009435513
140254	0.26	5.08	5471.588	0.009380668
138614	0.25	4.92	5303.464	0.009868085
136564	0.25	4.92	5303.464	0.00972214
133694	0.25	4.92	5303.464	0.009517817
130824	0.24	4.77	5135.341	0.009933295
127544	0.24	4.77	5135.341	0.009684243
123034	0.24	4.61	4967.218	0.009984873
118524	0.24	4.61	4967.218	0.009618853
113194	0.23	4.46	4799.095	0.009841191
109094	0.23	4.46	4799.095	0.009484723
103763	0.22	4.30	4630.971	0.009688226
98433	0.21	4.14	4462.848	0.009896051
93923	0.20	3.99	4294.725	0.010196385
85723	0.20	3.83	4126.601	0.010079901
81623	0.19	3.68	3958.478	0.010430364
78067	0.20	3.83	4126.601	0.009179669
73195	0.20	3.83	4126.601	0.008606806
69256	0.19	3.68	3958.478	0.008850079
63452	0.17	3.36	3622.231	0.009683545
56262	0.16	3.21	3454.108	0.009442485
51255	0.16	3.05	3285.985	0.009504946
47031	0.15	2.90	3117.862	0.009687475
42806	0.15	2.90	3117.862	0.008817303
38425	0.13	2.58	2781.615	0.009944094
33105	0.13	2.58	2781.615	0.008567392
34754	0.13	2.58	2781.615	0.008994012
29460	0.12	2.43	2613.492	0.00863645
25989	0.12	2.27	2445.368	0.008702412
23732	0.11	2.11	2277.245	0.009163556
19480	0.11	2.11	2277.245	0.007521599
17397	0.10	1.96	2109.122	0.007830975
13231	0.07	1.37	1474.027	0.012193785
11756	0.05	1.00	1073.934	0.020410349
11669	0.04	0.74	800.186	0.036492675
10628	0.03	0.53	568.5532	0.065833572

30% vol. water-in-EDM 244 oil emulsion with 0.1% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
147635	0.76	7.44	11346.34	0.00744551
144764	0.75	7.36	11227.58	0.007456023
141484	0.75	7.29	11108.83	0.007443715
136564	0.73	7.13	10871.32	0.007502226
132464	0.71	6.97	10633.82	0.00760568
127134	0.70	6.82	10396.31	0.007636975
120984	0.68	6.66	10158.8	0.007611329
112784	0.66	6.43	9802.539	0.00762056
104173	0.63	6.12	9327.524	0.007773956
95973	0.60	5.88	8971.263	0.007742136
85723	0.57	5.57	8496.248	0.007710112
78482	0.55	5.34	8139.987	0.007690222
70708	0.52	5.11	7783.725	0.007577195
66250	0.51	4.95	7546.218	0.007553481
62726	0.48	4.72	7189.957	0.007877948
60643	0.49	4.79	7308.71	0.007370818
54228	0.46	4.48	6833.695	0.007539264
48126	0.44	4.25	6477.434	0.007447145
43119	0.41	4.01	6121.173	0.007471661
39051	0.39	3.78	5764.912	0.007628942
34357	0.37	3.63	5527.404	0.007301157
32167	0.36	3.47	5289.897	0.007463262
32758	0.35	3.39	5171.143	0.007953535
29634	0.33	3.24	4933.635	0.007904391
26162	0.31	3.00	4577.374	0.008106997
23819	0.29	2.85	4339.867	0.008210883
21823	0.28	2.69	4102.359	0.008419097

19306	0.26	2.53	3864.852	0.008391718
17657	0.25	2.46	3746.098	0.00816932
15922	0.24	2.38	3627.344	0.00785651
14707	0.24	2.30	3508.59	0.007756543
13665	0.23	2.22	3389.837	0.007721108
11062	0.21	2.07	3152.329	0.007227358
9847	0.20	1.91	2914.822	0.007524693
8632	0.19	1.83	2796.068	0.007168438
6549	0.17	1.68	2558.56	0.006495326
5942	0.16	1.52	2321.053	0.007160511
1509	0.04	0.43	654.4546	0.0228762
3172	0.09	0.90	1371.023	0.010956726
3754	0.11	1.06	1608.53	0.009420548
3338	0.10	0.98	1489.777	0.009766058
3172	0.09	0.90	1371.023	0.010956726
2756	0.08	0.74	1133.515	0.01392846
1842	0.06	0.54	818.0682	0.017867516

30% vol. water-in-EDM 244 oil emulsion with 0.1% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
111964	1.22	7.56	14446.38	0.007271011
109094	1.20	7.46	14256.98	0.007274116
107454	1.19	7.36	14067.57	0.007358992
104583	1.18	7.31	13972.87	0.007259851
101303	1.15	7.16	13688.76	0.007327089
96383	1.12	6.96	13309.95	0.007373683
92283	1.09	6.76	12931.14	0.007479705
86133	1.05	6.52	12457.63	0.00752202
82853	1.03	6.37	12173.52	0.007577239
79163	1.00	6.22	11889.42	0.007589898
70086	0.96	5.97	11415.9	0.007288597
62311	0.90	5.57	10658.29	0.007434105
55470	0.85	5.28	10090.07	0.007384252
53758	0.84	5.23	9995.369	0.007292644
45153	0.77	4.78	9143.048	0.007320497
36548	0.69	4.29	8196.024	0.00737374
26377	0.58	3.59	6870.191	0.00757411
23874	0.56	3.44	6586.084	0.00745947
21736	0.52	3.25	6207.275	0.007645721
20261	0.51	3.15	6017.87	0.007582444
18786	0.48	3.00	5733.763	0.007744279
17310	0.46	2.85	5449.656	0.007899524
16095	0.44	2.75	5260.251	0.007883536
14360	0.42	2.60	4976.144	0.007859441
13058	0.40	2.45	4692.037	0.008038657
12277	0.39	2.40	4597.335	0.007872402
11843	0.38	2.36	4502.632	0.007916962
10975	0.36	2.26	4313.228	0.00799531
10107	0.35	2.16	4123.823	0.008054981
9500	0.34	2.11	4029.12	0.007930916
8719	0.32	2.01	3839.716	0.008014648
8458	0.32	1.96	3745.013	0.008173526
7938	0.31	1.91	3650.311	0.008073504
7504	0.30	1.86	3555.609	0.008044123
6809	0.29	1.81	3460.906	0.007704802
6549	0.28	1.71	3271.502	0.008293083
6375	0.28	1.76	3366.204	0.007625424
5855	0.28	1.71	3271.502	0.007413914
5334	0.26	1.61	3082.097	0.00761022
4640	0.25	1.56	2987.394	0.007046023
3945	0.24	1.46	2797.99	0.006830328
2507	0.20	1.27	2419.18	0.005805534
187	0.17	1.07	2040.371	0.000608867
1509	0.12	0.72	1377.454	0.010779694
1218	0.09	0.57	1093.347	0.013810244
969	0.08	0.47	903.9426	0.016066399

30% vol. water-in-EDM 244 oil emulsion with 0.1% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
31977	2.54	5.61	17986.35	0.006717149
31977	2.54	5.59	17929.88	0.006759522
31543	2.53	5.57	17873.42	0.006709991
30935	2.50	5.52	17704.03	0.006707294
30241	2.48	5.47	17534.63	0.006684059
29373	2.44	5.38	17252.31	0.006706462
28245	2.38	5.26	16857.06	0.006754834
26683	2.32	5.12	16405.35	0.006737498
25294	2.25	4.96	15897.18	0.006801746
23385	2.17	4.78	15332.54	0.006760022
21823	2.10	4.62	14824.36	0.006748374
20001	2.02	4.45	14259.72	0.006684304
18178	1.93	4.25	13638.61	0.006641156
16442	1.84	4.06	13017.51	0.006593946
15141	1.77	3.90	12509.33	0.006575243
13405	1.66	3.65	11718.84	0.00663334
12190	1.58	3.48	11154.2	0.006658281
11149	1.51	3.32	10646.02	0.006684674
9847	1.43	3.14	10081.38	0.006584018
9153	1.37	3.02	9686.13	0.006629428
8719	1.34	2.95	9460.274	0.006620262
7330	1.27	2.81	9008.562	0.006138072
7156	1.22	2.69	8613.313	0.006555337
6289	1.15	2.55	8161.601	0.006415668
5594	1.09	2.40	7709.889	0.006395735
4900	1.03	2.28	7314.64	0.006223777
4293	0.98	2.16	6919.392	0.00609285
3859	0.94	2.07	6637.072	0.005952803
3512	0.90	1.98	6354.751	0.005909307
3164	0.87	1.91	6128.895	0.005724841
3390	0.82	1.81	5790.111	0.006871077
3107	0.72	1.59	5112.542	0.008076767
2848	0.71	1.56	4999.614	0.007743796
2474	0.66	1.45	4660.83	0.007737979
2374	0.64	1.42	4547.902	0.007798647
2315	0.64	1.40	4491.438	0.007799557
2099	0.62	1.37	4378.51	0.007439456
1907	0.60	1.31	4209.118	0.007315496
1724	0.58	1.28	4096.19	0.006982281
1416	0.54	1.19	3813.869	0.006614497
1024	0.49	1.08	3475.085	0.005764181
874	0.43	0.94	3023.373	0.006500688
666	0.35	0.77	2458.732	0.00748858
583	0.29	0.64	2063.484	0.009302829
433	0.22	0.49	1555.307	0.012163385
283	0.14	0.31	990.6668	0.019599002

30% vol. water-in-EDM 244 oil emulsion with 0.1% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
44371	2.43	6.68	19199.07	0.005877623
44058	2.42	6.64	19072.99	0.005913587
43432	2.41	6.62	19009.95	0.005868312
42650	2.38	6.53	18757.78	0.005918589
41398	2.34	6.42	18442.57	0.005942942
40146	2.30	6.31	18127.36	0.005965424
38269	2.24	6.16	17686.07	0.005973743
37017	2.20	6.05	17370.86	0.005989961
35609	2.15	5.92	16992.61	0.006021477
34357	2.12	5.83	16740.44	0.005986162
33105	2.08	5.72	16425.23	0.005991582

34060	2.08	5.72	16425.23	0.006164284
31716	2.01	5.52	15857.86	0.006158309
29634	1.94	5.32	15290.48	0.006188828
27985	1.87	5.15	14786.15	0.006249955
25381	1.78	4.88	14029.64	0.006296288
22257	1.67	4.58	13147.06	0.006287448
18612	1.52	4.18	12012.31	0.006298055
16095	1.43	3.92	11255.81	0.006203132
13231	1.30	3.57	10247.14	0.006152707
10715	1.17	3.22	9238.467	0.006129763
8458	1.05	2.89	8292.84	0.00600537
7070	0.96	2.65	7599.38	0.005977375
6115	0.91	2.49	7158.088	0.005827381
4987	0.84	2.32	6653.753	0.005499979
4206	0.79	2.16	6212.461	0.005320947
3512	0.73	2.01	5771.168	0.005147974
2817	0.68	1.88	5392.917	0.00472984
2682	0.69	1.90	5455.959	0.004398552
2066	0.65	1.79	5140.75	0.00381762
1925	0.61	1.68	4825.541	0.004036243
1842	0.60	1.64	4699.457	0.004071889
1675	0.57	1.57	4510.332	0.004021372
254	0.49	1.35	3879.914	0.000822397
1301	0.40	1.11	3186.454	0.006257641
1010	0.34	0.93	2682.119	0.006856866
761	0.25	0.69	1988.659	0.009392844
644	0.21	0.58	1673.45	0.011234828
478	0.16	0.45	1295.2	0.013914588
262	0.08	0.23	664.7815	0.028932238

30% vol. water-in-EDM 244 oil emulsion with 0.5% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
141484	0.27	5.24	8040.938	0.008907154
140254	0.26	5.08	7801.232	0.009380668
130004	0.24	4.77	7321.822	0.009871032
114014	0.23	4.46	6842.411	0.009912484
107454	0.22	4.30	6602.706	0.010032764
96383	0.21	4.14	6363	0.009689948
85313	0.20	3.99	6123.295	0.009261652
82421	0.20	3.99	6123.295	0.008947657
77031	0.20	3.83	5883.59	0.009057783
62364	0.17	3.36	5164.473	0.009517547
56731	0.17	3.36	5164.473	0.00865793
51412	0.16	3.21	4924.768	0.008628447
44371	0.15	2.90	4445.357	0.009139589
39051	0.14	2.74	4205.652	0.008986879
34357	0.13	2.58	3965.947	0.008891322
22604	0.12	2.43	3726.241	0.00662657
19740	0.12	2.27	3486.536	0.006610087
18005	0.12	2.27	3486.536	0.006028885
16790	0.11	2.11	3246.831	0.00648281
13492	0.09	1.80	2767.42	0.007170699
11756	0.08	1.65	2527.715	0.007489436
9586	0.08	1.49	2288.009	0.007453937
9413	0.07	1.33	2048.304	0.009132238
8719	0.08	1.49	2288.009	0.006779146
7851	0.06	1.18	1808.599	0.009769468
5334	0.05	1.02	1568.893	0.008820861
4379	0.04	0.71	1089.482	0.015018146
3772	0.03	0.55	849.7771	0.021261466

30% vol. water-in-EDM 244 oil emulsion with 0.5% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
149275	0.75	7.36	16007.97	0.007688314
148865	0.76	7.44	16177.28	0.007507543
146405	0.75	7.29	15838.65	0.00770257
143534	0.75	7.29	15838.65	0.007551571
140254	0.73	7.13	15500.02	0.007704943
134514	0.71	6.97	15161.39	0.007723387
127544	0.70	6.82	14822.76	0.007661605
121394	0.68	6.59	14314.81	0.007818856
113194	0.65	6.35	13806.86	0.007836997
105403	0.63	6.12	13298.92	0.007865748
96383	0.60	5.81	12621.65	0.007985215
84903	0.56	5.42	11775.07	0.008081891
82421	0.56	5.49	11944.39	0.007624748
73092	0.52	5.03	10928.5	0.008077263
65628	0.49	4.79	10420.55	0.007976789
61586	0.48	4.64	10081.92	0.007996721
59861	0.48	4.64	10081.92	0.007772695
51724	0.44	4.33	9404.655	0.007718406
45153	0.40	3.94	8558.077	0.008136768
37799	0.37	3.63	7880.814	0.008032648
34357	0.35	3.39	7372.867	0.008341825
35795	0.36	3.47	7542.183	0.008305189
31890	0.33	3.24	7034.235	0.008506255
28332	0.31	3.00	6526.288	0.008779302
25294	0.29	2.85	6187.657	0.008719458
23559	0.28	2.77	6018.341	0.00858451
21129	0.27	2.61	5679.71	0.008644485
18699	0.25	2.46	5341.079	0.008651137
17137	0.24	2.38	5171.763	0.008456038
16095	0.24	2.30	5002.447	0.008488885
13665	0.22	2.15	4663.816	0.0082919
12797	0.21	2.07	4494.5	0.008361392
10281	0.20	1.91	4155.869	0.007856286
9673	0.20	1.99	4325.184	0.006824638
9239	0.20	1.91	4155.869	0.007060463
7156	0.19	1.83	3986.553	0.005943223
4553	0.16	1.60	3478.606	0.004965925
3859	0.16	1.52	3309.29	0.004650358
3337	0.13	1.29	2801.343	0.005612523
2896	0.12	1.13	2462.712	0.006302462
2430	0.11	1.06	2293.396	0.006096972
2090	0.09	0.90	1954.765	0.007220656
1878	0.08	0.74	1616.134	0.009492243
1641	0.07	0.67	1446.818	0.010346751
1268	0.05	0.51	1108.186	0.013626018
1149	0.04	0.43	938.8708	0.017206095

30% vol. water-in-EDM 244 oil emulsion with 0.5% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
110324	1.23	7.61	20732.26	0.007071488
109504	1.22	7.56	20597.23	0.007111253
108274	1.21	7.51	20462.21	0.007124475
107044	1.20	7.46	20327.19	0.007137423
103353	1.18	7.31	19922.11	0.007174466
99663	1.15	7.16	19517.04	0.007208468
96793	1.13	7.01	19111.97	0.007300788
93103	1.11	6.91	18841.92	0.007225195
89413	1.09	6.76	18436.85	0.00724708
82033	1.04	6.47	17626.71	0.007274131
81073	1.04	6.47	17626.71	0.007189024
74646	0.99	6.17	16816.56	0.007272273
67494	0.94	5.82	15871.4	0.00738196
61689	0.89	5.53	15061.25	0.007492459
59704	0.89	5.53	15061.25	0.00725132
48282	0.79	4.93	13440.97	0.007363126
37956	0.70	4.34	11820.68	0.0074839

33262	0.65	4.04	11010.54	0.007559011
34407	0.65	4.04	11010.54	0.0078192
26075	0.56	3.44	9390.249	0.008147292
22778	0.52	3.20	8715.13	0.008262222
19567	0.48	2.95	8040.01	0.008339472
16095	0.43	2.65	7229.867	0.008483461
13839	0.40	2.50	6824.795	0.008185723
12016	0.37	2.31	6284.7	0.008381871
11235	0.36	2.26	6149.676	0.008184978
9673	0.34	2.11	5744.604	0.008075822
8458	0.32	1.96	5339.532	0.008173526
7677	0.29	1.81	4934.461	0.00868677
7156	0.29	1.81	4934.461	0.008097589
6983	0.29	1.81	4934.461	0.007901196
6896	0.28	1.76	4799.437	0.008248223
6723	0.28	1.76	4799.437	0.008040623
6462	0.28	1.76	4799.437	0.007729224
5942	0.28	1.71	4664.413	0.00752381
4900	0.25	1.56	4259.341	0.007441402
4466	0.25	1.56	4259.341	0.006782437
3772	0.24	1.46	3989.293	0.006529848
2123	0.22	1.36	3719.246	0.004228382
1921	0.22	1.36	3719.246	0.003825832
1853	0.20	1.22	3314.174	0.004648026
1700	0.17	1.07	2909.102	0.005535602
1556	0.15	0.92	2504.03	0.006837953
1361	0.13	0.82	2233.983	0.007514258
1158	0.12	0.72	1963.935	0.008268963
903	0.09	0.57	1558.863	0.010240233

30% vol. water-in-EDM 244 oil emulsion with 0.5% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
29286	2.55	5.63	25724.92	0.006113568
29200	2.55	5.63	25724.92	0.006095452
28505	2.53	5.57	25483.4	0.006063846
28072	2.51	5.54	25322.39	0.00604772
27898	2.50	5.50	25161.39	0.006087494
27290	2.46	5.42	24758.86	0.006150138
26423	2.42	5.33	24356.34	0.006153004
25642	2.38	5.24	23953.81	0.006173485
24253	2.30	5.06	23148.76	0.006252379
22691	2.22	4.90	22424.22	0.006233789
21736	2.17	4.78	21860.69	0.006283368
20174	2.09	4.61	21055.64	0.006286277
17657	1.95	4.31	19687.06	0.006293617
15922	1.85	4.08	18640.5	0.006330093
13752	1.71	3.78	17271.91	0.006368299
11149	1.55	3.41	15581.31	0.006343754
9066	1.39	3.07	14051.72	0.006342781
7504	1.27	2.79	12763.64	0.006362929
6202	1.15	2.55	11636.58	0.00632713
5247	1.06	2.33	10670.52	0.006366408
3945	0.94	2.07	9462.946	0.006086685
3338	0.87	1.93	8818.907	0.0059291
2817	0.83	1.82	8335.879	0.005600939
2760	0.83	1.82	8335.879	0.005487991
2303	0.79	1.74	7933.354	0.00505385
1760	0.74	1.63	7450.326	0.004379614
1480	0.71	1.56	7128.306	0.004023394
1166	0.68	1.49	6806.287	0.003477401
996	0.64	1.42	6484.268	0.003274091
734	0.57	1.26	5759.724	0.003054871
649	0.55	1.21	5518.21	0.00294339
649	0.52	1.15	5276.696	0.003218994
564	0.48	1.07	4874.171	0.00327949
327	0.30	0.66	3022.561	0.004937604
250	0.22	0.49	2217.512	0.007029257

30% vol. water-in-EDM 244 oil emulsion with 0.5% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
45466	2.43	6.68	27373.49	0.006022706
43119	2.38	6.53	26744.3	0.005983727
41711	2.34	6.42	26294.89	0.005987864
39833	2.28	6.27	25665.71	0.00600213
39051	2.26	6.20	25396.06	0.006009868
37799	2.22	6.11	25036.52	0.005985508
36548	2.18	6.00	24587.11	0.006000802
35765	2.16	5.94	24317.46	0.006003308
34826	2.14	5.87	24047.81	0.005977564
33575	2.10	5.76	23598.39	0.005984308
34667	2.09	5.74	23508.51	0.006226345
32498	2.02	5.54	22699.56	0.006260093
30762	1.95	5.37	21980.49	0.006319791
27724	1.85	5.08	20812.01	0.006353296
25642	1.78	4.88	20003.06	0.006360874
23646	1.70	4.69	19194.12	0.006370566
21563	1.63	4.47	18295.28	0.006394257
19567	1.55	4.27	17486.33	0.006351618
17831	1.48	4.07	16677.39	0.006363328
15748	1.39	3.81	15598.79	0.00642411
14012	1.31	3.61	14789.84	0.006358471
10801	1.15	3.17	12992.17	0.006351598
8719	1.04	2.87	11733.81	0.006285421
7851	0.99	2.73	11194.51	0.006218233
6723	0.93	2.56	10475.45	0.006080726
5855	0.87	2.40	9846.263	0.005994167
5160	0.83	2.29	9396.847	0.005800807
4466	0.78	2.14	8767.664	0.005766775
3685	0.72	1.99	8138.482	0.005522418
3164	0.69	1.90	7778.949	0.005190578
3337	0.70	1.92	7868.832	0.005349564
3091	0.68	1.86	7599.183	0.005313227
2642	0.64	1.77	7239.65	0.00500286
2447	0.63	1.72	7059.884	0.004872441
2260	0.61	1.68	6880.117	0.004739166
1989	0.60	1.64	6700.351	0.004396885
1887	0.58	1.59	6520.585	0.004405089
1556	0.56	1.53	6250.935	0.00395317
903	0.52	1.42	5801.519	0.002663622
734	0.41	1.13	4633.037	0.003392303
394	0.22	0.60	2475.841	0.006386094
225	0.12	0.34	1397.242	0.011427699
157	0.08	0.23	947.8264	0.017338013

30% vol. water-in-EDM 244 oil emulsion with 0.75% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
146405	0.26	5.08	6327.297	0.00979201
138614	0.24	4.77	5938.465	0.010524794
134514	0.24	4.77	5938.465	0.010213479
130414	0.24	4.61	5744.048	0.010583816
126314	0.24	4.61	5744.048	0.01025107
120984	0.23	4.46	5549.632	0.01051848
116064	0.23	4.46	5549.632	0.010090718
107044	0.22	4.30	5355.216	0.009994482
98023	0.21	4.14	5160.799	0.009854831
86953	0.20	3.83	4771.967	0.010224537
78343	0.19	3.68	4577.55	0.010011211
73817	0.19	3.68	4577.55	0.009432898
62000	0.16	3.21	3994.301	0.010405596

59704	0.16	3.21	3994.301	0.01002019
54071	0.16	3.05	3799.885	0.010027218
49378	0.16	3.05	3799.885	0.009156765
42024	0.14	2.74	3411.052	0.009671013
35765	0.14	2.74	3411.052	0.00823073
29037	0.13	2.58	3216.636	0.00751462
30241	0.13	2.58	3216.636	0.007826142
25381	0.12	2.43	3022.22	0.007440699
21216	0.12	2.43	3022.22	0.006219506
18786	0.12	2.27	2827.803	0.006290426
18091	0.11	2.11	2633.387	0.00698545
16963	0.11	2.11	2633.387	0.006549829
16356	0.10	1.96	2438.971	0.007362201
14533	0.09	1.80	2244.554	0.007724197
13579	0.09	1.80	2244.554	0.007216824
12971	0.08	1.65	2050.138	0.008263465
12450	0.08	1.65	2050.138	0.007931738
11235	0.08	1.49	1855.722	0.00873604
9673	0.07	1.33	1661.305	0.009384829
6809	0.05	1.02	1272.472	0.011260621
8024	0.05	1.02	1272.472	0.013269836
7156	0.04	0.87	1078.056	0.016488102
7156	0.04	0.87	1078.056	0.016488102
6289	0.04	0.87	1078.056	0.014488644
4553	0.03	0.55	689.2235	0.025664149
2854	0.02	0.40	494.8071	0.031210185

30% vol. water-in-EDM 244 oil emulsion with 0.75% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
150915	0.77	7.52	13258.13	0.007454082
149685	0.76	7.44	13120.81	0.007548898
142714	0.75	7.29	12846.16	0.007508429
139024	0.73	7.13	12571.51	0.007637371
133694	0.71	6.97	12296.85	0.007676304
128774	0.70	6.82	12022.2	0.007735493
120164	0.68	6.59	11610.22	0.00773963
112374	0.65	6.35	11198.25	0.007780223
104583	0.62	6.04	10648.94	0.008007142
95973	0.60	5.81	10236.97	0.007951246
81213	0.54	5.26	9275.686	0.008195215
78378	0.55	5.34	9413.011	0.007680065
70293	0.51	4.95	8726.382	0.008014393
62104	0.48	4.64	8177.079	0.008064018
53293	0.44	4.25	7490.45	0.008246789
51724	0.44	4.25	7490.45	0.008004011
42650	0.40	3.86	6803.821	0.007999023
35765	0.36	3.47	6117.191	0.008298215
30289	0.32	3.16	5567.888	0.008482665
31890	0.32	3.16	5567.888	0.008931024
27464	0.30	2.92	5155.911	0.008969759
24513	0.28	2.77	4881.259	0.008932365
22344	0.27	2.61	4606.607	0.009141574
19393	0.25	2.46	4331.956	0.008972349
17571	0.24	2.38	4194.63	0.008670155
15488	0.23	2.22	3919.978	0.008750832
13839	0.21	2.07	3645.327	0.009041812
12450	0.20	1.99	3508.001	0.008783931
10368	0.20	1.91	3370.675	0.007922604
9673	0.20	1.99	3508.001	0.006824638
9066	0.19	1.83	3233.349	0.007528796
4293	0.16	1.52	2684.046	0.005173306
5074	0.16	1.52	2684.046	0.006114614
3772	0.12	1.21	2134.742	0.007186148
2210	0.07	0.67	1173.462	0.013932793
1387	0.04	0.43	756.8057	0.021018972
1666	0.05	0.51	898.8099	0.017909666
1158	0.04	0.35	624.1583	0.025799292
649	0.02	0.20	349.5066	0.046113212

30% vol. water-in-EDM 244 oil emulsion with 0.75% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
110324	1.24	7.70	17034.21	0.006890807
105813	1.22	7.56	16705.67	0.006871615
103353	1.19	7.41	16377.13	0.006983849
100073	1.18	7.31	16158.11	0.006946773
96793	1.15	7.16	15829.57	0.007000881
94743	1.15	7.11	15720.05	0.006948413
91463	1.12	6.96	15391.51	0.006997275
80555	1.05	6.52	14405.9	0.007034877
76720	1.02	6.32	13967.85	0.007126772
72055	0.99	6.12	13529.79	0.007133911
66043	0.94	5.82	12872.72	0.007223242
60173	0.91	5.62	12434.66	0.007053137
55323	0.87	5.38	11887.1	0.007095783
51724	0.84	5.23	11558.56	0.007016718
47187	0.79	4.93	10901.48	0.0071961
44371	0.78	4.83	10682.46	0.007046926
41711	0.75	4.63	10244.4	0.007203128
38112	0.71	4.39	9696.839	0.00734597
33018	0.65	4.04	8930.248	0.007503641
29026	0.61	3.79	8382.683	0.007486325
25468	0.56	3.49	7725.605	0.007733481
22951	0.53	3.30	7287.553	0.007832278
20261	0.50	3.10	6849.501	0.007826846
17831	0.47	2.90	6411.449	0.007861543
16095	0.44	2.75	6082.91	0.007883536
15314	0.43	2.65	5863.884	0.008071782
13752	0.41	2.55	5644.858	0.007821829
12364	0.39	2.40	5316.319	0.007928052
11062	0.37	2.31	5097.293	0.007715984
9673	0.35	2.16	4768.754	0.007709163
8805	0.33	2.06	4549.728	0.007709445
8024	0.32	1.96	4330.702	0.007754211
6462	0.29	1.81	4002.163	0.007312015
6375	0.28	1.76	3892.65	0.007625424
4553	0.25	1.56	3454.598	0.00691423
3512	0.23	1.41	3126.059	0.006512521
2457	0.22	1.36	3016.546	0.004893715
2673	0.21	1.31	2907.033	0.005733014
2507	0.20	1.27	2797.52	0.005805534
2257	0.19	1.17	2578.494	0.00615372
2091	0.17	1.07	2359.468	0.006807834
1842	0.16	0.97	2140.442	0.007285582
1675	0.14	0.87	1921.416	0.008224855
1343	0.12	0.72	1592.877	0.009591801
1010	0.08	0.52	1154.824	0.013728703
428	0.04	0.23	497.7465	0.031321301

30% vol. water-in-EDM 244 oil emulsion with 0.75% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
30588	2.57	5.66	20995.14	0.006306127
30415	2.57	5.66	20995.14	0.006270343
27898	2.46	5.43	20146.31	0.006246354
25728	2.36	5.20	19297.48	0.0062785
23559	2.26	4.98	18448.65	0.006290251
21736	2.16	4.76	17665.12	0.006329904
19220	2.03	4.48	16620.41	0.006322729
15835	1.83	4.04	14988.04	0.006405773
12797	1.67	3.67	13616.86	0.006272141

10715	1.53	3.37	12506.85	0.006224828
9066	1.42	3.13	11592.73	0.006130243
6809	1.24	2.74	10156.25	0.005999079
5508	1.13	2.49	9242.122	0.005859534
4813	1.07	2.35	8719.766	0.005752803
3859	0.99	2.18	8066.82	0.005388644
3425	0.94	2.07	7675.053	0.00528339
3390	0.94	2.07	7675.053	0.005229324
3065	0.88	1.95	7217.991	0.005345978
2607	0.84	1.86	6891.519	0.004987961
2315	0.81	1.79	6630.34	0.004786068
1999	0.78	1.72	6369.162	0.00447763
1616	0.75	1.65	6107.984	0.003935505
1357	0.71	1.58	5846.806	0.003608592
1166	0.69	1.52	5650.922	0.003317948
1008	0.65	1.44	5324.45	0.003230041
916	0.63	1.38	5128.566	0.003164951
958	0.63	1.38	5128.566	0.003308834
916	0.61	1.35	4997.977	0.003332502
333	0.22	0.49	1798.544	0.009355556
183	0.12	0.27	1015.01	0.016150539
749	0.49	1.08	4018.559	0.004217485
333	0.26	0.57	2125.017	0.006701732
100	0.08	0.17	623.2423	0.023350671

30% vol. water-in-EDM 244 oil emulsion with 0.75% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
45779	2.45	6.73	22347.45	0.005985287
39520	2.27	6.25	20743.62	0.005996907
38112	2.23	6.14	20379.12	0.005991959
37173	2.20	6.05	20087.52	0.006015279
36078	2.18	5.98	19868.81	0.005967282
34983	2.14	5.87	19504.31	0.006004419
33888	2.10	5.76	19139.8	0.006040084
34927	2.10	5.76	19139.8	0.006225409
32584	2.02	5.54	18410.79	0.006276811
30415	1.94	5.35	17754.68	0.006299893
26857	1.82	4.99	16588.27	0.0063727
24860	1.74	4.78	15859.26	0.006453862
22604	1.66	4.56	15130.25	0.006447195
16182	1.39	3.83	12724.51	0.006525698
13405	1.27	3.48	11558.1	0.006551917
12364	1.21	3.33	11047.79	0.006614055
10801	1.14	3.13	10391.68	0.006531082
6723	0.91	2.49	8277.552	0.006406292
2557	0.61	1.68	5580.214	0.005361547
2449	0.62	1.70	5653.115	0.005003117
1767	0.55	1.50	4997.006	0.004620255
1068	0.48	1.31	4340.897	0.003702209
844	0.38	1.04	3466.085	0.004586673
594	0.26	0.71	2372.57	0.006895484
345	0.16	0.45	1497.758	0.0100422
179	0.08	0.23	768.7477	0.019745224

30% vol. water-in-EDM 244 oil emulsion with 1% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
57201	0.16	3.21	4693.304	0.009600041
48126	0.15	2.90	4236.426	0.009913075
44371	0.14	2.74	4007.986	0.010211119
39207	0.13	2.58	3779.547	0.01014655
35139	0.12	2.43	3551.108	0.010301397
31697	0.12	2.43	3551.108	0.009292294
33452	0.12	2.43	3551.108	0.00980676
30154	0.12	2.27	3322.669	0.010097295
27204	0.12	2.27	3322.669	0.009109253
24079	0.11	2.11	3094.23	0.009297593
20348	0.10	1.96	2865.79	0.009159167
17657	0.10	1.96	2865.79	0.007948168
16269	0.10	1.96	2865.79	0.007323137
13926	0.09	1.80	2637.351	0.007401323
12624	0.09	1.80	2637.351	0.006709451
12277	0.09	1.80	2637.351	0.006524951
12016	0.08	1.65	2408.912	0.0076553
11930	0.08	1.49	2180.473	0.009275873
11062	0.08	1.49	2180.473	0.008601082
10715	0.08	1.49	2180.473	0.008331165
8632	0.07	1.33	1952.034	0.008374466
8979	0.07	1.33	1952.034	0.008711254
8892	0.06	1.18	1723.594	0.011065399
8545	0.07	1.33	1952.034	0.008290269
8285	0.06	1.18	1723.594	0.01030944
8111	0.06	1.18	1723.594	0.010093451
7938	0.06	1.18	1723.594	0.009877463
7504	0.06	1.18	1723.594	0.009337491
6983	0.05	1.02	1495.155	0.011547652
6809	0.05	1.02	1495.155	0.011260621
6289	0.04	0.87	1266.716	0.014488644
5942	0.04	0.87	1266.716	0.013688861
4206	0.04	0.71	1038.277	0.014422931
3512	0.03	0.55	809.8376	0.019793905
2383	0.02	0.40	581.3984	0.02606567

30% vol. water-in-EDM 244 oil emulsion with 1% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
150915	0.77	7.52	15578.31	0.007454082
149275	0.75	7.36	15255.59	0.007688314
144764	0.75	7.29	15094.23	0.007616285
139844	0.73	7.13	14771.52	0.007682419
132464	0.71	6.90	14287.45	0.007778442
125494	0.68	6.66	13803.37	0.007895069
118934	0.67	6.51	13480.66	0.007844887
113604	0.65	6.35	13157.94	0.007865384
104583	0.63	6.12	12673.87	0.007804553
89413	0.56	5.49	11383	0.00827162
75473	0.52	5.03	10414.86	0.008340396
54384	0.44	4.33	8962.636	0.008115316
45153	0.40	3.86	7994.489	0.008468542
41398	0.38	3.70	7671.774	0.008431215
37956	0.36	3.55	7349.058	0.00842398
30289	0.32	3.16	6542.269	0.008482665
31716	0.32	3.16	6542.269	0.008882415
25294	0.29	2.85	5896.837	0.008719458
22344	0.27	2.61	5412.764	0.009141574
18438	0.24	2.38	4928.69	0.00909839
16356	0.24	2.30	4767.332	0.008626199
14707	0.22	2.15	4444.617	0.008923813
13318	0.21	2.07	4283.259	0.008701602
12103	0.20	1.99	4121.901	0.00853902
11062	0.20	1.91	3960.543	0.008453153
10194	0.20	1.91	3960.543	0.007789967
9760	0.20	1.99	4121.901	0.006885866
9673	0.20	1.91	3960.543	0.007392056
9239	0.20	1.91	3960.543	0.007060463
8458	0.19	1.83	3799.185	0.007024295
4813	0.16	1.60	3315.112	0.005249893
3685	0.13	1.29	2669.68	0.006197768
2904	0.11	1.06	2185.607	0.007287248
2752	0.11	1.06	2185.607	0.006905634
2006	0.09	0.90	1862.891	0.006927733

1751	0.06	0.59	1217.46	0.014162729
1242	0.04	0.43	894.7438	0.018602858
818	0.03	0.28	572.0281	0.029980457

30% vol. water-in-EDM 244 oil emulsion with 1% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
110734	1.25	7.75	20143.87	0.006828335
110324	1.25	7.75	20143.87	0.006803052
108274	1.23	7.66	19886.52	0.006850562
107454	1.23	7.61	19757.84	0.006887523
106224	1.22	7.56	19629.16	0.006898241
104173	1.20	7.46	19371.81	0.006946053
100073	1.18	7.31	18985.77	0.006946773
96793	1.15	7.16	18599.74	0.007000881
92283	1.12	6.96	18085.03	0.007060009
87773	1.09	6.76	17570.32	0.007114152
78343	1.03	6.42	16669.57	0.007054583
78482	1.03	6.42	16669.57	0.007067093
70708	0.97	6.02	15640.15	0.007232776
63763	0.91	5.67	14739.41	0.007343908
61269	0.91	5.62	14610.73	0.007181514
48126	0.79	4.93	12809.24	0.007339265
39677	0.71	4.44	11522.46	0.007477691
27786	0.59	3.64	9463.619	0.007762962
29460	0.60	3.69	9592.297	0.008011422
23646	0.53	3.30	8562.874	0.008069204
20434	0.48	3.00	7790.808	0.008424032
15661	0.42	2.60	6761.385	0.008571937
13665	0.39	2.40	6246.674	0.008762801
11409	0.36	2.21	5731.963	0.008688781
9586	0.33	2.06	5345.93	0.008393292
8371	0.31	1.91	4959.897	0.008514859
7590	0.29	1.81	4702.541	0.008588573
7417	0.29	1.81	4702.541	0.00839218
7070	0.28	1.76	4573.863	0.008455822
6809	0.28	1.71	4445.185	0.008622772
5855	0.26	1.61	4187.83	0.00835313
4640	0.24	1.46	3801.797	0.008032246
1516	0.19	1.17	3029.73	0.004131141
1463	0.17	1.07	2772.374	0.004762566
988	0.12	0.72	1871.63	0.00705743
903	0.11	0.67	1742.952	0.007439448
734	0.08	0.52	1356.919	0.00996952
522	0.06	0.37	970.8854	0.013845648

30% vol. water-in-EDM 244 oil emulsion with 1% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
32237	2.58	5.68	24746.01	0.006604921
31456	2.56	5.64	24592.57	0.006525568
30849	2.53	5.57	24285.68	0.006562301
30068	2.50	5.50	23978.8	0.006560915
29026	2.46	5.42	23595.19	0.00654129
27811	2.40	5.29	23058.15	0.006562835
25815	2.31	5.10	22214.22	0.006563469
24427	2.26	4.98	21677.17	0.006521968
23212	2.21	4.87	21216.84	0.00646941
22083	2.15	4.75	20679.79	0.006478801
20521	2.07	4.57	19912.58	0.006493374
18786	1.98	4.36	18991.93	0.006534432
17310	1.90	4.20	18301.44	0.006484167
14620	1.74	3.85	16767.02	0.006524619
12797	1.64	3.62	15769.64	0.006456565
11322	1.54	3.39	14772.27	0.006509612
9413	1.41	3.11	13544.73	0.006437287
7417	1.27	2.79	12163.75	0.006289338
5942	1.14	2.51	10936.21	0.006232806
4727	1.03	2.26	9862.12	0.006097089
3859	0.95	2.09	9094.909	0.005852795
2991	0.87	1.91	8327.698	0.005410832
2905	0.87	1.91	8327.698	0.005254862
2752	0.84	1.86	8097.534	0.005265748
2124	0.78	1.72	7483.766	0.004759046
1650	0.73	1.61	7023.439	0.004195411
1514	0.71	1.56	6793.276	0.004115618
1344	0.68	1.51	6563.113	0.00391531
1234	0.67	1.47	6409.67	0.003768333
1107	0.66	1.45	6332.949	0.003462243
1005	0.64	1.42	6179.507	0.003301954
988	0.64	1.42	6179.507	0.003246227
929	0.63	1.38	6026.065	0.003208545
708	0.61	1.35	5872.623	0.002576255
734	0.60	1.31	5719.181	0.002813937
649	0.57	1.26	5489.017	0.002701723
649	0.54	1.19	5182.133	0.003031188
564	0.48	1.07	4645.085	0.00327949
420	0.39	0.85	3724.432	0.003797224
327	0.31	0.68	2957.221	0.004684728
233	0.22	0.49	2113.289	0.006552763
165	0.14	0.31	1346.078	0.01145328
123	0.11	0.24	1039.194	0.014290318

30% vol. water-in-EDM 244 oil emulsion with 1% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
45779	2.44	6.71	26172.59	0.006024529
45779	2.43	6.68	26086.93	0.006064158
43588	2.38	6.53	25487.32	0.006048865
42493	2.34	6.44	25144.69	0.006058679
41085	2.30	6.31	24630.73	0.006104919
39990	2.27	6.25	24373.76	0.006068133
38112	2.22	6.09	23774.15	0.006078627
37017	2.18	6.00	23431.51	0.006077871
35139	2.12	5.83	22746.24	0.006122467
33731	2.07	5.70	22232.29	0.006151985
34667	2.07	5.70	22232.29	0.006322672
33626	2.04	5.61	21889.66	0.006326229
32237	1.99	5.48	21375.7	0.006360148
31022	1.95	5.37	20947.41	0.006373279
29720	1.90	5.24	20433.46	0.006416858
28245	1.86	5.10	19919.51	0.006417073
26423	1.78	4.91	19148.58	0.006496119
24860	1.73	4.75	18548.97	0.006513607
22517	1.63	4.49	17521.06	0.006612215
21129	1.58	4.34	16921.45	0.006651968
19393	1.51	4.14	16150.52	0.006702314
17657	1.43	3.92	15293.94	0.006805174
14446	1.29	3.55	13837.74	0.006801109
12364	1.19	3.28	12809.84	0.006792149
10628	270.64	744.07	2903619	1.14E-07
9500	1.04	2.87	11182.32	0.006848502
8632	0.99	2.73	10668.37	0.006836875
7851	0.95	2.60	10154.42	0.006863617
7243	0.91	2.49	9726.123	0.0069025
6028	0.83	2.29	8955.195	0.006776341
5334	0.79	2.19	8526.902	0.006613372
4553	0.74	2.03	7927.291	0.006531232
4032	0.69	1.90	7413.339	0.006614103
3512	0.65	1.79	6985.045	0.006488
3338	0.64	1.75	6813.728	0.006481338
3380	0.64	1.75	6813.728	0.006562039

3168	0.62	1.70	6642.411	0.006471717
2794	0.60	1.66	6471.093	0.006015629
2362	0.56	1.55	6042.8	0.005830835
1878	0.52	1.44	5614.506	0.005371977
1124	0.45	1.24	4843.578	0.004317896
649	0.37	1.02	3986.991	0.003679337
479	0.27	0.74	2873.428	0.005231841
157	0.09	0.25	988.9373	0.014464561
72	0.04	0.12	474.9851	0.028816559

30% vol. water-in-EDM 244 oil emulsion with 1.5% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
61269	0.17	3.36	5164.473	0.009350399
50473	0.15	2.90	4445.357	0.010396504
39677	0.14	2.74	4205.652	0.009130907
38269	0.13	2.58	3965.947	0.009903602
27160	0.13	2.58	3965.947	0.007028725
29807	0.13	2.58	3965.947	0.007713847
19133	0.12	2.43	3726.241	0.00560891
16703	0.11	2.11	3246.831	0.006449301
15835	0.10	1.96	3007.125	0.007127815
13839	0.08	1.65	2527.715	0.008816342
11322	0.08	1.49	2288.009	0.008803519
10801	0.08	1.49	2288.009	0.008398644
10454	0.07	1.33	2048.304	0.010142601
10541	0.07	1.33	2048.304	0.010226798
9760	0.07	1.33	2048.304	0.009469026
4727	0.04	0.71	1089.482	0.016208578
2383	0.02	0.40	610.0717	0.02606567

30% vol. water-in-EDM 244 oil emulsion with 1.5% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
149275	0.78	7.60	16515.91	0.007222678
148045	0.77	7.52	16346.6	0.007312321
143534	0.75	7.36	16007.97	0.007392671
139844	0.74	7.21	15669.34	0.007517291
133694	0.72	7.05	15330.7	0.007507683
127134	0.71	6.90	14992.07	0.00746545
118524	0.68	6.66	14484.13	0.007456561
96793	0.61	5.96	12960.28	0.007605602
83263	0.56	5.49	11944.39	0.007702668
80555	0.55	5.34	11605.76	0.007893361
69671	0.51	4.95	10759.18	0.007943483
55263	0.44	4.33	9404.655	0.008246407
52976	0.44	4.33	9404.655	0.007905187
38582	0.37	3.63	7880.814	0.008198896
27316	0.31	3.00	6526.288	0.008464597
28592	0.31	3.00	6526.288	0.008859978
24687	0.28	2.77	6018.341	0.008995611
19306	0.25	2.46	5341.079	0.008932197
17050	0.23	2.22	4833.132	0.009633452
14533	0.21	2.07	4494.5	0.009495425
12537	0.20	1.99	4325.184	0.008845159
11756	0.20	1.91	4155.869	0.008983701
11409	0.20	1.91	4155.869	0.008718427
11149	0.19	1.83	3986.553	0.009258512
10541	0.19	1.83	3986.553	0.008754012
6202	0.17	1.68	3647.922	0.006151033
4466	0.16	1.52	3309.29	0.005382486
4032	0.14	1.37	2970.659	0.00603058
3078	0.11	1.06	2293.396	0.007722791
2998	0.11	1.06	2293.396	0.007522771
1692	0.07	0.67	1446.818	0.010667574
903	0.04	0.35	769.5551	0.020129287
734	0.03	0.28	600.2394	0.026873805

30% vol. water-in-EDM 244 oil emulsion with 1.5% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
111964	1.23	7.66	20867.28	0.007084038
110734	1.23	7.61	20732.26	0.007097769
107454	1.21	7.51	20462.21	0.007070518
103353	1.19	7.36	20057.14	0.007078195
97203	1.15	7.11	19382.02	0.007128833
88593	1.09	6.76	18436.85	0.007180616
83263	1.05	6.52	17761.73	0.007271375
80762	1.05	6.52	17761.73	0.007052982
73817	0.99	6.17	16816.56	0.007191485
60757	0.89	5.53	15061.25	0.007379154
58296	0.89	5.53	15061.25	0.007080292
49065	0.81	5.03	13711.01	0.007190589
43432	0.75	4.68	12765.85	0.007342523
34357	0.66	4.09	11145.56	0.007619879
35361	0.66	4.09	11145.56	0.007842616
25989	0.56	3.44	9390.249	0.008120176
23646	0.52	3.25	8850.154	0.008317301
20174	0.48	2.95	8040.01	0.008598389
16182	0.43	2.65	7229.867	0.008529203
13145	0.38	2.36	6419.724	0.008787194
10888	0.34	2.11	5744.604	0.009090164
9239	0.32	1.96	5339.532	0.008928293
8545	0.30	1.86	5069.485	0.009160551
7938	0.29	1.81	4934.461	0.008981361
7764	0.28	1.76	4799.437	0.00928622
7504	0.28	1.76	4799.437	0.008974821
7156	0.28	1.71	4664.413	0.009062357
6723	0.27	1.66	4529.389	0.009027989
6636	0.26	1.61	4394.365	0.009467493
5855	0.26	1.61	4394.365	0.00835313
4813	0.22	1.36	3719.246	0.009586703
3512	0.20	1.22	3314.174	0.00880811
1342	0.16	1.02	2774.078	0.004804289
1327	0.16	1.02	2774.078	0.004751687
1158	0.16	0.97	2639.054	0.0045794
903	0.11	0.67	1828.911	0.007439448
734	0.08	0.47	1288.815	0.012167876
394	0.04	0.27	748.7197	0.019382599

30% vol. water-in-EDM 244 oil emulsion with 1.5% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
30849	2.57	5.66	25885.93	0.006359801
30675	2.56	5.64	25805.42	0.006363538
30154	2.54	5.59	25563.91	0.006374273
29720	2.51	5.54	25322.39	0.006402959
29200	2.50	5.50	25161.39	0.006371546
28419	2.46	5.42	24758.86	0.006404387
27290	2.40	5.29	24195.33	0.00643996
26075	2.34	5.17	23631.79	0.006450216
24600	2.27	5.01	22907.25	0.006476301
22951	2.19	4.83	22102.2	0.006490384
20608	2.06	4.55	20814.13	0.006571374
18699	1.96	4.32	19767.56	0.006610632
17744	1.90	4.20	19204.03	0.006646707
16529	1.83	4.04	18479.49	0.006686631
14360	1.70	3.76	17191.41	0.006712038
11149	1.49	3.28	15017.78	0.006828778
9500	1.36	3.00	13729.7	0.006961798
7504	1.21	2.67	12200.11	0.006964323
6115	1.11	2.44	11153.55	0.006790646

4813	0.99	2.18	9945.975	0.006721781
3512	0.87	1.91	8738.403	0.00635286
2644	0.76	1.68	7691.84	0.006172868
2625	0.77	1.70	7772.345	0.006002359
1887	0.70	1.54	7047.801	0.005247958
1650	0.67	1.47	6725.782	0.005037358
1556	0.65	1.44	6564.773	0.004988455
1421	0.64	1.40	6403.763	0.004785359
666	0.55	1.21	5518.21	0.003020337
564	0.48	1.07	4874.171	0.00327949
479	0.41	0.91	4149.628	0.003844333
335	0.31	0.68	3103.065	0.004806397
276	0.25	0.56	2539.532	0.005904595
199	0.17	0.38	1734.484	0.009152976
131	0.12	0.26	1170.95	0.013247341
98	0.08	0.19	848.9306	0.01870108

30% vol. water-in-EDM 244 oil emulsion with 1.5% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
45935	2.44	6.71	27463.37	0.006045119
45622	2.43	6.68	27373.49	0.006043432
45153	2.42	6.64	27193.72	0.006060594
44058	2.39	6.58	26924.07	0.006032632
42337	2.34	6.42	26294.89	0.006077709
40146	2.27	6.25	25575.82	0.006091875
37486	2.19	6.03	24676.99	0.006110185
34201	2.08	5.72	23418.63	0.006189804
35709	2.09	5.74	23508.51	0.006413386
33712	2.02	5.57	22789.44	0.006443013
31022	1.93	5.30	21710.84	0.006532575
28679	1.85	5.08	20812.01	0.006572058
26336	1.77	4.86	19913.18	0.006592212
22257	1.60	4.40	18025.63	0.006799082
19740	1.51	4.14	16947.04	0.006822286
16008	1.35	3.70	15149.37	0.006923515
12624	1.19	3.26	13351.71	0.007028868
10888	1.10	3.02	12362.99	0.007070903
9673	1.03	2.84	11643.93	0.00708171
7590	0.91	2.49	10205.8	0.007233306
6723	0.86	2.36	9666.496	0.007141053
5681	0.79	2.19	8947.431	0.00704377
5247	0.76	2.10	8587.898	0.007061904
4640	0.72	1.99	8138.482	0.006953001
4293	0.69	1.90	7778.949	0.00704116
3685	0.64	1.77	7239.65	0.006978804
3164	0.60	1.66	6790.234	0.006812211
3040	0.60	1.66	6790.234	0.006545071
2972	0.60	1.64	6700.351	0.006571852
2803	0.58	1.59	6520.585	0.00654325
2472	0.56	1.55	6340.818	0.006103006
2184	0.54	1.48	6071.169	0.005880704
1709	0.49	1.35	5531.869	0.005542807
1047	0.44	1.20	4902.687	0.004325165
657	0.39	1.07	4363.388	0.003426625
564	0.32	0.87	3554.439	0.00443094
394	0.24	0.65	2655.607	0.005550768
327	0.20	0.54	2206.191	0.006659017
157	0.09	0.25	1037.71	0.014464561

30% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
150915	0.25	4.92	6310.101	0.010743756
148865	0.25	4.92	6310.101	0.010597811
148045	0.25	4.92	6310.101	0.010539433
147635	0.25	4.92	6310.101	0.010510244
147225	0.25	4.92	6310.101	0.010481055
146815	0.24	4.77	6110.067	0.011147425
145995	0.24	4.77	6110.067	0.011085162
143124	0.24	4.77	6110.067	0.010867241
139024	0.24	4.77	6110.067	0.010555926
134104	0.24	4.77	6110.067	0.010182347
127134	0.23	4.46	5709.998	0.011053182
120574	0.23	4.46	5709.998	0.010482833
109914	0.22	4.30	5509.964	0.010262456
97613	0.20	3.99	5109.895	0.010596985
87363	0.19	3.68	4709.826	0.011163881
82033	0.19	3.68	4709.826	0.010482758
76305	0.19	3.68	4709.826	0.009750799
68427	0.17	3.36	4309.758	0.010442868
54123	0.15	2.90	3709.655	0.011148311
52194	0.15	2.90	3709.655	0.010751018
39051	0.12	2.43	3109.552	0.011448105
30758	0.12	2.27	2909.517	0.010299587
32237	0.12	2.27	2909.517	0.010794737
20434	0.11	2.11	2709.483	0.007890202
16442	0.10	1.96	2509.449	0.007401266
14707	0.09	1.80	2309.414	0.007816447
12711	0.08	1.49	1909.346	0.009883185
11322	0.07	1.33	1709.311	0.010984571
10194	0.07	1.33	1709.311	0.009890011
9760	0.06	1.18	1509.277	0.012145342
9586	0.06	1.18	1509.277	0.011929353
9066	0.06	1.18	1509.277	0.011281388
8024	0.05	1.02	1309.243	0.013269836
7156	0.04	0.87	1109.208	0.016488102
6115	0.04	0.87	1109.208	0.014088752
4727	0.03	0.55	709.1397	0.026642523
2991	0.02	0.40	509.1054	0.03270954
1497	0.01	0.24	309.0711	0.044418043
30	0.00	0.09	109.0367	0.00708513

30% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
150915	0.78	7.60	13782.54	0.007302032
150505	0.77	7.52	13641.25	0.00743383
149685	0.77	7.52	13641.25	0.007393327
148455	0.77	7.52	13641.25	0.007332573
146405	0.76	7.44	13499.96	0.007383477
142304	0.75	7.29	13217.37	0.007486857
138614	0.74	7.21	13076.07	0.007451171
134514	0.72	7.05	12793.49	0.007553732
128774	0.71	6.90	12510.9	0.007561755
116474	0.66	6.43	11663.13	0.007869892
97613	0.60	5.81	10532.78	0.008087121
77933	0.52	5.03	9119.84	0.008612255
75061	0.52	5.11	9261.134	0.008043731
56403	0.44	4.33	7848.193	0.008416552
53915	0.44	4.33	7848.193	0.008045273
38269	0.36	3.55	6435.252	0.008493431
28724	0.32	3.08	5587.487	0.008456475
29807	0.32	3.08	5587.487	0.008775239
24166	0.28	2.77	5022.311	0.008805872
20174	0.25	2.46	4457.135	0.009333711
16529	0.23	2.22	4033.253	0.009339246
14967	0.22	2.15	3891.958	0.009081791
14012	0.21	2.07	3750.664	0.009155215
12884	0.20	1.99	3609.37	0.009090071
11496	0.20	1.91	3468.076	0.008784746
11235	0.20	1.91	3468.076	0.00858579

10715	0.19	1.83	3326.782	0.008898155
9500	0.19	1.83	3326.782	0.007889153
4900	0.16	1.60	2902.9	0.005344549
3685	0.13	1.29	2337.723	0.006197768
2557	0.10	0.98	1772.547	0.007479829
2871	0.10	0.98	1772.547	0.008397761
1929	0.07	0.67	1207.371	0.012164747
1666	0.05	0.51	924.7826	0.017909666
1158	0.04	0.35	642.1944	0.025799292
903	0.03	0.28	500.9003	0.033087109
394	0.01	0.12	218.3121	0.076055473

30% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
112374	1.25	7.75	17639.12	0.006929468
111144	1.24	7.70	17526.44	0.006942025
110324	1.23	7.66	17413.76	0.006980271
108684	1.23	7.66	17413.76	0.006876504
105813	1.21	7.51	17075.73	0.006962602
99253	1.16	7.21	16399.67	0.007080504
90643	1.10	6.81	15498.25	0.007240338
84903	1.07	6.62	15047.54	0.007194178
81488	1.07	6.62	15047.54	0.006904792
71744	0.99	6.12	13920.76	0.007103123
65732	0.94	5.82	13244.69	0.007189231
59409	0.88	5.48	12455.95	0.007346626
57044	0.88	5.48	12455.95	0.007054182
48595	0.81	5.03	11441.85	0.007121799
41554	0.74	4.58	10427.76	0.007332029
33575	0.67	4.14	9413.657	0.00726918
33626	0.65	4.04	9188.302	0.007641698
28245	0.59	3.64	8286.882	0.007891317
22083	0.52	3.20	7272.784	0.008010386
17571	0.45	2.80	6371.363	0.008304452
14707	0.41	2.55	5807.975	0.008364796
12450	0.38	2.36	5357.265	0.00832307
11235	0.36	2.21	5019.232	0.008556594
9500	0.33	2.06	4681.2	0.008317309
8285	0.31	1.91	4343.167	0.008426588
7851	0.30	1.86	4230.489	0.008416266
7330	0.28	1.76	4005.134	0.008767221
7156	0.28	1.76	4005.134	0.008559622
6983	0.28	1.76	4005.134	0.008352023
6289	0.27	1.66	3779.779	0.008445259
5421	0.25	1.56	3554.424	0.008232159
4379	0.24	1.46	3329.069	0.007581526
3078	0.22	1.36	3103.714	0.006129722
3439	0.22	1.36	3103.714	0.006849283
2599	0.19	1.17	2653.003	0.007085554
1666	0.13	0.82	1864.26	0.009199656
1073	0.08	0.52	1188.195	0.014579486
479	0.04	0.23	512.1297	0.03505363

30% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
31977	2.58	5.68	21669.01	0.006551578
31196	2.54	5.59	21333.1	0.006594415
30675	2.51	5.54	21131.56	0.006608624
30068	2.49	5.49	20930.02	0.006603101
29286	2.45	5.40	20594.11	0.006643093
28332	2.40	5.29	20191.02	0.006685711
27030	2.34	5.17	19720.75	0.006686359
25728	2.29	5.05	19250.48	0.006679092
24253	2.23	4.92	18780.21	0.006615359
22431	2.15	4.75	18108.4	0.006580644
20608	2.06	4.55	17369.41	0.006571374
19133	1.98	4.38	16697.59	0.006601736
17310	1.89	4.17	15891.42	0.006594278
13665	1.70	3.74	14279.06	0.006447763
10628	1.50	3.30	12599.53	0.006440596
8458	1.35	2.99	11390.27	0.006271939
6462	1.22	2.69	10248.18	0.005919381
4466	1.06	2.33	8904.557	0.005418757
3512	0.96	2.12	8098.381	0.005150989
2644	0.86	1.89	7225.023	0.004872171
3066	0.87	1.91	7292.205	0.005546369
2167	0.78	1.72	6553.21	0.004854036
1751	0.70	1.54	5881.397	0.004870583
1387	0.66	1.45	5545.49	0.004337725
1327	0.64	1.42	5411.127	0.004360773
1005	0.60	1.31	5008.039	0.003854882
895	0.57	1.26	4806.495	0.003725851
734	0.52	1.14	4336.226	0.00375341
649	0.45	1.00	3798.775	0.004325245
437	0.31	0.68	2589.511	0.006266418
327	0.23	0.50	1917.697	0.008542003
216	0.15	0.33	1245.884	0.01340502
157	0.11	0.24	909.9773	0.01823137

30% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
45153	2.45	6.73	22993.21	0.005903461
43432	2.40	6.60	22543.17	0.005907429
42024	2.36	6.49	22168.13	0.005910934
40459	2.32	6.38	21793.09	0.005888412
38895	2.26	6.22	21268.04	0.005943642
37017	2.22	6.09	20817.99	0.005903944
35765	2.17	5.96	20367.95	0.005959174
33888	2.11	5.81	19842.89	0.005949101
35101	2.11	5.81	19842.89	0.006162106
33365	2.05	5.63	19242.83	0.006228405
30501	1.94	5.35	18267.73	0.006317868
27290	1.82	5.02	17142.62	0.00641912
24774	1.73	4.75	16242.53	0.006490869
23298	1.67	4.58	15642.47	0.006581641
20434	1.55	4.25	14517.35	0.006702055
18091	1.44	3.96	13542.25	0.006818789
15227	1.31	3.61	12342.13	0.006909796
12537	1.18	3.24	11067	0.007075491
9934	1.04	2.87	9791.875	0.007161325
7938	0.91	2.51	8591.753	0.007432616
6375	0.82	2.25	7691.662	0.007448829
5508	0.75	2.05	7016.593	0.007732635
4813	0.70	1.92	6566.548	0.007715935
4379	0.68	1.86	6341.525	0.007527399
4032	0.64	1.77	6041.494	0.007636207
3685	0.62	1.70	5816.472	0.007529229
3512	0.60	1.64	5591.449	0.007763693
3425	0.60	1.64	5591.449	0.007571821
3312	0.60	1.64	5591.449	0.00732184
3100	0.57	1.57	5366.426	0.00743987
1878	0.47	1.29	4391.327	0.006733386
946	0.37	1.02	3491.236	0.005362604
530	0.25	0.69	2366.122	0.006544515
411	0.19	0.52	1766.061	0.009116123
318	0.15	0.41	1391.023	0.011361959
233	0.11	0.30	1015.985	0.015619454
199	0.09	0.25	865.9696	0.018373043

35% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
80658	0.20	3.83	4804.679	0.009484383
72988	0.19	3.68	4608.93	0.009326931
65939	0.17	3.36	4217.432	0.010063207
57336	0.16	3.21	4021.683	0.009622747
55167	0.16	3.21	4021.683	0.00925867
45466	0.16	3.05	3825.934	0.008431388
32792	0.14	2.74	3434.436	0.007546595
34060	0.14	2.74	3434.436	0.007838209
21997	0.12	2.43	3042.937	0.00644848
19914	0.11	2.11	2651.439	0.007689146
17831	0.10	1.96	2455.69	0.008026297
15922	0.09	1.80	2259.941	0.008462194
14446	0.08	1.65	2064.192	0.009203357
12624	0.08	1.65	2064.192	0.008042314
11409	0.07	1.33	1672.694	0.011068768
10368	0.07	1.33	1672.694	0.010058405
10454	0.07	1.33	1672.694	0.010142601
8979	0.06	1.18	1476.945	0.011173394
8024	0.05	1.02	1281.196	0.013269836
7764	0.05	1.02	1281.196	0.01283929
5855	0.04	0.87	1085.446	0.013488915
4032	0.03	0.55	693.9482	0.022729027
3164	0.02	0.40	498.1991	0.034607789
1666	0.01	0.24	302.45	0.049451133
564	0.00	0.09	106.7009	0.134469519

35% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
155835	0.78	7.60	13487.29	0.007540093
154195	0.77	7.52	13349.02	0.007616094
150915	0.76	7.44	13210.75	0.007610931
148045	0.75	7.29	12934.22	0.007788855
141074	0.72	7.05	12519.42	0.007922122
138204	0.71	6.97	12381.15	0.007935261
133694	0.70	6.82	12104.62	0.008031046
127954	0.69	6.74	11966.35	0.007864884
123034	0.67	6.51	11551.55	0.00811533
118114	0.66	6.43	11413.28	0.007980706
112374	0.63	6.12	10860.21	0.008385898
97613	0.59	5.73	10168.88	0.008308539
89413	0.56	5.49	9754.074	0.00827162
85313	0.55	5.34	9477.539	0.0083596
78689	0.55	5.34	9477.539	0.007710536
73817	0.52	5.11	9062.738	0.007910435
63037	0.48	4.64	8233.134	0.008185152
51739	0.43	4.17	7403.531	0.008308026
48908	0.43	4.17	7403.531	0.007853528
42963	0.40	3.86	6850.462	0.008057713
35296	0.36	3.55	6297.393	0.007833643
31228	0.33	3.24	5744.324	0.008329627
32584	0.33	3.24	5744.324	0.008691443
28072	0.31	3.00	5329.523	0.008698625
24774	0.29	2.85	5052.988	0.008539961
21997	0.27	2.61	4638.186	0.008999549
19480	0.25	2.46	4361.652	0.0090125
15748	0.23	2.22	3946.85	0.008897935
14446	0.22	2.15	3808.583	0.008765835
13318	0.21	2.07	3670.316	0.008701602
10888	0.20	1.91	3393.781	0.008320516
10454	0.20	1.99	3532.049	0.007375689
10107	0.20	1.99	3532.049	0.007130778
8805	0.19	1.83	3255.514	0.007312581
7764	0.19	1.83	3255.514	0.006447723
5247	0.16	1.60	2840.713	0.005723173
4379	0.15	1.44	2564.178	0.005862438
3772	0.12	1.21	2149.376	0.007186148
3346	0.12	1.13	2011.109	0.007280578
2701	0.10	0.98	1734.575	0.007901592
2167	0.08	0.82	1458.04	0.008971074
1709	0.07	0.67	1181.506	0.010774515
1582	0.06	0.59	1043.239	0.012791063
988	0.04	0.35	628.437	0.022019289
564	0.02	0.20	351.9026	0.040085662

35% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
116064	1.24	7.70	17150.98	0.007249336
115654	1.24	7.70	17150.98	0.007223727
112374	1.22	7.56	16820.19	0.007297638
109094	1.19	7.41	16489.4	0.007371725
104583	1.16	7.21	16048.35	0.007460744
98843	1.13	7.01	15607.29	0.007455417
91463	1.07	6.66	14835.44	0.007635273
83263	1.02	6.32	14063.6	0.007734609
78171	1.02	6.32	14063.6	0.007261578
73195	0.98	6.07	13512.28	0.007365554
68427	0.94	5.82	12960.96	0.007483993
64695	0.91	5.62	12519.91	0.007583183
61895	0.91	5.67	12630.17	0.007128752
57514	0.87	5.43	12078.85	0.00724267
51881	0.82	5.08	11307	0.007455763
45622	0.76	4.73	10535.16	0.007552237
37017	0.68	4.24	9432.521	0.007644071
31697	0.62	3.84	8550.411	0.007965752
33365	0.63	3.89	8660.675	0.008172816
26596	0.55	3.40	7558.038	0.008554223
19306	0.46	2.85	6345.137	0.008810416
15054	0.40	2.45	5463.027	0.009267459
13492	0.37	2.31	5132.235	0.009410969
11496	0.34	2.11	4691.181	0.009597335
10975	0.33	2.06	4580.917	0.009609018
10107	0.32	2.01	4470.653	0.009291083
8458	0.29	1.81	4029.598	0.009570541
7938	0.28	1.76	3919.334	0.00949382
7677	0.28	1.71	3809.071	0.009721734
6549	0.26	1.61	3588.543	0.009343675
5594	0.24	1.51	3368.016	0.009061126
3425	0.23	1.41	3147.488	0.006351571
2904	0.21	1.31	2926.961	0.006228021
2896	0.22	1.36	3037.225	0.005768273
1480	0.13	0.82	1824.323	0.00816969
1039	0.10	0.62	1383.268	0.009975651
479	0.04	0.27	611.4224	0.023550535
225	0.02	0.13	280.6311	0.052437799

35% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
32584	2.58	5.70	21270.55	0.00663484
31890	2.55	5.63	21007.58	0.006657056
31109	2.52	5.56	20744.61	0.006659696
29373	2.44	5.38	20087.19	0.006706462
28332	2.38	5.26	19627	0.006775588
25902	2.26	4.99	18640.86	0.006867191
24253	2.18	4.80	17917.7	0.006959539
23212	2.12	4.68	17457.51	0.007016492
21649	2.05	4.52	16865.83	0.00701151

19653	1.96	4.32	16142.66	0.006948124
17571	1.85	4.08	15222.27	0.006985658
13318	1.60	3.53	13184.27	0.007058498
11582	1.47	3.25	12132.39	0.007249174
8892	1.30	2.86	10686.06	0.007173843
6202	1.09	2.40	8976.768	0.007090246
4727	0.95	2.09	7793.409	0.007169129
4032	0.87	1.91	7135.988	0.007294888
2964	0.78	1.72	6412.824	0.006639836
2362	0.71	1.58	5886.887	0.006278616
1878	0.65	1.44	5360.95	0.006021463
1709	0.63	1.38	5163.723	0.005904209
1471	0.60	1.33	4966.497	0.005495575
1327	0.58	1.28	4769.27	0.005375583
1030	0.55	1.21	4506.302	0.004674704
759	0.51	1.12	4177.591	0.004006773
649	0.46	1.01	3783.138	0.004176225
564	0.41	0.91	3388.685	0.004524698
437	0.30	0.66	2468.295	0.006604671
318	0.22	0.49	1810.873	0.008935234
208	0.14	0.31	1153.452	0.014389407
148	0.10	0.22	824.7412	0.02010515
127	0.08	0.19	693.2569	0.024390702

35% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
46718	2.45	6.73	22500.64	0.006108026
44214	2.38	6.53	21840.04	0.006135716
41867	2.30	6.33	21179.43	0.006178118
39364	2.23	6.14	20518.82	0.006188751
37486	2.18	5.98	20005.02	0.00620019
35139	2.10	5.76	19271.01	0.006263185
33105	2.02	5.57	18610.4	0.006326986
33886	2.02	5.57	18610.4	0.006476185
31196	1.93	5.30	17729.59	0.006569125
29113	1.86	5.10	17068.99	0.006614241
24513	1.69	4.64	15527.57	0.006729849
22344	1.60	4.40	14720.16	0.006825593
20001	1.51	4.16	13912.75	0.006839522
17223	1.39	3.81	12738.34	0.007025941
14446	1.27	3.48	11637.33	0.007060926
12450	1.17	3.22	10756.52	0.007122736
10628	1.07	2.95	9875.712	0.007213044
8892	0.99	2.71	9068.303	0.007157566
8024	0.94	2.58	8627.899	0.007135234
8024	0.92	2.54	8481.097	0.007384383
6809	0.86	2.36	7893.891	0.00723324
5594	0.78	2.14	7159.884	0.007223516
4900	0.73	2.01	6719.479	0.007183608
4553	0.70	1.92	6425.876	0.007298578
4032	0.68	1.86	6205.674	0.006930731
3685	0.63	1.72	5765.269	0.007338732
3251	0.60	1.66	5545.067	0.006999038
3405	0.60	1.66	5545.067	0.007330106
2175	0.49	1.35	4517.456	0.007055702
946	0.40	1.09	3636.647	0.004732844
734	0.33	0.91	3049.441	0.005221916
479	0.22	0.60	2021.831	0.007759327
225	0.09	0.25	847.4184	0.020718133

40% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
150095	0.26	5.08	5548.19	0.010038816
148455	0.25	4.92	5377.713	0.010568622
144764	0.25	4.92	5377.713	0.010305921
139024	0.24	4.77	5207.236	0.010555926
133284	0.24	4.61	5036.759	0.010816738
125494	0.24	4.61	5036.759	0.010184521
119754	0.23	4.46	4866.282	0.010411539
105813	0.21	4.14	4525.328	0.010638023
96383	0.20	3.99	4354.851	0.010463452
90643	0.20	3.83	4184.374	0.010658444
71329	0.18	3.52	3843.42	0.009941531
63763	0.16	3.21	3502.466	0.010701339
61582	0.16	3.21	3502.466	0.010335301
47500	0.16	3.05	3331.989	0.008808584
37173	0.15	2.90	3161.512	0.007657074
29037	0.14	2.74	2991.035	0.006682425
30068	0.14	2.74	2991.035	0.006919504
26336	0.12	2.43	2650.081	0.007720556
22344	0.11	2.11	2309.127	0.008627407
17744	0.09	1.80	1968.173	0.009430816
14360	0.08	1.49	1627.219	0.011165288
12711	0.07	1.33	1456.741	0.012331721
10194	0.06	1.18	1286.264	0.012685313
9847	0.05	1.02	1115.787	0.016283657
9500	0.05	1.02	1115.787	0.015709596
8892	0.05	1.02	1115.787	0.014704989
7677	0.05	1.02	1115.787	0.012695774
6549	0.04	0.87	945.3104	0.015088481
5074	0.04	0.71	774.8334	0.01739901
2644	0.02	0.40	433.8794	0.028913043

40% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
160345	0.76	7.44	11505.19	0.008086517
159525	0.75	7.36	11384.77	0.008216249
157065	0.75	7.36	11384.77	0.008089544
152555	0.74	7.21	11143.94	0.00820053
145585	0.71	6.97	10782.69	0.008359008
140664	0.70	6.82	10541.86	0.008449747
130414	0.68	6.59	10180.61	0.008399839
122214	0.65	6.35	9819.359	0.008461515
113604	0.63	6.12	9458.11	0.008477689
105403	0.60	5.81	8976.444	0.008732528
91053	0.55	5.34	8253.947	0.008922062
79163	0.51	4.95	7651.865	0.009025688
73817	0.51	4.95	7651.865	0.008416213
66354	0.48	4.64	7170.2	0.008615852
60549	0.45	4.40	6808.951	0.008718508
57670	0.46	4.48	6929.367	0.008017829
45466	0.40	3.94	6086.453	0.008193158
37956	0.36	3.55	5484.372	0.00842398
33575	0.35	3.39	5243.539	0.008151881
34927	0.34	3.31	5123.123	0.008883646
28419	0.31	3.00	4641.457	0.008806194
24340	0.28	2.77	4280.208	0.008869118
21042	0.26	2.53	3918.96	0.009146156
17050	0.24	2.30	3557.711	0.00899237
14446	0.23	2.22	3437.294	0.008162418
12884	0.22	2.15	3316.878	0.007817966
9066	0.21	2.07	3196.462	0.00592322
8285	0.21	2.07	3196.462	0.005412904
7677	0.20	1.99	3076.045	0.005416396
4900	0.15	1.44	2233.131	0.006559478
3685	0.12	1.13	1751.466	0.008019379
3600	0.11	1.06	1631.05	0.009033692
2684	0.08	0.74	1149.384	0.013563333
1836	0.05	0.51	788.1356	0.019732495

1073	0.03	0.28	426.8867	0.039300414
479	0.01	0.12	186.0541	0.092410058

40% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
119344	1.24	7.70	14936.71	0.00745421
115654	1.23	7.61	14744.66	0.007413138
112374	1.20	7.46	14456.57	0.007492825
110324	1.19	7.36	14264.52	0.00755555
102943	1.15	7.11	13784.38	0.007549812
98023	1.11	6.91	13400.26	0.007607017
91053	1.07	6.62	12824.09	0.007715307
82443	1.00	6.22	12055.87	0.007904383
76305	0.99	6.17	11959.84	0.007433848
69775	0.95	5.87	11383.67	0.007503167
65214	0.91	5.62	10903.53	0.007643932
62990	0.91	5.67	10999.56	0.007254897
53602	0.83	5.18	10039.28	0.00741119
48282	0.79	4.88	9463.107	0.00751332
39207	0.70	4.34	8406.797	0.007730703
33418	0.64	3.99	7734.599	0.007784318
34754	0.64	3.99	7734.599	0.008095423
29981	0.60	3.69	7158.43	0.008153024
23646	0.52	3.25	6294.177	0.008317301
19914	0.48	2.95	5718.007	0.008487425
17137	0.44	2.70	5237.866	0.008704213
14360	0.40	2.45	4757.725	0.00884005
11756	0.36	2.26	4373.613	0.008564313
9586	0.32	2.01	3893.472	0.00881242
7764	0.29	1.81	3509.359	0.008784967
7070	0.29	1.81	3509.359	0.007999393
6462	0.28	1.76	3413.331	0.007729224
4119	0.25	1.56	3029.218	0.006255266
3598	0.24	1.51	2933.19	0.005828165
2817	0.20	1.27	2453.049	0.006524201
3083	0.21	1.31	2549.077	0.006611183
2192	0.16	0.97	1876.88	0.008672221
1760	0.13	0.82	1588.795	0.009714639
1302	0.10	0.62	1204.682	0.012500018
903	0.07	0.42	820.5696	0.018692664
479	0.04	0.23	436.4568	0.03505363

40% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
33712	2.58	5.70	18524.43	0.006864564
32324	2.54	5.59	18180.9	0.006832903
29981	2.43	5.36	17436.59	0.006890191
27551	2.31	5.10	16577.77	0.007004765
25989	2.24	4.94	16062.48	0.007038348
23298	2.11	4.66	15146.41	0.00709607
19740	1.95	4.31	14001.32	0.007035998
16269	1.74	3.85	12512.7	0.007260495
12364	1.51	3.34	10852.32	0.007335161
9760	1.35	2.99	9707.227	0.00723722
8285	1.25	2.76	8962.918	0.007205906
6896	1.14	2.51	8161.354	0.007234237
5594	1.03	2.28	7417.045	0.0071056
4640	0.95	2.09	6787.245	0.007037495
3598	0.84	1.86	6042.936	0.006885195
3251	0.82	1.81	5871.173	0.006590286
3413	0.82	1.81	5871.173	0.00691921
2693	0.75	1.65	5355.882	0.006558783
1692	0.64	1.40	4554.318	0.005699555
1488	0.60	1.31	4268.045	0.005709066
1259	0.57	1.26	4096.282	0.005244386
886	0.52	1.15	3752.754	0.004397125
903	0.50	1.10	3580.991	0.00492148
818	0.46	1.01	3294.718	0.005267991
649	0.38	0.84	2722.173	0.006117713
394	0.22	0.49	1577.082	0.011079457
293	0.16	0.36	1176.3	0.014776451
165	0.09	0.20	661.0089	0.026451265

40% vol. water-in-EDM 244 oil emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
47656	2.44	6.71	19531.78	0.006271616
46092	2.40	6.60	19212.16	0.006269212
43588	2.33	6.40	18636.84	0.006300398
40772	2.25	6.18	17997.6	0.006319393
37643	2.15	5.92	17230.51	0.006365431
35296	2.08	5.72	16655.19	0.006388026
33575	2.02	5.57	16207.72	0.006416694
35014	2.02	5.57	16207.72	0.006691801
32584	1.94	5.32	15504.55	0.006805059
30415	1.86	5.13	14929.23	0.006850944
28332	1.78	4.91	14289.98	0.006965518
25815	1.70	4.67	13586.82	0.007020701
23212	1.59	4.38	12755.8	0.00716195
18699	1.42	3.90	11349.46	0.007287943
14446	1.23	3.37	9815.277	0.007528273
10888	1.04	2.87	8345.016	0.007849536
9413	0.97	2.67	7769.696	0.007828095
7070	0.83	2.27	6619.057	0.008101222
5855	0.75	2.05	5979.813	0.008220016
5247	0.71	1.94	5660.191	0.008222608
3598	0.59	1.61	4701.325	0.008173381
3164	0.56	1.53	4445.628	0.008038364
3261	0.56	1.53	4445.628	0.00828325
2430	0.50	1.37	3998.157	0.007630924
1302	0.43	1.18	3422.837	0.005578447
784	0.31	0.85	2463.971	0.006487173
318	0.12	0.34	993.7104	0.016170544
131	0.04	0.12	354.4665	0.052536499
564	0.22	0.60	1760.803	0.009132561
471	0.16	0.45	1313.332	0.013700659
259	0.09	0.25	738.0129	0.023844918

55% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
151325	0.26	4.86	4646.609	0.010585237
150505	0.27	5.01	4789.384	0.009909546
149275	0.26	4.86	4646.609	0.010441834
144764	0.25	4.71	4503.835	0.01077855
137794	0.24	4.56	4361.06	0.010942342
131644	0.24	4.56	4361.06	0.010453954
125084	0.24	4.41	4218.286	0.010616782
115654	0.23	4.26	4075.511	0.010516196
107864	0.21	3.96	3789.962	0.011341437
95973	0.20	3.81	3647.188	0.010896753
88183	0.19	3.51	3361.639	0.01178545
57670	0.17	3.22	3076.09	0.009204821
40459	0.17	3.22	3076.09	0.006457758
33262	0.16	2.92	2790.541	0.006451086
35275	0.16	2.92	2790.541	0.006841456
29286	0.13	2.47	2362.217	0.007926669
26075	0.12	2.32	2219.443	0.007994795
19914	0.09	1.72	1648.344	0.011069315
16269	0.08	1.42	1362.795	0.013229949

15314	0.08	1.42	1362.795	0.012453639
13231	0.07	1.28	1220.021	0.013425602
12450	0.06	1.13	1077.246	0.016203679
11843	0.05	0.98	934.472	0.020482653
11496	0.05	0.98	934.472	0.019882266
11149	0.05	0.98	934.472	0.019281878
10715	0.05	0.98	934.472	0.018531394
10194	0.04	0.83	791.6975	0.02456328
9153	0.04	0.83	791.6975	0.022053897
7504	0.04	0.68	648.923	0.026912101
5768	0.03	0.53	506.1485	0.034003801
3251	0.02	0.38	363.374	0.037187551

55% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
158295	0.78	7.26	9837.291	0.00801037
157885	0.78	7.26	9837.291	0.007989622
157065	0.76	7.12	9635.594	0.008284357
154605	0.76	7.12	9635.594	0.008154601
152145	0.75	7.04	9534.745	0.0081955
146815	0.74	6.89	9333.048	0.008253896
138614	0.71	6.67	9030.502	0.008323793
134514	0.70	6.52	8828.805	0.008450868
129594	0.68	6.37	8627.107	0.008526911
124264	0.68	6.30	8526.259	0.008370764
117294	0.64	6.00	8122.864	0.008705496
108684	0.62	5.78	7820.318	0.008702658
93923	0.57	5.33	7215.226	0.008835066
82443	0.52	4.88	6610.134	0.009239949
77652	0.52	4.88	6610.134	0.008703052
64592	0.48	4.43	6005.042	0.008771672
61895	0.48	4.51	6105.891	0.008130009
45779	0.41	3.84	5198.253	0.00829635
35139	0.36	3.32	4492.312	0.008526902
30133	0.32	3.02	4088.918	0.008825851
31456	0.32	3.02	4088.918	0.009213504
25555	0.29	2.72	3685.523	0.009213196
21476	0.27	2.50	3382.977	0.009189459
18265	0.26	2.42	3282.129	0.00830314
15575	0.24	2.27	3080.431	0.00803766
12797	0.24	2.20	2979.583	0.007059109
11235	0.24	2.20	2979.583	0.006197441
10281	0.23	2.13	2878.734	0.006075153
9673	0.22	2.05	2777.885	0.006138746
9066	0.21	1.98	2677.037	0.006194858
8371	0.20	1.83	2475.339	0.006690656
6983	0.16	1.53	2071.945	0.007965577
5594	0.13	1.23	1668.55	0.009840318
4119	0.10	0.93	1265.155	0.012602136
2123	0.06	0.56	760.9122	0.017956273
2175	0.06	0.56	760.9122	0.018398657
1353	0.04	0.34	458.3662	0.031528803
818	0.02	0.19	256.6689	0.060835909
479	0.01	0.12	155.8203	0.096647977

55% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
120164	1.23	7.32	12429.07	0.007951539
119344	1.23	7.27	12348.65	0.008000477
118524	1.23	7.27	12348.65	0.007945505
111964	1.19	7.04	11946.53	0.008019517
109094	1.17	6.94	11785.69	0.008028685
102533	1.13	6.70	11383.57	0.008088417
94333	1.07	6.37	10820.6	0.008236005
84493	0.98	5.80	9855.519	0.008892347
78482	1.01	5.99	10177.21	0.007745788
71018	0.95	5.61	9533.824	0.007987154
63659	0.89	5.28	8970.859	0.008086232
65806	0.93	5.52	9372.977	0.007657128
51255	0.79	4.71	8005.776	0.008174944
45466	0.75	4.43	7523.234	0.008211678
39833	0.69	4.10	6960.269	0.008405218
34514	0.64	3.81	6477.727	0.008408126
28099	0.58	3.44	5834.338	0.008438321
29807	0.59	3.48	5914.762	0.008709664
24253	0.52	3.10	5271.373	0.008922216
21997	0.50	2.96	5030.102	0.008887034
18699	0.46	2.73	4627.984	0.008924519
16356	0.43	2.54	4306.29	0.009016032
14273	0.40	2.35	3984.595	0.009189578
13231	0.39	2.30	3904.171	0.008873652
12277	0.37	2.20	3743.324	0.008956197
10368	0.35	2.06	3502.053	0.008641387
8719	0.34	2.02	3421.63	0.007612645
7417	0.33	1.97	3341.206	0.00679152
6723	0.32	1.92	3260.783	0.006463175
6028	0.32	1.92	3260.783	0.005795689
5681	0.31	1.83	3099.935	0.006043462
5334	0.30	1.78	3019.512	0.005980471
4293	0.27	1.59	2697.817	0.006029069
3512	0.23	1.35	2295.699	0.006811185
2730	0.19	1.12	1893.581	0.007784423
2769	0.19	1.12	1893.581	0.007894047
2175	0.15	0.88	1491.463	0.009996505
1751	0.12	0.69	1169.769	0.013083008
1158	0.08	0.45	767.6506	0.020081556
564	0.04	0.22	365.5326	0.043149427
310	0.02	0.12	204.6853	0.075534737

55% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
34927	2.59	5.46	15562.16	0.007392347
33626	2.55	5.38	15322.4	0.00734129
33018	2.52	5.31	15130.6	0.00739258
31543	2.48	5.23	14890.85	0.007291507
29894	2.42	5.09	14507.24	0.007280627
28419	2.36	4.98	14171.59	0.007253058
27377	2.32	4.89	13931.84	0.007229825
26509	2.28	4.81	13692.08	0.007247957
25815	2.24	4.72	13452.33	0.007311963
24079	2.15	4.54	12924.87	0.00738837
22431	2.07	4.37	12445.36	0.007422994
20782	1.98	4.18	11917.91	0.007499536
19653	1.93	4.07	11582.25	0.007509433
17484	1.80	3.80	10815.04	0.007661871
15835	1.70	3.60	10239.63	0.007741086
14273	1.61	3.39	9664.224	0.007833034
12364	1.49	3.14	8944.964	0.007920282
9153	1.31	2.75	7842.099	0.007628359
7504	1.16	2.45	6978.986	0.007896617
6549	1.08	2.28	6499.479	0.007946434
5421	0.99	2.08	5924.071	0.007917307
4553	0.92	1.95	5540.466	0.007602485
3945	0.85	1.79	5108.91	0.007748122
3338	0.79	1.66	4725.304	0.007662636
3201	0.79	1.68	4773.255	0.007202304
2862	0.75	1.59	4533.502	0.00713823
2353	0.71	1.49	4245.797	0.006691598
2116	0.68	1.42	4053.995	0.006599185

2065	0.66	1.39	3958.093	0.006756367
1700	0.63	1.32	3766.291	0.006144331
1480	0.60	1.27	3622.439	0.005780728
1344	0.58	1.22	3478.587	0.005693953
1013	0.56	1.17	3334.734	0.004671316
988	0.51	1.07	3047.03	0.005454646
903	0.47	0.99	2807.277	0.005874552
734	0.40	0.83	2375.721	0.006662309
420	0.23	0.48	1368.757	0.011485966
259	0.13	0.28	793.3484	0.021067303
191	0.10	0.21	601.5456	0.027033538

55% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
48908	2.45	6.43	16411.41	0.006687664
48595	2.43	6.39	16304.33	0.006732437
47343	2.41	6.33	16143.72	0.006690183
46248	2.38	6.24	15929.58	0.006712309
44684	2.34	6.14	15661.89	0.006708802
42650	2.27	5.97	15233.6	0.006768541
39990	2.20	5.78	14751.77	0.006767768
37486	2.13	5.59	14269.94	0.006779753
35296	2.06	5.41	13788.11	0.006837533
31854	1.94	5.11	13038.6	0.00690054
33018	1.94	5.09	12985.06	0.007211917
28158	1.77	4.65	11860.79	0.007371641
25121	1.66	4.36	11111.27	0.007493614
21042	1.51	3.96	10094.08	0.007605682
16269	1.29	3.39	8648.588	0.008010343
14012	1.19	3.14	8006.147	0.008051036
11322	1.07	2.80	7149.561	0.008157451
7677	0.87	2.28	5811.144	0.008372671
5855	0.77	2.03	5168.703	0.008071008
4900	0.69	1.82	4633.337	0.008406233
4293	0.65	1.71	4365.653	0.008294821
3859	0.61	1.61	4097.97	0.008462255
3685	0.60	1.59	4044.433	0.008296982
3598	0.59	1.54	3937.36	0.008548212
3078	0.56	1.46	3723.213	0.008176439
2989	0.56	1.48	3776.75	0.00771857
1980	0.50	1.31	3348.456	0.006504506
996	0.37	0.98	2491.87	0.005910326
572	0.20	0.52	1314.063	0.012209755
428	0.14	0.37	939.3059	0.017878103
225	0.08	0.22	564.5491	0.025972766
165	0.05	0.14	350.4024	0.049613535

50% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
153375	0.26	4.79	3773.896	0.010885
151735	0.26	4.79	3773.896	0.010769
148865	0.26	4.79	3773.896	0.010565
145995	0.25	4.64	3657.937	0.011029
135744	0.25	4.64	3657.937	0.010255
130004	0.24	4.49	3541.978	0.010475
123444	0.23	4.20	3310.06	0.011389
116474	0.23	4.20	3310.06	0.010746
99253	0.21	3.91	3078.142	0.010589
91873	0.20	3.76	2962.183	0.010584
89003	0.20	3.76	2962.183	0.010253
77523	0.20	3.76	2962.183	0.008931
71951	0.20	3.61	2846.224	0.008978
67391	0.20	3.61	2846.224	0.008409
64592	0.20	3.61	2846.224	0.00806
60799	0.20	3.76	2962.183	0.007004
54228	0.20	3.76	2962.183	0.006247
39677	0.16	2.88	2266.429	0.007808
34201	0.14	2.58	2034.511	0.008352
36142	0.14	2.58	2034.511	0.008826
31369	0.12	2.29	1802.593	0.009758
25728	0.11	1.99	1570.675	0.010542
22083	0.08	1.55	1222.798	0.014929
19220	0.08	1.40	1106.839	0.015858
17050	0.07	1.26	990.88	0.017553
15575	0.06	1.11	874.921	0.020566
14186	0.05	0.96	758.962	0.024894
12624	0.04	0.82	643.003	0.030863
5421	0.03	0.52	411.0851	0.032424

50% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
161165	0.77	7.09	7907.771	0.008447
160755	0.76	7.01	7825.863	0.008603
159525	0.76	7.01	7825.863	0.008537
157065	0.75	6.87	7662.048	0.008769
154195	0.75	6.87	7662.048	0.008608
149275	0.73	6.72	7498.233	0.008702
143944	0.71	6.57	7334.418	0.00877
134514	0.68	6.28	7006.788	0.00898
126314	0.67	6.13	6842.973	0.008841
118114	0.64	5.84	6515.342	0.00912
107864	0.60	5.55	6187.712	0.009233
98843	0.58	5.32	5941.99	0.009176
86133	0.53	4.88	5450.544	0.009502
80555	0.53	4.88	5450.544	0.008887
72573	0.50	4.59	5122.914	0.009063
65421	0.48	4.37	4877.192	0.009014
63146	0.48	4.37	4877.192	0.008701
59391	0.45	4.15	4631.469	0.009075
49690	0.41	3.78	4221.931	0.009137
38425	0.36	3.34	3730.486	0.00905
28412	0.31	2.83	3157.133	0.009342
29807	0.31	2.83	3157.133	0.009801
24253	0.28	2.61	2911.411	0.009378
20261	0.27	2.46	2747.596	0.008796
15314	0.25	2.32	2583.781	0.007518
12624	0.24	2.24	2501.873	0.00661
11062	0.23	2.10	2338.058	0.006632
10368	0.22	2.02	2256.151	0.006676
9934	0.21	1.95	2174.243	0.006887
9760	0.20	1.88	2092.335	0.007307
8024	0.17	1.58	1764.705	0.008445
7417	0.16	1.51	1682.798	0.008584
6375	0.15	1.36	1518.983	0.009056
5160	0.12	1.07	1191.353	0.011917
4119	0.10	0.92	1027.537	0.012786
2557	0.07	0.63	699.9073	0.017107
2676	0.07	0.63	699.9073	0.017902
2515	0.06	0.55	617.9998	0.021579
1760	0.04	0.41	454.1847	0.02796
1548	0.04	0.33	372.2771	0.036602
1005	0.02	0.19	208.4621	0.075797
479	0.01	0.11	126.5545	0.098061

50% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
121804	1.23	7.21	10094.68	0.008178
120164	1.22	7.12	9964.042	0.008281

118934	1.21	7.07	9898.724	0.008304
116474	1.19	6.98	9768.086	0.008352
111964	1.17	6.84	9572.13	0.00836
109094	1.15	6.70	9376.174	0.00849
102943	1.11	6.51	9114.9	0.008477
96793	1.07	6.28	8788.306	0.008574
89003	1.03	6.00	8396.394	0.008637
80803	0.97	5.67	7939.164	0.008771
75372	0.97	5.67	7939.164	0.008181
68012	0.91	5.30	7416.614	0.008459
63452	0.87	5.07	7090.021	0.008636
58139	0.87	5.07	7090.021	0.007913
54854	0.83	4.83	6763.428	0.008204
47343	0.75	4.37	6110.241	0.008676
39207	0.68	3.99	5587.691	0.008591
32949	0.62	3.62	5065.142	0.008787
34407	0.62	3.62	5065.142	0.009175
30415	0.57	3.34	4673.23	0.009528
27638	0.54	3.15	4411.955	0.009714
23993	0.50	2.92	4085.362	0.009835
20521	0.46	2.69	3758.769	0.009938
17223	0.41	2.41	3366.857	0.010395
14099	0.38	2.22	3105.582	0.010002
12364	0.36	2.13	2974.945	0.009558
10801	0.36	2.08	2909.626	0.008729
9066	0.35	2.03	2844.307	0.007667
7677	0.33	1.94	2713.67	0.007133
7156	0.32	1.89	2648.351	0.006981
6896	0.32	1.85	2583.033	0.007071
2939	0.14	0.82	1146.022	0.015308
2608	0.12	0.73	1015.385	0.017305
1870	0.08	0.49	688.7913	0.026967
1183	0.05	0.31	427.5166	0.044286
556	0.03	0.17	231.5606	0.070881
30	0.00	0.03	35.60457	0.16038

50% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
34494	2.60	5.40	12678.26	0.007362
34407	2.59	5.39	12639.32	0.007389
33973	2.58	5.35	12561.43	0.007386
33192	2.54	5.29	12405.65	0.007399
32324	2.51	5.22	12249.87	0.00739
31456	2.48	5.15	12094.09	0.007378
30241	2.42	5.02	11782.53	0.007473
28939	2.36	4.90	11509.92	0.007494
27724	2.31	4.80	11276.25	0.00748
26770	2.26	4.71	11042.58	0.007531
25728	2.22	4.61	10808.91	0.007555
24687	2.16	4.49	10536.3	0.007629
23212	2.10	4.37	10263.69	0.007559
21910	2.02	4.21	9874.242	0.007709
21129	1.98	4.12	9679.518	0.007736
19567	1.91	3.98	9329.016	0.007713
18265	1.84	3.83	8978.513	0.007773
16529	1.74	3.63	8511.176	0.007828
14012	1.60	3.33	7810.172	0.007881
12884	1.52	3.16	7420.724	0.008027
10541	1.38	2.86	6719.72	0.008008
9066	1.29	2.68	6291.328	0.007857
8111	1.23	2.55	5979.77	0.007782
5855	1.05	2.18	5122.986	0.007653
4987	0.97	2.02	4733.539	0.007635
4119	0.89	1.85	4344.092	0.007488
3425	0.82	1.70	3993.589	0.007367
3481	0.82	1.70	3993.589	0.007488
2794	0.75	1.55	3643.087	0.007223
2472	0.70	1.45	3409.419	0.007296
2141	0.66	1.37	3214.695	0.007108
1845	0.64	1.32	3097.861	0.006594
1777	0.61	1.27	2981.027	0.006859
1175	0.56	1.17	2747.359	0.005339
1073	0.52	1.07	2513.69	0.005825
903	0.38	0.79	1851.63	0.009037
818	0.33	0.69	1617.962	0.010725
564	0.24	0.49	1150.625	0.014614

50% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
49378	2.44	6.32	13285.58	0.006895
47656	2.39	6.20	13024.69	0.006924
46092	2.35	6.09	12807.28	0.006926
43588	2.27	5.89	12372.47	0.007019
42024	2.22	5.76	12111.58	0.007061
38582	2.12	5.49	11546.32	0.007133
35452	2.02	5.24	11024.54	0.00719
32167	1.92	4.98	10459.28	0.007248
33712	1.92	4.98	10459.28	0.007596
30675	1.82	4.73	9937.499	0.007656
27551	1.71	4.44	9328.757	0.007803
25381	1.63	4.23	8893.941	0.007909
22257	1.52	3.94	8285.199	0.007992
19567	1.42	3.67	7719.939	0.008093
15922	1.26	3.26	6850.307	0.008363
13665	1.15	2.97	6241.565	0.008646
11235	1.03	2.68	5632.823	0.008728
10020	0.97	2.51	5284.971	0.008843
8024	0.87	2.27	4763.192	0.008718
6289	0.81	2.10	4415.34	0.007951
5681	0.72	1.87	3937.042	0.009034
4900	0.68	1.75	3676.153	0.008937
4119	0.64	1.65	3458.745	0.008487
3598	0.60	1.56	3284.819	0.00822
3164	0.59	1.52	3197.856	0.007627
3125	0.59	1.52	3197.856	0.007533
2616	0.55	1.42	2980.448	0.00726
2294	0.52	1.36	2850.003	0.006961
2074	0.48	1.23	2589.114	0.007624
1633	0.39	1.00	2110.817	0.009031
1319	0.33	0.86	1806.446	0.009961
1098	0.28	0.71	1502.075	0.011998
963	0.24	0.61	1284.667	0.014376
818	0.20	0.51	1067.259	0.01771
547	0.13	0.34	719.4064	0.026053
343	0.09	0.24	501.9986	0.033598
233	0.07	0.18	371.5539	0.041646
98	0.04	0.09	197.6276	0.061571

45% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
152965	0.26	4.72	3019.49	0.011012747
152555	0.26	4.72	3019.49	0.010983228
143534	0.25	4.57	2926.711	0.010999375
139024	0.24	4.43	2833.933	0.011362749
134104	0.24	4.28	2741.154	0.011715132
126314	0.24	4.28	2741.154	0.011034592
114014	0.23	4.14	2648.375	0.010670127
102533	0.23	4.14	2648.375	0.009595728
92693	0.23	4.14	2648.375	0.008674815

79573	0.22	3.99	2555.597	0.007997454
74335	0.21	3.85	2462.818	0.008044575
66976	0.21	3.85	2462.818	0.007248125
63866	0.20	3.70	2370.039	0.007463317
60956	0.20	3.70	2370.039	0.0071232
58609	0.19	3.41	2184.482	0.008061903
45466	0.16	2.83	1813.367	0.009075827
36860	0.13	2.40	1535.031	0.010268292
30133	0.12	2.25	1442.253	0.009508793
32237	0.11	1.96	1256.695	0.01339887
23212	0.08	1.38	885.5808	0.019427638
18612	0.06	1.09	700.0234	0.024931006
17223	0.06	1.09	700.0234	0.023071029
14967	0.05	0.95	607.2448	0.026642863
13405	0.04	0.80	514.4661	0.033244777
12537	0.04	0.80	514.4661	0.031092494
12016	0.04	0.80	514.4661	0.029801125
11409	0.04	0.66	421.6874	0.042114791
9326	0.03	0.51	328.9087	0.056587486
6896	0.02	0.37	236.1301	0.081184743
4032	0.01	0.22	143.3514	0.128799699

45% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
159935	0.75	6.84	6195.931	0.008866974
155835	0.74	6.70	6064.863	0.00901712
152555	0.73	6.62	5999.329	0.009021228
148045	0.71	6.48	5868.26	0.009149959
143124	0.71	6.41	5802.726	0.009046802
136974	0.69	6.26	5671.658	0.009062842
130824	0.67	6.05	5475.056	0.009288728
125904	0.65	5.90	5343.987	0.009383269
121394	0.64	5.76	5212.919	0.009507806
114014	0.61	5.54	5016.317	0.009643454
107454	0.60	5.39	4885.248	0.009582809
95973	0.56	5.03	4557.578	0.009833937
80393	0.50	4.53	4098.839	0.010184534
75268	0.50	4.53	4098.839	0.009535344
67909	0.48	4.31	3902.236	0.009491711
62104	0.45	4.09	3705.634	0.009625885
60017	0.45	4.09	3705.634	0.009302389
49690	0.41	3.73	3377.963	0.009268477
44684	0.39	3.51	3181.361	0.009396541
36391	0.36	3.22	2919.224	0.009088783
28412	0.34	3.08	2788.156	0.007778673
30675	0.33	3.01	2722.622	0.008807564
23732	0.32	2.86	2591.553	0.00752081
18005	0.29	2.64	2394.951	0.006680881
15835	0.26	2.35	2132.814	0.007408921
14186	0.23	2.07	1870.678	0.008627951
12884	0.21	1.92	1739.61	0.009061515
12190	0.20	1.85	1674.075	0.009257592
11496	0.19	1.70	1543.007	0.010276491
10281	0.17	1.56	1411.939	0.010975821
10020	0.17	1.56	1411.939	0.010697865
9413	0.16	1.41	1280.871	0.012211166
8719	0.15	1.34	1215.337	0.012563165
7938	0.13	1.20	1084.268	0.014370038
7070	0.12	1.05	953.2	0.016560683
5855	0.09	0.84	756.5975	0.021768149
3945	0.07	0.62	559.9951	0.026777798
2557	0.04	0.40	363.3927	0.041210614
2591	0.04	0.33	297.8586	0.062153601
1658	0.03	0.26	232.3244	0.065378586
895	0.01	0.11	101.2562	0.185735892

45% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
120984	1.23	7.07	8024.482	0.008347511
119344	1.21	6.97	7919.959	0.008453131
117704	1.19	6.88	7815.436	0.008561453
115654	1.19	6.84	7763.175	0.008525982
113604	1.17	6.74	7658.652	0.008605007
111144	1.15	6.65	7554.129	0.008653249
107454	1.13	6.51	7397.345	0.008724337
102943	1.10	6.33	7188.299	0.008851354
98023	1.07	6.19	7031.515	0.008808357
91873	1.03	5.96	6770.208	0.008905288
82443	0.97	5.59	6352.117	0.009077781
70293	0.91	5.27	5986.287	0.008714849
60653	0.83	4.81	5463.673	0.009027048
58296	0.83	4.81	5463.673	0.008676247
47813	0.75	4.35	4941.059	0.008700982
39364	0.68	3.89	4418.445	0.008958238
30602	0.60	3.43	3895.831	0.008958035
32931	0.60	3.43	3895.831	0.009639926
24253	0.50	2.88	3268.694	0.010085099
19046	0.44	2.56	2902.864	0.010041815
15314	0.42	2.42	2746.08	0.009022597
11062	0.40	2.28	2589.296	0.007330354
8892	0.37	2.14	2432.512	0.006676691
8719	0.36	2.05	2327.989	0.007147405
8198	0.34	1.96	2223.466	0.007367238
7677	0.32	1.82	2066.682	0.007985799
7504	0.31	1.77	2014.42	0.0082155
7243	0.30	1.73	1962.159	0.008358522
6375	0.27	1.54	1753.113	0.009216211
5160	0.22	1.27	1439.545	0.011063688
4813	0.20	1.18	1335.022	0.011998581
4293	0.18	1.04	1178.238	0.013737819
3425	0.14	0.81	916.931	0.018097553
3388	0.14	0.81	916.931	0.017903395
2837	0.12	0.67	760.1468	0.021811924
2090	0.08	0.49	551.1012	0.030580804
1234	0.05	0.30	342.0556	0.046856438
522	0.02	0.12	133.01	0.130985398

45% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
35448	2.60	5.33	10143.86	0.007674506
33712	2.54	5.19	9894.587	0.007671122
32584	2.49	5.10	9707.629	0.007702742
31456	2.44	5.00	9520.671	0.007730954
29807	2.37	4.85	9240.235	0.007777114
28419	2.31	4.74	9022.117	0.007777675
27117	2.26	4.62	8804	0.007793689
25815	2.19	4.49	8554.723	0.007858245
24253	2.11	4.33	8243.127	0.007951423
22691	2.04	4.18	7962.69	0.007972511
21302	1.97	4.03	7682.253	0.008041059
19740	1.89	3.87	7370.657	0.008094738
17223	1.77	3.62	6903.263	0.00805147
15835	1.67	3.43	6529.347	0.00827446
13839	1.56	3.20	6093.112	0.008303972
12103	1.46	2.99	5688.037	0.008333711
10801	1.35	2.77	5282.962	0.008621633
9066	1.24	2.54	4846.727	0.008597446
7330	1.14	2.33	4441.652	0.008277161
5855	0.99	2.04	3880.779	0.008660275
4553	0.88	1.81	3444.544	0.008548565

4206	0.83	1.69	3226.427	0.009000574
3425	0.77	1.58	3008.309	0.008430403
3583	0.77	1.58	3008.309	0.008820101
3252	0.74	1.51	2883.671	0.008712971
2718	0.70	1.43	2727.872	0.008137163
2252	0.66	1.35	2572.074	0.007582139
2074	0.64	1.32	2509.755	0.007333495
1980	0.63	1.28	2447.436	0.007364774
1836	0.60	1.24	2353.957	0.007381704
1539	0.57	1.17	2229.318	0.006899693
1446	0.56	1.14	2166.999	0.006859696
1225	0.52	1.07	2042.361	0.006544897
1124	0.49	1.01	1917.722	0.006806838
1022	0.45	0.92	1761.924	0.007333562
929	0.41	0.84	1606.126	0.008019711
903	0.38	0.78	1481.487	0.009167647
818	0.34	0.70	1325.689	0.010374084
649	0.29	0.60	1138.731	0.011146268
564	0.24	0.50	951.7737	0.013869743
479	0.20	0.42	795.9755	0.016848757
352	0.16	0.34	640.1774	0.019132759
250	0.12	0.24	453.2196	0.02713639
157	0.08	0.16	297.4215	0.039519381

45% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
49534	2.43	6.21	10594.99	0.007063106
46405	2.34	5.99	10212.3	0.007122103
44371	2.28	5.82	9933.987	0.007196854
41867	2.14	5.46	9307.775	0.007735292
40459	2.17	5.54	9446.934	0.007256521
38738	2.11	5.39	9203.407	0.007320387
36704	2.06	5.25	8959.88	0.007318177
34357	1.98	5.07	8646.774	0.007355322
35882	1.98	5.07	8646.774	0.007681802
34060	1.93	4.93	8403.247	0.007720388
30935	1.82	4.64	7916.193	0.007901624
28939	1.75	4.48	7637.877	0.007940302
25989	1.66	4.23	7220.402	0.007979121
23125	1.55	3.95	6733.348	0.00816412
17657	1.32	3.38	5759.24	0.00852098
13405	1.14	2.91	4959.081	0.008724821
11756	1.07	2.72	4645.975	0.008717689
9847	0.96	2.46	4193.71	0.008961726
7851	0.85	2.17	3706.657	0.009146194
6289	0.76	1.95	3323.971	0.009110363
5594	0.72	1.85	3150.024	0.009024367
4553	0.67	1.70	2906.497	0.008626747
3685	0.64	1.62	2767.339	0.007702283
3338	0.62	1.58	2697.759	0.007341249
3091	0.60	1.54	2628.18	0.007163244
1777	0.36	0.91	1549.704	0.011841661
1573	0.31	0.79	1340.967	0.014003454
1361	0.25	0.64	1097.44	0.018090158
1251	0.23	0.58	993.0711	0.020303038
1056	0.20	0.50	853.9128	0.023177903
903	0.15	0.38	645.1755	0.034731869
776	0.12	0.30	506.0173	0.04850957
445	0.06	0.15	262.4904	0.103438908
284	0.04	0.09	158.1217	0.181899859
157	0.02	0.05	88.54256	0.320391263

40% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
153785	0.27	4.80	2923.252	0.010569508
152965	0.26	4.65	2836.108	0.011169141
150915	0.26	4.65	2836.108	0.011019451
149685	0.25	4.51	2748.964	0.011633573
147635	0.25	4.51	2748.964	0.011474242
144764	0.25	4.51	2748.964	0.011251178
141484	0.25	4.51	2748.964	0.010996248
139434	0.24	4.37	2661.82	0.011558101
134924	0.24	4.22	2574.676	0.011954154
127544	0.24	4.22	2574.676	0.011300276
121394	0.24	4.37	2661.82	0.010062677
106224	0.23	4.08	2487.532	0.010082246
98843	0.22	3.94	2400.389	0.01007531
89413	0.22	3.94	2400.389	0.009114065
78753	0.21	3.80	2313.245	0.008643648
73299	0.21	3.80	2313.245	0.008045049
68012	0.21	3.80	2313.245	0.007464826
61793	0.20	3.65	2226.101	0.007323603
62677	0.21	3.80	2313.245	0.006879204
57357	0.20	3.51	2138.957	0.007363045
45935	0.16	2.79	1703.237	0.009299743
37799	0.14	2.51	1528.949	0.009496677
29507	0.11	1.94	1180.373	0.012438183
31369	0.12	2.08	1267.517	0.011467574
26770	0.09	1.65	1006.085	0.015532771
24079	0.09	1.65	1006.085	0.013971753
18872	0.07	1.22	744.6531	0.019989066
10628	0.04	0.79	483.2212	0.02673178
10281	0.04	0.65	396.0772	0.038489113
9066	0.04	0.65	396.0772	0.033940451
7677	0.03	0.51	308.9332	0.047244048
5074	0.02	0.36	221.7893	0.060577927
2817	0.01	0.22	134.6453	0.091268267

40% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
162395	0.75	6.67	5758.081	0.009327491
161165	0.74	6.60	5696.527	0.009457973
159935	0.75	6.67	5758.081	0.009186193
156245	0.73	6.53	5634.973	0.009370651
152145	0.71	6.39	5511.865	0.009536907
147225	0.71	6.32	5450.311	0.009438123
141894	0.69	6.17	5327.203	0.009521706
138204	0.68	6.10	5265.649	0.009492176
128364	0.64	5.75	4957.878	0.009944883
121804	0.64	5.68	4896.324	0.009675397
115654	0.61	5.46	4711.662	0.00992109
109504	0.60	5.32	4588.554	0.009904319
103353	0.58	5.18	4465.446	0.009870592
95973	0.55	4.89	4219.23	0.010266722
89003	0.52	4.68	4034.567	0.010412595
79983	0.49	4.39	3788.351	0.01061315
74646	0.49	4.39	3788.351	0.00990505
69671	0.48	4.25	3665.243	0.0098763
65939	0.46	4.11	3542.135	0.010008351
60342	0.44	3.96	3419.027	0.009830199
57514	0.44	3.89	3357.473	0.00971613
46874	0.40	3.53	3049.702	0.009597676
45779	0.40	3.53	3049.702	0.009373421
38582	0.37	3.32	2865.04	0.008950898
30289	0.36	3.18	2741.932	0.007672208
31803	0.36	3.25	2803.486	0.007705882
26770	0.35	3.11	2680.378	0.007095778
22951	0.33	2.96	2557.27	0.006683452
18959	0.28	2.46	2126.391	0.007985103

17831	0.26	2.32	2003.283	0.008461316
15835	0.23	2.04	1757.067	0.009767585
14446	0.20	1.82	1572.404	0.011126998
13145	0.19	1.68	1449.296	0.011917385
11930	0.17	1.54	1326.188	0.012917078
11322	0.16	1.39	1203.08	0.014896597
9760	0.14	1.25	1079.972	0.015935785
8458	0.12	1.04	895.3096	0.020094715
7243	0.10	0.90	772.2014	0.023132429
6115	0.08	0.75	649.0933	0.02763982
4640	0.06	0.54	464.431	0.04096367
11843	0.04	0.32	279.7688	0.288140964

40% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
123444	1.22	6.92	7488.046	0.008751828
123444	1.22	6.92	7488.046	0.008751828
122214	1.22	6.92	7488.046	0.008664622
120574	1.20	6.83	7389.871	0.008776987
118934	1.19	6.79	7340.784	0.008773776
116884	1.19	6.74	7291.696	0.008739027
114014	1.17	6.65	7193.521	0.008758706
110324	1.15	6.51	7046.259	0.008833183
105403	1.11	6.33	6849.909	0.008929996
100893	1.08	6.15	6653.56	0.009059839
94743	1.04	5.92	6408.122	0.009171755
88593	1.00	5.70	6162.685	0.009273115
84493	0.98	5.56	6015.423	0.009282267
72884	0.92	5.24	5671.811	0.009006508
68634	0.90	5.11	5524.549	0.008939521
63037	0.85	4.83	5230.024	0.009161237
60643	0.85	4.83	5230.024	0.008813288
54384	0.79	4.52	4886.412	0.009054394
47656	0.74	4.20	4542.8	0.009179945
42024	0.69	3.93	4248.276	0.009256258
25595	0.53	3.02	3266.527	0.009535676
26943	0.53	3.02	3266.527	0.010037932
23993	0.51	2.88	3119.265	0.009802559
21910	0.48	2.70	2922.915	0.010194648
20434	0.46	2.61	2824.74	0.01018058
17137	0.44	2.52	2726.566	0.009163486
12624	0.42	2.38	2579.303	0.00754318
9847	0.39	2.20	2382.954	0.006893341
9239	0.37	2.11	2284.779	0.007035857
8805	0.35	1.98	2137.516	0.007661175
8371	0.32	1.84	1990.254	0.008401372
7851	0.31	1.75	1892.079	0.008717638
7504	0.29	1.66	1793.904	0.009269113
5681	0.22	1.25	1352.118	0.012353022
4640	0.17	0.98	1057.593	0.016490058
3859	0.14	0.80	861.2433	0.020680109
3251	0.12	0.66	713.981	0.025353314
3286	0.12	0.66	713.981	0.025626716
2515	0.08	0.48	517.6313	0.037306077
988	0.04	0.21	223.1068	0.078905196
810	0.02	0.12	124.9319	0.20628376

40% vol. oil; EDM 244oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
35795	2.60	5.25	9527.8	0.007859716
34407	2.54	5.12	9293.662	0.007940283
33018	2.48	5.01	9088.792	0.007967228
31803	2.42	4.90	8883.921	0.008032077
29894	2.34	4.73	8591.249	0.008073039
27811	2.24	4.53	8210.775	0.008222742
26249	2.18	4.40	7976.637	0.008223177
24427	2.09	4.22	7654.698	0.008309449
22951	2.02	4.07	7391.293	0.008373965
21302	1.94	3.91	7098.621	0.008426459
19306	1.84	3.72	6747.414	0.008452595
17397	1.74	3.51	6366.94	0.008554205
15314	1.62	3.27	5927.932	0.008686687
12884	1.47	2.98	5401.122	0.008803536
8198	1.16	2.35	4259.7	0.00900555
6289	1.02	2.06	3732.89	0.008995644
4640	0.87	1.75	3176.813	0.009163811
3338	0.79	1.59	2884.141	0.007998635
3592	0.79	1.61	2913.408	0.008434223
2972	0.73	1.48	2679.27	0.008253727
2387	0.67	1.35	2445.133	0.00795921
2057	0.63	1.27	2298.796	0.007757256
1929	0.60	1.20	2181.728	0.008079384
1819	0.57	1.15	2093.926	0.008269953
1802	0.56	1.12	2035.391	0.008670846
1675	0.54	1.09	1976.857	0.008543103
1624	0.52	1.06	1918.323	0.008796803
1505	0.48	0.98	1771.986	0.009556033
1421	0.46	0.93	1684.185	0.009982423
1285	0.42	0.85	1537.849	0.010828971
1030	0.36	0.73	1332.978	0.011559388
963	0.32	0.65	1186.642	0.013625801
852	0.28	0.57	1040.306	0.015698262
734	0.24	0.48	864.7027	0.019556587
606	0.20	0.40	718.3666	0.023422252
479	0.15	0.30	542.7632	0.032422685
335	0.11	0.22	396.4271	0.042491804
310	0.08	0.17	308.6255	0.064784008
174	0.05	0.11	191.5566	0.094457377

40% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
49847	2.46	6.18	10049.56	0.007068714
44371	2.30	5.78	9396.023	0.007197874
41711	2.22	5.60	9101.933	0.007210705
39677	2.15	5.42	8807.842	0.007324768
36548	2.06	5.18	8415.722	0.007390465
33105	1.95	4.92	7990.925	0.007425071
34494	1.94	4.90	7958.248	0.007800077
31456	1.85	4.66	7566.128	0.007869615
27290	1.71	4.31	7010.624	0.00795231
21823	1.50	3.77	6128.354	0.00832192
16095	1.27	3.19	5180.729	0.008588404
12450	1.10	2.77	4494.519	0.008826945
10281	0.99	2.50	4069.722	0.008889761
8719	0.91	2.28	3710.278	0.009070473
7070	0.82	2.06	3350.835	0.009017601
6028	0.76	1.92	3122.098	0.008857211
5421	0.72	1.82	2958.714	0.008868561
4466	0.68	1.72	2795.331	0.00818587
4032	0.65	1.64	2664.624	0.008133386
3512	0.63	1.58	2566.594	0.007634482
3164	0.61	1.54	2501.24	0.007243978
3074	0.61	1.54	2501.24	0.007037561
2820	0.58	1.46	2370.534	0.007186624
1963	0.43	1.08	1749.677	0.009184665
1573	0.34	0.86	1390.233	0.011657315
1378	0.29	0.73	1194.173	0.013840448
1064	0.23	0.57	932.7592	0.017520195
530	0.12	0.29	475.2855	0.033606201

225	0.05	0.13	213.8719	0.070376102

35% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (experiment)
139844	0.28	5.01	2619.717	0.008680089
130004	0.28	5.01	2619.717	0.008069309
124674	0.28	5.01	2619.717	0.007738469
120574	0.28	4.87	2546.016	0.007923536
114834	0.28	4.87	2546.016	0.007546321
112784	0.28	4.87	2546.016	0.007411601
103763	0.27	4.73	2472.315	0.007231442
102123	0.26	4.59	2398.613	0.007561236
88183	0.23	4.03	2103.809	0.008487127
84493	0.22	3.88	2030.107	0.008733142
78689	0.22	3.88	2030.107	0.008133252
68116	0.20	3.60	1882.705	0.008186034
64177	0.19	3.32	1735.302	0.009078594
62207	0.19	3.32	1735.302	0.008799949
45622	0.14	2.47	1293.095	0.011622656
33575	0.11	1.91	998.2899	0.014351184
30241	0.09	1.63	850.8875	0.017792686
25208	0.08	1.49	777.1862	0.017777459
21649	0.07	1.21	629.7837	0.023251569
18959	0.06	1.06	556.0825	0.026117308
16529	0.69	12.20	6378.48	0.000173063
13752	0.05	0.92	482.3813	0.025175371
12103	0.04	0.78	408.68	0.030868889
11582	0.04	0.64	334.9788	0.04396986
11062	0.04	0.64	334.9788	0.041993137
10194	0.04	0.64	334.9788	0.038698598
9153	0.04	0.64	334.9788	0.034745151
7156	0.03	0.50	261.2775	0.044656377
4987	0.02	0.36	187.5763	0.060375473

35% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
165265	0.77	6.79	5026.023	0.009036367
164445	0.76	6.72	4973.964	0.00918073
162395	0.75	6.65	4921.905	0.00925908
159935	0.75	6.65	4921.905	0.009118818
154605	0.74	6.51	4817.787	0.009200032
143534	0.70	6.16	4557.493	0.00954478
136154	0.69	6.09	4505.435	0.009264451
129184	0.66	5.81	4297.199	0.00966273
123854	0.65	5.74	4245.141	0.009492652
114834	0.62	5.46	4036.905	0.009732718
105813	0.59	5.17	3828.67	0.009970272
101713	0.59	5.17	3828.67	0.009583939
95973	0.56	4.89	3620.435	0.010113245
88183	0.53	4.68	3464.258	0.010149072
83263	0.52	4.54	3360.141	0.010185878
71018	0.49	4.33	3203.964	0.0095556
63763	0.47	4.12	3047.788	0.009481091
65024	0.48	4.19	3099.847	0.009346599
55480	0.44	3.91	2891.611	0.009164629
49378	0.43	3.77	2787.494	0.008777345
39207	0.40	3.56	2631.317	0.007821386
31541	0.39	3.42	2527.2	0.006821106
32931	0.39	3.42	2527.2	0.007121856
28766	0.37	3.27	2423.082	0.006767085
24427	0.36	3.13	2318.964	0.006273876
21736	0.31	2.71	2006.612	0.007456237
19653	0.28	2.50	1850.435	0.007927792
18265	0.26	2.29	1694.259	0.008788586
15314	0.22	1.94	1433.965	0.010286779
14012	0.20	1.80	1329.847	0.010943904
11322	0.16	1.45	1069.553	0.013670528
11149	0.16	1.45	1069.553	0.013460959
10801	0.16	1.45	1069.553	0.013041819
10281	0.15	1.30	965.4354	0.015234872
9847	0.14	1.23	913.3766	0.016302606
8285	0.12	1.02	757.2001	0.019957958
7417	0.11	0.95	705.1413	0.020602889
6202	0.09	0.81	601.0237	0.02371375
4727	0.07	0.60	444.8472	0.032989949
3512	0.05	0.46	340.7296	0.041777245
2557	0.04	0.32	236.612	0.063081844
2591	0.04	0.32	236.612	0.063918912
1310	0.02	0.18	132.4944	0.103093421

35% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
123854	1.19	6.69	6208.403	0.00926467
120164	1.17	6.56	6083.857	0.009360429
118524	1.16	6.51	6042.342	0.00935998
115654	1.15	6.42	5959.311	0.009389607
110324	1.11	6.24	5793.25	0.009477717
107044	1.10	6.15	5710.22	0.009465305
103763	1.07	6.02	5585.674	0.009588994
100073	1.05	5.89	5461.128	0.009674612
94333	1.02	5.71	5295.067	0.009700664
90643	0.99	5.57	5170.521	0.009775657
85723	0.95	5.35	4962.945	0.010034556
79518	0.96	5.39	5004.46	0.00915445
72262	0.90	5.04	4672.338	0.009543847
63141	0.83	4.68	4340.216	0.009664207
60956	0.83	4.68	4340.216	0.009329788
55636	0.80	4.50	4174.155	0.009206588
50786	0.76	4.28	3966.579	0.009306553
41398	0.68	3.83	3551.426	0.009463518
36235	0.63	3.51	3260.819	0.0098254
28724	0.58	3.25	3011.728	0.009130609
23385	0.55	3.07	2845.667	0.008326296
19740	0.52	2.93	2721.121	0.007686626
15401	0.48	2.71	2513.545	0.00702838
12971	0.41	2.31	2139.908	0.008167033
11669	0.36	2.04	1890.816	0.009410763
10975	0.34	1.90	1766.27	0.010143077
9673	0.30	1.68	1558.694	0.011479672
8892	0.28	1.55	1434.148	0.012465205
8458	0.26	1.46	1351.118	0.013358995
8198	0.25	1.41	1309.602	0.013781711
7156	0.21	1.19	1102.026	0.016990086
6896	0.20	1.14	1060.511	0.017678887
6462	0.20	1.10	1018.996	0.017943868
5247	0.16	0.87	811.4194	0.022978355
4553	0.13	0.74	686.8736	0.027823982
3859	0.11	0.61	562.3279	0.035183512
3164	0.08	0.47	437.7821	0.047605347
3117	0.08	0.47	437.7821	0.046886741
2523	0.06	0.34	313.2363	0.074139991
1454	0.03	0.16	147.1753	0.193601331

35% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
36142	2.58	5.13	7983.795	0.008197448
35188	2.54	5.05	7860.032	0.00823424
34494	2.50	4.99	7761.022	0.008279037

33539	2.47	4.92	7662.012	0.008259299
32584	2.43	4.84	7538.25	0.008289857
31543	2.38	4.75	7389.735	0.008350711
29720	2.30	4.59	7142.21	0.00842305
28419	2.25	4.48	6968.943	0.008459592
27377	2.20	4.38	6820.428	0.008508366
25902	2.14	4.26	6622.408	0.008538461
24340	2.06	4.10	6374.883	0.008658688
22778	1.98	3.95	6152.11	0.00870043
21649	1.93	3.84	5978.843	0.008755737
20174	1.85	3.68	5731.318	0.008879033
18786	1.78	3.54	5508.546	0.008950156
17571	1.71	3.41	5310.526	0.009007234
15661	1.61	3.21	4988.743	0.009097596
13752	1.50	2.98	4642.208	0.0092257
12450	1.41	2.81	4369.931	0.009425653
9847	1.24	2.47	3850.129	0.009603386
8892	1.19	2.38	3701.614	0.009382216
8198	1.14	2.27	3528.346	0.009520063
6896	1.06	2.11	3280.821	0.009262328
4987	0.96	1.92	2983.791	0.008097882
3945	0.90	1.79	2785.771	0.007349992
3425	0.84	1.68	2612.504	0.007254304
3481	0.85	1.69	2637.256	0.007236303
2989	0.79	1.57	2439.237	0.00726374
2769	0.74	1.47	2290.722	0.007628655
2642	0.72	1.44	2241.217	0.007603264
2523	0.66	1.31	2043.197	0.008737286
2438	0.62	1.23	1919.434	0.009567567
2277	0.58	1.15	1795.672	0.010209417
2286	0.56	1.11	1721.414	0.011150607
2184	0.55	1.09	1696.662	0.010967245
1828	0.48	0.96	1498.642	0.011764236
1666	0.41	0.82	1275.869	0.014800046
1514	0.37	0.74	1152.107	0.016487944
1378	0.33	0.66	1028.345	0.018840436
1209	0.28	0.57	879.8296	0.022570135
963	0.23	0.45	706.5621	0.02787499
810	0.17	0.34	533.2947	0.041170995
666	0.14	0.28	434.2847	0.051032527
335	0.08	0.15	236.2648	0.086765656
30	0.03	0.06	87.74982	0.055793515

35% vol. water; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
51724	2.43	6.04	8416.415	0.007584929
48595	2.35	5.84	8140.055	0.007618134
45935	2.28	5.66	7891.331	0.007662249
43901	2.22	5.52	7697.879	0.007695651
42024	2.18	5.40	7532.063	0.00769444
40459	2.12	5.27	7338.611	0.00780367
38738	2.07	5.15	7172.794	0.007821155
36860	2.02	5.03	7006.978	0.007798472
34826	1.96	4.87	6785.89	0.007856079
33105	1.90	4.71	6564.802	0.007979311
34494	1.90	4.71	6564.802	0.008313894
31977	1.82	4.53	6316.078	0.008326261
29720	1.74	4.31	6012.081	0.008541123
27030	1.66	4.12	5735.721	0.008534565
25121	1.59	3.96	5514.633	0.008580465
23212	1.52	3.78	5265.909	0.008694969
21129	1.44	3.58	4989.548	0.008815794
18612	1.34	3.32	4630.28	0.009017554
16876	1.27	3.16	4409.192	0.009017162
14533	1.18	2.93	4077.56	0.009079649
12364	1.07	2.67	3718.291	0.009288937
11322	1.03	2.55	3552.475	0.009319143
9934	0.96	2.39	3331.387	0.009297488
7417	0.87	2.15	2999.755	0.008561643
5768	0.81	2.01	2806.303	0.007607838
5334	0.79	1.95	2723.394	0.007470383
4640	0.75	1.87	2612.85	0.007059506
4206	0.71	1.78	2474.67	0.007133876
3945	0.68	1.68	2336.49	0.007507235
3772	0.64	1.60	2225.946	0.007907518
3512	0.60	1.48	2060.13	0.008594459
3338	0.57	1.42	1977.222	0.008869149
3303	0.56	1.40	1949.586	0.009027372
3151	0.53	1.32	1839.042	0.009676415
2404	0.40	1.00	1396.865	0.012799243
2201	0.36	0.90	1258.685	0.014429258
1828	0.29	0.72	1009.961	0.018611456
1531	0.24	0.61	844.1448	0.022314498
1149	0.17	0.43	595.4206	0.033669653
827	0.12	0.29	401.9685	0.053158515
496	0.08	0.19	263.7883	0.0740643
259	0.04	0.11	153.2442	0.114425664
30	0.02	0.05	70.33617	0.062394852

30% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
134514	0.29	5.08	2364.966	0.008007644
132874	0.28	4.94	2300.253	0.008361342
130004	0.28	4.94	2300.253	0.008180738
129184	0.28	4.94	2300.253	0.008129136
127134	0.28	4.94	2300.253	0.008000133
120164	0.27	4.67	2170.825	0.008490056
114014	0.26	4.53	2106.112	0.008558166
107454	0.24	4.25	1976.684	0.009156563
99253	0.24	4.11	1911.971	0.009040012
92283	0.22	3.83	1782.543	0.009670047
84493	0.21	3.69	1717.83	0.009533374
78274	0.21	3.69	1717.83	0.008831733
71226	0.19	3.28	1523.689	0.010214833
68634	0.17	3.00	1394.262	0.011755467
62830	0.16	2.86	1329.548	0.011834323
61112	0.16	2.86	1329.548	0.011510826
51568	0.15	2.58	1200.121	0.011921115
45779	0.13	2.30	1070.693	0.01329601
39207	0.12	2.02	941.266	0.014734321
33262	0.10	1.75	811.8386	0.016803253
27811	0.08	1.47	682.4113	0.019884419
25034	0.08	1.33	617.6977	0.021845684
21736	0.06	1.05	488.2704	0.0303564
16876	0.05	0.91	423.5567	0.031321403
15748	0.04	0.77	358.8431	0.040719865
14880	0.04	0.77	358.8431	0.038475887
13926	0.04	0.77	358.8431	0.036007511
11843	0.04	0.63	294.1294	0.04557905
8979	0.03	0.49	229.4157	0.056802272
2370	0.01	0.21	99.98843	0.078940369

30% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
163625	0.74	6.42	4230.277	0.009871253
162805	0.74	6.42	4230.277	0.009821782
161165	0.74	6.42	4230.277	0.009722841
159115	0.73	6.35	4184.566	0.009810024
156245	0.72	6.28	4138.856	0.009847028

155015	0.72	6.28	4138.856	0.009769508
150505	0.71	6.21	4093.145	0.009698304
144764	0.69	6.01	3956.014	0.009986346
139024	0.68	5.87	3864.593	0.010049478
129184	0.64	5.59	3681.751	0.010288696
122214	0.63	5.45	3590.331	0.01023557
114424	0.60	5.24	3453.199	0.010359362
104583	0.58	5.03	3316.068	0.010267776
92693	0.55	4.76	3133.226	0.010193525
84083	0.52	4.48	2950.384	0.010428237
69567	0.50	4.34	2858.964	0.009188576
59824	0.48	4.20	2767.543	0.008432273
57670	0.48	4.20	2767.543	0.008128713
45153	0.47	4.06	2676.122	0.006806678
39207	0.45	3.92	2584.701	0.006335896
33418	0.42	3.65	2401.859	0.006253881
30849	0.37	3.23	2127.597	0.007357277
26857	0.32	2.81	1853.334	0.00844117
23125	0.28	2.40	1579.071	0.010012319
20001	0.24	2.12	1396.229	0.011076149
17310	0.21	1.84	1213.388	0.012693
15835	0.20	1.70	1121.967	0.013580503
14533	0.18	1.56	1030.546	0.014773561
13665	0.17	1.50	984.8355	0.015210803
12103	0.15	1.29	847.7042	0.018183242
11496	0.14	1.22	801.9938	0.01929539
11062	0.14	1.22	801.9938	0.018567058
10628	0.13	1.15	756.2833	0.02006027
10107	0.12	1.08	710.5729	0.021610838
9326	0.12	1.01	664.8625	0.022776983
8371	0.11	0.94	619.152	0.023575829
7938	0.10	0.87	573.4416	0.026059606
7243	0.09	0.80	527.7311	0.028078199
6549	0.08	0.73	482.0207	0.030430095
5594	0.07	0.59	390.5998	0.039586482
4293	0.05	0.45	299.1789	0.051774819
3512	0.04	0.38	253.4685	0.059007876
2642	0.04	0.32	207.7581	0.066074249
2286	0.03	0.25	162.0476	0.093964601

30% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
123854	1.19	6.60	5451.312	0.009392606
122214	1.18	6.51	5378.406	0.0095212
120984	1.18	6.51	5378.406	0.009425373
118934	1.16	6.42	5305.501	0.009522058
116474	1.15	6.38	5269.048	0.009454574
113604	1.13	6.25	5159.691	0.00961664
109504	1.11	6.16	5086.785	0.009537176
105403	1.09	6.03	4977.427	0.009587896
101713	1.06	5.85	4831.617	0.009819093
97203	1.03	5.72	4722.259	0.009823348
93103	1.01	5.59	4612.901	0.009860397
88593	0.98	5.41	4467.091	0.01000526
82033	0.94	5.19	4284.828	0.010069306
70811	0.90	4.97	4102.564	0.009481331
62830	0.84	4.66	3847.396	0.009565538
60017	0.83	4.61	3810.943	0.009312952
54228	0.79	4.39	3628.68	0.009281181
49534	0.75	4.17	3446.417	0.009398222
42806	0.71	3.91	3227.701	0.009259701
35765	0.65	3.60	2972.533	0.009121918
28099	0.63	3.47	2863.175	0.007724436
22864	0.60	3.29	2717.364	0.006978194
19046	0.56	3.07	2535.101	0.006678668
17744	0.53	2.94	2425.743	0.006795856
15835	0.48	2.63	2170.575	0.007574332
13839	0.43	2.36	1951.859	0.008186193
12103	0.36	2.01	1660.238	0.009895487
10801	0.32	1.79	1477.975	0.011143586
9847	0.29	1.61	1332.165	0.012504243
7851	0.24	1.35	1113.449	0.01427083
6636	0.20	1.08	894.7331	0.018680264
6115	0.19	1.04	858.2804	0.018707739
5508	0.16	0.86	712.4699	0.024451529
4813	0.14	0.77	639.5647	0.026518734
4206	0.12	0.69	566.6594	0.029517821
3425	0.10	0.55	457.3015	0.036906488
3405	0.10	0.55	457.3015	0.03669332
2582	0.08	0.42	347.9436	0.048070391
2031	0.05	0.29	238.5857	0.080412998
1488	0.04	0.24	202.1331	0.082094599
1005	0.03	0.16	129.2279	0.135619865
327	0.01	0.07	56.3226	0.231976264

30% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
36403	2.56	5.03	6966.733	0.008475292
35101	2.50	4.90	6792.861	0.008595926
33973	2.45	4.81	6662.457	0.008648509
32584	2.39	4.70	6510.319	0.008687243
30762	2.32	4.56	6314.713	0.008717321
28679	2.22	4.35	6032.171	0.008906252
27377	2.16	4.24	5880.032	0.008947636
25555	2.08	4.09	5662.692	0.009005423
23732	1.99	3.92	5423.618	0.009116743
21823	1.90	3.73	5162.81	0.009251691
19046	1.77	3.48	4815.065	0.00928274
15835	1.60	3.15	4358.651	0.009418675
13839	1.48	2.91	4032.641	0.009616123
10020	1.26	2.47	3424.088	0.009657661
8458	1.18	2.31	3206.748	0.009294564
5942	1.07	2.10	2902.472	0.007969638
4466	0.95	1.88	2598.195	0.007476009
4119	0.87	1.70	2359.121	0.008363208
3945	0.83	1.62	2250.451	0.00880313
3685	0.76	1.50	2076.579	0.00965677
3598	0.72	1.42	1967.909	0.010499505
3251	0.68	1.33	1837.505	0.010880868
2854	0.62	1.22	1685.367	0.011352826
2727	0.59	1.15	1598.43	0.012058725
2582	0.56	1.09	1511.494	0.012772692
2438	0.52	1.01	1402.824	0.014000381
2243	0.48	0.93	1294.154	0.015134313
2133	0.45	0.89	1228.952	0.015957964
2090	0.44	0.86	1185.484	0.016808735
1989	0.41	0.81	1120.282	0.017905978
1895	0.39	0.76	1055.08	0.019240532
1794	0.36	0.71	989.8779	0.020685111
1726	0.35	0.68	946.4099	0.021772935
1488	0.30	0.59	816.0057	0.025258244
1344	0.26	0.51	707.3356	0.030359298
1166	0.22	0.43	598.6655	0.036766257
1005	0.19	0.37	511.7295	0.043366544
835	0.15	0.29	403.0594	0.058105673
674	0.12	0.23	316.1233	0.076239279
488	0.08	0.15	207.4532	0.128044449
310	0.05	0.10	142.2511	0.172875018
123	0.04	0.07	98.78308	0.142438375

30% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
52820	2.42	5.92	7341.534	0.007956656
50629	2.36	5.78	7171.673	0.007992242
49690	2.33	5.70	7074.609	0.008060766
47343	2.27	5.57	6904.747	0.008062562
46248	2.23	5.47	6783.418	0.008160309
44684	2.19	5.37	6662.088	0.008174026
42963	2.14	5.25	6516.493	0.008214298
41398	2.10	5.15	6395.163	0.008218329
40303	2.07	5.08	6298.1	0.008249415
38895	2.02	4.96	6152.504	0.008342435
37173	1.98	4.84	6006.909	0.008364478
35452	1.93	4.72	5861.313	0.008378442
33888	1.89	4.63	5739.983	0.008350821
35275	1.88	4.61	5715.718	0.008766555
32931	1.81	4.43	5497.324	0.00884741
31456	1.77	4.33	5375.995	0.008836809
28853	1.68	4.12	5109.07	0.008974476
25121	1.56	3.82	4745.081	0.009058478
21997	1.46	3.57	4429.624	0.009101862
19046	1.34	3.28	4065.635	0.009355216
17050	1.26	3.08	3822.976	0.009471678
14967	1.19	2.91	3604.583	0.009352661
12971	1.11	2.71	3361.924	0.009317668
11322	1.05	2.57	3192.062	0.009021813
8805	0.97	2.38	2949.403	0.008218422
7070	0.92	2.26	2803.808	0.007301513
6375	0.88	2.16	2682.478	0.007193581
6028	0.84	2.06	2561.148	0.007461614
5421	0.78	1.91	2367.021	0.007855381
4987	0.71	1.75	2172.894	0.008575508
4727	0.66	1.61	2003.032	0.009564762
4466	0.64	1.56	1930.235	0.009732476
4119	0.58	1.42	1760.373	0.010791804
3945	0.56	1.36	1687.575	0.011248122
2904	0.40	0.97	1202.257	0.016312405
3057	0.40	0.99	1226.523	0.01650028
2879	0.37	0.91	1129.459	0.018324677
2353	0.29	0.71	886.8001	0.024296872
2074	0.24	0.60	741.2046	0.030643781
1751	0.20	0.48	595.6091	0.040080989
1259	0.12	0.30	377.2159	0.071860617
946	0.08	0.19	231.6204	0.143109913
598	0.04	0.09	110.2908	0.399087604

25% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
145585	0.30	5.15	1905.019	0.008322984
142714	0.29	5.02	1854.279	0.008611524
140254	0.28	4.88	1803.54	0.008945968
138614	0.28	4.88	1803.54	0.00884136
132054	0.28	4.74	1752.8	0.008917633
127954	0.27	4.60	1702.061	0.009163604
127544	0.27	4.60	1702.061	0.00913424
116474	0.24	4.19	1549.842	0.010060405
106634	0.22	3.78	1397.624	0.011325972
95563	0.20	3.37	1245.405	0.012782968
84083	0.17	2.96	1093.187	0.014597598
71329	0.16	2.68	991.7079	0.015047479
60135	0.13	2.27	839.4894	0.017703396
49847	0.12	2.00	738.0104	0.018987834
39051	0.09	1.58	585.792	0.023610615
34044	0.08	1.45	535.0525	0.024672445
35969	0.08	1.31	484.313	0.031815365
32498	0.08	1.31	484.313	0.02874485
27030	0.06	1.04	382.834	0.038263858
24427	0.05	0.90	332.0945	0.045951659
21042	0.05	0.90	332.0945	0.039584514
18699	0.04	0.76	281.355	0.049007952
16356	0.04	0.62	230.6156	0.063804621
14967	0.04	0.62	230.6156	0.058387777
13926	0.04	0.62	230.6156	0.054325143
12711	0.03	0.49	179.8761	0.081505009
11930	0.03	0.49	179.8761	0.076496605
5074	0.01	0.21	78.39709	0.171270966

25% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
164855	0.75	6.41	3352.637	0.009866546
163215	0.75	6.41	3352.637	0.00976839
159935	0.73	6.27	3280.958	0.009994891
154605	0.71	6.13	3209.278	0.010098207
148865	0.70	5.99	3137.598	0.01017262
144764	0.69	5.93	3101.759	0.010122369
137794	0.67	5.72	2994.239	0.010339378
132054	0.65	5.58	2922.56	0.010400674
126724	0.64	5.51	2886.72	0.01023024
119754	0.62	5.31	2779.2	0.010430038
113194	0.60	5.10	2671.681	0.01066815
100893	0.56	4.76	2492.482	0.010925333
92283	0.54	4.62	2420.802	0.010593509
79983	0.52	4.49	2349.123	0.009750378
75476	0.52	4.42	2313.283	0.009488241
62519	0.50	4.28	2241.603	0.008370061
42806	0.47	4.01	2098.244	0.006540778
35765	0.42	3.60	1883.205	0.006784252
32480	0.38	3.26	1704.006	0.007524947
30328	0.34	2.91	1524.807	0.008775024
27030	0.31	2.64	1381.448	0.009528276
25642	0.28	2.43	1273.929	0.010628938
22344	0.24	2.09	1094.73	0.012542323
19480	0.22	1.89	987.2105	0.013446285
17397	0.20	1.68	879.6911	0.01512345
15141	0.17	1.48	772.1717	0.017082544
13926	0.16	1.34	700.4921	0.019091734
13231	0.14	1.20	628.8125	0.022511221
12190	0.13	1.13	592.9727	0.023322196
11496	0.12	1.06	557.1329	0.024914595
11062	0.12	1.00	521.2931	0.027384009
10715	0.12	1.00	521.2931	0.026524652
10368	0.11	0.93	485.4533	0.029594793
9760	0.10	0.86	449.6135	0.032479381
8805	0.09	0.79	413.7737	0.034598609
8111	0.08	0.72	377.9339	0.038201874
7070	0.08	0.65	342.0941	0.040639259
6115	0.07	0.59	306.2543	0.043860458
5160	0.05	0.45	234.5747	0.063090028
4379	0.04	0.38	198.7349	0.074593473
2991	0.03	0.24	127.0553	0.124635836
2413	0.02	0.17	91.21552	0.19507931

25% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
125084	1.19	6.51	4274.164	0.009615093
120984	1.17	6.38	4188.421	0.009684586
118524	1.15	6.25	4102.677	0.009888378
115244	1.13	6.16	4045.515	0.00988835

111964	1.11	6.08	3988.353	0.009884257
108274	1.09	5.95	3902.61	0.009983121
104173	1.06	5.77	3788.285	0.01019356
92693	1.01	5.51	3616.798	0.00995069
86543	0.95	5.21	3416.731	0.010410331
80393	0.93	5.07	3330.987	0.010174791
74335	0.91	4.99	3273.825	0.009739559
70708	0.90	4.90	3216.663	0.009596407
65525	0.87	4.73	3102.339	0.009560509
61171	0.82	4.47	2930.852	0.010000307
59391	0.82	4.47	2930.852	0.009709299
54228	0.79	4.29	2816.528	0.009599498
50003	0.75	4.07	2673.622	0.009823207
41241	0.70	3.81	2502.135	0.009250525
40929	0.70	3.81	2502.135	0.009180335
30915	0.67	3.64	2387.811	0.007614163
24600	0.63	3.42	2244.905	0.006854809
20261	0.55	2.98	1959.094	0.007413143
17831	0.49	2.68	1759.027	0.008092521
15401	0.42	2.29	1501.797	0.009589159
13579	0.36	1.98	1301.729	0.011252925
12450	0.33	1.81	1187.405	0.012400448
11409	0.31	1.68	1101.661	0.013200861
10107	0.27	1.46	958.7557	0.015440694
9586	0.25	1.37	901.5935	0.016561133
9153	0.24	1.29	844.4313	0.018024624
8545	0.22	1.20	787.2691	0.019360713
7938	0.20	1.07	701.5258	0.022649197
7330	0.19	1.03	672.9447	0.022730154
6289	0.16	0.85	558.6203	0.028299412
5508	0.13	0.72	472.877	0.034587459
4727	0.12	0.63	415.7147	0.038406515
4293	0.09	0.50	329.9714	0.055363286
3512	0.08	0.42	272.8092	0.06625731
2210	0.04	0.24	158.4848	0.123545588
2252	0.04	0.20	129.9037	0.187372718

25% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
36403	2.54	4.93	5428.266	0.008698946
35361	2.49	4.82	5308.981	0.008834077
34667	2.46	4.78	5257.858	0.008829865
33712	2.42	4.68	5155.613	0.008930674
32498	2.37	4.59	5053.368	0.008960706
31369	2.32	4.50	4951.124	0.009010555
29981	2.26	4.39	4831.838	0.009042157
28332	2.20	4.27	4695.511	0.009048225
27464	2.15	4.17	4593.267	0.009165894
26596	2.10	4.08	4491.022	0.009285022
25121	2.05	3.97	4371.736	0.009255085
23472	1.97	3.82	4201.328	0.00936332
21649	1.88	3.65	4013.879	0.009461778
20087	1.81	3.51	3860.512	0.009490453
18525	1.72	3.34	3673.063	0.009668542
16529	1.63	3.15	3468.573	0.009673953
13665	1.47	2.86	3144.798	0.009729446
12190	1.39	2.69	2957.349	0.00981413
10541	1.31	2.55	2803.982	0.009440361
8458	1.21	2.35	2582.451	0.008930389
7070	1.17	2.27	2497.247	0.007982374
5942	1.11	2.16	2377.961	0.007398452
5160	0.99	1.93	2122.349	0.008066916
4727	0.91	1.77	1951.941	0.00873499
4379	0.83	1.60	1764.492	0.009904391
4119	0.78	1.51	1662.247	0.010496826
3338	0.61	1.18	1304.39	0.013814076
2972	0.53	1.03	1133.982	0.016276419
2854	0.49	0.95	1048.778	0.018268434
2803	0.48	0.92	1014.697	0.019168262
2667	0.44	0.86	946.5333	0.020962001
2591	0.43	0.83	912.4517	0.021911672
2464	0.40	0.78	861.3293	0.023382562
2243	0.36	0.71	776.1252	0.026220867
2031	0.32	0.63	690.9212	0.029959474
1819	0.28	0.53	588.6763	0.036962446
1624	0.24	0.46	503.4723	0.045113362
1488	0.20	0.40	435.309	0.055305731
1234	0.16	0.30	333.0642	0.078324495
1013	0.12	0.23	247.8601	0.116157613
903	0.08	0.16	179.6969	0.196953374
734	0.07	0.13	145.6153	0.243613332
708	0.06	0.12	128.5744	0.301631424

25% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
52976	2.41	5.82	5737.189	0.008142662
45935	2.23	5.39	5318.617	0.008215493
42493	2.14	5.18	5109.331	0.008235217
39364	2.05	4.95	4881.02	0.008359132
36704	1.97	4.76	4690.76	0.0084394
33262	1.86	4.51	4443.422	0.008523058
32150	1.80	4.35	4291.215	0.00883303
29373	1.71	4.14	4081.929	0.008918784
20782	1.43	3.45	3396.994	0.009111169
16703	1.27	3.06	3016.475	0.00928695
13145	1.14	2.75	2712.059	0.009041352
9500	1.04	2.52	2483.747	0.007790718
6983	0.93	2.25	2217.384	0.007185207
6375	0.87	2.09	2065.176	0.007562741
5855	0.81	1.96	1931.994	0.00793558
5681	0.78	1.88	1855.89	0.008344799
5334	0.73	1.77	1741.734	0.008895583
4900	0.67	1.61	1589.527	0.009811892
4293	0.58	1.40	1380.241	0.01139974
3685	0.50	1.21	1189.981	0.013166021
3078	0.40	0.98	961.6695	0.016836335
2820	0.33	0.80	790.4357	0.022833485
2379	0.27	0.65	638.228	0.029545809
1700	0.17	0.42	409.9163	0.051196609
1200	0.11	0.26	257.7085	0.091415484
835	0.06	0.15	143.5527	0.205087849
437	0.02	0.05	48.42282	0.942431523

20% vol. oil; EDM 244oil-in-water emulsion with 2% wt. surfactant (0.0089 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
152965	0.28	4.81	1729.366	0.009887791
150505	0.28	4.81	1729.366	0.00972877
145585	0.28	4.68	1680.713	0.009963451
140254	0.27	4.54	1632.06	0.010179484
131234	0.24	4.14	1486.102	0.011487653
122214	0.24	4.00	1437.45	0.011434503
108684	0.20	3.46	1242.839	0.013602423
83263	0.16	2.78	999.5749	0.016110269
63452	0.12	2.11	756.3112	0.021444875
62051	0.13	2.24	804.9639	0.018513039
47187	0.11	1.83	659.0057	0.021005166
46405	0.10	1.70	610.353	0.024081405
40929	0.10	1.70	610.353	0.021239571
37017	0.09	1.56	561.7003	0.022681579

33262	0.08	1.29	464.3948	0.029816287
28853	0.07	1.16	415.742	0.032271439
20695	0.05	0.89	318.4366	0.039454629
18005	0.04	0.75	269.7838	0.047822428

20% vol. oil; EDM 244oil-in-water emulsion with 2% wt. surfactant (0.0126 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
166495	0.75	6.32	3214.754	0.010098607
159935	0.73	6.18	3146.022	0.010129201
155015	0.71	6.05	3077.291	0.010261045
151325	0.71	5.98	3042.925	0.010244314
145995	0.70	5.91	3008.559	0.010110558
139434	0.68	5.71	2905.462	0.01035369
131644	0.66	5.58	2836.73	0.010254659
121394	0.64	5.37	2733.633	0.010182917
109094	0.62	5.24	2664.901	0.009629255
96793	0.60	5.04	2561.803	0.009245048
82853	0.59	4.97	2527.438	0.008130224
76409	0.60	5.04	2561.803	0.00729804
67080	0.58	4.90	2493.072	0.006765134
61689	0.56	4.77	2424.34	0.006579299
48282	0.48	4.09	2080.682	0.006990881
41241	0.41	3.48	1771.389	0.008238751
37017	0.37	3.14	1599.56	0.009068909
30133	0.31	2.60	1324.634	0.010764664
31369	0.30	2.54	1290.268	0.011811382
25468	0.24	2.06	1049.707	0.014488174
22431	0.22	1.86	946.6097	0.015691089
20087	0.20	1.66	843.5122	0.017696826
17918	0.17	1.46	740.4148	0.020487484
15314	0.15	1.25	637.3173	0.023634082
13839	0.13	1.12	568.5856	0.026832714
11496	0.12	0.98	499.854	0.028840622
10628	0.10	0.85	431.1224	0.035842653
9066	0.08	0.71	362.3907	0.043271768
5855	0.06	0.51	259.2932	0.05458574
3512	0.04	0.31	156.1958	0.090222506
2383	0.02	0.17	87.46412	0.195291222

20% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0158 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
126314	1.19	6.38	4070.976	0.009973054
117704	1.14	6.12	3906.542	0.010092045
111964	1.11	5.95	3796.919	0.010162206
105813	1.07	5.78	3687.297	0.010183535
99663	1.03	5.57	3550.268	0.01034634
93103	0.99	5.35	3413.24	0.010456936
85723	0.95	5.09	3248.806	0.01062731
79622	0.95	5.09	3248.806	0.009870946
72055	0.89	4.79	3056.966	0.0100892
63763	0.84	4.53	2892.532	0.009972019
55792	0.81	4.36	2782.91	0.009426512
43745	0.75	4.02	2563.665	0.008709198
32584	0.71	3.80	2426.636	0.007240565
25294	0.65	3.50	2234.797	0.006627077
22170	0.57	3.07	1960.74	0.007545752
20434	0.53	2.86	1823.712	0.008039422
18091	0.47	2.52	1604.467	0.009195644
15661	0.40	2.17	1385.221	0.010679829
13318	0.35	1.87	1193.382	0.01223656
11843	0.30	1.61	1028.948	0.014636681
10628	0.28	1.48	946.7309	0.015515514
9413	0.24	1.27	809.7026	0.018786455
8979	0.23	1.23	782.2969	0.019198004
8285	0.20	1.10	700.08	0.022118414
7156	0.17	0.93	590.4573	0.026859393
6028	0.16	0.84	535.646	0.027492342
5421	0.13	0.71	453.4291	0.034499914
4640	0.12	0.62	398.6177	0.038207954
4119	0.10	0.54	343.8064	0.045597471
3598	0.08	0.45	288.9951	0.056375847
2904	0.07	0.37	234.1838	0.069288981
2430	0.05	0.28	179.3725	0.098813626
1599	0.04	0.20	124.5612	0.134819598
717	0.02	0.11	69.74987	0.192747417

20% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.0265 m pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental)
36403	2.54	4.85	5188.679	0.008871454
31977	2.34	4.48	4796.52	0.009119188
29981	2.26	4.33	4633.12	0.009163665
28419	2.18	4.18	4469.72	0.009332893
26162	2.08	3.98	4257.301	0.009470657
24079	1.98	3.80	4061.221	0.0095787
20955	1.84	3.52	3767.101	0.009688369
16529	1.63	3.11	3325.922	0.009803951
10281	1.38	2.64	2819.383	0.008485727
6896	1.18	2.25	2410.883	0.007784429
5855	1.00	1.92	2051.404	0.009128036
5421	0.92	1.76	1888.004	0.009977712
4640	0.78	1.49	1593.884	0.011982665
4032	0.66	1.26	1348.785	0.014542381
3598	0.57	1.09	1169.045	0.017274745
3338	0.52	1.00	1071.005	0.019092962
3176	0.48	0.91	972.9654	0.022012004
3100	0.45	0.86	923.9454	0.023823051
2981	0.43	0.82	874.9255	0.025549712
2947	0.42	0.80	858.5855	0.026229534
2803	0.40	0.77	825.9056	0.026959623
2752	0.39	0.74	793.2256	0.028696206
2515	0.35	0.67	711.5257	0.032587214
2421	0.32	0.60	646.1658	0.038047149
2040	0.26	0.50	531.786	0.047320184
1836	0.21	0.41	433.7461	0.064031343
1514	0.16	0.31	335.7063	0.088130649
1242	0.11	0.21	221.3265	0.166410543
937	0.08	0.15	155.9665	0.252762793

20% vol. oil; EDM 244 oil-in-water emulsion with 2% wt. surfactant (0.023735 m PVC pipe)

ΔP (Pa)	Flow rate (kg/s)	Velocity (m/s)	Reynolds Number	Friction factor (Experimental
53446	2.41	5.74	5501.237	0.008325199
44527	2.18	5.21	4990.419	0.008428589
40459	2.08	4.96	4753.253	0.008441866
35765	1.94	4.62	4424.87	0.008611206
32010	1.82	4.33	4151.218	0.008756698
32845	1.82	4.35	4169.461	0.008906527
29547	1.72	4.10	3932.296	0.009007875
24340	1.54	3.67	3512.696	0.009299066
19393	1.37	3.27	3129.582	0.009334212
16182	1.26	3.00	2874.173	0.00923446
9239	1.09	2.60	2491.06	0.007018994
8198	0.99	2.37	2272.138	0.007485775
7851	0.96	2.30	2199.164	0.007652444
6028	0.77	1.84	1761.32	0.009160542
5594	0.69	1.65	1578.885	0.010579218
5074	0.61	1.46	1396.45	0.01226519
4640	0.56	1.32	1268.746	0.013587768
3859	0.44	1.06	1013.337	0.017714746

2297	0.24	0.58	557.2492	0.034864451
2498	0.25	0.60	575.4927	0.035549993
1650	0.15	0.35	338.3273	0.067933276
1225	0.09	0.22	210.6228	0.130225844
445	0.04	0.09	82.91833	0.305295002