Rheology of Suspensions of Solid Particles in Liquids Thickened by Starch Nanoparticles

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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Abstract

This study explores the rheological characteristics of suspensions containing solid particles dispersed in aqueous matrix phase thickened with starch nanoparticles (SNP). The SNP concentration ranged from 5 to 35 wt% relative to the aqueous matrix phase, while the solids concentration of the suspensions varied from 0 to 57 vol%. Two different size solid particles were used in the experiments. Observations revealed that suspensions at constant SNP concentrations exhibited Newtonian behavior at low solids concentrations but transitioned to non-Newtonian shear-thinning behavior at higher solids concentrations. Notably, an increase in SNP concentration led to an earlier onset of non-Newtonian behavior at lower solids concentrations. The rheological properties of non-Newtonian suspensions were effectively characterized using a power-law model, with the consistency index showing a positive correlation with suspension solids concentration at any given SNP level. Furthermore, the flow behavior index, indicative of shear-thinning behavior, decreased with increasing solids concentration, suggesting an amplification of shear-thinning tendencies in the suspensions. The effect of particle size on the rheological behavior of suspensions was found to be insignificant. Experimental viscosity and consistency data for both Newtonian and non-Newtonian suspensions aligned well with predictions from the Pal model.

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Dedication

I would like to express my gratitude to my family, my husband, Vahid, my parents, Sima and Ghasem, and my sister, Saghar, for their support and encouragement throughout my educational journey. Their belief in my abilities, numerous sacrifices, and constant encouragement have been crucial in achieving this milestone. I am also thankful for the guidance and support from my aunt, Mahtab, who assisted me in navigating my studies. Additionally, I extend my deepest appreciation to my friends and colleagues for their support and motivation during this challenging yet rewarding academic pursuit.

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1. Introduction

Colloidal dispersions consist of particles, droplets, or bubbles dispersed within a different phase, with typical dimensions ranging from 1 to 1000 nanometers. Although colloidal species are conventionally characterized as having sizes between one nanometer and one micrometer, practical applications often extend this upper limit to accommodate diverse requirements, sometimes reaching tens or even hundreds of micrometers. These dispersions encompass phases that may exist in gas, liquid, solid, or supercritical states [1]. Suspensions, a subtype of colloidal dispersions, are complex mixtures distinguished by the presence of two distinct phases. The continuous phase, referred to as the dispersion medium, commonly appears as a liquid or semisolid substance, while the dispersed phase comprises particulate matter that remains largely insoluble in the external medium. Suspensions, encompassing dispersions of rigid particles within liquids, represent a diverse category of materials with significant industrial significance [2], [3]. Suspensions find extensive application across various industries and everyday settings. Within the food industry, they are present in products such as jellies, chocolate drinks, and ice cream. Industrial sectors utilize suspensions in ink, gel, and paint formulations. In biological and medical contexts, they are employed in liniments, protein solutions, polymer-encapsulated drugs, and cough syrups. Additionally, suspensions are integral to cosmetics and personal care products, including exfoliating scrubs and facial masks. Furthermore, they play crucial roles in petroleum production and mineral processing, notably in drilling fluids and industrial process tailings [1], [4], [5].

Despite the multitude of applications for suspensions, they commonly encounter challenges arising from their inherent instability, notably creaming and sedimentation. These instabilities directly affect the shelf life of numerous products [5]. Although sedimentation in suspensions can be beneficial for processes such as purification and settling, the inherent instability of suspensions presents a notable drawback in industries including food, pharmaceuticals, cosmetics, and paints and coatings [6]. The underlying cause of these instabilities lies in gravitational effects, where the differences in density between the suspending medium and particles play a fundamental role. Sedimentation arises when particles are denser than the suspending medium, while creaming occurs when the opposite is true. These instabilities in particle suspensions carry considerable implications for various industries, driving extensive research into stabilization methods. To address these challenges and extend shelf life, rheological modifiers like thickeners are utilized to bolster stability and minimize sedimentation or creaming phenomena [7], [8].

Following Stokes' law, the settling speed of particles inversely correlates with the viscosity of the suspending fluid. Consequently, increasing the medium's viscosity reduces the particles' settling speed, leading to suspension stabilization. This viscosity enhancement can be accomplished by incorporating additives like polymers or surfactants. Within the context of this study, starch nanoparticles are employed to achieve the desired viscosity increase. The Stokes velocity, represented as V, frequently acts as a scaling parameter in sedimentation rate calculations, deriving from Stokes' law, which balances buoyancy and frictional drag forces for individual particles of any shape. Stokes' law is introduced as follows:

$$V = \frac{gD^2 \left|(\rho_p - \rho)\right|}{18\eta_m} \quad (1)$$

V represents the terminal velocity, also referred to as the sedimentation rate as explained earlier. ρ denotes the fluid density, whereas ρ_p indicates the particle density. The symbol g represents the acceleration due to gravity, and D stands for the particle diameter. η_m signifies the viscosity of the matrix phase [8], [9]. The growing interest in nanoparticles stems from their reputation as sustainable materials derived from renewable sources. Nano-sized starch has emerged prominently in various industrial sectors, including medicine, pharmaceuticals, food, and packaging, owing to its favorable characteristics such as biocompatibility, biodegradability, cost-effectiveness, renewable sourcing, and non-toxicity. Despite their potential, nanoparticles, particularly starch nanoparticles, have not received extensive research attention in this context.

This thesis research seeks to investigate the role of starch nanoparticles (SNP) as potential rheology modifiers and thickeners for solids-in-liquid suspensions, addressing a gap in current scientific research [10-14]. Since there has been limited research on the rheology of suspensions comprising solid particles stabilized and thickened by SNP, our study aims to investigate the rheological properties of suspensions containing two different type and size solid particles, both thickened by SNP.

2. Background

2.1. Starch

Starch, a natural and renewable polymer synthesized by various plant species, plays a crucial role as a primary source of stored energy for humans worldwide. Within plants, starch synthesis primarily occurs in specialized organelles called amyloplasts, which are found in tissues such as roots, tubers, and seeds. These amyloplasts produce storage starch, forming discrete granules with diverse shapes including round, oval, ogival, elongated, flat, lenticular, or polyhedral and sizes ranging from sub-microns to over 100 µm in diameter [12-14]. Figure 1 illustrates the varied shapes of starch granules originating from different plant sources. Starch, a natural polymer abundant in multiple renewable plant sources, is produced in quantities that often exceed market demands. As the most economically viable biopolymer and fully biodegradable, it sparks increasing interest in the non-food utilization of starch-based products. This trend is particularly notable in industries where synthetic polymers have historically held sway as the preferred materials [15]. Starch can be found in plant roots, stalks, crop seeds, and staple crops such as rice, corn, wheat, tapioca, and potato. Globally, maize constitutes the primary source, contributing 82% of starch production, followed by wheat (8%), potatoes (5%), and cassava (5%). The starch industry, crucial for extracting and refining starches through methods such as wet grinding, sieving, and drying, produces starch in various forms. Native starch, directly obtained from plants and comprised of smaller units known as granules, maintains its natural properties. The process of obtaining native starch involves cleaning, crushing, and separating plant material to isolate starch granules, which are then dried to form a fine white powder. In contrast, modified starch undergoes chemical modifications aimed at enhancing specific characteristics such as viscosity, stability, or gelatinization. These modifications cater to diverse industrial applications, including food processing, papermaking, textiles, and pharmaceuticals [16], [17].

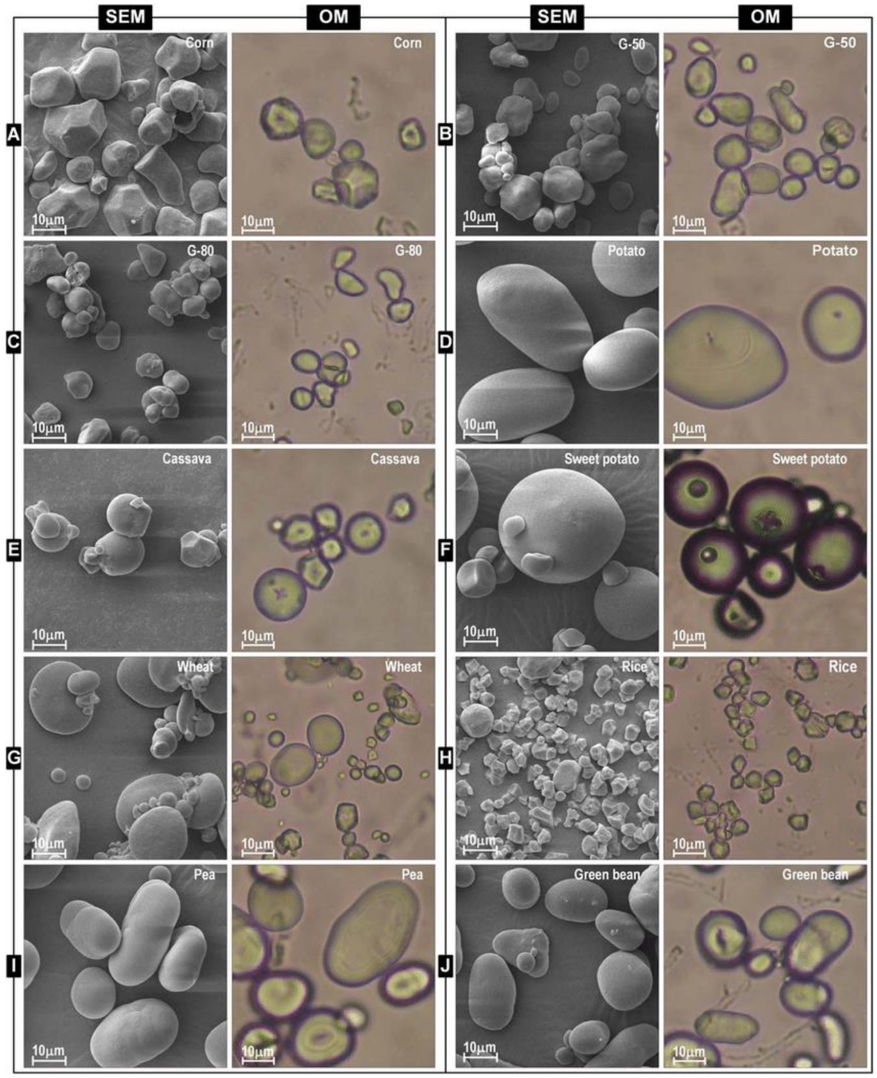


Figure 1 SEM and OM images illustrate starch granules sourced from different plants [18].

2.1.1 Chemical Content of Starch

Starches, classified as polysaccharides, are formed by linking together multiple Monosaccharide (glucose) molecules through glycosidic bonds. Monosaccharides, the simplest form of carbohydrates with the general formula $C_nH_{2n}O_n$, act as fundamental building blocks for more complex carbohydrate structures. Starch granules possess a semi-crystalline arrangement, typically exhibiting a crystallinity ranging from 15% to 45% [19].

Starch consists of two distinct types of glucose molecules, referred to as amylose and amylopectin [20]. Both amylose and amylopectin consist of lengthy chains of glucose molecules connected by α-1,4-glycosidic bonds. While amylose forms a linear chain, amylopectin features branching structures [20]. Figure 2 depicts the chemical structures of amylose and amylopectin.

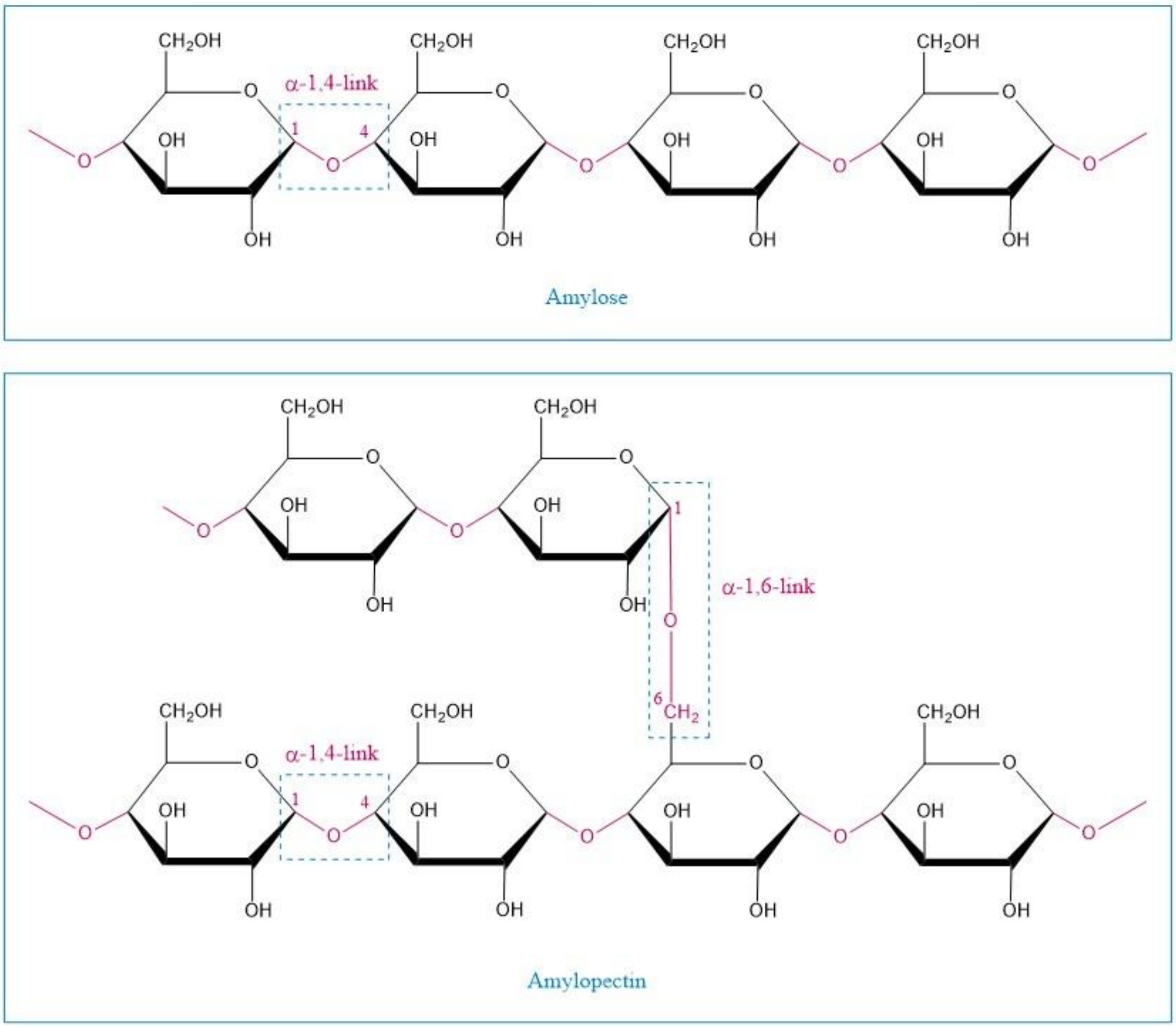


Figure 2 Chemical structures of amylose (linear) and amylopectin (branched), representing the main structural components of starch [21].

Amylose constitutes approximately one-quarter of starch and forms long, linear chains consisting of thousands of glucose units with α-1,4 glycosidic linkages. Upon cooling, amylose molecules associate to form a three-dimensional network, contributing to the gelation of cooked starch pastes. Starches with high amylose content are capable of gelation, retaining their shape when molded. In contrast, starches lacking amylose primarily function as thickeners without forming gels.

Amylopectin, comprising approximately three-quarters of starch polymers, features α-1,4 linkages in its glucose chain, similar to amylose, but with α-1,6 branching occurring every 15-30 glucose units. Unlike amylose, amylopectin molecules do not form chemical linkages upon association, thus unable to create gels. Starches with higher amylopectin content result in more viscous paste formations, while those with greater amylose content exhibit stronger gel properties [20].

2.1.2 Structure of Starch

Starch exhibits a hierarchical structure that varies depending on the botanical origin, encompassing multiple levels of organization. At the macroscopic level, starch granules range from 2 to 100 micrometers in size and display variations in shape and size based on the plant source [17]. These granules consist of concentric growth rings composed of blocklets, further divided into amorphous and crystalline lamellae. Treatment with acid or degrading enzymes can render the concentric rings of starch granules visible, which can be observed using microscopy techniques such as light microscopy, atomic force microscopy, and scanning and transmission electron microscopy (SEM and TEM) [22], [23].

The arrangement of starch granules is complex and subject to extensive research, particularly concerning the crystalline structure. Despite this research, unanswered questions persist, including the specific roles of amylose and amylopectin in determining crystallinity. Amylopectin, a major constituent of starch, is presumed to underpin the crystalline regions within the granule, while the role of amylose in crystallinity remains uncertain. Both amylopectin and amylose potentially contribute to the formation of crystalline structures within starch granules, with amylopectin likely exerting greater influence due to its branching pattern and molecular configuration [12].

Within the solid growth rings of starch granules, a densely packed and orderly amylopectin configuration is observed, derived from the tight alignment of double helices formed between α-1,4 chains. The creation of these double helices serves as a physical mechanism to stabilize adjacent chains, occurring independently of enzyme activity and requiring chains with a minimum of 9 glucose residues. This process is pivotal in defining the crystalline structure of growth rings, with resulting double helices exhibiting behavior akin to biopolymer liquid crystals, arranging into more or less compact configurations known as A-type or B-type structures [24]. Figure 3 depicts the structure of starch.

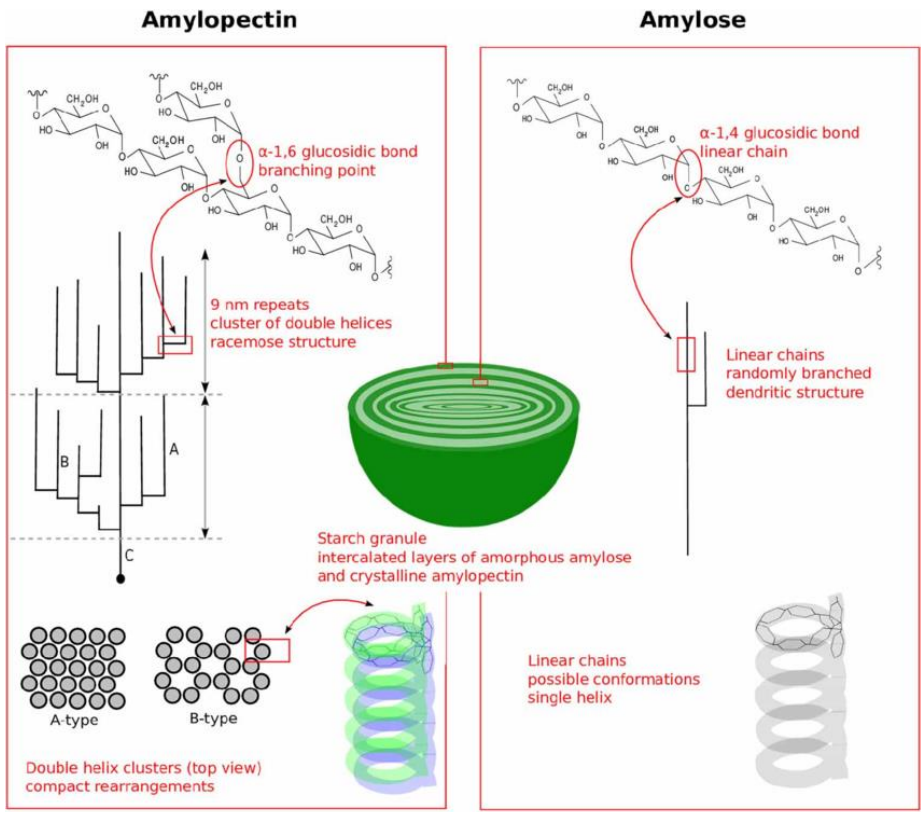


Figure 3 Composition and Structure of Starch Granules [24].

2.2 Nano Starch

Most starch utilized in food or industrial applications undergoes modification before use due to its elevated viscosity, propensity for retrogradation, variable digestibility, and solubility limitations. Therefore, in response to the challenges presented by starch, various modifications are pursued. It is worth discussing one particular type of modification: reducing particle size to the nanoscale, which will be explored in the following [25], [26].

The properties of materials are heavily influenced by the size and internal structure of their components. Nanomaterials, characterized by particle sizes in the nanometer range, display distinct and qualitatively different properties compared to larger particles. Biomaterials, characterized by their internal nanostructures, biocompatibility, and biodegradability, are favored over synthetic polymer-based materials. Given its widespread availability, starch presents a promising option for nanoparticle synthesis [27], [28].

As discussed in previous section, starch granules exhibit a unique structure, comprising concentric layers of alternating amorphous and semi-crystalline growth rings that develop from the granule's hilum [29]. Starch nanocrystals (SNC) form as crystalline platelets when the semi-crystalline structure of starch granules is disrupted. While, the production of starch nanoparticles (SNP) often involves the precipitation of amorphous starch, resulting in modified starch with amorphous properties.

Different methodologies are employed to produce Starch Nanocrystals (SNC), including hydrolysis techniques like acid [16], [30] or enzymatic methods [31], [32], and regeneration through co-crystallization [33]. In contrast, techniques such as cross-linking regeneration [34], [35], mechanical treatments like extrusion [36], or the utilization of microfluidizers [37], are employed to generate starch nanoparticles (SNP), as illustrated in Figure 4 [38]. Approaches involving methods such as acid or enzyme hydrolysis, along with physical treatments, are classified as top-down, while bottom-up methods encompass processes like self-assembly and nanoprecipitation [39].

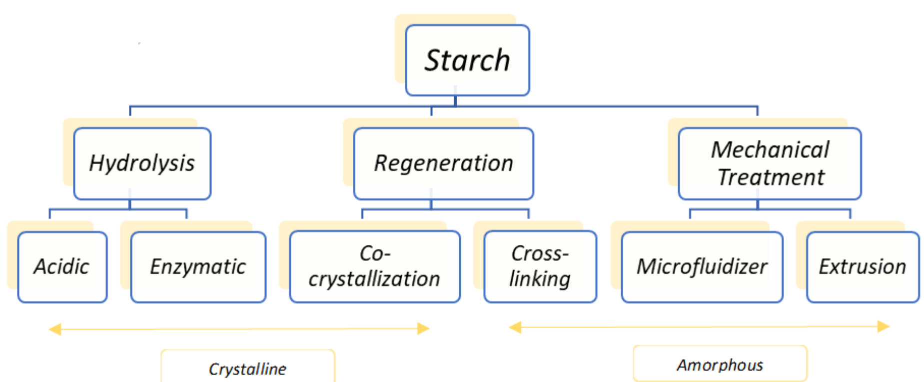


Figure 4 Different Techniques for Fabricating Crystalline and Amorphous Starch Nanoparticles.

2.2.1 Crystalline Nano Starch

Hydrolysis, a chemical process involving the addition of water molecules to a substance, has long been utilized for starch modification and enhancement of its properties. There are two primary methods of hydrolysis employed for producing SNC: acid and enzymatic. Acid hydrolysis is the more widely adopted approach and has been the subject of extensive research in this field. Unlike the crystalline region, the amorphous portion of starch is more susceptible to hydrogen ion action. Thus, through mild acid hydrolysis, the amorphous component is selectively removed from starch granules, yielding nano-scale particles with increased crystallinity, known as starch nanocrystals (SNCs) [40]. The resulting products, including starch crystallites, starch nanocrystals, microcrystalline starch, and hydrolyzed starches, all represent varying degrees of hydrolysis. While these entities share similarities, they differ in the extent of hydrolysis they undergo [38].

Hao et al. conducted research with the objective of improving the preparation efficiency and dispersion of starch nanocrystals (SNCs). Their study revealed a reduction in the duration of acid hydrolysis as a result of enzymatic pretreatment [41]. In recent years, there has been a notable shift towards the exclusive adoption of this method. For instance, Dukare et al. recently conducted research specifically targeting the synthesis of starch nanocrystals through enzyme hydrolysis [39].

Kim and Lim, describe the production of nanocrystals through the co-crystallization method, where crystalline starch nanoparticles were created via complex formation with n-butanol followed by enzymatic hydrolysis. The formation of the amylose–butanol complex, which included substantial amorphous matrices, necessitated the targeted removal of these for isolating the nanoparticles. This process was facilitated by enzymatic hydrolysis, specifically designed to preserve the crystalline particles [33].

2.2.2. Amorphous Nano Starch

Gelatinization is a crucial method for modifying native starch and producing starch nanoparticles. This process significantly affects the functional properties of starch through hydrothermal treatment involving heat and moisture. When raw starch granules are heated in water, their semi-crystalline structure is either reduced or eliminated, resulting in their breakdown and the formation of a dense, viscous solution. The viscosity of this solution is dependent on the source and concentration of the starch. Gelatinization, defined as the breakdown of starch granules in water under heat, plays a pivotal role in starch modification processes [42].

In recent times, mechanical modification methods have gained popularity to fulfill the growing demand for functionally enhanced starches across various industries. These techniques are favored for their environmentally friendly and sustainable characteristics [43]. In the realm of mechanical treatment for native starch, extrusion emerges as a notable method. It is characterized as an energy-efficient technique engineered to break down the structure of starch granules through the application of elevated shear, temperature, and pressure, ultimately promoting starch melting. Giezen et al. patented a method for preparing starch nanoparticles through reaction extrusion. involving the use of a twin-screw extruder and reversible crosslinkers like glyoxal. The findings suggest that by adding appropriate crosslinkers, starch particles with an average size of approximately 160 nm can be obtained [19].

Microfluidization, a process of high-pressure homogenization, utilizes brief yet intense pressure application to reduce particle size. This method induces cavitation, shear, and turbulence simultaneously, as described by Koh et al. making it a dynamic process [44]. In the process of microfluidization, shear forces disrupt the covalent bonds of polymer chains, resulting in what is referred to as the mechanochemical action of homogenization [45]. Liu et al. aimed to produce starch nanoparticles through fluidization. In their study, an upgraded apparatus called the "industry-scale microfluidizer (ISM)" was employed to process potato starch. The ISM treatment significantly altered the structure of potato starch, resulting in changes to its thermal, pasting, and rheological properties [46].

2.3. Applications of Starch nanoparticles

Starch nanoparticles have garnered significant interest in both academic and industrial sectors due to their renewable nature and various advantageous properties. These nanoparticles find applications in diverse fields such as food, pharmaceuticals, cosmetics, and materials science. Starch's increasing popularity stems from its abundance in nature, biocompatibility, and biodegradability, making it an environmentally friendly alternative to conventional materials. Additionally, starch nanoparticles offer unique characteristics such as low density, non-toxicity, ease of surface modification, and functionalization, further contributing to their growing appeal and exploration in various industries.

2.3.1. Pickering Emulsions

Emulsions consist of two immiscible liquids, where one liquid forms a droplet dispersed in the other liquid. The stability of emulsions is often achieved by adding a surfactant, which reduces the tension between the two liquids [47]. Pickering emulsions rely on solid particles, rather than surfactants, to stabilize the interface between the two phases [48]. In fact, in Pickering emulsions, the deposition of solid particles at the interface of liquids is intended to create a barrier that impedes the merging, or coalescence, of droplets. Pickering emulsions are recognized for their compatibility with biological systems, environmental sustainability, and non-toxic nature [49]. They are increasingly valued across diverse sectors such as cosmetics, food, biomedicine, and chemicals [50-53].To be effective, the solid particles in Pickering emulsions need to meet three criteria: they should infiltrate both the continuous and dispersed phases without dissolving in either, their absorption efficiency at the interface must be high, and their size should be smaller than that of the emulsion droplets they stabilize [54], [55].

Starch is considered a viable option as a stabilizer for Pickering emulsions due to its biodegradability and non-toxic properties, making starch granules highly suitable for this purpose. However, employing food-grade starch particles to stabilize Pickering emulsions encounters several challenges. Specifically, native starch granules prove unsuitable due to their pronounced affinity for the water phase and larger particle size. Nano starch emerges as a favorable candidate for stabilizing Pickering emulsions due to its reduced particle size and modifiable hydrophilicity through modifications. Starch-based nanoparticles possess versatile characteristics such as amphipathicity, manageable size, and adaptable surface properties [55].

2.3.2. Suspensions

Suspensions, comprising solid particles dispersed in a liquid, are prevalent in everyday life and industrial applications. They find extensive use across various industries such as food, cosmetics, paints, ceramics, pulp and paper, petroleum, construction, pharmaceuticals, mineral processing, polymers, biotechnology, biomedicine, and more. Suspensions can experience instabilities, like creaming and sedimentation, caused by gravitational forces arising from differences in particle and suspending medium densities. The rheology of suspensions can be adjusted to minimize instabilities by increasing the viscosity of the suspending fluid or matrix phase. This is commonly accomplished through the addition of polymers, surfactants, and clays. Additionally, nanoparticles are being investigated as potential rheological modifiers for suspension matrix fluids. Starch nanoparticles (SNP) are attracting significant interest across multiple scientific and technological domains owing to their distinctive characteristics at the nanoscale. Moreover, SNP are economical, renewable, biocompatible, and biodegradable nanomaterials, aligning with the principles of sustainable development [8].

2.3.3. Pharmaceutical industry

The utilization of nanotechnology in addressing degenerative diseases, encompassing their diagnosis, monitoring, and management, has gained significant traction in recent times. Particularly, nanomedicine is spearheading research endeavors towards precise targeting and delivery of diagnostic, therapeutic, and pharmaceutical agents. Collaborative efforts between scientists, engineers, and physicians are directed toward meeting diverse requirements, spanning from laboratory development to practical pharmaceutical applications. Presently, drug delivery systems are being engineered to modify both the pharmacokinetic and pharmacodynamic profiles of medications, while also serving as reservoirs for the drugs they transport. Recent investigations into biodegradable starch-based polymers have unveiled their potential for a variety of biomedical applications. These materials possess a diverse range of properties that make them suitable for use in fields such as bone implants, drug delivery systems, and tissue engineering scaffolds. Additionally, starch nanoparticles (SNPs) have garnered significant interest in pharmaceutical applications due to their biocompatibility, biodegradability, and potential for controlled drug release [56].

3. Literature review

3.1 Fundamentals of Rheology

Rheology is the branch of science that investigates how materials respond to applied forces, particularly focusing on their deformation and flow properties. It encompasses the study of various substances, including liquids, solids, and viscoelastic materials, to understand their behavior under different conditions such as temperature, pressure, and shear rate [57]. In general, the assessment of rheological behavior involves subjecting a material to controlled and precisely defined deformation or strain over a specific duration. Concurrently, the resulting force response is measured (or vice versa). This method yields valuable insights into material parameters such as stiffness, modulus, viscosity, hardness, strength, or toughness [58]. This field is crucial in numerous industries, including manufacturing, food processing, cosmetics, and medicine, where understanding material flow and deformation is essential for product development and quality control [59].

In Figure 5, we illustrate a configuration comprising two large parallel plates, each possessing an area denoted as A and separated by a distance labeled as Y.

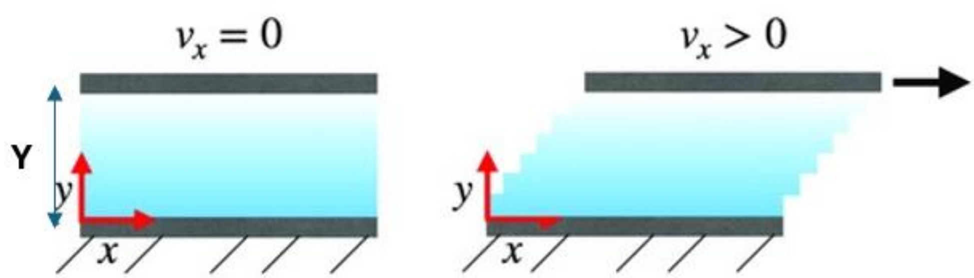


Figure 5 Graphical illustration of one directional shear flow.

Positioned between these plates is a fluid, which could be either gas or liquid. Initially, the system is stationary, but at time t = 0, the lower plate is initiated into motion in the positive x direction at a constant velocity V. As time progresses, the fluid gradually acquires momentum, resulting in the establishment of a linear steady-state velocity profile, as depicted in the figure. It is crucial for the flow regime to remain laminar, characterized by a regular, organized motion akin to the pouring of syrup, as opposed to turbulent flow observed in high-speed mixers. Once the state of steady motion is attained, a constant force denoted as F becomes necessary to sustain the motion of the lower plate. It is logical to express this force in the following manner:

$$Shear\ Stress = \frac{F}{A} \propto \frac{V}{Y} \tag{2}$$

$$\frac{F}{A} = \mu \frac{V}{Y}$$

This implies that the force should be directly proportional to the area and the velocity, and inversely proportional to the distance between the plates. The constant of proportionality, denoted as μ, is a characteristic property of the fluid, known as viscosity.

As a consequence of the linear velocity profile, Equation 2 can be reformulated to apply to an infinitesimal segment of fluid, representing the differential form of this equation:

$$Shear\ Stress = \tau_{y,x} = -\mu \frac{dV}{dY} \tag{3}$$

$$Shear\ rate = \gamma = \frac{dV}{dY}$$

Shear stress is denoted by the symbol τ, which represents a force exerted in the negative direction on a unit area perpendicular to the y-axis. The negative sign indicates that the shear stress opposes the direction of motion of a faster-moving fluid. Equation 3, also recognized as Newton's Law of Viscosity, asserts that the shear force per unit area (shear stress) is directly proportional to the negative velocity gradient [60], [61].

3.2 Flow Behaviour of Suspensions

One of the most ubiquitous rheological parameters encountered is viscosity, particularly in the context of suspensions, where it holds vital significance in describing their flow behavior. Fluids can be categorized into two main groups based on their flow behavior: Newtonian and non-Newtonian. Understanding these behaviors is crucial for optimizing processes in various industries.

3.2.1. Newtonian Fluids

For a Newtonian fluid, the plot depicting shear stress versus shear rate, known as the flow curve, forms a straight line with a slope represented by μ. The constant μ, also known as the Newtonian viscosity, represents the ratio of shear stress to shear rate. As per its definition, this viscosity remains unaffected by changes in shear rate or shear stress, being solely determined by the material's properties, as well as its temperature and pressure. Newtonian fluids exhibit behavior consistent with Equation 3, known as Newton's Law of Viscosity, wherein the relationship between shear stress and shear rate remains linear [62].

3.2.2 Non-Newtonian Fluids

A non-Newtonian fluid is identified by its flow curve, where the relationship between shear stress and shear rate deviates from linearity. An example of flow curves for Newtonian and non-Newtonian fluids is illustrated in Figure 6. In non-Newtonian fluids, the apparent viscosity, does not remain constant under fixed temperature and pressure conditions. Rather, it is contingent upon various flow conditions such as flow geometry and shear rate [62]. Non-Newtonian fluids can be further classified into categories such as shear-thinning, shear-thickening, viscoelastic, and plastic fluids, depending on how their viscosity changes under different conditions [63-65].

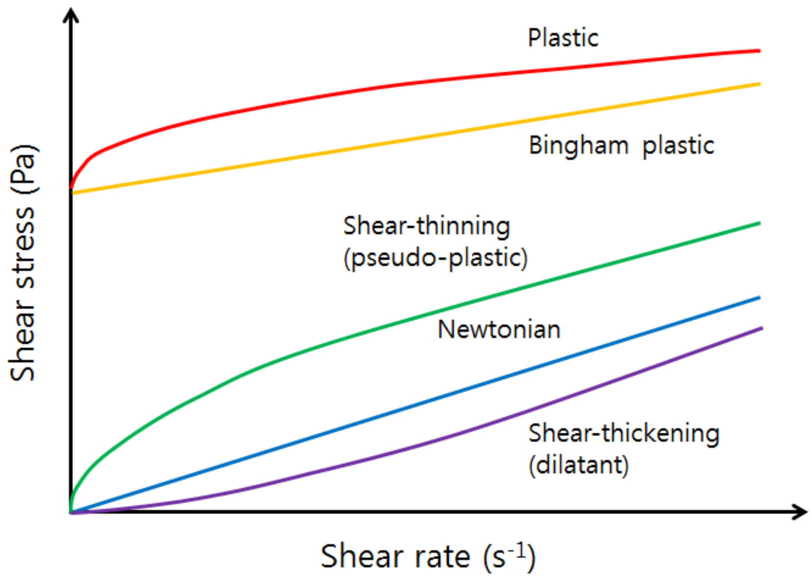


Figure 6 Flow behavior diagrams of Newtonian and non-Newtonian materials [66].

When suspensions are subjected to shear rate, they can exhibit two distinct types of non-Newtonian behavior: shear thinning, Shear thinning, commonly encountered in engineering applications, is the prevailing type of time-independent non-Newtonian fluid behavior. It is characterized by a gradual decrease in apparent viscosity (η) with increasing shear rate, and shear thickening, marked by an increase in viscosity with shear rate. This non-Newtonian behavior is believed to originate from the arrangement of suspended particles and their mutual interactions within the suspension. Specifically, in non-Newtonian suspensions displaying shear thinning or shear thickening behavior, the deviation from Newton's Law of Viscosity is often described using models such as the power law model. This model allows for a quantitative understanding of how viscosity varies with shear rate in these complex systems, providing valuable insights into the underlying mechanisms governing their flow behavior. This model will be further discussed in the following section [67].

3.3. Power Law Model

The power law model, also known as the Ostwald-de Waele model, is a fundamental mathematical framework extensively employed in rheological studies to elucidate the relationship between viscosity (η) and shear rate (γ) in non-Newtonian fluids, particularly those exhibiting shear-thinning behavior. This Relationship is formulated as:

$$\tau = K\gamma^{n} \tag{4}$$

Where τ represents the shear stress, K denotes the consistency index, γ signifies the shear rate, and n denotes the flow behavior index.

In this model, the consistency index (K) reflects the fluid's resistance to flow, while the flow behavior index (n) quantifies the extent of shear thinning. By utilizing a log-log plot depicting viscosity against shear rate, we can generate a linear representation that facilitates the determination of both the flow behavior index (n) and the consistency index (K). These indices can be ascertained from the slope and intercept of the plot, respectively.

A value of n less than 1 indicates significant shear thinning behavior, wherein viscosity diminishes as shear rate increases. Conversely, a value of n greater than 1 denotes shear thickening behavior, with viscosity increasing as shear rate rises. When n equals 1, the fluid behaves as a Newtonian fluid, maintaining constant viscosity irrespective of shear rate. Table 1 illustrates various values for the power-law index and the corresponding fluid behavior they indicate [62].

Table 1 Power Law index values for different fluid behaviour

Power-Law Index (n)	Corresponding Fluid Behavior
n < 1	Shear Thinning Fluid
n = 1	Newtonian Fluid
n > 1	Shear Thickening Fluid

Thus, the apparent viscosity for a power law fluid can be expressed as:

$$\eta = \frac{\tau}{\gamma} = K\gamma^{n-1} \tag{5}$$

3.4 Stability of Suspensions Thickened by Starch Nanoparticles

Sedimentation and creaming are typical occurrences in suspensions and emulsions, representing the natural tendency of particles or droplets to either settle to the bottom or rise to the top of a fluid under the influence of gravitational forces. This process occurs due to the density disparity between the dispersed phase and the surrounding medium, leading to the separation of components based on their respective densities. Sedimentation often results in the formation of a sediment layer at the bottom of the container, while creaming leads to the accumulation of a concentrated phase at the top. Sedimentation and creaming are typically considered undesirable phenomena in various products, as they can significantly impact the shelf-life and overall quality. According to some estimates, sedimentation and creaming can lead to product instability, compromising its appearance, texture, and functionality. This instability may result in product separation, uneven distribution of ingredients, and altered sensory characteristics, ultimately reducing consumer satisfaction and market appeal. Moreover, these phenomena can also impact product performance and efficacy, leading to potential issues such as reduced effectiveness of active ingredients or compromised functionality in formulations such as emulsions and suspensions. As a result, manufacturers often invest considerable efforts in formulating products to minimize sedimentation and creaming, employing strategies such as particle size optimization, stabilizer incorporation, and proper storage conditions to ensure product stability and quality over time [68], [69].

As per Stokes' Law, the settling velocity of particles decreases as the viscosity of the surrounding fluid increases. This phenomenon results in the stabilization of suspensions. Stokes' Law pertains to the movement of solid particles within a fluid medium under conditions of low Reynolds numbers, specifically describing the behavior of small particles in such systems.

The forces acting on the particle are gravity force (F_G), drag force (F_D), and buoyancy force (F_B).

The net force acting on the particle is given by:

$$F_{net} = m\frac{dU}{dt} = F_G - F_D - F_B \tag{6}$$

$$m\frac{dU}{dt} = mg - \frac{mg\rho}{\rho_p} - \frac{C_D A_P \rho U^t}{2} \tag{7}$$

In the equation 7, C_D denotes the drag coefficient, and A_P represents the projected area of the particle measured in a plane perpendicular to its motion, where ρ_p is the particle density. By setting the net force to zero ($F_{net} = 0$) we establish the condition for the terminal velocity, as the particle ceases to accelerate when the net force acting upon it reaches equilibrium. When substituting the particle mass (m), the projected area (A_P), and the drag coefficient (C_D) into the equation 7, particularly when Reynolds number (Re) is less than 1, the terminal velocity of particles can be derived.

For spherical particles:

$$m = \frac{\pi D_p^3 \rho_p}{6} \ and \ A_P = \frac{\pi D_p^2}{4} \tag{8}$$

In the regime of creeping flow around a spherical particle where the Reynolds number (Re_P) is less than 0.1, the drag coefficient (C_D) is determined by Stokes' Law as:

$$C_D = \frac{24}{Re_p} \tag{9}$$

Therefore, utilizing the expression, the terminal settling velocity of spherical rigid particles can be derived:

$$U_t = \frac{g D_P^2 (\rho_P - \rho)}{18\mu} \tag{10}$$

Hence, as demonstrated in the equation 10, this increase in viscosity can be achieved by introducing additives such as polymers or surfactants. In the scope of this investigation, starch nanoparticles are utilized to attain the targeted enhancement in viscosity [9].

4. Materials and Methods

4.1. Materials

Two sets of experiments were conducted, each utilizing a suspension made with a distinct solid particle. Firstly, SG hollow spheres, also referred to as extendospheres, supplied by Sphere One, Inc. of Chattanooga, Tennessee, were employed. These commercially available hollow ceramic particles are known for their low density, high strength, and widespread use as lightweight additives across various resin systems. They effectively replace heavier and more expensive additives, thereby reducing material costs and overall density. SG hollow spheres find application in specialty cements, cementitious coatings, grouts, insulating roofing materials, high strength anchoring compounds, adhesives, mastics, industrial coatings, and thermoset coatings.

Secondly, commercially available S-32 solospheres, also supplied by Sphere One, Inc., were utilized. These microsphere ceramic particles possess a semi-solid texture, offering exceptional properties such as durability, heat resistance, and corrosion protection. They are easily dispersible in high intensity mixing setups, making them valuable for a variety of applications including flame-resistant materials, refractory castings, coatings, self-leveling cements, and more.

The liquid matrix was thickened using starch biopolymer nanoparticles obtained from EcoSynthetix Inc. in Burlington, Ontario, Canada. These nanoparticles are created via reactive extrusion, a method that alters native starch through a combination of mechanical and chemical processes. This customized approach yields starch biopolymer nanoparticles suitable for diverse applications.

In experiments, a non-ionic surfactant, Triton X-100, supplied by the Dow Chemical Company, was utilized.

To prevent bacterial growth in the dispersion, a biocide was incorporated. Specifically, Thor Acticide GA from Thor Specialties, Inc., Shelton, CT, USA, was utilized. Additionally, deionized water served as the solvent in all experiments.

4.2. Preparation of SNP Dispersions

To prepare SNP dispersions, we initially mixed 1wt% surfactant, 0.15 wt% biocide, and 98.85 wt% deionized water to form a solution, with the biocide serving as protection against bacterial growth.

Subsequently, SNP powder was added at concentrations ranging from 5 to 35 wt%. This dispersion process occurred at room temperature, around 22°C, and involved agitating the mixture in a homogenizer (Gifford-Wood, model 1L, NOV process and flow technologies, Dayton, OH, USA) for 40-45 minutes to ensure thorough mixing. After homogenization and the removal of any entrapped air, the dispersion was left to settle overnight. It's important to note that "dispersion" refers to the blend of SNP and the aqueous phase before the addition of solid particles, while "suspension" describes the mixture of SNP dispersion and solid particles.

4.3. Preparation of Suspensions of SG solid particles in SNP dispersions

At room temperature (approximately 22°C), suspensions consisting of solid particles (SG hollow spheres) in SNP dispersion were meticulously prepared. This involved the gradual addition of a specified quantity of solid particles to a known amount of SNP dispersion, while ensuring gentle mixing using a homogenizer. Following the addition of the required solid particles, the mixture underwent high-speed shearing in the homogenizer for a minimum of 30 minutes. The process of suspension preparation is depicted in Figure 7. Subsequently, the prepared suspension was left overnight to facilitate the removal of any trapped air during the homogenization process. For the preparation of suspensions with higher solids concentration, a similar procedure was followed, with the gradual addition of solid particles to an existing suspension of lower concentration, followed by high-speed shearing in the homogenizer for approximately 30 minutes.

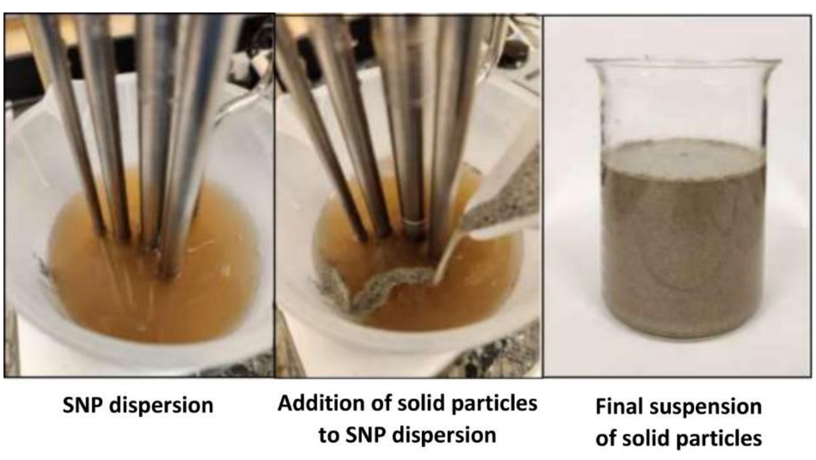


Figure 7 Creating a suspension of solid particles (specifically SG hollow spheres) within an SNP dispersion.

Table 2 provides comprehensive information regarding the compositions of Suspensions of SG Particles in Starch Nanoparticle (SNP) Dispersion, as investigated in this study.

Table 2 Compositions of Suspensions of SG Particles in SNP Dispersion.

SNP Concentration in the Dispersion Medium (wt%)	SG Particle Concentration in Suspension (wt%)	SG Particle Concentration in Suspension (vol%)
9.89	Fourteen concentrations: 5, 10, 15, 20, 25, 28, 31, 34, 37, 39, 41, 43, 45, 47	Fourteen concentrations: 6.78, 13.32, 19.62, 25.69, 31.55, 34.97, 38.32, 41.60, 44.82, 46.93, 49.01, 51.06, 53.08, 55.08
14.83	Thirteen concentrations: 5, 10, 15, 20, 25, 28, 31, 34, 37, 40, 42, 44, 46	Thirteen concentrations: 6.90, 13.53, 19.91, 26.04, 31.95, 35.39, 38.76, 42.05, 45.27, 48.43, 50.49, 52.53, 54.54
19.75	Eleven concentrations: 5, 10, 15, 20, 25, 30, 35, 38, 41, 44, 47	Eleven concentrations: 7.02, 13.75, 20.21, 26.40, 32.36, 38.08, 43.59, 46.79, 49.93, 53.00, 56.00
24.71	Twelve concentrations: 5, 10, 15, 20, 25, 28, 31, 34, 37, 40, 42, 44	Twelve concentrations: 7.15, 13.98, 20.46, 26.73, 32.73, 36.22, 39.62, 42.94, 46.18, 49.34, 51.41, 53.44
29.67	Eleven concentrations: 5, 10, 15, 20, 25, 28, 31, 34, 37, 40, 42	Eleven concentrations: 7.28, 14.22, 20.84, 27.16, 33.21, 36.71, 40.12, 43.45, 46.70, 49.86, 51.93
34.60	Ten concentrations: 5, 10, 15, 20, 25, 28, 31, 34, 37, 40.01	Ten concentrations: 7.41, 14.46, 21.17, 27.56, 33.65, 37.17, 40.60, 43.94, 47.19, 50.36

4.4. Preparation of Suspensions of S-32 solid particles in SNP dispersions

Following the preparation of SNP dispersions, we gradually introduced known concentrations of solid particles, specifically S-32 solospheres, to form well-mixed suspensions. This process entailed slowly adding solid particles while continuously agitating the mixture using a homogenizer. Once all solid particles were added, the homogenization process continued for an additional 40 minutes. Subsequently, the suspensions were left undisturbed for at least 3 hours to allow any trapped air to escape.

To account for the temperature increase resulting from mixing, the suspensions were initially prepared at 22°C (room temperature). The 3-hour resting period ensured that the suspensions returned to room temperature, ensuring stability for subsequent measurements.

To achieve higher concentrations, we incrementally added more solid particles to existing suspensions with lower concentrations. This gradual addition continued until reaching a concentration where the mixture transitioned from a suspension to a more solid-like paste, making further homogenization impractical.

Table 3 provides comprehensive information regarding the compositions of Suspensions of S-32 Particles in Starch Nanoparticle (SNP) Dispersion, as investigated in this study.

Table 3 Compositions of Suspensions of S-32 Particles in SNP Dispersion.

SNP Concentration in the Dispersion Medium (wt%)	S-32 Particle Concentration in Suspension (wt%)	S-32 Particle Concentration in Suspension (vol%)
5	Nineteen concentrations: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 62, 64, 66, 68, 71, 73, 75	Nineteen concentrations: 2.30, 4.74, 7.32, 10.07, 12.99, 16.10, 19.43, 22.99, 26.81, 30.93, 35.37, 40.18, 42.22, 44.32, 46.50, 48.76, 52.30, 54.76, 57.32
10	Twenty-six concentrations: 5, 10, 15, 20, 25, 28, 31, 34, 37, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58, 60, 63, 66, 69, 72, 75, 77	Twenty-six concentrations: 2.23, 4.57, 7.04, 9.65, 12.41, 14.15, 15.94, 17.81, 19.74, 21.74, 23.12, 24.53, 25.98, 27.47, 28.99, 30.57, 32.18, 33.84, 35.55, 37.30, 40.03, 42.88, 45.87, 48.99, 52.27, 54.55
15	Twenty concentrations: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 58, 61, 64, 67, 69, 71, 73, 75, 77	Twenty concentrations: 2.14, 4.38, 6.75, 9.25, 11.88, 14.66, 17.61, 20.74, 24.07, 27.61, 31.39, 33.78, 36.27, 38.87, 41.58, 43.45, 45.39, 47.38, 49.43, 51.54
20	Seventeen concentrations: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 58, 61, 64, 66, 68, 70	Seventeen concentrations: 2.68, 5.49, 8.45, 11.57, 14.85, 18.32, 21.98, 25.86, 29.98, 34.35, 39.01, 41.95, 45.01, 48.19, 50.39, 52.65, 54.98

25	Seventeen concentrations: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 58, 61, 64, 66, 68, 70	Seventeen concentrations: 2.74, 5.62, 8.65, 11.82, 15.17, 18.69, 22.41, 26.34, 30.49, 34.91, 39.59, 42.55, 45.62, 48.81, 51.01, 53.26
30	Thirteen concentrations: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 58, 61	Thirteen concentrations: 2.81, 5.75, 8.84, 12.07, 15.48, 19.06, 22.83, 26.80, 31.01, 35.46, 40.17, 43.14, 46.21
35	Nine concentrations: 5, 10, 15, 20, 25, 30, 35, 40, 45	Nine concentrations: 2.87, 5.88, 9.03, 12.33, 15.78, 19.42, 23.24, 27.27, 31.51

4.5. Measurements

4.5.1. Viscosity Measurements

Rheological assessments were carried out using Fann and Haake co-axial Couette viscometers. The Fann Model 35 viscometers are available in both six-speed and twelve-speed variants, providing direct-reading capabilities. With a rotational velocity range spanning from 0.9 to 600 revolutions per minute (rpm), these instruments are well-suited for evaluating the rheological properties of fluids, irrespective of their Newtonian or non-Newtonian nature. Operating as Couette rotational viscometers, they function by encapsulating the test fluid within the shear gap formed between an outer cylinder and an inner cylinder (bob), whereby viscosity measurements are derived from the viscous drag induced by the rotating outer cylinder on the fluid. The shear rate can be adjusted by modifying the rotor speed and the rotor-bob combination. Figure 8 depicts the configuration of the Fann Model 35 Viscometer setup.

Figure 8 Fann Model 35 Viscometer setup.

The Haake Rotovisco RV 12 viscometer adopts a coaxial cylinder configuration for precise determination of shear viscosity across various temperatures and shear rates. Featuring a stationary outer cylinder and a rotating inner cylinder (bob), the rotational velocity can be adjusted from 0.01 to 512 rpm. The test fluid is confined within the annular space between these cylinders. Controlled rotation of the bob at a specified speed (rpm) imparts momentum to the adjacent fluid layer. The resistance to flow exhibited by the fluid, directly proportional to its viscosity, is gauged by the torque experienced by the bob. Utilizing the magnitude of this torque, in conjunction with the set rotational speed and the bob geometry, enables computation of crucial rheological parameters such as viscosity, shear rate, and shear stress. The resulting measurements are digitally displayed for streamlined data acquisition. Calibration of the viscometers was performed using a viscosity standard with known viscosities. Figure 9 depicts the configuration of the Haake Rotovisco RV 12 setup. All measurements and calibrations were executed at room temperature, approximately 22°C. Detailed dimensions of the viscometers utilized in this study are provided in Table 4.

Figure 9 Haake Rotovisco RV 12 setup.

Table 4 Relevant dimensions of viscometers used in this study.

Viscometer model	Fann 35 A/SR-12 (low torsion spring constant)	Fann 35 A (high torsion spring constant)	Haake Roto-Visco RV 12 with MV I	Haake Roto-Visco RV 12 with MV II
Radius of the Inner Cylinder, R_i	1.72 cm	1.72 cm	2.00 cm	1.84 cm
Radius of the Outer Cylinder, R_o	1.84 cm	1.84 cm	2.1 cm	2.1 cm
Length of Inner Cylinder	3.8 cm	3.8 cm	6.0 cm	6.0 cm
Gap Width	0.12 cm	0.12 cm	0.10 cm	0.26 cm

4.5.2. Size Distribution and Mean Diameter Measurements

Size Distribution of Solid Particles: The size distribution and average diameter of the solid particles were determined by analyzing photomicrographs obtained using a Zeiss optical microscope equipped with transmitted light. To capture the photomicrographs, dilute suspensions were prepared, and images were taken using the Zeiss optical microscope. Subsequently, the size of the particles was measured from these images.

Size distribution of starch nanoparticles: In this study, Dynamic Light Scattering (DLS) was employed to determine the size of starch nanoparticles (SNP). The measurements were conducted using a Zetasizer Nano zs90 instrument manufactured by Malvern Instruments Ltd. Specifically, the Zetasizer 6.20 software was utilized for both data acquisition and analysis. The SNP samples, comprising a dilute concentration of SNP in water, were tested in ZEN0112 low-volume disposable sizing cuvettes, and analyzed at a standard temperature of 25°C. Prior to analysis, a 120-second equilibration period was observed to ensure optimal sample stability. This method enabled precise and reproducible determination of both the average diameter of SNP particles and the particle size distribution.

5. Results and Discussion

5.1. Analysis and Discussions on the Rheological Properties of SNP Dispersions

Utilizing Dynamic Light Scattering (DLS), data was collected from four different concentrations of Starch Nanoparticle (SNP) dispersions: 0.05, 0.075, 0.085, and 0.09 wt% of SNP. Analysis revealed that the starch nanoparticles within the dispersions exhibited an average diameter of 21.73 nanometers. Figure 10 visually illustrates the particle size distribution of these starch nanoparticles, as determined by the DLS measurements.

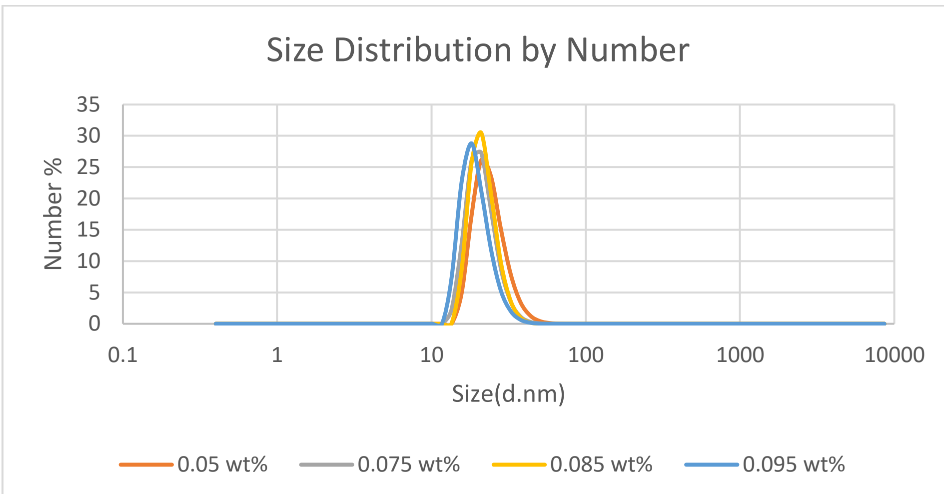


Figure 10 Size distribution of starch nanoparticles.

In this experimental setup, we meticulously prepared SNP dispersions across concentrations ranging from 5 to 35 wt%. As shown in Figure 11, these dispersions exhibit complete uniformity, attributable to thorough agitation with the homogenizer.

Figure 11 Samples of SNP dispersions in the order of increasing SNP concentration from approximately 5 to 35 wt%.

Throughout the analysis of SNP dispersions at various concentrations, consistent Newtonian fluid behavior was observed in the examination of viscosity and shear rate. This indicates that viscosity remains constant as shear rate increases. Newtonian fluids, such as these dispersions, display a linear correlation between shear stress and shear rate, wherein viscosity remains consistent irrespective of the applied shear force. However, it is noteworthy that the viscosity of the dispersion increases with rising SNP concentration. Figure 12 depicts viscosity plotted against shear rate for all SNP dispersions investigated in this study.

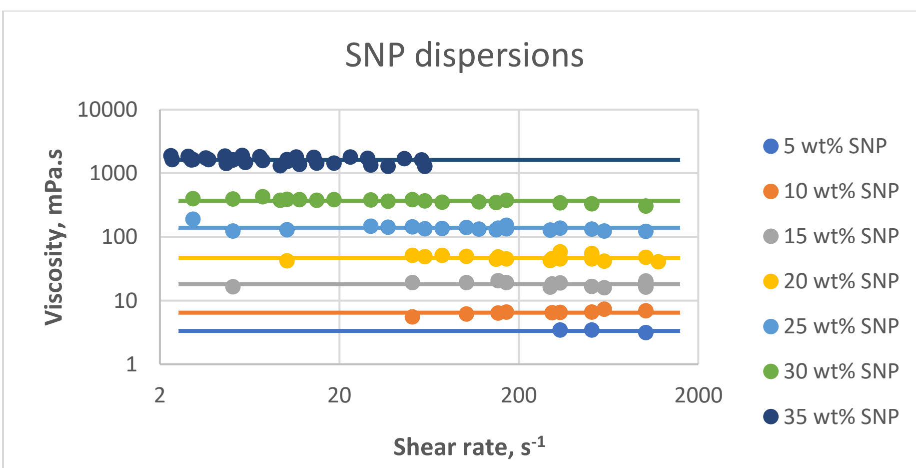


Figure 12 Viscosity versus shear rate plots of SNP dispersions.

5.2. Rheology of Suspensions of SG Particles in SNP Dispersions

Figure 13 displays the particle size distribution of the SG hollow spheres, spanning from 10 to 340 µm. A comprehensive analysis of 500 particles was conducted to establish this distribution, resulting in a calculated Sauter mean diameter of 138 µm. Furthermore, Figure 14 showcases typical photomicrographs depicting the particles within the suspension.

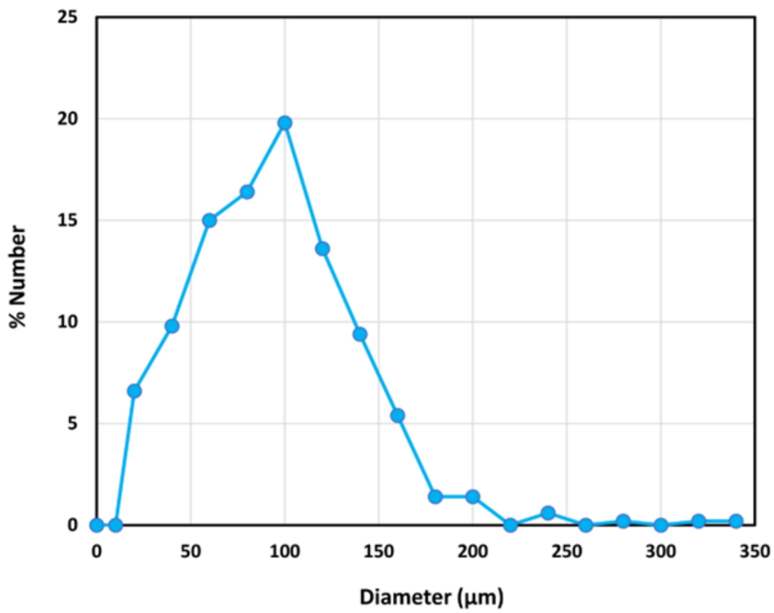


Figure 13 Size distribution of SG particles.

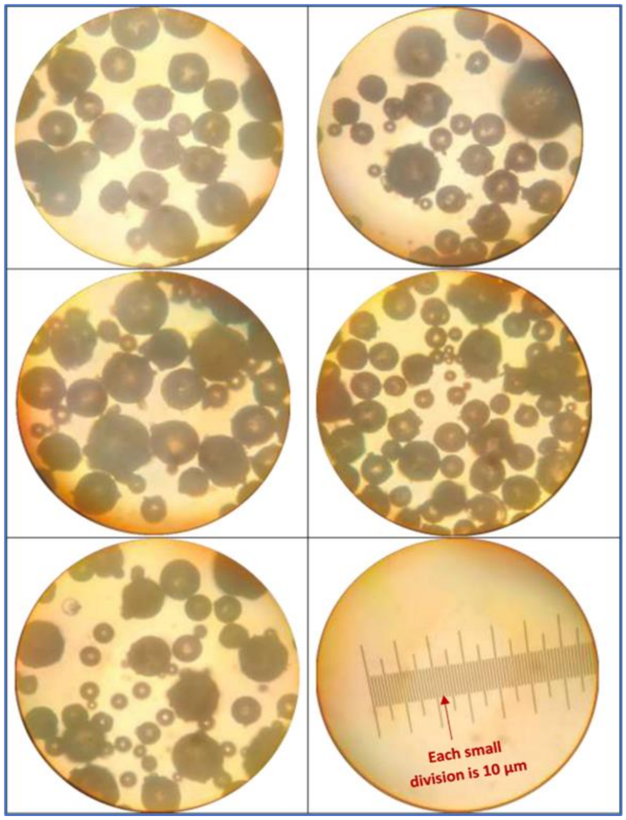


Figure 14 Typical photomicrographs of the SG particles.

Figures 15 through 20 depict the flow curves, illustrating the relationship between viscosity and shear rate, for suspensions comprising SG particles in SNP dispersions. Within each figure, the concentration of SNP remains constant, while the concentration of SG particles varies.

In this manner, we can observe how altering the concentration of SG particles impacts the flow behavior of the suspensions across various SNP concentrations.

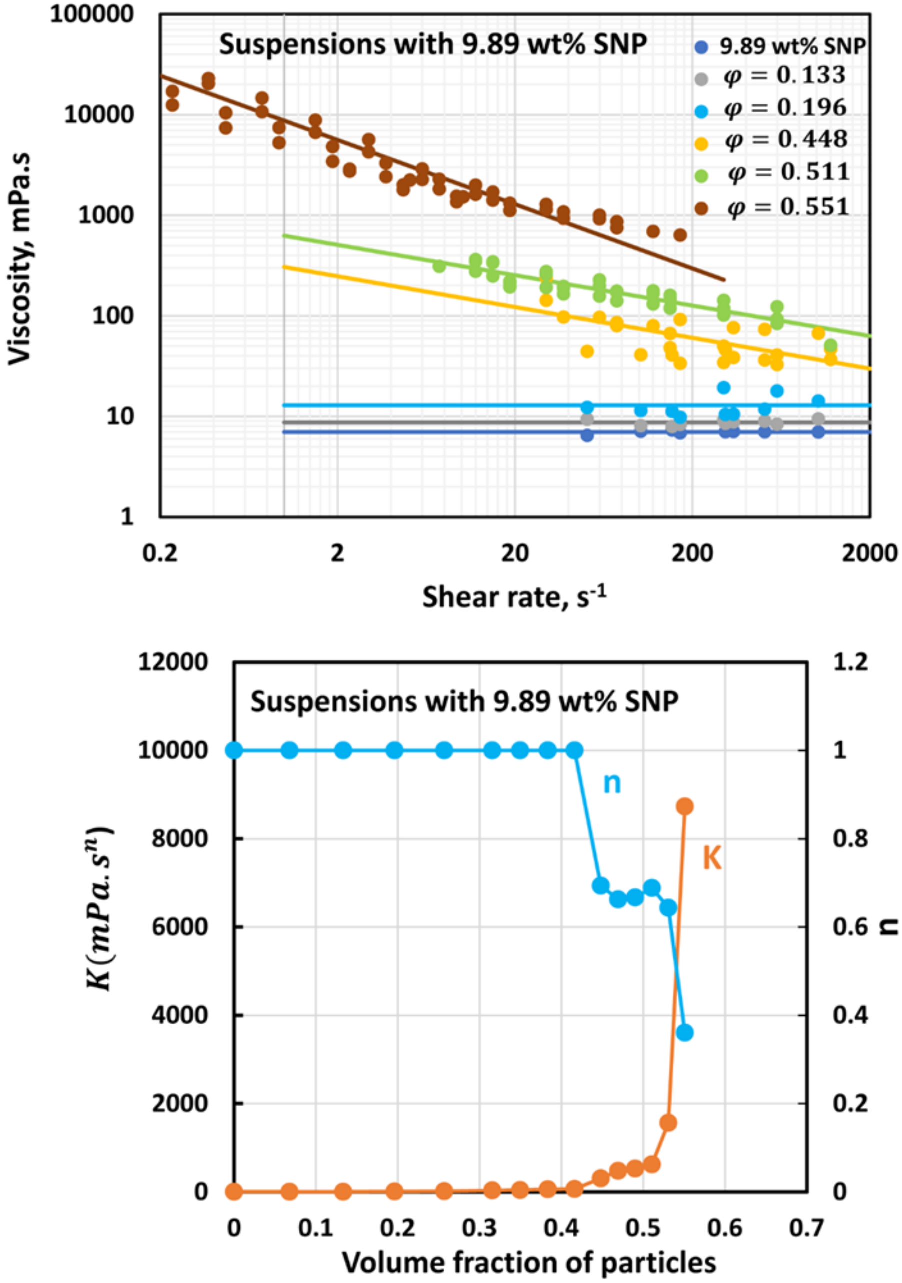
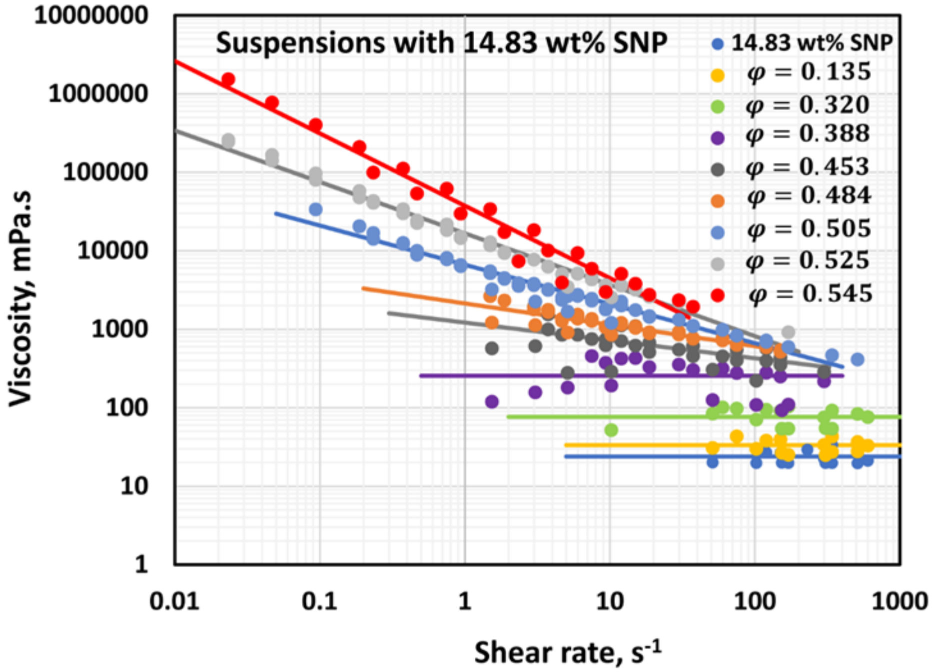


Figure 15 Viscous flow behavior of suspensions at various SG volume fractions (φ) with a constant SNP concentration of 9.89 wt%.



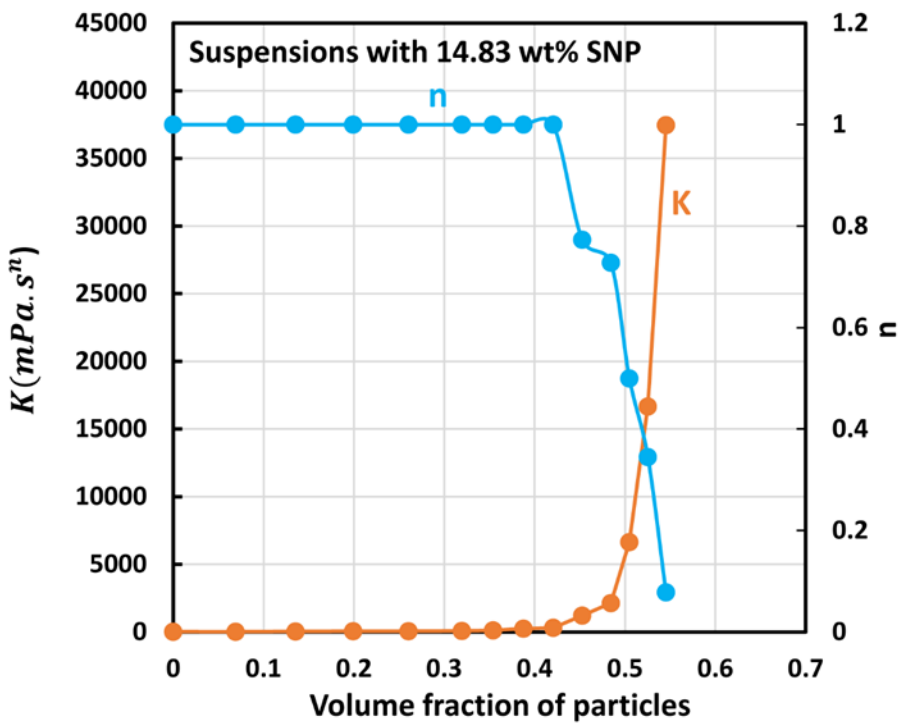


Figure 16 Viscous flow behavior of suspensions at various SG volume fractions (φ) with a constant SNP concentration of 14.83 wt%.

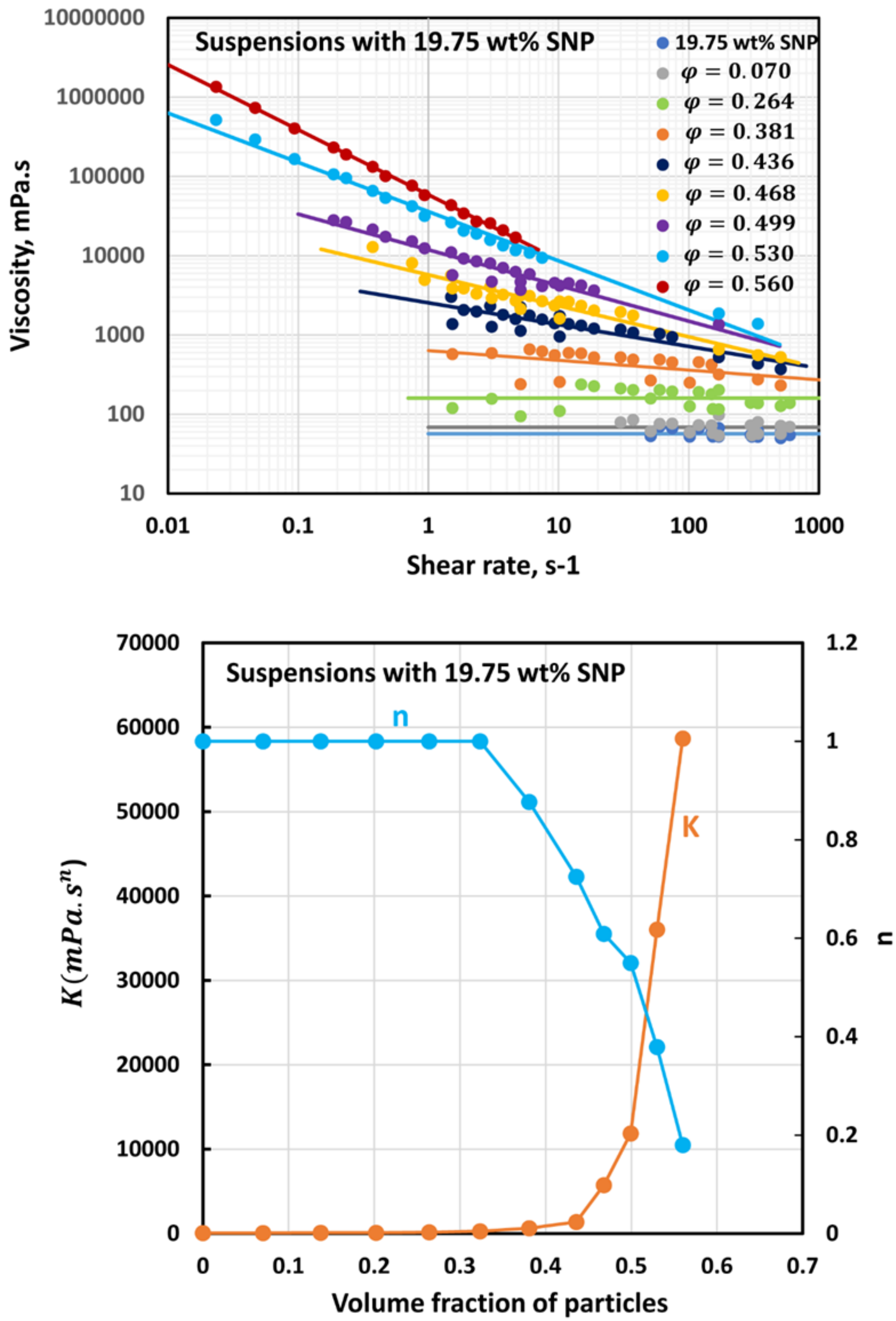
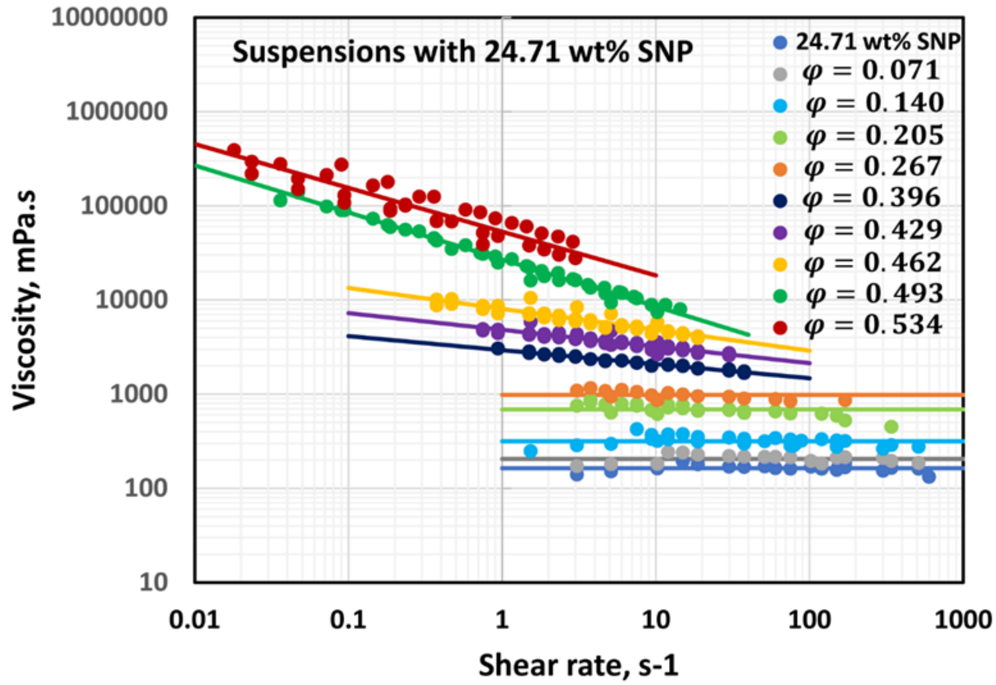


Figure 17 Viscous flow behavior of suspensions at various SG volume fractions (φ) with a constant SNP concentration of 19.75 wt%.



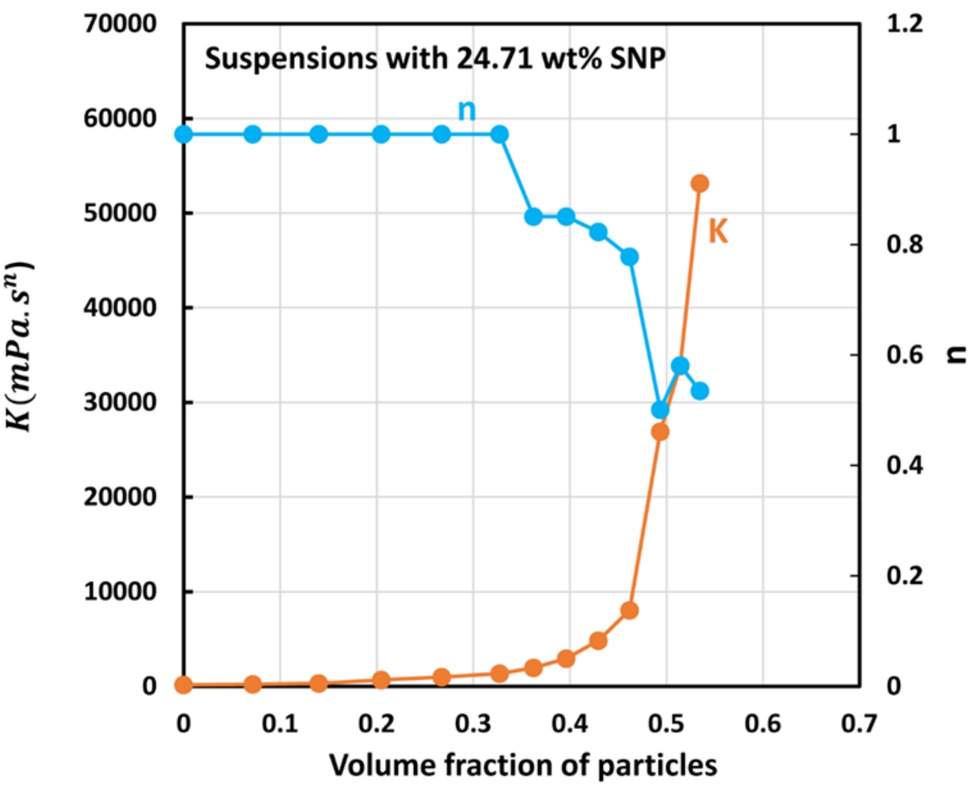


Figure 18 Viscous flow behavior of suspensions at various SG volume fractions (φ) with a constant SNP concentration of 24.71 wt%.

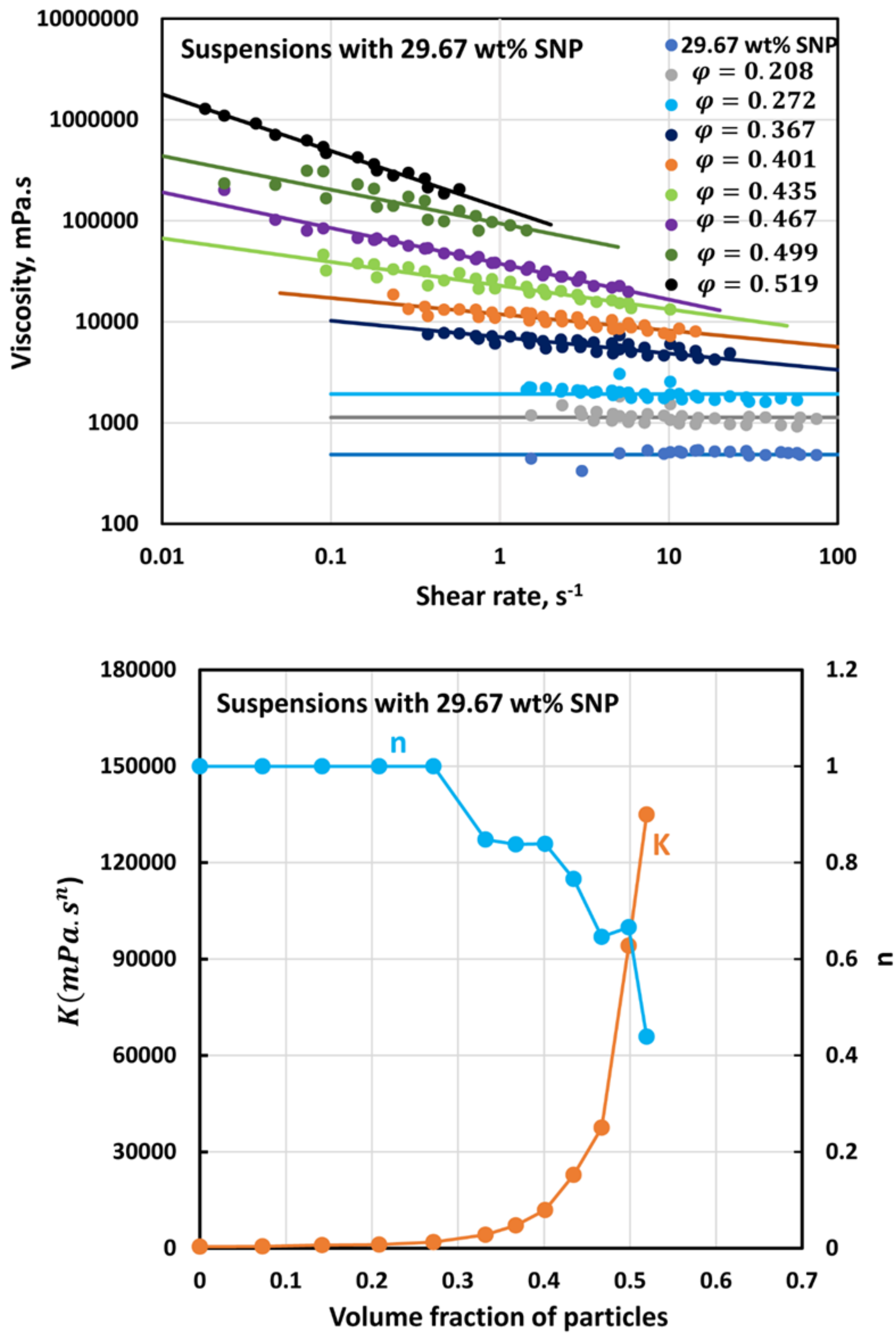


Figure 19 Viscous flow behavior of suspensions at various SG volume fractions (φ) with a constant SNP concentration of 29.67 wt%.

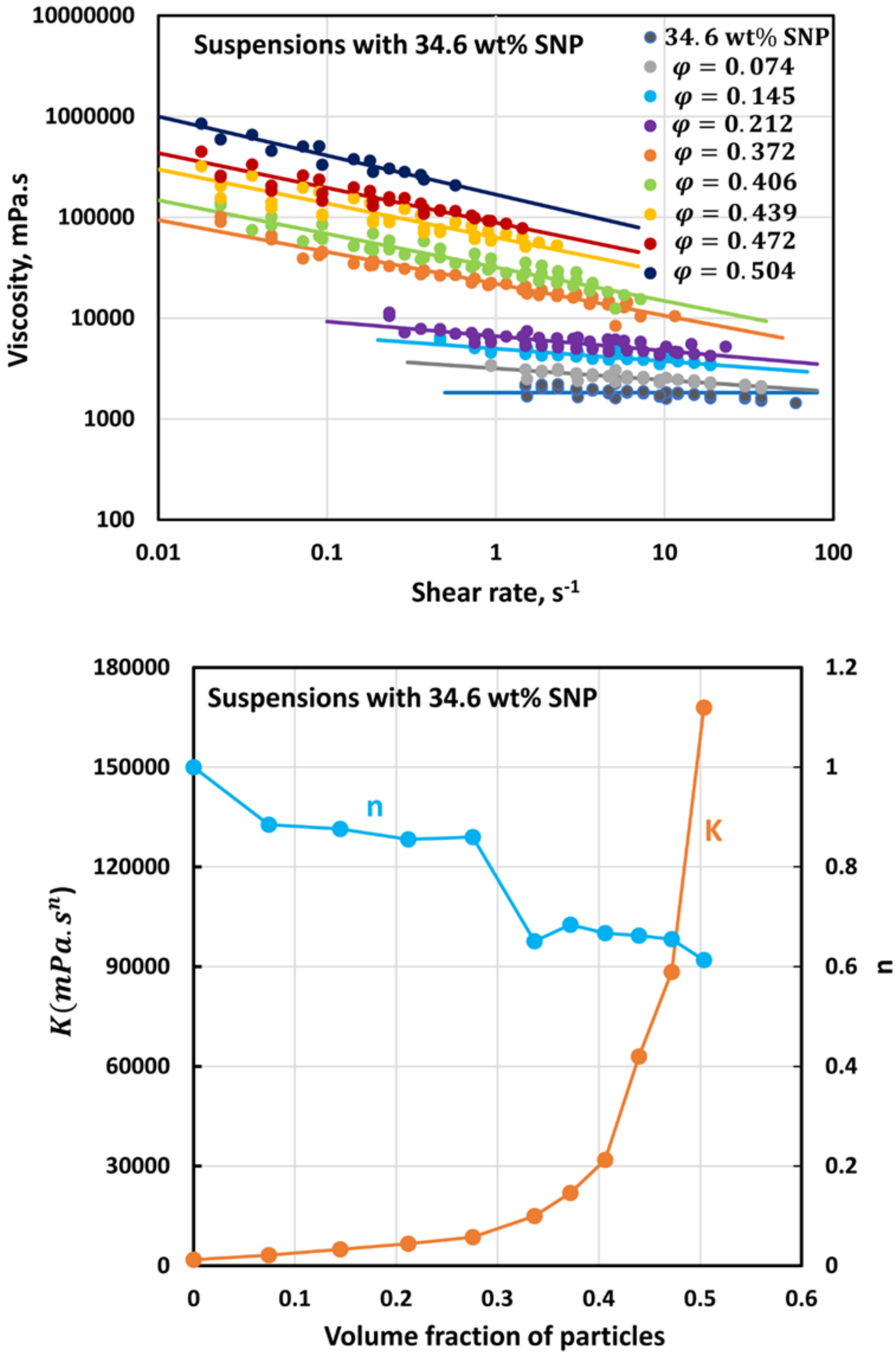


Figure 20 Viscous flow behavior of suspensions at various SG volume fractions (φ) with a constant SNP concentration of 34.6 wt%.

5.3. Rheology of Suspensions of S-32 Particles in SNP Dispersions

Based on the analysis of approximately 1000 particles, the Sauter mean diameter of S-32 particles was determined to be 14 micrometers. Additionally, the size distribution of S-32 particles was found to span from 2 to 20 micrometers. Moreover, Figure 21 presents photomicrographs depicting S-32 particles, acquired within our laboratory setting.

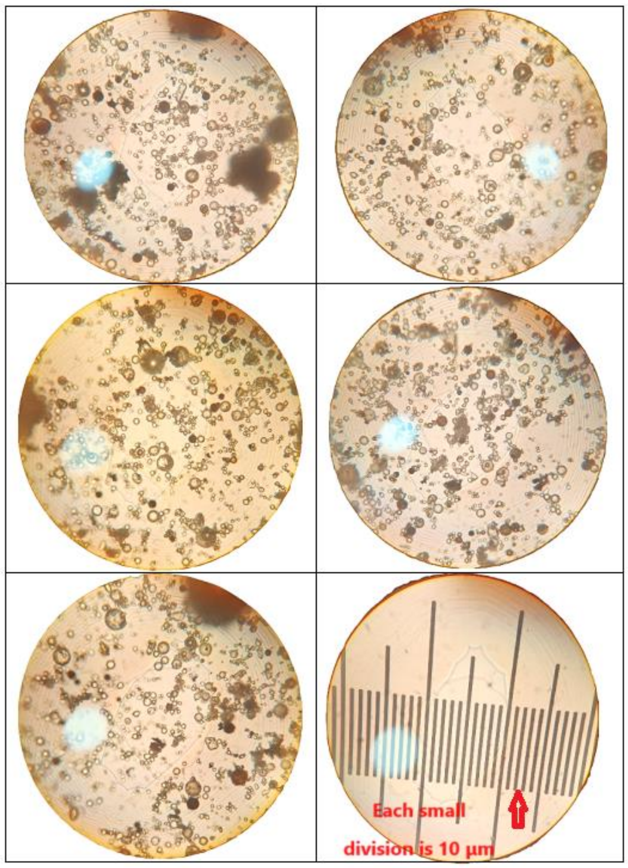


Figure 21 Typical photomicrographs of the S-32 particles.

The methodology employed for SG particles was replicated for S-32 particles. Figures 22 through 2showcase the results derived from these experiments. Each figure illustrates the relationship between viscosity and shear rate for suspensions comprising S-32 particles in SNP dispersions. Across each figure, the concentration of SNP remains constant, while the concentration of solid particles is varied.

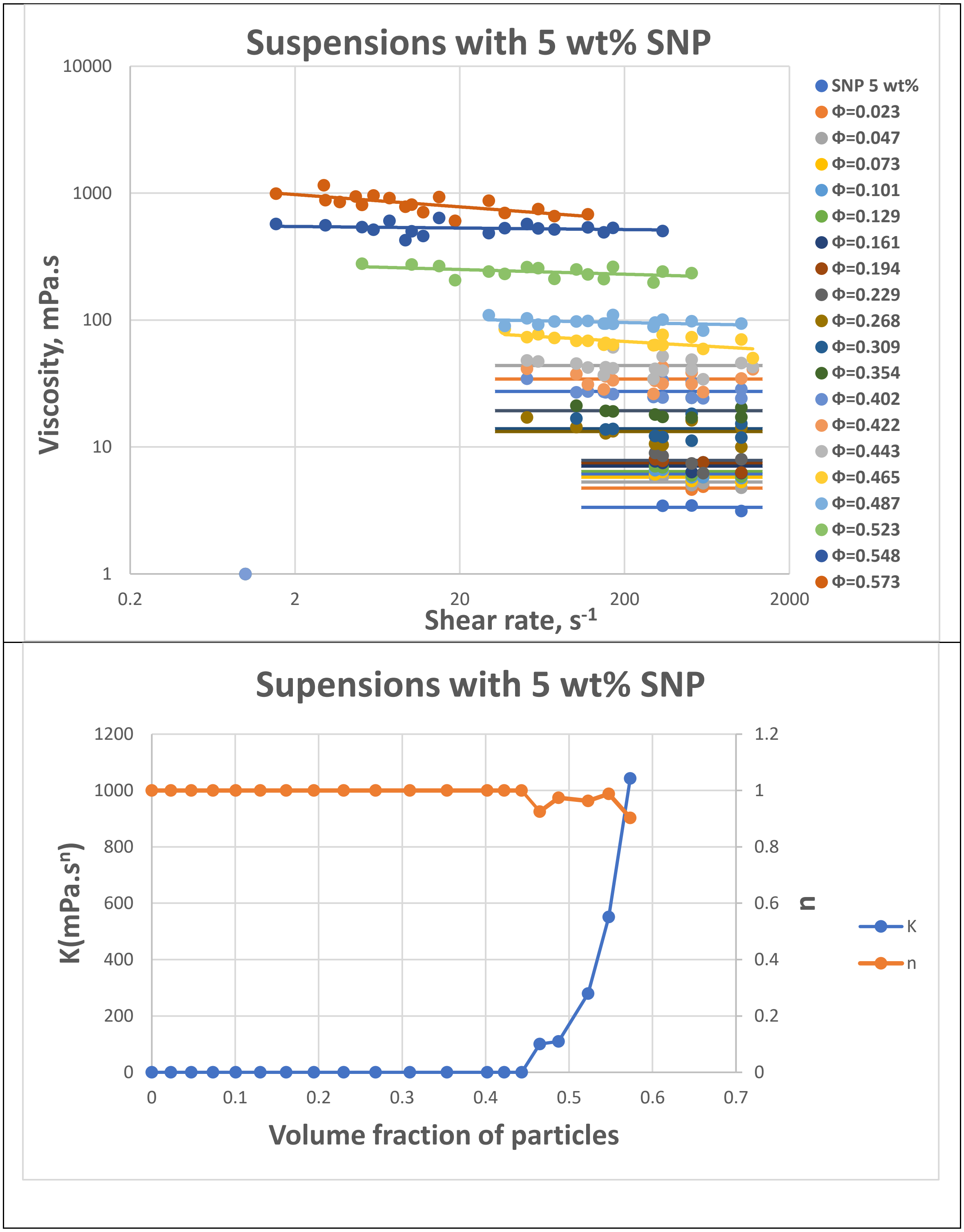


Figure 22 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 5 wt%.

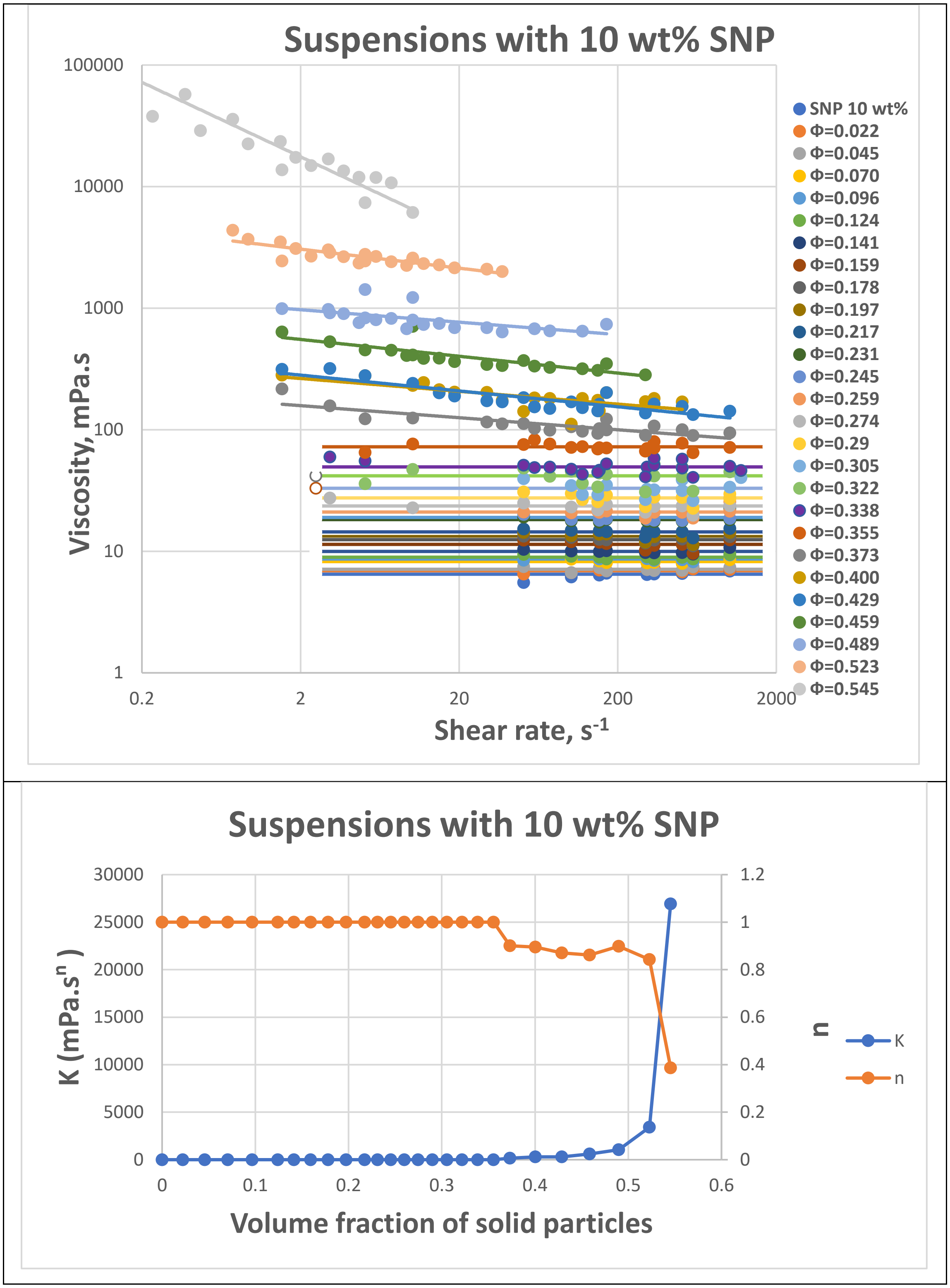


Figure 23 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 10 wt%.

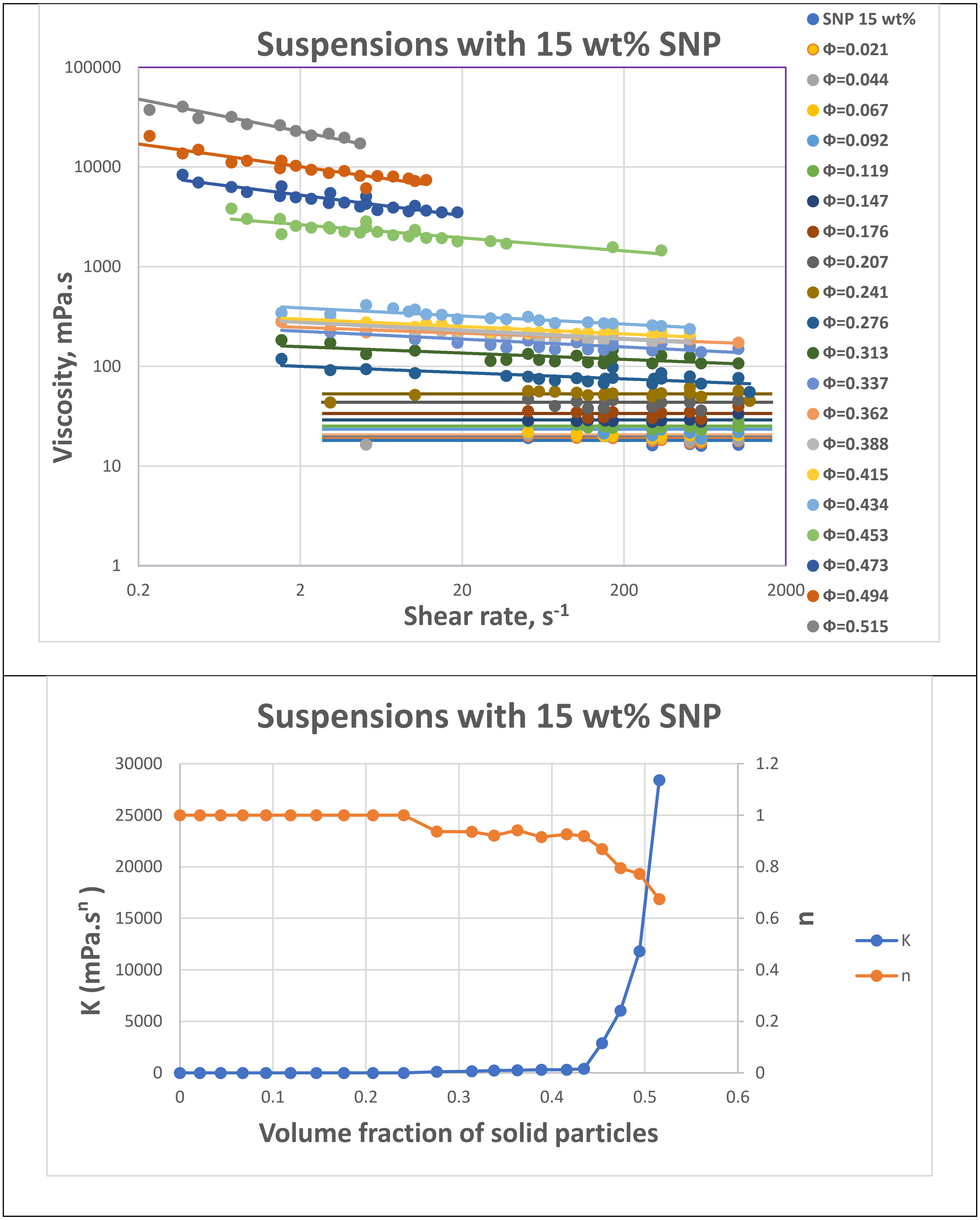


Figure 24 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 15 wt%.

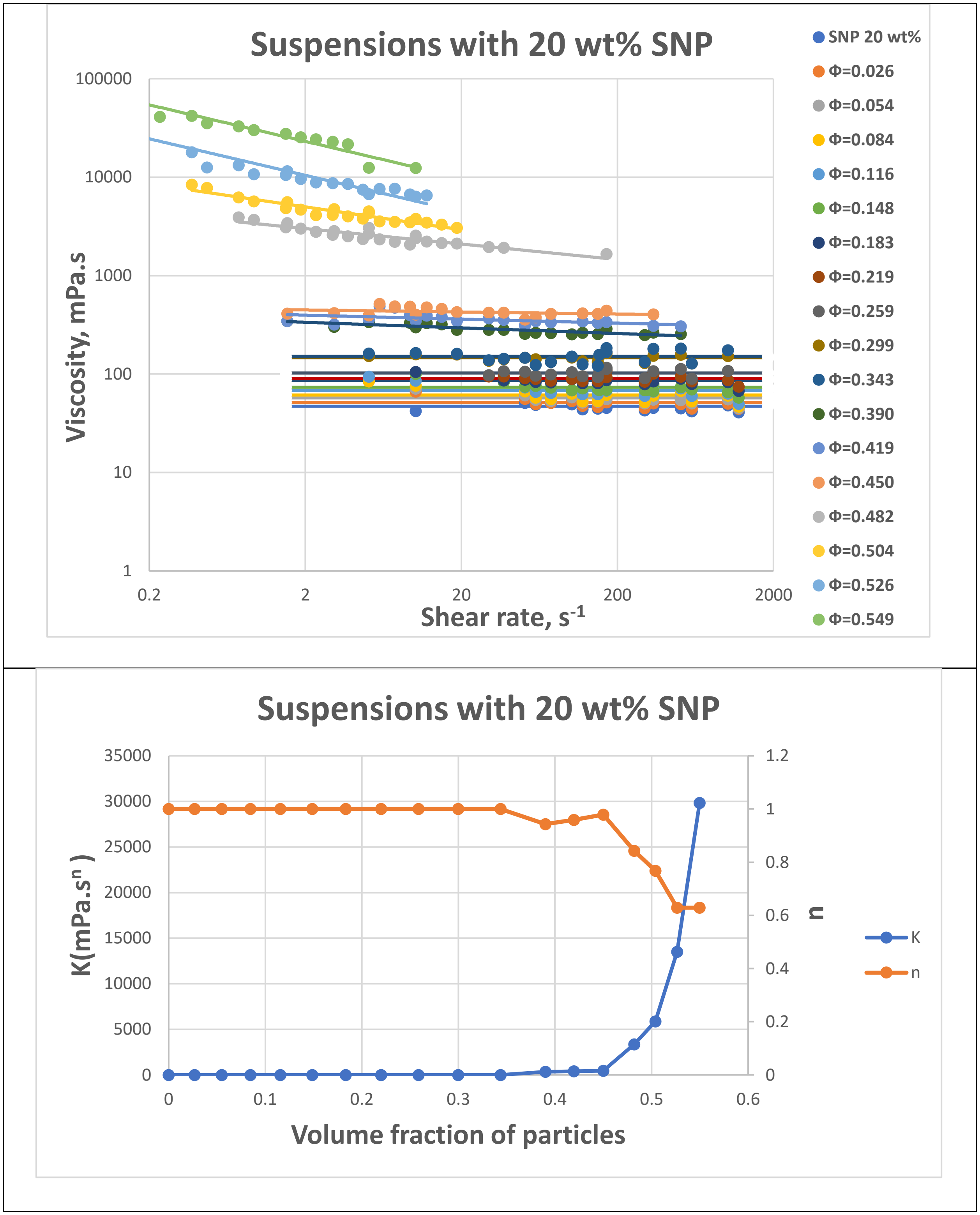


Figure 25 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 20 wt%.

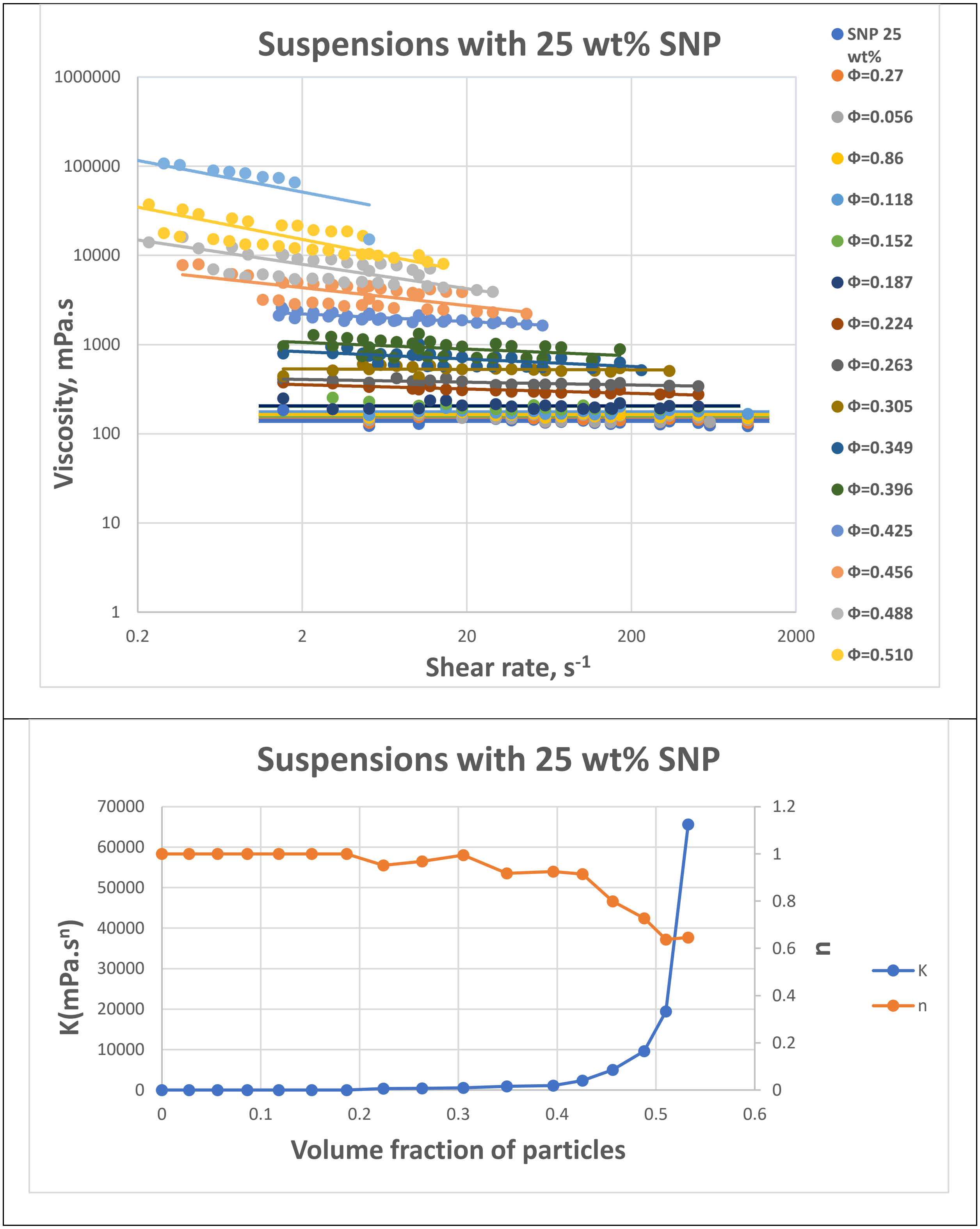


Figure 26 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 25 wt%.

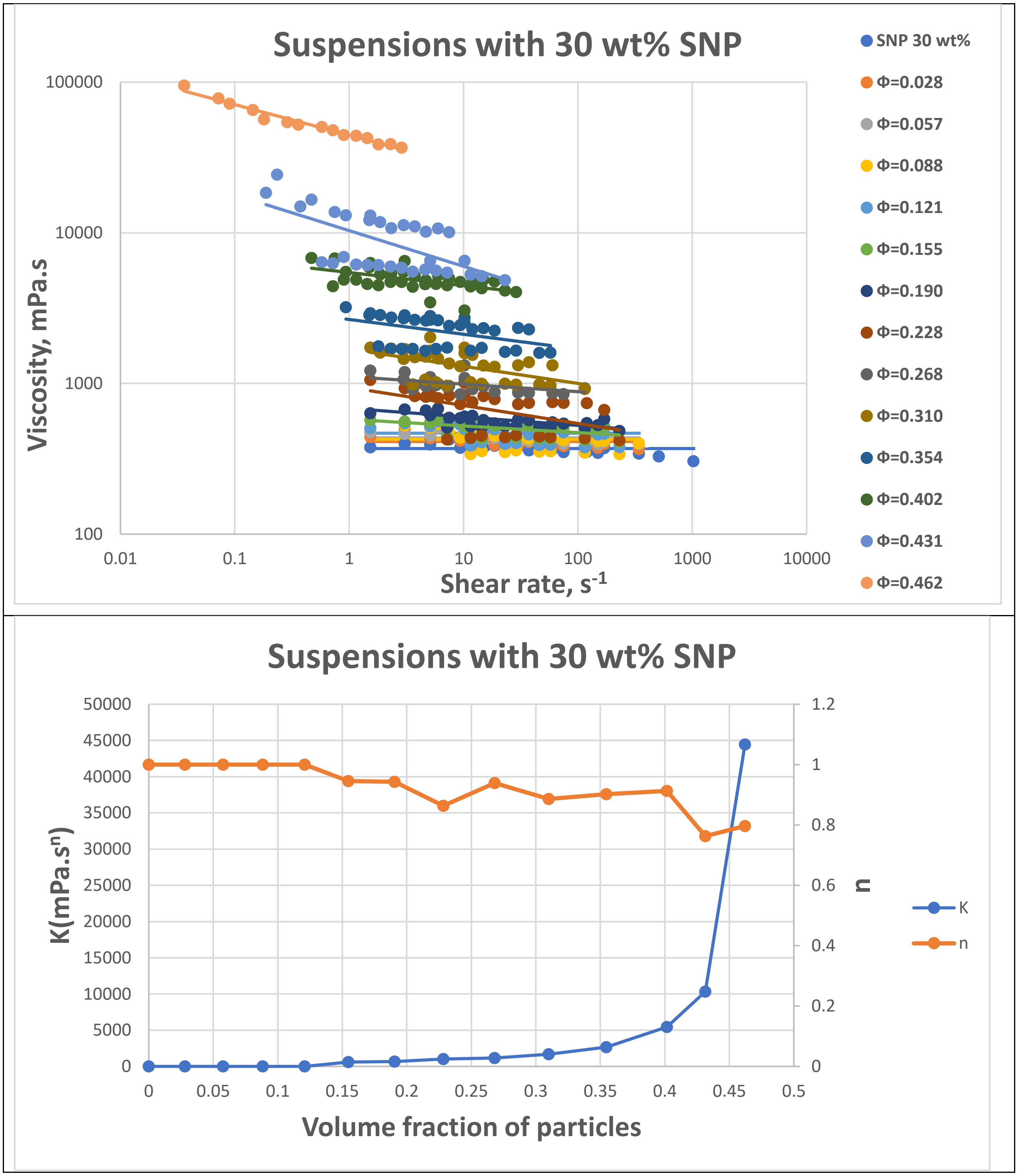


Figure 27 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 30 wt%.

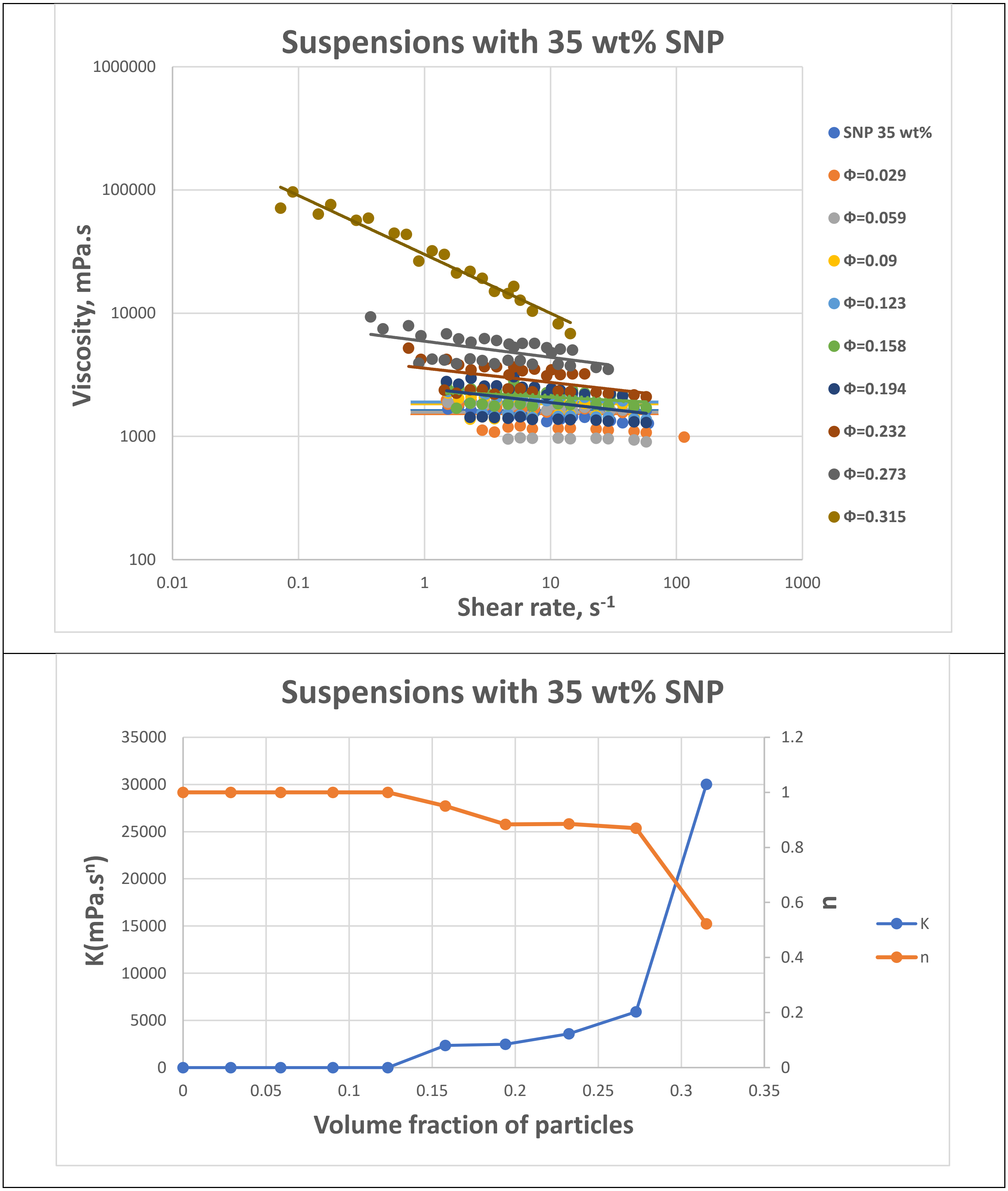


Figure 28 Viscous flow behavior of suspensions at various S-32 volume fractions (φ) with a constant SNP concentration of 35 wt%.

5.4. Analysis and Discussions on the Rheological Properties of Suspensions of Solid Particles in SNP Dispersion

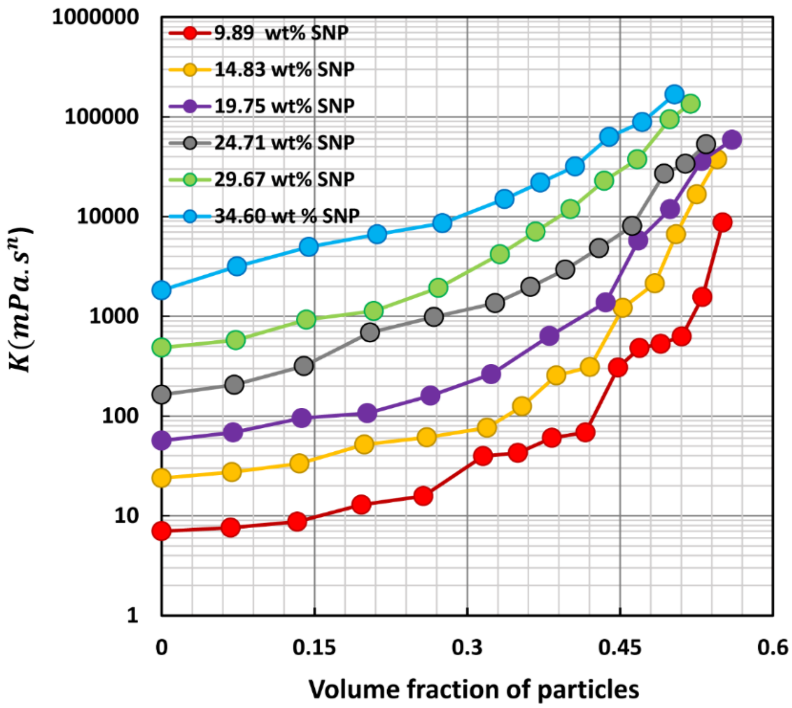
The depicted behavior in the graphs aligns well with the predictions of a power law model, as expressed by Equation 4.

Some of the key findings observed through the plots include:

- Within each SNP concentration, suspensions with lower solid concentrations exhibit Newtonian behavior, where viscosity remains constant regardless of shear rate. However, an increase in solid particle concentration leads to shear-thinning behavior, resulting in decreased viscosity with higher shear rates. Notably, both the degree of shear thinning and viscosity at high shear rates increase with higher SG and S-32 concentration.
- Across all plots with increasing SNP concentrations, distinct patterns emerge. At lower SNP concentrations, most suspensions demonstrate Newtonian behavior, while non-Newtonian behavior is observed in fewer cases, primarily at higher solid particle concentrations. However, as SNP concentration rises, even suspensions with lower solid particle concentrations show shear-thinning behavior.
- With increasing SG and S-32 concentration within each SNP concentration, the consistency index (K) increases while the flow behavior index (n) decreases, indicating a shift towards shear-thinning behavior.

Figure 29 and 30 illustrates the trend of the consistency index (K) and the behavior index (n) across all suspension sets with varying SNP concentrations. With a constant solid particle concentration, an increase in SNP concentration results in a noticeable rise in the consistency index. Moreover, there is a clear transition towards non-Newtonian shear-thinning behavior in suspensions with lower solid particle concentration as the SNP concentration increases. The increase in the consistency index as the particle volume fraction rises is a foreseeable outcome, as particles serve as impediments to flow, resulting in heightened flow resistance and consistency. Additionally, elevating the SNP concentration in a suspension with a fixed particle volume fraction leads to an increase in the viscosity of the matrix fluid (as illustrated in Figure 12). This relationship is widely acknowledged, with suspension viscosity being directly proportional to the viscosity of the matrix fluid. Hence, the viscosity, and consequently the consistency index K, of the suspension correspondingly increase.

At lower shear rates, particles collide and aggregate, trapping the matrix fluid within these aggregates and consequently increasing the viscosity of the suspension. With increasing shear rates, these aggregates break up, resulting in a decrease in viscosity. The rise in volume fraction of particles likely contributes to the observed enhancement of shear-thinning behavior and the reduction in the flow behavior index n of the suspension, as it is probable that these changes are caused by the formation and subsequent breakup of particle aggregates under shear flow conditions [70].



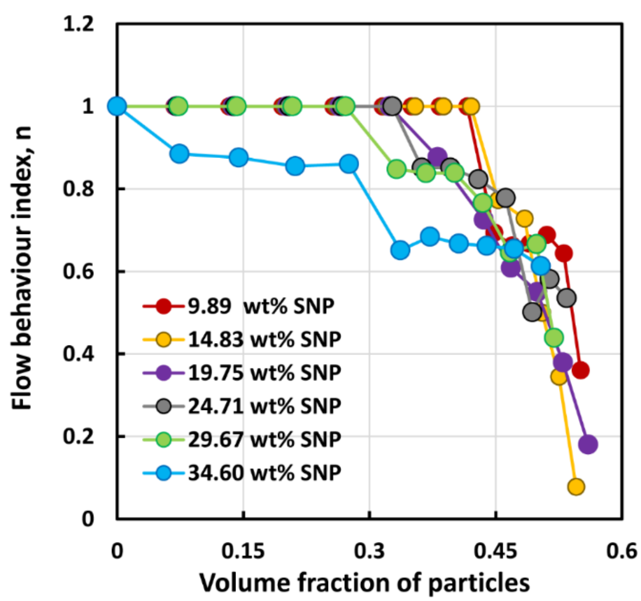


Figure 29 Comparison of consistency index (K) and flow behavior index (n) of suspensions of SG particles in SNP dispersions with different concentrations of SNP.

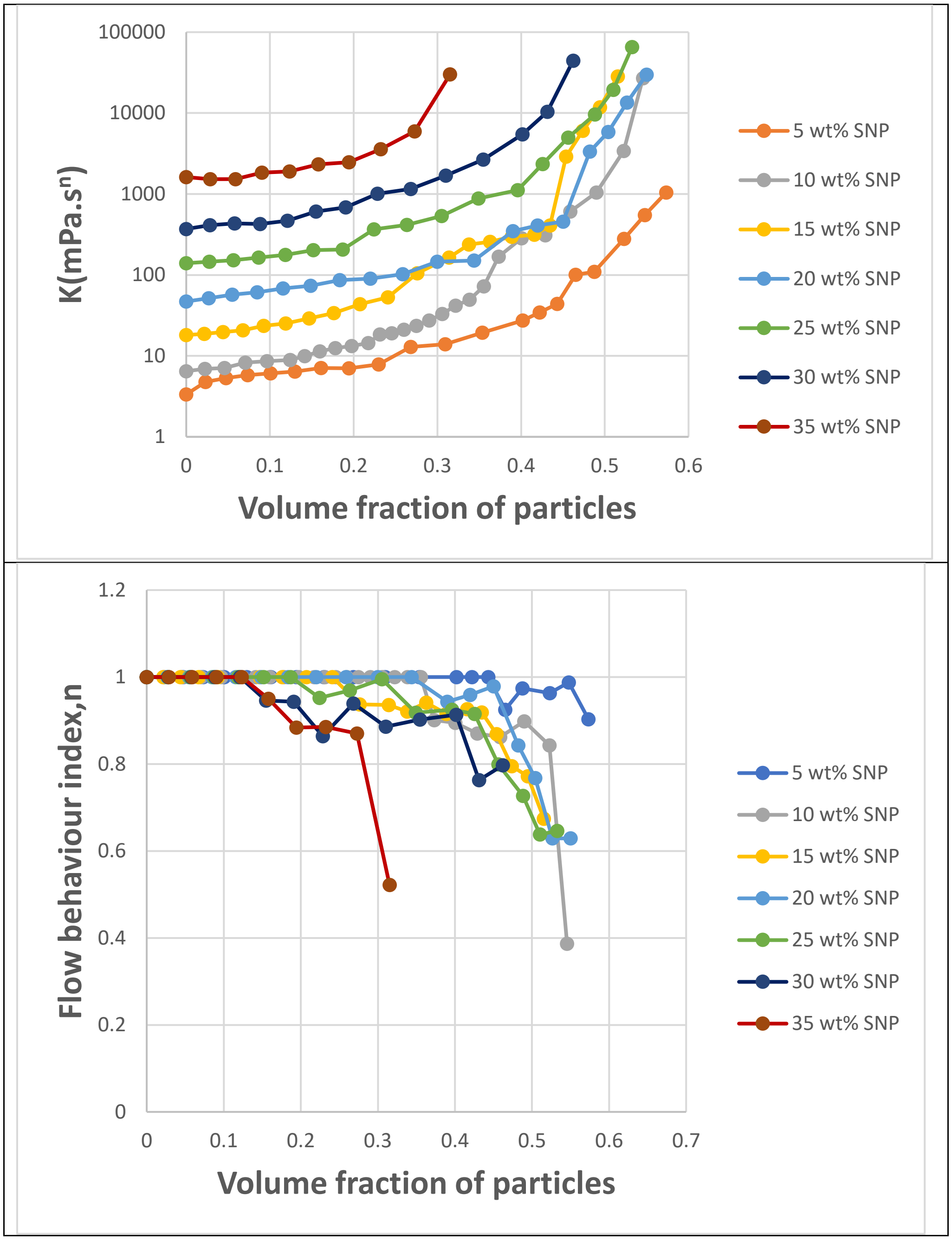


Figure 30 Comparison of consistency index (K) and flow behavior index (n) of suspensions of S-32 particles in SNP dispersions with different concentrations of SNP.

5.5 Evaluating Experimental Results in Comparison to Modeled Predictions

The Mooney Model, expressed by Equation 11, and the Krieger-Dougherty model, represented by Equation 12, are commonly employed in literature to correlate relative viscosity against particle volume fraction data for concentrated suspensions of solid particles [71], [72].

$$\eta_r = \frac{\eta}{\eta_m} = \left[\frac{2.5\Phi}{1 - \frac{\Phi}{\Phi_m}} \right] \quad (11)$$

$$\eta_r = \frac{\eta}{\eta_m} = \left[1 - \frac{\Phi}{\Phi_m} \right]^{-2.5\Phi_m} \quad (12)$$

The relative viscosity of the suspension, denoted as η_r, is defined as the ratio of suspension viscosity (η) to the viscosity of the matrix fluid (η_m). φ represents the volume fraction of particles, while φ_m stands for the maximum packing volume fraction of particles. This maximum packing fraction, often assumed to be 0.58, corresponds to the glass transition volume fraction of hard spheres.

Figure 31 illustrates our experimental findings for both Newtonian and non-Newtonian suspensions of SG hollow spheres, in SNP dispersions compared to the predictions generated by the Mooney and Krieger-Dougherty models. In the case of Newtonian suspensions, the plot depicts the relationship between relative viscosity (η_r) and particle volume fraction (φ). Conversely, for non-Newtonian suspensions, the plot shows how the relative consistency index (K_r), defined as the ratio of the consistency index (K) to the matrix fluid viscosity (η_m), varies with φ.

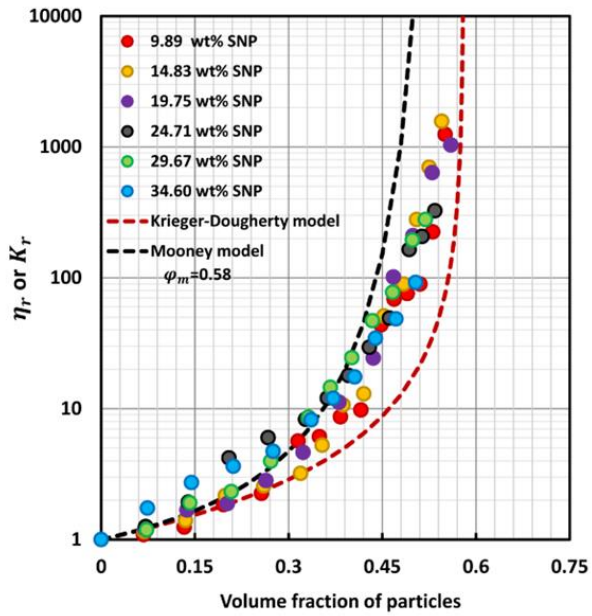


Figure 31 Comparison of experimental data for Newtonian and non-Newtonian suspensions of SG particles in SNP dispersions with the predictions of Mooney and Krieger-Dougherty models.

Pal developed a novel viscosity model for asphaltene solutions, effectively addressing the challenge of accurately describing their viscosity behavior by accounting for the clustering of asphaltene nanoaggregates. This model was successfully applied to predict viscosity across various asphaltene systems and experimental conditions [73]. The Pal model is formulated as follows:

$$\eta_r = \left[1 - \left\{1 + \left(\frac{1-\Phi_m}{\Phi_m}\right)\sqrt{1-\left(\frac{\Phi_m - \Phi}{\Phi_m}\right)^2}\right\}\Phi\right]^{-2.5} \tag{13}$$

Figure 32 illustrates the comparison between the Pal model predictions and experimental data for both Newtonian and non-Newtonian suspensions of SG hollow spheres, and Figure 33 presents a similar comparison for suspensions of S-32 solospheres. In the case of non-Newtonian suspensions, the model employs the relative consistency index (K_r) instead of relative viscosity (η_r). Overall, the model provides a reasonable description of the experimental data, with an average percent error of approximately 10 percent. However, it's worth noting that the model tends to overestimate relative viscosities.

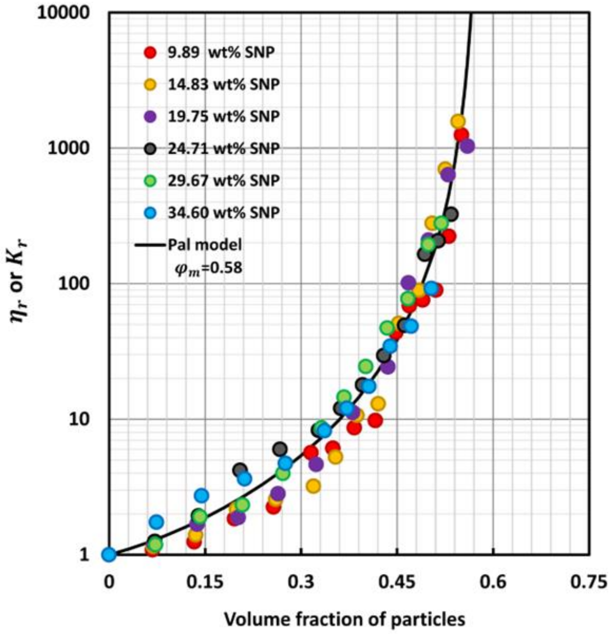


Figure 32 Comparison of experimental data for Newtonian and non-Newtonian suspensions of SG particles in SNP dispersions with the predictions of Pal model.

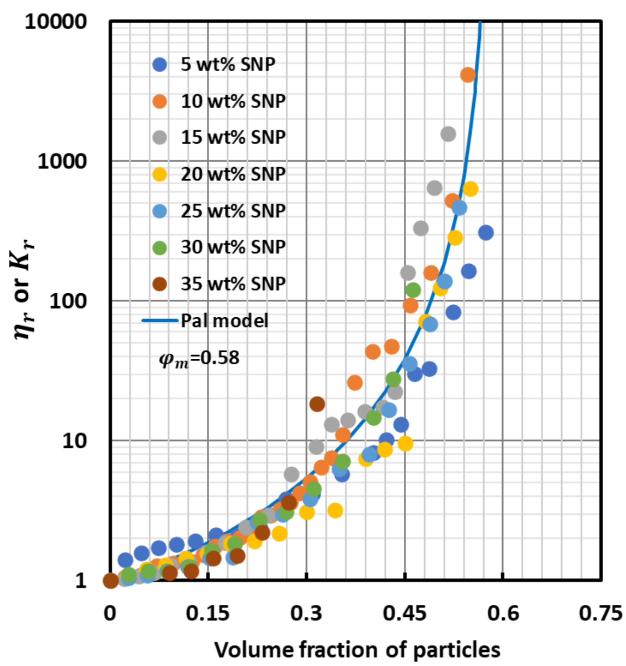


Figure 33 Comparison of experimental data for Newtonian and non-Newtonian suspensions of S-32 particles in SNP dispersions with the predictions of Pal model.

5.6 Stability of Suspensions

5.6.1 Stability of Suspensions of SG Particles in SNP Dispersion

Given the disparate densities between the suspended SG hollow sphere particles and the matrix phase, characteristic phenomena such as creaming, and sedimentation were anticipated. The SG hollow spheres exhibited an average density of 0.7486 g/ml, whereas the density of the matrix phase exhibited variability corresponding to the SNP content. Specifically, the matrix phase displayed a density of 0.9988 g/ml in the absence of SNP (0% content), which increased to 1.139 g/ml at 35 wt% SNP. Given the lighter nature of the particles relative to the matrix phase, an upward creaming effect was expected, signifying their tendency to rise within the suspension.

Figure 34 illustrates samples of suspensions left undisturbed for a duration exceeding two months. In these samples, the matrix phase contains approximately 30 wt% SNP. The particle concentration, consisting of SG hollow spheres, ranges from 0 wt% in the leftmost bottle to 37 wt% in the rightmost bottle. As anticipated, the particles ascend to the surface of the sample, forming a highly concentrated suspension layer at the top. Concurrently, with an increase in particle concentration, the top layer of highly concentrated suspension expands. Intriguingly, certain particles also settle at the bottom of the bottles, implying that some particles exhibit greater density than that of the matrix phase. This observation suggests the possibility of non-hollow particles within the suspension, potentially comprising solid particles characterized by elevated density.

Figure 34 Creaming/sedimentation in suspensions of particles (SG hollow spheres) in SNP dispersion when left unstirred for more than two months. The SNP concentration of the matrix phase is approximately 30 wt%. The particle concentration varies from 0 to 37 wt%.

An experiment conducted in our laboratory aimed to observe changes in the top layer of a suspension over time. As depicted in Figure 35, the formation and expansion of distinct layers are observed, with a top layer composed of light particles and a bottom layer of heavier particles. At the initial time point (t = 0), the suspension, comprising 25 wt% SG hollow particles in an aqueous phase without any SNP, exhibits a uniform distribution. Over time, distinct layers form and grow, with a top layer of light particles and a bottom layer of heavy particles becoming increasingly evident. The impact of SNP addition to the matrix phase significantly alters the creaming and sedimentation dynamics. The inclusion of SNP results in an increase in the viscosity of the matrix phase, leading to a reduction in the creaming and sedimentation rates of the particles. This effect is clearly illustrated in Figure 36, which demonstrates the growth of the top creamed particle layer over time. In cases where the SNP concentration is 0 wt%, the top layer undergoes rapid growth. Conversely, as the SNP concentration in the matrix phase increases, the growth rate of the top layer comprising light particles slows down considerably. This decrease in the upward movement of light particles, indicating reduced creaming, corresponds to the elevated viscosity of the matrix phase caused by the increased SNP concentration. Consistent with Stokes' law (Equation (1)), the velocity of particles exhibits an inverse correlation with the viscosity of the matrix phase.

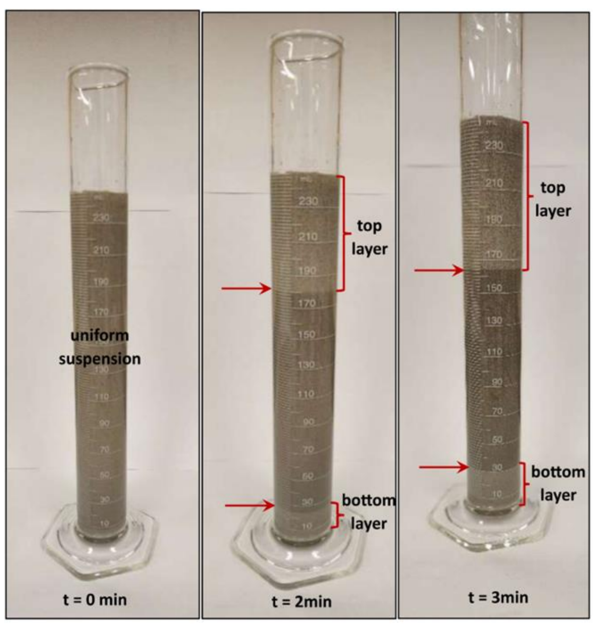


Figure 35 Separation of particles (SG hollow spheres) in a suspension (25 wt% particles, 0 wt% SNP) with time.

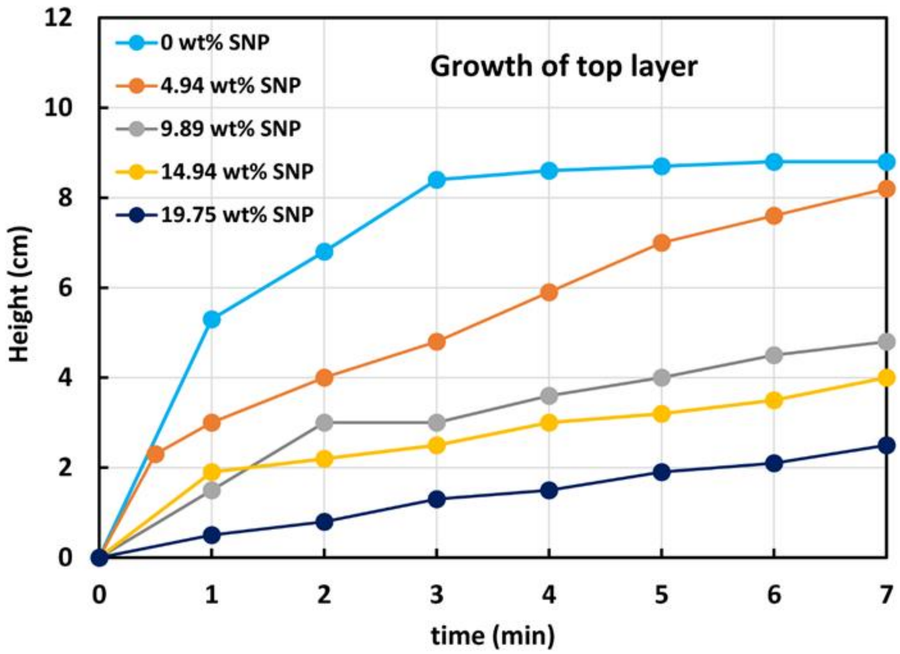


Figure 36 Growth of top creamed layer of SG hollow spheres with time in a suspension (25 wt% particles) with different SNP concentrations of the matrix phase.

5.6.2 Stability of Suspensions of S-32 Particles in SNP Dispersion

For S-32, a different form of instability, namely sedimentation, is observed. The S-32 particles demonstrated an average density of 2.0968 g/mL, while the density of the matrix phase varied with the SNP content. In particular, the matrix phase exhibited a density of 0.9988 g/mL when devoid of SNP (0% content), which increased to 1.19172 g/mL at 35 wt% SNP. Consequently, sedimentation of particles was anticipated and indeed occurred.

Figure 37 depicts suspensions that have been left undisturbed for over 5 months. These suspensions contain approximately 30% by weight of SNP in the matrix phase. The particle concentration, composed of S-32 solospheres, varies from 0% in the leftmost bottle to 61% in the rightmost bottle. As expected, the particles create a densely packed suspension layer at the bottom. With increasing particle concentration, the highly concentrated suspension layer at the bottom expands.

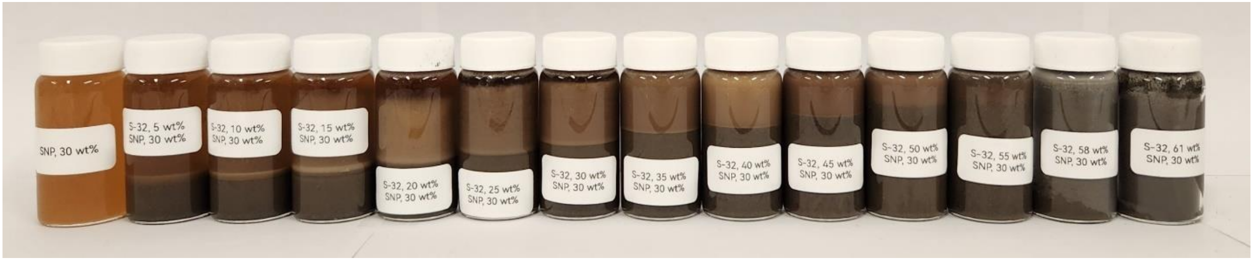


Figure 37 sedimentation in suspensions of particles (S-32 solospheres) in SNP dispersion when left unstirred for more than five months. The SNP concentration of the matrix phase is 30 wt%. The particle concentration varies from 0 to 61 wt%.

In a laboratory experiment, we investigated the evolution of the sedimentation process in a suspension over time. Figure 38 demonstrates the development and growth of the sediment layer as time progresses. Initially, at t = 0, the suspension contained 25wt% S-32 solospheres in an aqueous solution without SNP, showing a uniform distribution. With time, a distinct sediment layer formed and expanded. The introduction of SNP into the matrix phase notably influenced the sedimentation dynamics by increasing the viscosity of the solution, thereby slowing down the sedimentation rate of particles. This effect is evident in Figure 39, which compares the sedimentation process of a suspension containing SNP 20 wt% after 40 days that clearly indicates many particles have not yet settled, with the case of the S-32 suspension without SNP, in which the majority of particles settled within an hour, with complete settlement occurring after three days.

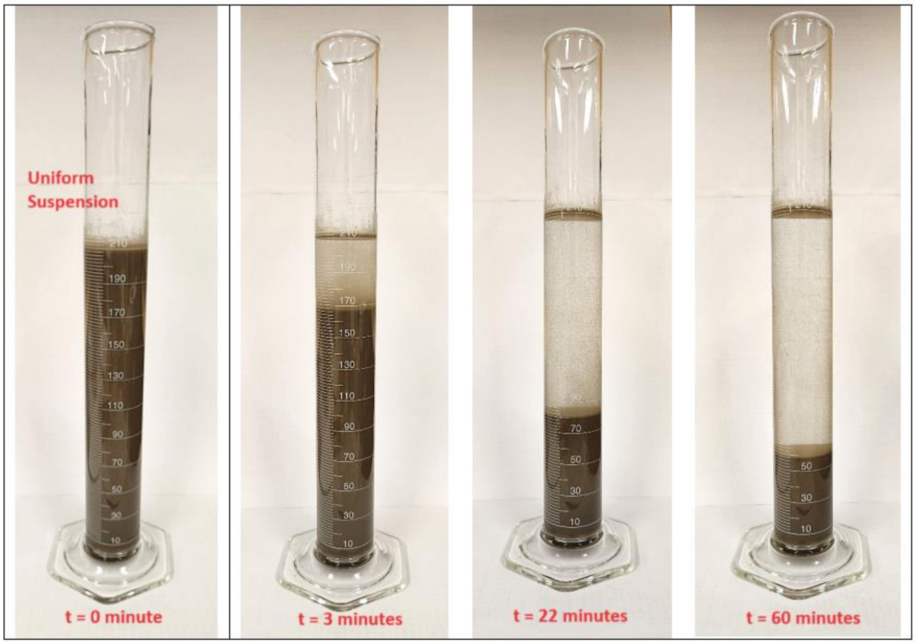


Figure 38 Separation of particles (S-32 solospheres) in a suspension (25 wt% particles, 0 wt% SNP) with time.

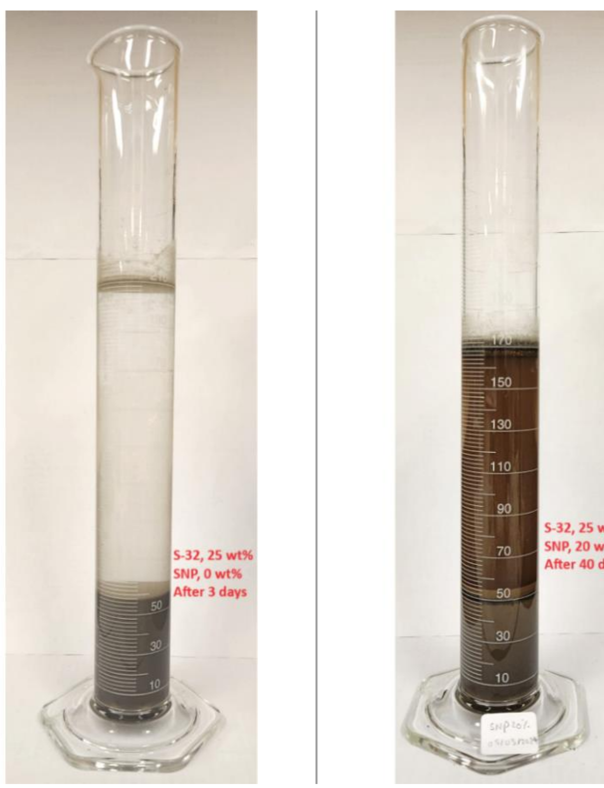


Figure 39 Comparison of sedimentation behavior between suspensions with 20 wt% SNP and those without SNP.

6. Conclusions

- The SNP dispersions maintain Newtonian characteristics throughout the entire concentration range investigated in this study, spanning from 5 to 35 wt% SNP.
- At low particle concentrations, suspensions of SG hollow spheres and S-32 solospheres in SNP dispersions generally exhibit Newtonian properties.
- At higher particle concentrations, the suspensions undergo a transition to non-Newtonian behavior characterized by shear-thinning.
- The suspensions of SG particles exhibit non-Newtonian behavior at lower particle concentrations when the SNP concentration of the matrix phase is increased. For instance, in suspensions with a low SNP concentration of 9.89 wt%, the transition to non-Newtonian behavior occurs at a particle volume fraction of approximately 0.45. Conversely, with a high SNP concentration of 34.6 wt%, the suspension displays non-Newtonian characteristics at a considerably lower particle volume fraction of 0.074. Similarly, this trend is observed in suspensions with S-32 particles. At 10 wt% SNP, the suspension transitions to non-Newtonian behavior at a particle volume fraction of approximately 0.37. Conversely, with a high SNP concentration of 35 wt%, the suspension exhibits non-Newtonian characteristics at a considerably lower particle volume fraction of 0.158.
- The power-law model provides a suitable description for the rheological behavior of non-Newtonian suspensions comprising particles in SNP dispersions.
- As the particle concentration rises at a constant SNP concentration, the consistency index increases while the flow behavior index decreases.
- The experimental viscosity and consistency index data for both Newtonian and non-Newtonian suspensions align with the predictions of the Pal model across the entire range of particle concentrations examined.
- Comparing the consistency data for S-32 suspensions using the Pal model and relating it to the results obtained for SG, it appears that the particle size of suspensions has a negligible effect on rheology within the investigated range of particle sizes.
- Creaming and sedimentation in particle suspensions are notably diminished when the liquid matrix is thickened with starch nanoparticles, leading to more stable suspensions.

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Appendices

Appendix A: Rheological Data

The following section contains all rheological data obtained from both viscometers. Section A.1 presents data for Suspensions of SG Hollow Spheres, ordered by increasing SNP concentration, while Section A.2 presents data for Suspensions of S-32 Solo Spheres, also ordered by increasing SNP concentration.

Appendix A.1: Rheological Data of suspensions of SG hollow spheres in SNP dispersions

Table 5 Rheological Data for Suspensions of SG Solid Particles in SNP Dispersion with SNP Concentration of 9.89 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 9.89 wt%		
331.4325	51.069	6.489896023
727.2525	102.138	7.120293133
1123.0725	153.207	7.330425503
2162.1	306.414	7.056139733
1172.55	170.23	6.888033837
2409.4875	340.46	7.07715297
3596.9475	510.69	7.043309052
7159.3275	1021.38	7.009465135
SG, 5 wt%+ SNP, 9.89 wt%		
405.64875	51.069	7.943150444
776.73	102.138	7.604711273
1123.0725	153.207	7.330425503
2211.5775	306.414	7.217612446
1222.0275	170.23	7.178684721
2508.4425	340.46	7.367803854
3943.29	510.69	7.721494449
8247.8325	1021.38	8.075185044
4848.2475	599.04	8.093361879
SG, 10 wt%+ SNP, 9.89 wt%		
479.865	51.069	9.396404864
826.2075	102.138	8.089129413
1222.0275	153.207	7.976316356
2607.3975	306.414	8.509394153
1419.9375	170.23	8.341288257
3003.2175	340.46	8.821058274

4586.4975	510.69	8.980981613
9682.68	1021.38	9.47999765
2737.783	299.52	9.140568243
5027.8615	599.04	8.393198284
SG, 15 wt%+ SNP, 9.89 wt%		
628.2975	51.069	12.3029137
1172.55	102.138	11.48005639
1716.8025	153.207	11.20577062
3201.1275	306.414	10.44706671
1667.325	170.23	9.794542678
3596.9475	340.46	10.56496358
6021.345	510.69	11.79060683
14531.475	1021.38	14.22729542
5791.221	299.52	19.33500601
10730.606	599.04	17.91300414
SG, 20 wt%+ SNP, 9.89 wt%		
677.775	51.069	13.27174999
1271.505	102.138	12.44889267
1716.8025	153.207	11.20577062
3596.9475	306.414	11.73884842
1716.8025	170.23	10.08519356
4240.155	340.46	12.45419433
6763.5075	510.69	13.24386125
17104.305	1021.38	16.74626975
8754.852	299.52	29.22960737
16298.64	599.04	27.20793269
SG, 25 wt%+ SNP, 9.89 wt%		
776.73	51.069	15.20942255
1271.505	102.138	12.44889267
1914.7125	153.207	12.49755233
5328.66	306.414	17.39039339
2656.875	170.23	15.60756036
5714.5845	340.46	16.7848925
9979.545	510.69	19.54129707
8485.431	149.76	56.66019631
12571.6495	299.52	41.97265458
23573.007	599.04	39.35130709
47282.055	1198.08	39.46485627
7048.519	119.808	58.8317892

4084.888	74.88	54.55245726
6958.712	149.76	46.46575855
9697.8255	299.52	32.37788962
18992.85	599.04	31.70547877
54017.58	1198.08	45.08678886
4354.309	59.904	72.68811765
5656.5105	119.808	47.21312851
SG, 28 wt%+ SNP, 9.89 wt%		
1172.55	51.069	22.96011279
1667.325	102.138	16.3242378
2261.055	153.207	14.75817032
5477.0925	306.414	17.87481153
2607.3975	170.23	15.31690948
5130.75	340.46	15.07005228
8989.995	510.69	17.60362451
4713.537	74.88	62.9478766
8216.01	149.76	54.86117788
12257.325	299.52	40.92322716
22136.095	599.04	36.95261585
51323.37	1198.08	42.83801583
5970.835	59.904	99.6733941
7228.133	119.808	60.33097122
4623.73	74.88	61.74853098
7946.589	149.76	53.06215946
11493.9655	299.52	38.37461772
22270.8055	599.04	37.17749316
49527.23	1198.08	41.3388338
5521.8	59.904	92.17748397
6464.7735	119.808	53.95944762
SG, 31 wt%+ SNP, 9.89 wt%		
1469.415	51.069	28.77313047
2310.5325	102.138	22.62167362
3300.0825	153.207	21.54002428
6466.6425	306.414	21.1042658
3300.0825	170.23	19.38602185
6763.5075	340.46	19.86579187
13442.97	510.69	26.32315103
12457.36	170.23	73.17958057
16633.36	340.46	48.85554838

24463.36	510.69	47.9025632
43777.36	1021.38	42.86099199
5297.2825	37.44	141.4872463
9428.4045	74.88	125.9135216
16837.482	149.76	112.4297676
26626.445	299.52	88.89705195
44902.1695	599.04	74.95688017
56711.79	1198.08	47.3355619
5701.414	29.952	190.351696
8036.396	59.904	134.1545807
12975.781	119.808	108.304796
4938.0545	74.88	65.94624065
8216.01	149.76	54.86117788
11538.869	299.52	38.52453592
21687.06	599.04	36.20302484
50874.335	1198.08	42.46322032
4893.151	59.904	81.6832098
7677.168	119.808	64.07892628
SG, 34 wt%+ SNP, 9.89 wt%		
16633.36	170.23	97.71109675
27073.36	340.46	79.51994361
32293.36	510.69	63.23476081
54217.36	1021.38	53.08245707
3231.7215	37.44	86.31734776
5252.379	74.88	70.14395032
8844.659	149.76	59.05888755
14008.5615	299.52	46.77003706
26357.024	599.04	43.99877137
41669.1175	1198.08	34.77991244
4848.2475	59.904	80.93361879
7452.6505	119.808	62.20494875
3501.1425	29.952	116.8917768
3276.625	29.952	109.3958667
5791.221	74.88	77.34002404
10101.957	149.76	67.45430689
14547.4035	299.52	48.56905549
24920.112	599.04	41.60008013
38301.355	1198.08	31.96894615
5431.993	59.904	90.67830195
8934.466	119.808	74.57320045

SG, 37 wt%+ SNP, 9.89 wt%		
2261.055	51.069	44.27451096
4190.6775	102.138	41.02956294
6268.7325	153.207	40.91674989
14135.655	306.414	46.13253637
5724.48	170.23	33.62791517
13146.105	340.46	38.61277389
18588.63	510.69	36.39904835
15589.36	170.23	91.57821771
26029.36	340.46	76.45350408
37513.36	510.69	73.45622589
68833.36	1021.38	67.39250818
3635.853	37.44	97.11145833
6419.87	74.88	85.73544338
10012.15	149.76	66.85463408
14951.535	299.52	49.91831931
24381.27	599.04	40.70057091
44138.81	1198.08	36.84128773
4264.502	29.952	142.3778713
5791.221	59.904	96.67503005
9563.115	119.808	79.82033754
5970.835	74.88	79.73871528
7228.133	149.76	48.26477698
10281.571	299.52	34.32682626
19621.499	599.04	32.75490618
56442.369	1198.08	47.1106846
7183.2295	29.952	239.8247029
9383.501	59.904	156.642311
9563.115	119.808	79.82033754
SG, 39 wt%+ SNP, 9.89 wt%		
3399.0375	51.069	66.5577454
5081.2725	102.138	49.74908947
6615.075	153.207	43.17736787
14630.43	306.414	47.74726351
8792.085	170.23	51.64826999
19578.18	340.46	57.50508136
21853.36	170.23	128.375492
37513.36	340.46	110.1843388
46909.36	510.69	91.85486303

79273.36	1021.38	77.61397325
3950.1775	37.44	105.5068777
7273.0365	74.88	97.12922676
11538.869	149.76	77.04907185
20160.341	299.52	67.3088308
35337.724	599.04	58.99059161
53568.545	1198.08	44.71199336
5476.8965	29.952	182.8557859
8575.238	59.904	143.1496728
10506.0885	119.808	87.69104317
4578.8265	37.44	122.2977163
8305.817	74.88	110.9217014
14682.114	149.76	98.03762019
21687.06	299.52	72.40604968
37133.864	599.04	61.98895566
50874.335	1198.08	42.46322032
6150.449	29.952	205.3435163
9652.922	59.904	161.1398571
12526.746	119.808	104.5568409
3546.046	14.976	236.7819177
3052.1075	11.9808	254.7498915
3905.274	14.976	260.7688301
3052.1075	11.9808	254.7498915
SG, 43 wt%+ SNP, 9.89 wt%		
3995.081	18.72	213.4124466
7093.4225	37.44	189.461071
12751.2635	74.88	170.2893096
21866.674	149.76	146.011445
35427.531	299.52	118.2810196
55723.913	599.04	93.02202357
5162.572	14.976	344.7230235
8260.9135	29.952	275.8050714
13604.43	59.904	227.1038662
19890.92	119.808	166.023304
4354.309	11.9808	363.4405883
4129.7915	18.72	220.6085203
7362.8435	37.44	196.6571448
13155.395	74.88	175.6863649
23932.235	149.76	159.8039196
42701.898	299.52	142.5677684

73775.12	599.04	123.1555823
5072.765	14.976	338.7262954
7766.975	29.952	259.3140692
11898.097	59.904	198.6194077
21238.025	119.808	177.2671691
4174.695	11.9808	348.448768
3635.853001	18.72	194.2229167
6195.352502	37.44	165.4741587
10550.992	74.88	140.9053419
17915.16599	149.76	119.6258413
30398.33901	299.52	101.490181
50425.3	599.04	84.17684963
61202.14	1198.08	51.08351696
2333.6515	7.488	311.6521768
3725.66	14.976	248.7753739
5746.317501	29.952	191.8508781
9383.500998	59.904	156.642311
15759.798	119.808	131.5421174
3321.5285	11.9808	277.2376219
SG, 47 wt%+ SNP, 9.89 wt%		
11413.36	5.1069	2234.890051
15589.36	10.2138	1526.303628
108505.36	170.23	637.4044528
6419.87	2.34	2743.534188
8395.623999	4.68	1793.936752
12706.36	9.36	1357.517094
20878.79701	18.72	1115.320353
34888.689	37.44	931.8560096
56352.562	74.88	752.5716079
2917.397001	0.234	12467.50855
3456.239	0.468	7385.126068
4938.0545	0.936	5275.699252
6419.87	1.872	3429.417735
9024.273	3.744	2410.329327
13694.237	7.488	1828.824386
21238.025	14.976	1418.137353
34260.04001	29.952	1143.831464
55185.071	59.904	921.2251436
82755.82001	119.808	690.7370126
3097.010999	0.0234	132350.8974

4444.116	0.0468	94959.74359
5476.8965	0.0936	58513.8515
6419.87	0.1872	34294.17735
7632.264501	0.3744	20385.32185
8036.395998	0.7488	10732.36645
10012.15	1.4976	6685.463408
12796.167	2.9952	4272.224559
13604.43	5.9904	2271.038662
19352.078	11.9808	1615.257579
6734.194499	2.34	2877.860897
9383.500999	4.68	2005.021581
14457.5965	9.36	1544.615011
24650.69101	18.72	1316.810417
40546.53001	37.44	1082.973558
64794.42	74.88	865.3100962
3995.081001	0.234	17072.99573
4893.150998	0.468	10455.45085
6958.712	0.936	7434.521368
9024.273	1.872	4820.658654
12392.0355	3.744	3309.838542
17106.903	7.488	2284.575721
25458.954	14.976	1699.983574
38570.776	29.952	1287.752938
59855.035	59.904	999.1826088
3321.5285	0.0234	141945.6624
4578.8265	0.0468	97838.17308
5925.9315	0.0936	63311.23397
7362.843499	0.1872	39331.42895
8575.238	0.3744	22903.94765
10955.1235	0.7488	14630.23972
13245.202	1.4976	8844.285524
16927.289	2.9952	5651.472022
17376.324	5.9904	2900.695112
23932.235	11.9808	1997.548995

Table 6 Rheological Data for Suspensions of SG Solid Particles in SNP Dispersion with SNP Concentration of 14.83 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 14.83 wt%		
1024.1175	51.069	20.05360395
2013.6675	102.138	19.71516478
3052.695	153.207	19.92529715
6070.8225	306.414	19.81248409
3349.56	170.23	19.67667274
6714.03	340.46	19.72046643
10029.0225	510.69	19.6381807
19875.045	1021.38	19.45901134
11413.36	340.46	33.52335076
14545.36	510.69	28.48177955
24985.36	1021.38	24.46235485
3995.081	149.76	26.67655582
6689.291	299.52	22.33337006
12616.553	599.04	21.06128639
41803.828	1198.08	34.8923511
3231.7215	119.808	26.97417117
6727.95	230.4	29.20117188
SG, 5 wt%+ SNP, 14.83 wt%		
1222.0275	51.069	23.92894907
2409.4875	102.138	23.5905099
3300.0825	153.207	21.54002428
6367.6875	306.414	20.78132037
3596.9475	170.23	21.12992716
7010.895	340.46	20.59241908
11414.3925	510.69	22.35092228
22893.1725	1021.38	22.41396199
12457.36	340.46	36.58979028
15589.36	510.69	30.52607257
28117.36	1021.38	27.52879438
6240.256	149.76	41.66837607
8575.238	299.52	28.62993456
16882.3855	599.04	28.18240101
33137.4525	1198.08	27.65879783
5027.8615	119.808	41.96599142
SG, 10 wt%+ SNP, 14.83 wt%		

1568.37	51.069	30.71080303
3052.695	102.138	29.88794572
4091.7225	153.207	26.70715111
7654.1025	306.414	24.97961092
4289.6325	170.23	25.19903953
9336.3375	340.46	27.42271486
14234.61	510.69	27.87328908
29275.77	1021.38	28.662956
14545.36	340.46	42.72266933
18721.36	510.69	36.65895161
35425.36	1021.38	34.68381993
3231.7215	74.88	43.15867388
5881.028	149.76	39.26968483
10057.0535	299.52	33.57723524
19621.499	599.04	32.75490618
54017.58	1198.08	45.08678886
4578.8265	119.808	38.21803636
SG, 15 wt%+ SNP, 14.83 wt%		
2211.5775	51.069	43.30567468
3943.29	102.138	38.60747224
4537.02	153.207	29.61365995
10127.9775	306.414	33.05324659
5427.615	170.23	31.88400987
10919.6175	340.46	32.073129
17252.7375	510.69	33.78319039
11413.36	170.23	67.04670152
17677.36	340.46	51.9219879
22897.36	510.69	44.83612368
43777.36	1021.38	42.86099199
6419.87	74.88	85.73544338
11179.641	149.76	74.65038061
15400.57	299.52	51.41750134
24381.27	599.04	40.70057091
45036.88	1198.08	37.59087874
6599.484	59.904	110.1676683
9922.343	119.808	82.81870159
SG, 20 wt%+ SNP, 14.83 wt%		
2854.785	51.069	55.90054632
3547.47	102.138	34.73212712
5279.1825	153.207	34.45784135

11364.915	306.414	37.09006442
5922.39	170.23	34.79051871
13690.3575	340.46	40.21135376
22546.83	510.69	44.14973859
14545.36	170.23	85.44533866
22897.36	340.46	67.25418551
31249.36	510.69	61.1904678
57349.36	1021.38	56.14889659
7407.747	74.88	98.92824519
13335.009	149.76	89.04252804
16298.64	299.52	54.41586538
33541.584	599.04	55.99222756
54915.65	1198.08	45.83637987
6779.098	59.904	113.1660323
11089.834	119.808	92.56338475
SG, 25 wt%+ SNP, 14.83 wt%		
4289.6325	51.069	83.99679845
7208.805	102.138	70.57906949
8297.31	153.207	54.15751239
16856.9175	306.414	55.01353561
529.3425	10.2138	51.82620572
9237.3825	170.23	54.26412794
18390.72	340.46	54.01727075
17677.36	170.23	103.8439758
31249.36	340.46	91.7857017
42733.36	510.69	83.67769097
79273.36	1021.38	77.61397325
7317.94	74.88	97.72889957
13604.43	149.76	90.84154647
22585.13	299.52	75.40441373
45485.915	599.04	75.93134849
71080.91	1198.08	59.3290181
6060.642	59.904	101.1725761
11314.3515	119.808	94.43736228
SG, 28 wt%+ SNP, 14.83 wt%		
232.4775	3.06414	75.87039104
4141.2	51.069	81.09028961
7406.715	102.138	72.51674205
10771.185	153.207	70.30478372
22992.1275	306.414	75.03615207

232.4775	5.1069	45.52223462
578.82	10.2138	56.67038712
11216.4825	170.23	65.89016331
22645.785	340.46	66.51525877
6330.063	37.44	169.0721955
11538.869	74.88	154.0981437
20968.604	149.76	140.0147169
31565.83	299.52	105.3880542
44138.81	599.04	73.68257545
69284.77	1198.08	57.82983607
5566.7035	14.976	371.7082999
9114.08	29.952	304.2895299
14682.114	59.904	245.0940505
18004.973	119.808	150.2818927
SG, 31 wt%+ SNP, 14.83 wt%		
3501.1425	9.36	374.0536859
6150.449	18.72	328.5496261
11359.255	37.44	303.3989049
20699.183	74.88	276.4313969
37493.092	149.76	250.3545139
64794.42	299.52	216.327524
3411.3355	7.488	455.5736512
6419.87	14.976	428.6772169
10640.799	29.952	355.2617188
18903.043	59.904	315.5556056
33272.163	119.808	277.7123648
5072.765	11.9808	423.4078693
183	1.53207	119.4462394
479.865	3.06414	156.6067477
6417.165	51.069	125.6567585
11068.05	102.138	108.3636844
14234.61	153.207	92.9109636
925.1625	5.1069	181.1593139
1964.19	10.2138	192.3074664
18737.0625	170.23	110.0690977
SG, 34 wt%+ SNP, 14.83 wt%		
281.955	1.53207	184.0353248
727.2525	3.06414	237.3431044
8495.22	51.069	166.3478823
13146.105	102.138	128.7092463

17895.945	153.207	116.8089252
529.3425	5.1069	103.6524114
1172.55	10.2138	114.8005639
18440.1975	170.23	108.3251924
5342.186	18.72	285.3731838
10012.15	37.44	267.4185363
18543.815	74.88	247.647102
34170.233	149.76	228.1666199
61202.14	299.52	204.3340678
5431.993	14.976	362.7132078
9473.308	29.952	316.2829861
16029.219	59.904	267.5817808
29320.655	119.808	244.7303602
4533.923	11.9808	378.4324085
4399.2125	9.36	470.0013355
7228.133	18.72	386.1182158
13335.009	37.44	356.1701122
24560.884	74.88	328.0032585
45485.915	149.76	303.725394
78265.47	299.52	261.3029848
4623.73	7.488	617.4853098
8665.045	14.976	578.5954193
13155.395	29.952	439.2159121
22585.13	59.904	377.0220686
38930.004	119.808	324.9365986
3905.274	5.9904	651.9220753
6599.484	11.9808	550.8383413
SG, 37 wt%+ SNP, 14.83 wt%		
875.685	1.53207	571.5698369
1865.235	3.06414	608.7303452
15619.98	51.069	305.8603066
22546.83	102.138	220.7486929
1419.9375	5.1069	278.0429419
2953.74	10.2138	289.1910944
5836.1245	9.36	623.5175748
9608.0185	18.72	513.2488515
17106.903	37.44	456.9151442
30218.725	74.88	403.5620326
52670.475	149.76	351.6992188
85450.03	299.52	285.2898972

3725.66	3.744	995.1014957
5611.607	7.488	749.413328
9293.694	14.976	620.572516
16568.061	29.952	553.153746
27075.48	59.904	451.9811699
47371.862	119.808	395.3981537
5072.765	5.9904	846.8157385
8485.431	11.9808	708.2524539
3995.081	4.68	853.6497863
6958.712	9.36	743.4521368
12616.553	18.72	673.9611645
22944.358	37.44	612.8300748
40995.565	74.88	547.4835069
65692.49	149.76	438.6517762
5791.221	3.744	1546.800481
9922.343	7.488	1325.099225
16478.254	14.976	1100.310764
27075.48	29.952	903.9623397
45845.143	59.904	765.310213
67488.63	119.808	563.3065405
5791.221	2.9952	1933.500601
8485.431	5.9904	1416.504908
13424.816	11.9808	1120.527511
SG, 40 wt%+ SNP, 14.83 wt%		
1865.235	1.53207	1217.46069
3448.515	3.06414	1125.443028
4635.975	5.1069	907.7865241
8693.13	10.2138	851.116137
6330.063	4.68	1352.577564
10057.0535	9.36	1074.471528
16657.868	18.72	889.8433761
28422.585	37.44	759.1502404
47282.055	74.88	631.4377003
77277.593	149.76	516.0095686
6195.3525	3.744	1654.741587
9563.115	7.488	1277.125401
15580.184	14.976	1040.343483
25728.375	29.952	858.986879
43240.74	59.904	721.8339343
70631.875	119.808	589.5422259

5342.186	2.9952	1783.582399
8216.01	5.9904	1371.529447
13784.044	11.9808	1150.511151
5970.835	4.68	1275.819444
9877.4395	9.36	1055.281998
17196.71	18.72	918.6276709
28871.62	37.44	771.1436966
49886.458	74.88	666.2187233
80959.68	149.76	540.5961538
4354.309	1.872	2326.019765
6644.3875	3.744	1774.676149
10146.8605	7.488	1355.082866
16298.64	14.976	1088.317308
27614.322	29.952	921.952524
45934.95	59.904	766.809395
75571.26	119.808	630.7697316
3950.1775	1.4976	2637.671942
5701.414	2.9952	1903.51696
9203.887	5.9904	1536.43947
14502.5	11.9808	1210.478432
SG, 42 wt%+ SNP, 14.83 wt%		
4932.84	1.53207	3219.722336
6911.94	3.06414	2255.752022
8594.175	5.1069	1682.855548
12354.465	10.2138	1209.585561
13501.36	5.1069	2643.748654
22897.36	10.2138	2241.806184
101197.36	170.23	594.4742995
158617.36	340.46	465.8913235
209773.36	510.69	410.7645734
8305.817	2.34	3549.494444
11089.834	4.68	2369.62265
17106.903	9.36	1827.660577
27524.515	18.72	1470.326656
41624.214	37.44	1111.757853
62100.21	74.88	829.3297276
3321.5285	0.234	14194.56624
4174.695	0.468	8920.288462
5970.835	0.936	6379.097222
8216.01	1.872	4388.894231

12077.711	3.744	3225.884348
18274.394	7.488	2440.490652
26267.217	14.976	1753.954127
39648.46	29.952	1323.733307
58956.965	59.904	984.1907886
86258.293	119.808	719.971062
3141.9145	0.0936	33567.46261
3860.3705	0.1872	20621.63729
4713.537	0.3744	12589.57532
6060.642	0.7488	8093.80609
8216.01	1.4976	5486.117788
11359.255	2.9952	3792.486311
16523.1575	5.9904	2758.27282
23932.235	11.9808	1997.548995
9024.273	2.34	3856.526923
11987.904	4.68	2561.517949
16747.675	9.36	1789.281517
26895.866	18.72	1436.744979
40995.565	37.44	1094.967014
62010.403	74.88	828.1303819
3950.1775	0.234	16881.10043
4668.6335	0.468	9975.712607
6150.449	0.936	6570.992521
8395.624	1.872	4484.84188
11853.1935	3.744	3165.917067
17331.4205	7.488	2314.559362
26357.024	14.976	1759.950855
39558.653	29.952	1320.734943
58507.93	59.904	976.6948785
82755.82	119.808	690.7370126
3141.9145	0.0936	33567.46261
3815.467	0.1872	20381.76816
4578.8265	0.3744	12229.77163
5836.1245	0.7488	7793.969685
7766.975	1.4976	5186.281384
10910.22	2.9952	3642.568109
15894.5085	5.9904	2653.330078
26985.673	11.9808	2252.409939
SG, 44 wt%+ SNP, 14.83 wt%		
17677.36	5.1069	3461.46586

26029.36	10.2138	2548.450136
156529.36	170.23	919.5168889
18094.78	2.34	7732.811966
23662.814	4.68	5056.156838
33541.584	9.36	3583.502564
50874.335	18.72	2717.6461
71889.173	37.44	1920.1168
10101.957	0.234	43170.75641
11359.255	0.468	24271.91239
14143.272	0.936	15110.33333
18004.973	1.872	9618.041132
23662.814	3.744	6320.196047
32374.093	7.488	4323.463275
47955.6075	14.976	3202.163962
67398.823	29.952	2250.227798
5701.414	0.0234	243650.1709
6599.484	0.0468	141014.6154
7497.554	0.0936	80102.07265
8979.3695	0.1872	47966.71741
11269.448	0.3744	30100.02137
13784.044	0.7488	18408.17842
17555.938	1.4976	11722.71501
23213.779	2.9952	7750.326856
30577.953	5.9904	5104.492688
42881.512	11.9808	3579.186031
18184.587	2.34	7771.191026
23662.814	4.68	5056.156838
34170.233	9.36	3650.665919
48539.353	18.72	2592.914156
71978.98	37.44	1922.515491
9563.115	0.234	40868.01282
10550.992	0.468	22544.8547
13613.4107	0.936	14544.2422
17555.938	1.872	9378.172009
23483.2	3.744	6272.222222
33721.198	7.488	4503.365118
48808.774	14.976	3259.132879
66590.56	29.952	2223.242521
6060.642	0.0234	259001.7949
7766.975	0.0468	165961.0043

9114.08	0.0936	97372.64957
10820.413	0.1872	57801.3515
12706.36	0.3744	33937.92735
16208.833	0.7488	21646.41159
19172.464	1.4976	12802.12607
23213.779	2.9952	7750.326856
30847.374	5.9904	5149.468149
43240.74	11.9808	3609.169671
SG, 46 wt%+ SNP, 14.83 wt%		
17196.71	2.34	7349.021368
18454.008	4.68	3943.164103
27973.55	9.36	2988.627137
51323.37	18.72	2741.633013
72877.05	37.44	1946.502404
23213.779	0.234	99204.18376
25189.533	0.468	53823.78846
27883.743	0.936	29790.32372
32374.093	1.872	17293.8531
37852.32	3.744	10110.12821
44138.81	7.488	5894.606036
57071.018	14.976	3810.831864
70182.84	29.952	2343.177083
35966.373	0.0234	1537024.487
36325.601	0.0468	776188.0556
37762.513	0.0936	403445.6517
39379.039	0.1872	210358.1143
41893.635	0.3744	111895.3926
46294.178	0.7488	61824.48985
50874.335	1.4976	33970.57626
54915.65	2.9952	18334.55195
55813.72	5.9904	9317.194177
60753.105	11.9808	5070.872145

Table 7 Rheological Data for Suspensions of SG Solid Particles in SNP Dispersion with SNP Concentration of 19.57 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 19.57 wt%		
2706.3525	51.069	52.99403748

5328.66	102.138	52.17118017
8000.445	153.207	52.21983982
15966.3225	306.414	52.10702677
8891.04	170.23	52.22957176
17648.5575	340.46	51.83738912
25564.9575	510.69	50.0596399
4982.958	74.88	66.54591346
8934.466	149.76	59.65856036
16478.254	299.52	55.01553819
32733.321	599.04	54.64296374
55364.685	1198.08	46.21117538
4174.695	59.904	69.68975361
7946.589	119.808	66.32769932
11413.36	170.23	67.04670152
20809.36	340.46	61.12130647
30205.36	510.69	59.14617478
53173.36	1021.38	52.06031056
SG, 5 wt%+ SNP, 19.75 wt%		
3102.1725	51.069	60.74472772
6021.345	102.138	58.95303413
8841.5625	153.207	57.70991208
16609.53	306.414	54.20617204
9187.905	170.23	53.97347706
19281.315	340.46	56.63312871
28830.4725	510.69	56.45395935
16633.36	170.23	97.71109675
27073.36	340.46	79.51994361
36469.36	510.69	71.41193288
65701.36	1021.38	64.32606865
3186.818	37.44	85.11800214
5701.414	74.88	76.14067842
10820.413	149.76	72.25168937
21776.867	299.52	72.70588608
41534.407	599.04	69.33494758
64974.034	1198.08	54.23179921
2378.555	29.952	79.41222623
4533.923	59.904	75.6864817
8754.852	119.808	73.07401843
SG, 10 wt%+ SNP, 19.75 wt%		

158.26125	3.06414	51.64948403
4289.6325	51.069	83.99679845
8445.7425	102.138	82.689523
10919.6175	153.207	71.27362
21705.7125	306.414	70.83786152
232.4775	5.1069	45.52223462
628.2975	10.2138	61.51456852
12107.0775	170.23	71.12187922
23932.2	340.46	70.29372026
9669.485844	87.92291667	109.9768548
13562.69426	142.98775	94.85214122
11778.67052	140.762375	83.67769097
9540.848327	121.3290833	78.63611976
5252.379	37.44	140.2879006
9563.115	74.88	127.7125401
18184.587	149.76	121.4248598
34170.233	299.52	114.08331
57609.86	599.04	96.17030582
4893.151	29.952	163.3664196
8395.624	59.904	140.1513088
14861.728	119.808	124.0462073
SG, 15 wt%+ SNP, 19.75 wt%		
232.4775	3.06414	75.87039104
5773.9575	51.069	113.0618869
11216.4825	102.138	109.8169388
13344.015	153.207	87.09794592
25861.8225	306.414	84.40156945
281.955	5.1069	55.21059743
776.73	10.2138	76.04711273
14383.0425	170.23	84.49181989
28335.6975	340.46	83.2276846
22897.36	170.23	134.508371
41689.36	340.46	122.4500969
57349.36	510.69	112.2977932
103285.36	1021.38	101.1233429
5342.186	37.44	142.6865919
9563.115	74.88	127.7125401
18004.973	149.76	120.2255142
32823.128	299.52	109.5857639
62818.666	599.04	104.8655616

4219.5985	29.952	140.8786892
7856.782	59.904	131.1562166
14861.728	119.808	124.0462073
SG, 20 wt%+ SNP, 19.75 wt%		
183	1.53207	119.4462394
479.865	3.06414	156.6067477
8049.9225	51.069	157.6283558
12898.7175	102.138	126.2871556
17895.945	153.207	116.8089252
479.865	5.1069	93.96404864
1123.0725	10.2138	109.9563825
19627.6575	170.23	115.3008136
34381.36	170.23	201.9700405
46909.36	340.46	137.7822945
64657.36	510.69	126.6078443
134605.36	1021.38	131.7877382
4219.5985	18.72	225.4059028
7587.361	37.44	202.6538729
14502.5	74.88	193.6765491
26716.252	149.76	178.3937767
41893.635	299.52	139.8692408
83294.662	599.04	139.0469117
3546.046	14.976	236.7819177
6330.063	29.952	211.3402444
12167.518	59.904	203.1169538
22944.358	119.808	191.5093984
SG, 25 wt%+ SNP, 19.75 wt%		
479.865	1.53207	313.2134955
1024.1175	3.06414	334.2267325
11661.78	51.069	228.3534042
18588.63	102.138	181.9952417
23932.2	153.207	156.2082672
727.2525	5.1069	142.4058627
1568.37	10.2138	153.5540152
26158.6875	170.23	153.6667303
43777.36	170.23	257.1659519
71965.36	340.46	211.3768431
99109.36	510.69	194.0695138
174277.36	1021.38	170.6293054

3635.853	9.36	388.4458333
5970.835	18.72	318.9548611
11269.448	37.44	301.0002137
21687.06	74.88	289.6241987
39648.46	149.76	264.7466613
73326.085	299.52	244.8119825
5791.221	14.976	386.7001202
10461.185	29.952	349.2649907
19082.657	59.904	318.5539697
34260.04	119.808	285.9578659
4713.537	11.9808	393.4242288
SG, 30 wt%+ SNP, 19.75 wt%		
875.685	1.53207	571.5698369
1815.7575	3.06414	592.5830739
13640.88	51.069	267.1068554
25515.48	102.138	249.8137814
1222.0275	5.1069	239.2894907
2607.3975	10.2138	255.2818246
54217.36	170.23	318.4947424
93889.36	340.46	275.7720731
117901.36	510.69	230.8667881
5207.4755	9.36	556.3542201
9742.729	18.72	520.4449252
18274.394	37.44	488.0981303
33721.198	74.88	450.3365118
63357.508	149.76	423.0602831
4668.6335	7.488	623.4820379
8799.7555	14.976	587.5905115
15580.184	29.952	520.1717415
29320.655	59.904	489.4607205
54376.808	119.808	453.8662527
3950.1775	5.9904	659.4179854
7138.326	11.9808	595.8138021
SG, 35 wt%+ SNP, 19.75 wt%		
2112.6225	1.53207	1378.933404
3893.8125	3.06414	1270.76847
5773.9575	5.1069	1130.618869
9781.635	10.2138	957.6881278
11413.36	5.1069	2234.890051

17677.36	10.2138	1730.73293
89713.36	170.23	527.01263
148177.36	340.46	435.2269283
188893.36	510.69	369.8787131
4623.73	2.34	1975.952991
7452.6505	4.68	1592.446688
13155.395	9.36	1405.490919
22495.323	18.72	1201.673237
40277.109	37.44	1075.777484
70362.454	74.88	939.6695246
3860.3705	1.872	2062.163729
6734.1945	3.744	1798.663061
11763.3865	7.488	1570.965077
19711.306	14.976	1316.192975
35158.11	29.952	1173.815104
62100.21	59.904	1036.662159
4533.923	1.4976	3027.459268
6958.712	2.9952	2323.287927
10550.992	5.9904	1761.316774
16478.254	11.9808	1375.388455
SG, 38 wt%+ SNP, 19.75 wt%		
5922.39	1.53207	3865.61319
8891.04	3.06414	2901.642875
10870.14	5.1069	2128.520237
16510.575	10.2138	1616.496798
16111.36	5.1069	3154.821908
27073.36	10.2138	2650.664787
111637.36	170.23	655.8030899
189937.36	340.46	557.8845092
268237.36	510.69	525.2449823
7766.975	2.34	3319.220085
12706.36	4.68	2715.034188
22046.288	9.36	2355.37265
38031.934	18.72	2031.620406
66141.525	37.44	1766.600561
4623.73	0.936	4939.882479
7228.133	1.872	3861.182158
12077.711	3.744	3225.884348
19980.727	7.488	2668.366319
34978.496	14.976	2335.636752

58418.123	29.952	1950.391393
4803.344	0.3744	12829.44444
6060.642	0.7488	8093.80609
8485.431	1.4976	5666.019631
12077.711	2.9952	4032.355435
18633.622	5.9904	3110.580596
31565.83	11.9808	2634.701356
SG, 41 wt%+ SNP, 19.75 wt%		
8693.13	1.53207	5674.10758
14383.0425	3.06414	4693.989994
18934.9725	5.1069	3707.723374
23941.36	5.1069	4688.041669
42733.36	10.2138	4183.884548
230653.36	170.23	1354.951301
19890.92	2.34	8500.393162
29230.848	4.68	6245.907692
42342.67	9.36	4523.78953
68386.7	18.72	3653.135684
6240.256	0.234	26667.76068
8126.203	0.468	17363.68162
11628.676	0.936	12423.79915
17196.71	1.872	9186.276709
26267.217	3.744	7015.816506
31026.988	7.488	4143.561432
62998.28	14.976	4206.615919
5252.379	0.1872	28057.58013
8036.396	0.3744	21464.73291
11359.255	0.7488	15169.94525
16568.061	1.4976	11063.07492
24022.042	2.9952	8020.179621
35158.11	5.9904	5869.075521
53927.773	11.9808	4501.182976
SG, 44 wt%+ SNP, 19.75 wt%		
318349.36	170.23	1870.113141
470773.36	340.46	1382.756741
44138.81	2.34	18862.73932
54915.65	4.68	11734.11325
22315.709	0.234	95366.27778
25009.919	0.468	53439.99786

29769.69	0.936	31805.22436
38750.39	1.872	20699.99466
50335.493	3.744	13444.30903
70182.84	7.488	9372.708333
12077.711	0.0234	516141.4957
13694.237	0.0468	292611.9017
15490.377	0.0936	165495.4808
19890.92	0.1872	106254.9145
24560.884	0.3744	65600.65171
31476.023	0.7488	42035.28713
39379.039	1.4976	26294.76429
47102.441	2.9952	15725.97523
64974.034	5.9904	10846.35984
SG, 47 wt%+ SNP, 19.75 wt%		
63447.315	2.34	27114.23718
79612.575	4.68	17011.23397
44138.81	0.234	188627.3932
47282.055	0.468	101030.0321
54466.615	0.936	58190.82799
63896.35	1.872	34132.6656
78265.47	3.744	20904.23878
31565.83	0.0234	1348967.094
34260.04	0.0468	732052.1368
37672.706	0.0936	402486.1752
43240.74	0.1872	230986.859
49527.23	0.3744	132284.2682
57520.053	0.7488	76816.3101
64794.42	1.4976	43265.50481
76918.365	2.9952	25680.54387

Table 8 Rheological Data for Suspensions of SG Solid Particles in SNP Dispersion with SNP Concentration of 24.71 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 24.71 wt%		
430.3875	3.06414	140.4594764
8742.6075	51.069	171.1920637
17401.17	102.138	170.3692064
25812.345	153.207	168.4801935

776.73	5.1069	152.0942255
1667.325	10.2138	163.242378
28484.13	170.23	167.3273219
31249.36	170.23	183.5714034
56305.36	340.46	165.3802502
82405.36	510.69	161.3608255
153397.36	1021.38	150.1863753
3366.432	18.72	179.8307692
6330.063	37.44	169.0721955
12122.6145	74.88	161.8938902
23617.9105	149.76	157.7050648
45934.95	299.52	153.361879
79612.575	599.04	132.9002654
2917.397	14.976	194.804821
5072.765	29.952	169.3631477
9832.536	59.904	164.1382212
19307.1745	119.808	161.1509624
SG, 5 wt%+ SNP, 24.71 wt%		
529.3425	3.06414	172.7540191
11068.05	51.069	216.7273689
20023.4775	102.138	196.0433678
925.1625	5.1069	181.1593139
1865.235	10.2138	182.6191036
36469.36	170.23	214.2357986
66745.36	340.46	196.0446455
94933.36	510.69	185.8923417
177409.36	1021.38	173.695745
4264.502	18.72	227.804594
8126.203	37.44	217.0460203
15939.412	74.88	212.8660791
31700.5405	149.76	211.6756177
62908.473	299.52	210.0309595
3590.9495	14.976	239.7802818
6599.484	29.952	220.3353365
12930.8775	59.904	215.860001
22046.288	119.808	184.0134882
2917.397	11.9808	243.5060263
SG, 10 wt%+ SNP, 24.71 wt%		
380.91	1.53207	248.6244101

875.685	3.06414	285.7849184
16164.2325	51.069	316.5175057
1518.8925	5.1069	297.4196675
3250.605	10.2138	318.2561828
54217.36	170.23	318.4947424
98065.36	340.46	288.0378312
140869.36	510.69	275.8412344
249445.36	1021.38	244.223854
3456.239	9.36	369.2563034
6599.484	18.72	352.5365385
12616.553	37.44	336.9805823
24785.4015	74.88	331.0016226
48269.932	149.76	322.3152511
3186.818	7.488	425.5900107
5656.5105	14.976	377.705028
10416.2815	29.952	347.7658086
20429.762	59.904	341.0417001
39828.074	119.808	332.4325087
4489.0195	11.9808	374.6844535
3141.9145	9.36	335.6746261
5881.028	18.72	314.1574786
11179.641	37.44	298.6015224
21282.9285	74.88	284.2271434
41354.793	149.76	276.1404447
78894.119	299.52	263.4018396
28347.61219	88.38297656	320.7361111
24518.23123	81.37719922	301.2911659
23148.63702	79.80375781	290.0695112
22011.19527	77.78920703	282.9595019
3995.081	11.9808	333.4569478
SG, 15 wt%+ SNP, 24.71 wt%		
2310.5325	3.06414	754.0557873
3250.605	5.1069	636.5123656
6268.7325	10.2138	613.7512483
89713.36	170.23	527.01263
153397.36	340.46	450.5591259
3635.853	4.68	776.8916667
6419.87	9.36	685.883547
12841.0705	18.72	685.9546207
24875.2085	37.44	664.4019364

47371.862	74.88	632.6370459
88234.047	149.76	589.1696514
3097.011	3.744	827.193109
5656.5105	7.488	755.4100561
10595.8955	14.976	707.5250735
20339.955	29.952	679.0850361
39289.232	59.904	655.8699252
74493.576	119.808	621.7746394
4713.537	5.9904	786.8484575
8665.045	11.9808	723.2442742
3546.046	4.68	757.7021368
6330.063	9.36	676.2887821
12436.939	18.72	664.3663996
23752.621	37.44	634.4182959
46743.213	74.88	624.2416266
3231.7215	3.744	863.1734776
5881.028	7.488	785.3936966
11493.9655	14.976	767.4923544
20699.183	29.952	691.0784923
39468.846	59.904	658.8682893
74224.155	119.808	619.5258664
9248.7905	11.9808	771.96769
SG, 20 wt%+ SNP, 24.71 wt%		
3349.56	3.06414	1093.148485
4833.885	5.1069	946.5399753
8841.5625	10.2138	865.6486812
147133.36	170.23	864.3209775
5072.765	4.68	1083.924145
9114.08	9.36	973.7264957
17780.4555	18.72	949.8106571
33721.198	37.44	900.6730235
63447.315	74.88	847.3199119
4354.309	3.744	1163.009882
7946.589	7.488	1061.243189
14861.728	14.976	992.3696581
28153.164	29.952	939.9427083
53029.703	59.904	885.244775
6689.291	5.9904	1116.668503
12302.2285	11.9808	1026.828634

SG, 31 wt%+ SNP, 24.71 wt%		
6240.256	2.34	2666.776068
10685.7025	4.68	2283.269765
18813.236	9.36	2009.961111
35337.724	18.72	1887.698932
65602.683	37.44	1752.208413
4938.0545	1.872	2637.849626
8844.659	3.744	2362.355502
16253.7365	7.488	2170.637887
30128.918	14.976	2011.813435
54915.65	29.952	1833.455195
4084.888	1.4976	2727.622863
7452.6505	2.9952	2488.19795
13649.3335	5.9904	2278.534572
24875.2085	11.9808	2076.256051
5970.835	2.34	2551.638889
10461.185	4.68	2235.29594
18723.429	9.36	2000.366346
34888.689	18.72	1863.712019
62908.473	37.44	1680.247676
2872.4935	0.936	3068.903312
4982.958	1.872	2661.836538
8844.659	3.744	2362.355502
16119.026	7.488	2152.647703
29859.497	14.976	1993.823251
53029.703	29.952	1770.48955
4264.502	1.4976	2847.557425
7587.361	2.9952	2533.173411
13604.43	5.9904	2271.038662
24560.884	11.9808	2050.020366
SG, 34 wt%+ SNP, 24.71 wt%		
8989.995	1.53207	5867.874836
13344.015	3.06414	4354.897296
16955.8725	5.1069	3320.188862
26950.3275	10.2138	2638.619074
23941.36	5.1069	4688.041669
36469.36	10.2138	3570.596644
9338.5975	2.34	3990.853632
16208.833	4.68	3463.425855

27614.322	9.36	2950.248077
50874.335	18.72	2717.6461
4174.695	0.936	4460.144231
7587.361	1.872	4053.077457
13649.3335	3.744	3645.655315
24246.5595	7.488	3238.055489
43555.0645	14.976	2908.324286
77097.979	29.952	2574.051115
3546.046	0.7488	4735.638355
6374.9665	1.4976	4256.788528
11449.062	2.9952	3822.469952
20788.99	5.9904	3470.384282
36460.3115	11.9808	3043.228457
10506.0885	2.34	4489.78141
17376.324	4.68	3712.889744
29949.304	9.36	3199.711966
53927.773	18.72	2880.757105
4533.923	0.936	4843.934829
8126.203	1.872	4340.920406
14637.2105	3.744	3909.511351
26177.41	7.488	3495.914797
46743.213	14.976	3121.208133
81857.75	29.952	2732.96441
3680.7565	0.7488	4915.540198
6599.484	1.4976	4406.706731
11853.1935	2.9952	3957.396334
21687.06	5.9904	3620.302484
38660.583	11.9808	3226.878255
SG, 37 wt%+ SNP, 24.71 wt%		
16114.755	1.53207	10518.28898
25713.39	3.06414	8391.715131
36469.36	5.1069	7141.193288
59437.36	10.2138	5819.318961
14322.886	2.34	6120.891453
23707.7175	4.68	5065.751603
41085.372	9.36	4389.462821
73685.313	18.72	3936.18125
4264.502	0.468	9112.183761
6734.1945	0.936	7194.652244
12167.518	1.872	6499.742521

21103.3145	3.744	5636.569044
36684.829	7.488	4899.149172
63716.736	14.976	4254.589744
3276.625	0.3744	8751.669338
5970.835	0.7488	7973.871528
10461.185	1.4976	6985.299813
17825.359	2.9952	5951.308427
30937.181	5.9904	5164.459969
54062.4835	11.9808	4512.426841
16029.219	2.34	6850.09359
24201.656	4.68	5171.294017
44049.003	9.36	4706.090064
76828.558	18.72	4104.089637
4803.344	0.468	10263.55556
8126.203	0.936	8681.840812
13424.816	1.872	7171.376068
22854.551	3.744	6104.313835
39199.425	7.488	5234.965946
66500.753	14.976	4440.488315
3770.5635	0.3744	10070.94952
6509.677	0.7488	8693.4789
10820.413	1.4976	7225.168937
18813.236	2.9952	6281.128472
32463.9	5.9904	5419.320913
56172.948	11.9808	4688.580729
SG, 40 wt%+ SNP, 24.71 wt%		
24624.885	1.53207	16072.95032
47953.36	5.1069	9389.915604
76141.36	10.2138	7454.753373
38031.934	2.34	16252.96325
55185.071	4.68	11791.68184
83474.276	9.36	8918.19188
13065.588	0.234	55835.84615
16298.64	0.468	34826.15385
23303.586	0.936	24896.99359
33631.391	1.872	17965.48665
50604.914	3.744	13516.26976
77726.628	7.488	10380.15865
5072.765	0.0234	216784.8291
6509.677	0.0468	139095.6624

8395.624	0.0936	89696.83761
11179.641	0.1872	59720.30449
16029.219	0.3744	42813.08494
23123.972	0.7488	30881.37286
33182.356	1.4976	22157.0219
48539.353	2.9952	16205.71347
71170.717	5.9904	11880.79544
26056.09	0.9	28951.21111
36698.8	1.8	20388.22222
52051.215	3.6	14458.67083
77801.68	7.2	10805.78889
114867.67	14.4	7976.921528
8073.58	0.09	89706.44444
11254.16	0.18	62523.11111
16392.02	0.36	45533.38889
22875.51	0.72	31771.54167
33090.065	1.44	22979.21181
47953.16	2.88	16650.40278
69972.56	5.76	12148.01389
102512.34	11.52	8898.640625
4097.855	0.036	113829.3056
7094.94	0.072	98540.83333
10520.18	0.144	73056.80556
15413.38	0.288	53518.68056
22019.2	0.576	38227.77778
31316.28	1.152	27184.27083
44527.92	2.304	19326.35417
62143.44	4.608	13485.98958
SG, 44 wt%+ SNP, 24.71 wt%		
71889.17299	2.34	30721.8688
24201.65599	0.234	103425.8803
31925.058	0.468	68215.9359
45126.687	0.936	48212.27244
64075.964	1.872	34228.61325
6868.905	0.0234	293542.9487
9069.176498	0.0468	193785.8226
12167.518	0.0936	129994.8504
17466.131	0.1872	93301.98184
25997.796	0.3744	69438.55769
29096.1375	0.7488	38857.02123

56621.983	1.4976	37808.48224
83564.08301	2.9952	27899.33327
70631.87501	2.34	30184.56197
23573.00701	0.234	100739.3462
32194.479	0.468	68791.62179
44767.459	0.936	47828.48184
64614.80601	1.872	34516.4562
5162.571999	0.0234	220622.735
7048.518998	0.0468	150609.3803
10101.957	0.0936	107926.891
16568.061	0.1872	88504.59936
25638.568	0.3744	68479.0812
38570.776	0.7488	51510.11752
56621.983	1.4976	37808.48224
83115.04799	2.9952	27749.41506
66424.99	0.9	73805.54444
91563.80501	1.8	50868.78056
24588.13	0.09	273201.4444
32172.59	0.18	178736.6111
44894.90999	0.36	124708.0833
61654.12	0.72	85630.72222
86854.1	1.44	60315.34722
119883.2	2.88	41626.11111
5443.485	0.009	604831.6667
7033.775	0.018	390765.2778
10030.86	0.036	278635
15291.05	0.072	212375.6944
23731.82001	0.144	164804.3056
35964.81999	0.288	124877.8472
52234.71	0.576	90685.26042
75844.4	1.152	65837.15278
108873.5	2.304	47254.12326

Table 9 Rheological Data for Suspensions of SG Solid Particles in SNP Dispersion with SNP Concentration of 29.67 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 29.67 wt%		

677.775	1.53207	442.3916662
1024.1175	3.06414	334.2267325
25762.8675	51.069	504.4717441
2557.92	5.1069	500.8752864
5229.705	10.2138	512.0234389
83449.36	170.23	490.2153557
153397.36	340.46	450.5591259
218125.36	510.69	427.1189175
395605.36	1021.38	387.3243651
4623.73	9.36	493.9882479
9742.729	18.72	520.4449252
18004.973	37.44	480.9020566
36056.18	74.88	481.5194979
71529.945	149.76	477.6305088
3995.081	7.488	533.5311165
8036.396	14.976	536.6183226
14233.079	29.952	475.1962807
28871.62	59.904	481.9648104
58418.123	119.808	487.5978482
6060.642	11.9808	505.8628806
7645.425	14.4	530.9322917
15168.72	28.8	526.6916667
28930.845	57.6	502.2716146
56271.6	115.2	488.46875
106671.56	230.4	462.9842014
5993.97	11.52	520.3098958
11926.975	23.04	517.6638455
23548.325	46.08	511.0313585
SG, 5 wt%+ SNP, 29.67 wt%		
875.685	1.53207	571.5698369
1964.19	3.06414	641.0248879
3300.0825	5.1069	646.2007284
6615.075	10.2138	647.6605181
9325.36	10.2138	913.0157238
99109.36	170.23	582.2085414
185761.36	340.46	545.6187511
270325.36	510.69	529.3335683
6240.256	9.36	666.6940171
11898.097	18.72	635.5821047
23213.779	37.44	620.0261485

45485.915	74.88	607.4507879
88054.433	149.76	587.9703058
4803.344	7.488	641.4722222
9383.501	14.976	626.5692441
18274.394	29.952	610.1226629
36056.18	59.904	601.8993723
71799.366	119.808	599.2869091
3905.274	5.9904	651.9220753
7317.94	11.9808	610.8056223
6911.445	14.4	479.9614583
13456.1	28.8	467.2256944
25933.76	57.6	450.2388889
50522.09	115.2	438.559809
84896.82	230.4	368.4757813
5382.32	11.52	467.2152778
10642.51	23.04	461.9144965
20918.23	46.08	453.9546441
SG, 10 wt%+ SNP, 29.67 wt%		
1271.505	1.53207	829.9261783
2607.3975	3.06414	850.9394153
4289.6325	5.1069	839.9679845
8544.6975	10.2138	836.5835928
13501.36	10.2138	1321.874327
130429.36	170.23	766.1949128
236917.36	340.46	695.8742877
328789.36	510.69	643.8139772
5342.186	4.68	1141.492735
9114.08	9.36	973.7264957
18364.201	18.72	980.9936432
36505.215	37.44	975.0324519
71978.98	74.88	961.2577457
4399.2125	3.744	1175.003339
7677.168	7.488	1025.262821
15131.149	14.976	1010.359842
29769.69	29.952	993.9132612
59585.614	59.904	994.6850628
3725.66	2.9952	1243.87687
6554.5805	5.9904	1094.180773
12436.939	11.9808	1038.072499
3669.7	3.6	1019.361111

6238.63	7.2	866.4763889
11926.975	14.4	828.2621528
22875.51	28.8	794.2885417
43855.105	57.6	761.3733507
83428.86	115.2	724.2088542
5015.33	5.76	870.7170139
9602.705	11.52	833.5681424
18410.465	23.04	799.0653212
35353.17	46.08	767.2128906
4159.02	4.608	902.5651042
SG, 15 wt%+ SNP, 29.67 wt%		
1815.7575	1.53207	1185.166148
3646.425	3.06414	1190.032113
5971.8675	5.1069	1169.37232
10944.35625	10.2138	1071.526391
9325.36	5.1069	1826.031448
15589.36	10.2138	1526.303628
171145.36	170.23	1005.377196
269281.36	340.46	790.9339129
3501.1425	2.34	1496.214744
5746.3175	4.68	1227.84562
11044.9305	9.36	1180.013942
20699.183	18.72	1105.725588
42342.67	37.44	1130.947382
82037.364	74.88	1095.584455
4803.344	3.744	1282.944444
9158.9835	7.488	1223.154848
16747.675	14.976	1118.300948
34260.04	29.952	1143.831464
67488.63	59.904	1126.613081
3905.274	2.9952	1303.844151
6958.712	5.9904	1161.643964
13963.658	11.9808	1165.502971
3792.03	3.6	1053.341667
7217.27	7.2	1002.398611
13945.42	14.4	968.4319444
27401.72	28.8	951.4486111
53152.185	57.6	922.7809896
100677.39	115.2	873.9356771
5871.64	5.76	1019.381944

11376.49	11.52	987.5425347
22386.19	23.04	971.6228299
43610.445	46.08	946.4072266
4831.835	4.608	1048.575304
SG, 20 wt%+ SNP, 29.67 wt%		
3399.0375	1.53207	2218.591513
6367.6875	3.06414	2078.132037
10276.41	5.1069	2012.259884
19578.18	10.2138	1916.836045
15589.36	5.1069	3052.607257
26029.36	10.2138	2548.450136
205597.36	170.23	1207.762204
380989.36	340.46	1119.042942
5072.765	2.34	2167.848291
8799.7555	4.68	1880.289637
16433.3505	9.36	1755.69984
31476.023	18.72	1681.411485
60304.07	37.44	1610.68563
4129.7915	1.872	2206.085203
7587.361	3.744	2026.538729
13245.202	7.488	1768.857105
26536.638	14.976	1771.944311
48629.16	29.952	1623.569712
3366.432	1.4976	2247.884615
5970.835	2.9952	1993.467882
10550.992	5.9904	1761.316774
20429.762	11.9808	1705.2085
7156.105	3.6	1987.806944
13823.09	7.2	1919.873611
26790.07	14.4	1860.421528
51378.4	28.8	1783.972222
96518.17	57.6	1675.662674
3058.05	1.44	2123.645833
6055.135	2.88	2102.477431
11498.82	5.76	1996.322917
22263.86	11.52	1932.626736
42203.65	23.04	1831.755642
80370.61	46.08	1744.153863
4709.505	2.304	2044.05599
9602.705	4.608	2083.920356

SG, 25 wt%+ SNP, 29.67 wt%		
7901.49	1.53207	5157.394897
15224.16	3.06414	4968.493607
25416.525	5.1069	4976.898901
23941.36	5.1069	4688.041669
48997.36	10.2138	4797.172453
293293.36	170.23	1722.924044
458245.36	340.46	1345.959467
6868.905	2.34	2935.429487
13290.1055	4.68	2839.766132
23213.779	9.36	2480.104594
46473.792	18.72	2482.574359
85450.03	37.44	2282.319177
3501.1425	0.936	3740.536859
5342.186	1.872	2853.731838
10820.413	3.744	2890.067575
19441.885	7.488	2596.405582
37403.285	14.976	2497.548411
70182.84	29.952	2343.177083
5162.572	1.4976	3447.230235
8844.659	2.9952	2952.944378
16029.219	5.9904	2675.817808
30308.532	11.9808	2529.758614
3486.205	0.9	3873.561111
6544.455	1.8	3635.808333
12599.79	3.6	3499.941667
23731.82	7.2	3296.086111
46362.87	14.4	3219.64375
87221.09	28.8	3028.510069
5321.155	1.44	3695.246528
10520.18	2.88	3652.840278
19817.26	5.76	3440.496528
38411.42	11.52	3334.324653
72174.5	23.04	3132.573785
4342.515	1.152	3769.544271
8562.9	2.304	3716.536458
16208.525	4.608	3517.475043
SG, 28 wt%+ SNP, 29.67 wt%		
10523.7975	1.53207	6869.005659

18638.1075	3.06414	6082.655329
27296.67	5.1069	5345.056688
37513.36	5.1069	7345.622589
61525.36	10.2138	6023.748262
358021.36	170.23	2103.162545
13155.395	2.34	5621.963675
22809.6475	4.68	4873.856303
43510.161	9.36	4648.521474
79253.347	18.72	4233.618964
3635.853	0.468	7768.916667
5701.414	0.936	6091.254274
10191.764	1.872	5444.318376
18813.236	3.744	5024.902778
34798.882	7.488	4647.286592
65692.49	14.976	4386.517762
2827.59	0.3744	7552.323718
5072.765	0.7488	6774.525908
9158.9835	1.4976	6115.774239
16837.482	2.9952	5621.488381
30128.918	5.9904	5029.533587
55813.72	11.9808	4658.597089
6483.29	0.9	7203.655556
11621.15	1.8	6456.194444
22508.52	3.6	6252.366667
40001.71	7.2	5555.793056
74131.78	14.4	5148.040278
5198.825	0.72	7220.590278
10092.025	1.44	7008.350694
18899.785	2.88	6562.425347
34680.355	5.76	6020.894965
63672.565	11.52	5527.132378
113032.72	23.04	4905.934028
4403.68	0.576	7645.277778
8257.075	1.152	7167.599826
15352.215	2.304	6663.28776
28258.03	4.608	6132.384983
SG, 31 wt%+ SNP, 29.67 wt%		
18489.675	1.53207	12068.42703
43777.36	5.1069	8572.198398
74053.36	10.2138	7250.324071

23662.814	2.34	10112.31368
39828.074	4.68	8510.272222
71978.98	9.36	7690.061966
4354.309	0.234	18608.15812
6150.449	0.468	13141.98504
10236.6675	0.936	10936.61058
18543.815	1.872	9905.884081
33361.97	3.744	8910.782585
61202.14	7.488	8173.362714
4264.502	0.3744	11390.2297
8350.7205	0.7488	11152.13742
15400.57	1.4976	10283.50027
28781.813	2.9952	9609.312567
52850.089	5.9904	8822.464109
11131.83	0.9	12368.7
20184.25	1.8	11213.47222
35781.325	3.6	9939.256944
66180.33	7.2	9191.7125
115846.31	14.4	8044.882639
5076.495	0.36	14101.375
9480.375	0.72	13167.1875
17615.32	1.44	12232.86111
31989.095	2.88	11107.32465
56026.94	5.76	9726.899306
98475.45	11.52	8548.216146
3853.195	0.288	13379.14931
7645.425	0.576	13273.30729
14312.41	1.152	12423.96701
26423.08	2.304	11468.35069
47830.83	4.608	10379.95443
SG, 34 wt%+ SNP, 29.67 wt%		
78229.36	5.1069	15318.36535
135649.36	10.2138	13280.98847
7766.975	0.234	33192.20085
12032.8075	0.468	25711.12714
19980.727	0.936	21346.93056
35068.303	1.872	18733.06784
58867.158	3.744	15723.06571
3007.204	0.0936	32128.24786
5162.572	0.1872	27577.84188

8575.238	0.3744	22903.94765
15939.412	0.7488	21286.60791
29141.041	1.4976	19458.49426
49886.458	2.9952	16655.46808
81857.75	5.9904	13664.82205
23731.82	0.9	26368.68889
37310.45	1.8	20728.02778
4159.02	0.09	46211.33333
6666.785	0.18	37037.69444
11376.49	0.36	31601.36111
19205.61	0.72	26674.45833
32050.26	1.44	22257.125
53213.35	2.88	18476.85764
88689.05	5.76	15397.40451
5443.485	0.144	37801.97917
9969.695	0.288	34616.99653
17492.99	0.576	30369.77431
28747.35	1.152	24954.29688
46362.87	2.304	20122.77344
75232.75	4.608	16326.55165
SG, 37 wt%+ SNP, 29.67 wt%		
115813.36	5.1069	22677.8202
65692.49	2.34	28073.71368
14727.0175	0.234	62935.97222
22225.902	0.468	47491.24359
36056.18	0.936	38521.55983
59046.772	1.872	31542.07906
4713.537	0.0234	201433.2051
4803.344	0.0468	102635.5556
12526.746	0.1872	66916.37821
20160.341	0.3744	53847.06464
32912.935	0.7488	43954.24012
52131.633	1.4976	34810.11819
83564.083	2.9952	27899.33327
34374.53	0.9	38193.92222
51990.05	1.8	28883.36111
81471.58	3.6	22630.99444
7584.26	0.09	84269.55556
11621.15	0.18	64561.94444
19083.28	0.36	53009.11111

30092.98	0.72	41795.80556
47096.85	1.44	32706.14583
73214.305	2.88	25421.63368
114256.02	5.76	19836.11458
5749.31	0.072	79851.52778
9725.035	0.144	67534.96528
16269.69	0.288	56491.97917
26423.08	0.576	45873.40278
41225.01	1.152	35785.59896
64467.71	2.304	27980.77691
100677.39	4.608	21848.39193
SG, 40 wt%+ SNP, 29.67 wt%		
32912.935	0.234	140653.5684
46383.985	0.468	99111.07906
5476.8965	0.0234	234055.406
10595.8955	0.0468	226408.0235
15669.991	0.0936	167414.4338
25638.568	0.1872	136958.1624
38301.355	0.3744	102300.6277
59855.035	0.7488	79934.60871
87588.08	0.9	97320.08889
27768.71	0.09	308541.2222
37432.78	0.18	207959.8889
56760.92	0.36	157669.2222
80370.61	0.72	111625.8472
115846.31	1.44	80448.82639
22508.52	0.072	312618.3333
33090.065	0.144	229792.1181
49788.11	0.288	172875.3819
72541.49	0.576	125940.0868
103980.3	1.152	90260.67708
SG, 42 wt%+ SNP, 29.67 wt%		
65692.49	0.234	280737.1368
87246.17	0.468	186423.4402
25728.375	0.0234	1099503.205
33182.356	0.0468	709024.7009
43689.775	0.0936	466771.1004
58956.965	0.1872	314941.0524
80061.61	0.3744	213839.7703

48320.15	0.09	536890.5556
65446.35	0.18	363590.8333
94193.9	0.36	261649.7222
17370.66	0.009	1930073.333
23120.17	0.018	1284453.889
33028.9	0.036	917469.4444
45017.24	0.072	625239.4444
61164.8	0.144	424755.5556
86120.12	0.288	299028.1944
118415.24	0.576	205582.0139

Table 10 Rheological Data for Suspensions of SG Solid Particles in SNP Dispersion with SNP Concentration of 34.60 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 34.60 wt%		
2557.92	1.53207	1669.584288
5031.795	3.06414	1642.155711
8198.355	5.1069	1605.348646
16263.1875	10.2138	1592.275891
11413.36	5.1069	2234.890051
18721.36	10.2138	1832.947581
4713.537	2.34	2014.332051
8395.624	4.68	1793.936752
15580.184	9.36	1664.549573
30128.918	18.72	1609.450748
56891.404	37.44	1519.535363
3815.467	1.872	2038.176816
7138.326	3.744	1906.604167
13424.816	7.488	1792.844017
25907.989	14.976	1729.967214
47820.897	29.952	1596.584435
86348.1	59.904	1441.441306
3186.818	1.4976	2127.950053
5791.221	2.9952	1933.500601
10910.22	5.9904	1821.284054
21058.411	11.9808	1757.679871
5162.572	2.34	2206.22735
8934.466	4.68	1909.073932
15939.412	9.36	1702.928632

32104.672	18.72	1714.993162
60483.684	37.44	1615.483013
4084.888	1.872	2182.098291
7407.747	3.744	1978.564904
14053.465	7.488	1876.79821
26446.831	14.976	1765.947583
49886.458	29.952	1665.546808
3276.625	1.4976	2187.917334
5970.835	2.9952	1993.467882
11314.3515	5.9904	1888.747246
21821.7705	11.9808	1821.395107
SG, 5 wt%+ SNP, 34.60 wt%		
3794.8575	1.53207	2476.947855
7307.759999	3.06414	2384.930192
11909.1675	5.1069	2331.975856
15589.36	5.1069	3052.607257
26029.36	10.2138	2548.450136
26029.36	10.2138	2548.450136
7048.519	2.34	3012.187607
12347.132	4.68	2638.276068
22854.551	9.36	2441.725534
43061.126	18.72	2300.273825
79073.73299	37.44	2112.012099
3141.9145	0.936	3356.746261
5611.607	1.872	2997.653312
10371.378	3.744	2770.133013
19531.692	7.488	2608.399038
36056.18	14.976	2407.597489
65602.68301	29.952	2190.260517
4623.73	1.4976	3087.426549
8485.431001	2.9952	2833.009816
15939.412	5.9904	2660.825988
29410.46201	11.9808	2454.799513
7317.939999	2.34	3127.324786
12436.939	4.68	2657.465598
21597.253	9.36	2307.398825
41714.02101	18.72	2228.313088
75571.26	37.44	2018.463141
3186.818	0.936	3404.720085
5431.992999	1.872	2901.705662

9922.343001	3.744	2650.198451
18723.429	7.488	2500.457933
34439.65401	14.976	2299.656384
63088.08699	29.952	2106.306323
4623.73	1.4976	3087.426549
8216.009999	2.9952	2743.058894
15041.342	5.9904	2510.907786
27973.55	11.9808	2334.864951
SG, 10 wt%+ SNP, 34.60 wt%		
7703.579999	1.53207	5028.216726
14185.1325	3.06414	4629.400909
22447.875	5.1069	4395.597133
23941.36	5.1069	4688.041669
41689.36	10.2138	4081.669898
10012.15	2.34	4278.696581
18184.587	4.68	3885.595513
32643.514	9.36	3487.554915
63986.15699	18.72	3418.063942
2827.59	0.468	6041.858974
4264.502	0.936	4556.09188
7946.588999	1.872	4244.972756
14816.8245	3.744	3957.485176
28961.427	7.488	3867.711939
54017.58	14.976	3606.943109
3770.5635	0.7488	5035.47476
6599.484	1.4976	4406.706731
12436.939	2.9952	4152.289997
23528.1035	5.9904	3927.634799
44498.038	11.9808	3714.112413
10281.571	2.34	4393.833761
18364.201	4.68	3923.974573
33990.619	9.36	3631.476389
66231.33199	18.72	3537.998504
3007.204	0.468	6425.649573
4623.73	0.936	4939.882479
8350.7205	1.872	4460.854968
15310.763	3.744	4089.413194
28871.62	7.488	3855.718483
54466.61499	14.976	3636.926749
3815.467	0.7488	5095.442041

6734.1945	1.4976	4496.657652
12571.6495	2.9952	4197.265458
24022.042	5.9904	4010.08981
45485.91501	11.9808	3796.567425
SG, 15 wt%+ SNP, 34.60 wt%		
11364.915	1.53207	7418.012885
19677.135	3.06414	6421.748027
31249.36	5.1069	6119.04678
53173.36	10.2138	5206.031056
11987.904	2.34	5123.035897
21866.674	4.68	4672.366239
41714.021	9.36	4456.626175
79432.96101	18.72	4243.213729
2647.976	0.234	11316.13675
3546.046	0.468	7577.021368
5521.8	0.936	5899.358974
9922.343001	1.872	5300.396902
18813.236	3.744	5024.902778
35337.724	7.488	4719.247329
66051.718	14.976	4410.504674
4264.502	0.7488	5695.11485
7946.589001	1.4976	5306.215946
14951.535	2.9952	4991.831931
28871.62	5.9904	4819.648104
55454.492	11.9808	4628.613448
12347.132	2.34	5276.552137
22495.323	4.68	4806.692949
40277.109	9.36	4303.109936
79073.73301	18.72	4224.024199
2468.362001	0.234	10548.55556
3635.853	0.468	7768.916667
5431.993	0.936	5803.411325
10101.957	1.872	5396.344551
18543.815	3.744	4952.942041
35427.531	7.488	4731.240785
65961.911	14.976	4404.507946
4803.344	0.7488	6414.722222
8216.009999	1.4976	5486.117788
15131.149	2.9952	5051.799212
28602.199	5.9904	4774.672643

53927.773	11.9808	4501.182976
6238.63	0.9	6931.811111
11498.82	1.8	6388.233333
21040.56	3.6	5844.6
41958.99	7.2	5827.6375
79636.63	14.4	5530.321528
2813.39	0.36	7814.972222
5137.66	0.72	7135.638889
9480.375	1.44	6583.59375
17982.31	2.88	6243.857639
34252.2	5.76	5946.5625
53580.34001	11.52	4651.071181
120372.52	23.04	5224.501736
2079.41	0.288	7220.173611
4036.69	0.576	7008.142361
7584.26	1.152	6583.559028
14557.07	2.304	6318.172743
28380.36	4.608	6158.932292
SG, 28 wt%+ SNP, 34.60 wt%		
26801.895	1.53207	17493.9102
42733.36	5.1069	8367.769097
41444.6	2.34	17711.36752
67488.63002	4.68	14420.64744
7677.168001	0.234	32808.41026
12436.939	0.468	26574.65598
20699.183	0.936	22114.51175
35337.72401	1.872	18876.98932
60932.719	3.744	16274.76469
2378.555001	0.0234	101647.6496
3097.011	0.0468	66175.44872
4264.502	0.0936	45560.9188
6330.063	0.1872	33814.4391
10730.606	0.3744	28660.80662
18274.394	0.7488	24404.90652
30847.37401	1.4976	20597.8726
52131.63299	2.9952	17405.05909
86348.09999	5.9904	14414.41306
41175.179	2.34	17596.23034
68835.73498	4.68	14708.49038
7677.168001	0.234	32808.41026

12347.132	0.468	26382.76068
20878.797	0.936	22306.40705
35427.531	1.872	18924.96314
59855.03499	3.744	15986.92174
2109.134	0.0234	90133.93162
2827.59	0.0468	60418.58974
4174.695	0.0936	44601.44231
6958.712	0.1872	37172.60684
11179.641	0.3744	29860.15224
18454.008	0.7488	24644.77564
30757.56701	1.4976	20537.90532
51502.984	2.9952	17195.17361
85629.64401	5.9904	14294.4785
19083.28	0.9	21203.64444
30459.97001	1.8	16922.20556
49665.78	3.6	13796.05
74988.09	7.2	10415.0125
3792.03	0.09	42133.66667
5993.969999	0.18	33299.83333
9786.2	0.36	27183.88889
16147.36	0.72	22426.88889
27524.05	1.44	19113.92361
45995.88001	2.88	15970.79167
73887.12	5.76	12827.625
120250.19	11.52	10438.38455
2813.39	0.072	39074.86111
5015.330001	0.144	34828.68056
8929.89	0.288	31006.5625
15413.38	0.576	26759.34028
25199.78	1.152	21874.80903
38166.76001	2.304	16565.43403
62755.09001	4.608	13618.72613
SG, 31 wt%+ SNP, 34.60 wt%		
63613.36001	5.1069	12456.35513
68386.7	2.34	29225.08547
13784.044	0.234	58906.17094
22944.358	0.468	49026.40598
36505.215	0.936	39001.29808
61920.59599	1.872	33077.24145
3276.625	0.0234	140026.7094

4713.537002	0.0468	100716.6026
7946.589	0.0936	84899.45513
12885.974	0.1872	68835.3312
21687.06	0.3744	57924.83974
32553.707	0.7488	43474.50187
53209.317	1.4976	35529.72556
85450.03001	2.9952	28528.98972
58507.93	2.34	25003.38889
11269.448	0.234	48160.03419
18813.236	0.468	40199.22222
30398.339	0.936	32476.85791
51952.019	1.872	27752.1469
83923.31099	3.744	22415.41426
3097.010999	0.0234	132350.8974
3905.274	0.0468	83446.02564
5701.414	0.0936	60912.54274
8844.658999	0.1872	47247.11004
14861.728	0.3744	39694.78632
25458.954	0.7488	33999.67147
42522.28399	1.4976	28393.61912
71170.717	2.9952	23761.59088
27157.06	0.9	30174.51111
42203.65	1.8	23446.47222
67281.3	3.6	18689.25
111075.44	7.2	15427.14444
5810.475	0.09	64560.83333
8807.56	0.18	48930.88889
13823.09	0.36	38397.47222
22997.84	0.72	31941.44444
37310.45	1.44	25910.03472
59941.49999	2.88	20813.02083
97741.47001	5.76	16969.00521
2691.06	0.036	74751.66667
4159.02	0.072	57764.16667
7461.93	0.144	51818.95833
12355.13	0.288	42899.75694
20184.25	0.576	35042.10069
32294.92	1.152	28033.78472
51623.05999	2.304	22405.84201
83673.51999	4.608	18158.31597

SG, 34 wt%+ SNP, 34.60 wt%		
22046.288	0.234	94214.90598
35786.759	0.468	76467.43376
57520.053	0.936	61453.04808
3635.852999	0.0234	155378.3333
5791.221002	0.0468	123744.0385
10012.15	0.0936	106967.4145
17645.745	0.1872	94261.45833
29141.041	0.3744	77833.97703
49257.809	0.7488	65782.3304
79073.73299	1.4976	52800.30248
20968.604	0.234	89609.4188
33361.97	0.468	71286.26068
54915.65	0.936	58670.56624
4803.344	0.0234	205271.1111
6599.484001	0.0468	141014.6154
9742.728996	0.0936	104088.985
16657.868	0.1872	88984.33761
26446.831	0.3744	70637.90331
45665.529	0.7488	60984.94792
76469.33001	1.4976	51061.25134
65813.34	0.9	73125.93333
101166.71	1.8	56203.72778
16025.03	0.09	178055.8889
24832.78999	0.18	137959.9444
37799.77	0.36	104999.3611
59207.52	0.72	82232.66667
91624.97	1.44	63628.45139
4036.69	0.009	448521.1111
5749.31	0.018	319406.1111
9296.880001	0.036	258246.6667
14190.08	0.072	197084.4444
22263.86	0.144	154610.1389
34863.84999	0.288	121055.0347
51500.73	0.576	89410.98958
78780.31999	1.152	68385.69444
121351.16	2.304	52669.77431
SG, 37 wt%+ SNP, 34.60 wt%		
36864.443	0.234	157540.3547

54287.00101	0.468	115997.8654
86258.293	0.936	92156.29594
5881.028	0.0234	251325.9829
9652.922	0.0468	206259.0171
16119.026	0.0936	172211.8162
27344.901	0.1872	146073.1891
45485.91501	0.3744	121490.1576
73954.734	0.7488	98764.33494
34170.23301	0.234	146026.6368
54825.84301	0.468	117149.2372
6060.642001	0.0234	259001.7949
8575.238	0.0468	183231.5812
13604.43	0.0936	145346.4744
24291.463	0.1872	129762.0887
40636.337	0.3744	108537.2249
72877.05	0.7488	97325.12019
83551.19	0.9	92834.65556
21285.22	0.09	236502.4444
32906.57	0.18	182814.2778
49054.12999	0.36	136261.4722
74988.09	0.72	104150.125
111809.42	1.44	77645.43056
5993.97	0.009	665996.6667
8073.58	0.018	448532.2222
11988.14	0.036	333003.8889
18716.29	0.072	259948.4722
28502.69	0.144	197935.3472
44650.25001	0.288	155035.5903
66669.64998	0.576	115745.9201
99576.42	1.152	86437.86458
SG, 40 wt%+ SNP, 34.60 wt%		
70991.10301	0.234	303380.7821
13873.851	0.0234	592899.6154
21327.832	0.0468	455722.906
31116.795	0.0936	332444.391
52760.28199	0.1872	281839.1132
88952.50301	0.3744	237586.8136
45628.89	0.09	506987.6667
65324.02	0.18	362911.2222
94560.89	0.36	262669.1389

10520.18	0.009	1168908.889
15291.05	0.018	849502.7778
23731.82	0.036	659217.2222
36209.48	0.072	502909.4444
54191.99	0.144	376333.2639
81226.92001	0.288	282037.9167
119149.22	0.576	206856.2847

Appendix A.2: Rheological Data of suspensions of S-32 solo spheres in SNP dispersions

Table 11 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 5 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 5wt%		
1172.55	340.46	3.444016918
1766.28	510.69	3.458614815
3201.1275	1021.38	3.134120014
S-32, 5 wt%+SNP, 5 wt%		
2360.01	510.69	4.621218352
2917.397	599.04	4.870120526
S-32, 10 wt%+SNP, 5 wt%		
1766.28	306.414	5.764358025
1964.19	340.46	5.769223991
2557.92	510.69	5.008752864
4883.3625	1021.38	4.781141691
3097.011	599.04	5.169956931
S-32, 15 wt%+SNP, 5 wt%		
1865.235	306.414	6.087303452
2162.1	340.46	6.350525759
2755.83	510.69	5.396287376
5427.615	1021.38	5.314001645
3456.239	599.04	5.769629741
S-32, 20 wt%+SNP, 5 wt%		
2013.6675	306.414	6.571721592
2261.055	340.46	6.641176643
2953.74	510.69	5.783821888
5823.435	1021.38	5.701536157
3456.239	599.04	5.769629741
S-32, 25 wt%+SNP, 5 wt%		

2162.1	306.414	7.056139733
2360.01	340.46	6.931827527
3052.695	510.69	5.977589144
5971.8675	1021.38	5.846861599
3725.66	599.04	6.219384348
S-32, 30 wt%+SNP, 5 wt%		
2360.01	306.414	7.702030586
2557.92	340.46	7.513129296
3250.605	510.69	6.365123656
6367.6875	1021.38	6.234396111
4533.923	599.04	7.56864817
S-32, 35 wt%+SNP, 5 wt%		
2458.965	306.414	8.024976013
2656.875	340.46	7.80378018
6417.165	1021.38	6.282837925
4533.923	599.04	7.56864817
S-32, 40 wt%+SNP, 5 wt%		
2755.83	306.414	8.993812293
2904.2625	340.46	8.53040739
3794.8575	510.69	7.430843565
8198.355	1021.38	8.02674323
3725.66	599.04	6.219384348
S-32, 45 wt%+SNP, 5 wt%		
875.685	51.069	17.14709511
1469.415	102.138	14.38656524
1964.19	153.207	12.82049776
3250.605	306.414	10.60853943
2261.055	170.23	13.28235329
3547.47	340.46	10.41963814
10226.9325	1021.38	10.0128576
14545.36	1021.38	14.24088978
8281.36	510.69	16.21602146
S-32, 50 wt%+SNP, 5 wt%		
1716.8025	102.138	16.80865594
2112.6225	153.207	13.78933404
3745.38	306.414	12.22326656
2360.01	170.23	13.86365505
4091.7225	340.46	12.018218
5724.48	510.69	11.20930506

12156.555	1021.38	11.90208835
9325.36	510.69	18.26031448
15589.36	1021.38	15.26303628
S-32, 55 wt%+SNP, 5 wt%		
2162.1	102.138	21.1684192
2953.74	153.207	19.27940629
5526.57	306.414	18.03628424
3250.605	170.23	19.09537097
5872.9125	340.46	17.24993391
8693.13	510.69	17.02232274
17599.08	1021.38	17.23068789
12457.36	510.69	24.39319352
20809.36	1021.38	20.37376882
S-32, 60 wt%+SNP, 5 wt%		
2755.83	102.138	26.98143688
4141.2	153.207	27.03009654
7703.58	306.414	25.14108363
4438.065	170.23	26.07099219
8346.7875	340.46	24.51620602
12502.8975	510.69	24.4823621
24674.3625	1021.38	24.1578673
11413.36	340.46	33.52335076
16633.36	510.69	32.57036558
29161.36	1021.38	28.55094088
1766.28	51.069	34.58614815
4084.888	149.76	27.27622863
7407.747	299.52	24.7320613
14502.5	599.04	24.20956864
3276.625	119.808	27.34896668
S-32, 62 wt%+SNP, 5 wt%		
2112.6225	51.069	41.36800211
3844.335	102.138	37.63863596
5526.57	153.207	36.07256849
10177.455	306.414	33.2147193
5724.48	170.23	33.62791517
10771.185	340.46	31.63715268
16015.8	510.69	31.36109969
14545.36	340.46	42.72266933
19765.36	510.69	38.70324463

35425.36	1021.38	34.68381993
4264.502	149.76	28.47557425
7856.782	299.52	26.23124332
16208.833	599.04	27.05801449
48988.388	1198.08	40.88907919
3725.66	119.808	31.09692174
S-32, 64 wt%+SNP, 5 wt%		
2458.965	51.069	48.14985608
4635.975	102.138	45.38932621
6516.12	153.207	42.53147702
12651.33	306.414	41.28835497
7109.85	170.23	41.76613993
13640.88	340.46	40.06602831
20815.1175	510.69	40.75881161
10369.36	170.23	60.91382248
17677.36	340.46	51.9219879
24985.36	510.69	48.92470971
46909.36	1021.38	45.92743151
5521.8	149.76	36.87099359
10281.571	299.52	34.32682626
20519.569	599.04	34.25408821
51323.37	1198.08	42.83801583
2827.59	59.904	47.20202324
5072.765	119.808	42.34078693
S-32, 66 wt%+SNP, 5 wt%		
3745.38	51.069	73.33959937
7010.895	102.138	68.64139693
10127.9775	153.207	66.10649318
19528.7025	306.414	63.73306213
10870.14	170.23	63.85560712
21656.235	340.46	63.60874993
26029.36	340.46	76.45350408
37513.36	510.69	73.45622589
71965.36	1021.38	70.4589477
3186.818	37.44	85.11800214
5431.993	74.88	72.54264156
9563.115	149.76	63.85627003
18992.85	299.52	63.41095753
35607.145	599.04	59.44034622

60214.263	1198.08	50.25896685
4623.73	59.904	77.18566373
8216.01	119.808	68.57647236
S-32, 68 wt%+SNP, 5 wt%		
5279.1825	51.069	103.3735241
9979.545	102.138	97.70648534
14383.0425	153.207	93.87979988
29374.725	306.414	95.8661321
15916.845	170.23	93.5019973
18721.36	170.23	109.9768548
34381.36	340.46	100.9850203
50041.36	510.69	97.98774207
95977.36	1021.38	93.96831737
3366.432	37.44	89.91538462
7317.94	74.88	97.72889957
14053.465	149.76	93.83991052
26626.445	299.52	88.89705195
49527.23	599.04	82.6776676
3276.625	29.952	109.3958667
5521.8	59.904	92.17748397
11808.29	119.808	98.56011285
S-32, 71 wt%+SNP, 5 wt%		
13393.4925	51.069	262.262674
25614.435	102.138	250.7826176
1419.9375	5.1069	278.0429419
2805.3075	10.2138	274.6585502
44821.36	170.23	263.298831
82405.36	340.46	242.0412383
119989.36	510.69	234.9553741
3860.3705	18.72	206.2163729
8665.045	37.44	231.4381677
15849.605	74.88	211.6667334
31565.83	149.76	210.7761084
59316.193	299.52	198.0375033
3995.081	14.976	266.7655582
7228.133	29.952	241.3238849
15400.57	59.904	257.0875067
27524.515	119.808	229.73854
S-32, 73 wt%+SNP, 5 wt%		

875.685	1.53207	571.5698369
1716.8025	3.06414	560.2885312
29275.77	51.069	573.25912
2755.83	5.1069	539.6287376
5130.75	10.2138	502.3350761
90757.36	170.23	533.145509
171145.36	340.46	502.6885978
3995.081	9.36	426.8248932
11269.448	18.72	602.0004274
19890.92	37.44	531.2745726
38750.39	74.88	517.4998665
73775.12	149.76	492.6223291
4533.923	7.488	605.4918536
9563.115	14.976	638.5627003
14502.5	29.952	484.1913729
31565.83	59.904	526.9402711
64345.385	119.808	537.070855
3097.011	5.9904	516.9956931
5521.8	11.9808	460.8874199
S-32, 75 wt%+SNP, 5 wt%		
1518.8925	1.53207	991.3988917
2706.3525	3.06414	883.233958
4141.2	5.1069	810.9028961
8297.31	10.2138	812.3626858
4399.2125	4.68	940.0026709
7317.94	9.36	781.8311966
11359.255	18.72	606.7978098
26177.41	37.44	699.1829594
49527.23	74.88	661.4213408
3186.818	3.744	851.1800214
6868.905	7.488	917.3217147
13963.658	14.976	932.4023771
26177.41	29.952	873.9786993
45036.88	59.904	751.8175748
81857.75	119.808	683.2411024
3456.239	2.9952	1153.925948
5746.3175	5.9904	959.2543904
8485.431	11.9808	708.2524539

Table 12 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 10 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 10wt%		
281.955	51.069	5.521059743
628.2975	102.138	6.151456852
974.64	153.207	6.361589222
1964.19	306.414	6.410248879
1123.0725	170.23	6.597382952
2211.5775	340.46	6.495851201
3349.56	510.69	6.558890912
7010.895	1021.38	6.864139693
4399.2125	599.04	7.343770867
S-32, 5 wt%+SNP, 10 wt%		
331.4325	51.069	6.489896023
677.775	102.138	6.635874993
1073.595	153.207	7.007480076
2162.1	306.414	7.056139733
1172.55	170.23	6.888033837
2458.965	340.46	7.222478412
3448.515	510.69	6.752658168
7208.805	1021.38	7.057906949
4264.502	599.04	7.118893563
S-32, 10 wt%+SNP, 10 wt%		
380.91	51.069	7.458732303
677.775	102.138	6.635874993
1123.0725	153.207	7.330425503
2162.1	306.414	7.056139733
1172.55	170.23	6.888033837
2360.01	340.46	6.931827527
3547.47	510.69	6.946425424
7505.67	1021.38	7.348557834
4444.116	599.04	7.418729968
S-32, 15 wt%+SNP, 10 wt%		
430.3875	51.069	8.427568584
875.685	102.138	8.573547553
1271.505	153.207	8.299261783
2458.965	306.414	8.024976013
1370.46	170.23	8.050637373

2755.83	340.46	8.094431064
4042.245	510.69	7.915261705
8693.13	1021.38	8.51116137
4893.151	599.04	8.16832098
S-32, 20 wt%+SNP, 10 wt%		
430.3875	51.069	8.427568584
925.1625	102.138	9.057965693
1320.9825	153.207	8.62220721
2656.875	306.414	8.670866866
1469.415	170.23	8.631939141
2854.785	340.46	8.385081948
4339.11	510.69	8.496563473
9484.77	1021.38	9.286230394
4893.151	599.04	8.16832098
S-32, 25 wt%+SNP, 10 wt%		
479.865	51.069	9.396404864
925.1625	102.138	9.057965693
1370.46	153.207	8.945152637
2755.83	306.414	8.993812293
1469.415	170.23	8.631939141
2904.2625	340.46	8.53040739
4537.02	510.69	8.884097985
9583.725	1021.38	9.383114022
5162.572	599.04	8.618075588
S-32, 28 wt%+SNP, 10 wt%		
529.3425	51.069	10.36524114
1024.1175	102.138	10.02680197
1518.8925	153.207	9.913988917
3052.695	306.414	9.962648573
1716.8025	170.23	10.08519356
3300.0825	340.46	9.693010926
4982.3175	510.69	9.756050637
10919.6175	1021.38	10.691043
2917.397	299.52	9.740241052
5656.5105	599.04	9.442625701
S-32, 31 wt%+SNP, 10 wt%		
628.2975	51.069	12.3029137
1222.0275	102.138	11.96447453
1815.7575	153.207	11.85166148

3547.47	306.414	11.57737571
1964.19	170.23	11.53844798
3794.8575	340.46	11.14626535
5823.435	510.69	11.40307231
12651.33	1021.38	12.38650649
3052.1075	299.52	10.18999566
5746.3175	599.04	9.592543904
S-32, 34 wt%+SNP, 10 wt%		
677.775	51.069	13.27174999
1320.9825	102.138	12.93331081
1914.7125	153.207	12.49755233
3893.8125	306.414	12.7076847
2112.6225	170.23	12.41040063
4190.6775	340.46	12.30886888
6417.165	510.69	12.56567585
13442.97	1021.38	13.16157552
3501.1425	299.52	11.68917768
6599.484	599.04	11.01676683
S-32, 37 wt%+SNP, 10 wt%		
727.2525	51.069	14.24058627
1370.46	102.138	13.41772895
2112.6225	153.207	13.78933404
4190.6775	306.414	13.67652098
2360.01	170.23	13.86365505
4487.5425	340.46	13.18082154
6763.5075	510.69	13.24386125
14531.475	1021.38	14.22729542
3546.046	299.52	11.83909589
6779.098	599.04	11.31660323
S-32, 40 wt%+SNP, 10 wt%		
776.73	51.069	15.20942255
1518.8925	102.138	14.87098338
2261.055	153.207	14.75817032
4537.02	306.414	14.80682998
2458.965	170.23	14.44495682
4932.84	340.46	14.48875051
7406.715	510.69	14.50334841
15718.935	1021.38	15.38989896
3905.274	299.52	13.03844151

7677.168	599.04	12.81578526
S-32, 42 wt%+SNP, 10 wt%		
974.64	51.069	19.08476767
1815.7575	102.138	17.77749222
2656.875	153.207	17.34173373
5427.615	306.414	17.71333882
3102.1725	170.23	18.22341832
5971.8675	340.46	17.5405848
8989.995	510.69	17.60362451
18539.1525	1021.38	18.15108236
22897.36	1021.38	22.41806184
S-32, 44 wt%+SNP, 10 wt%		
1024.1175	51.069	20.05360395
1865.235	102.138	18.26191036
2755.83	153.207	17.98762459
5576.0475	306.414	18.19775696
3151.65	170.23	18.5140692
6120.3	340.46	17.97656112
9138.4275	510.69	17.89427539
18984.45	1021.38	18.58705869
23941.36	1021.38	23.44020835
S-32, 46 wt%+SNP, 10 wt%		
1073.595	51.069	21.02244023
2112.6225	102.138	20.68400106
3201.1275	153.207	20.89413343
6466.6425	306.414	21.1042658
3646.425	170.23	21.42057804
7109.85	340.46	20.88306996
10672.23	510.69	20.89766786
21755.19	1021.38	21.29980027
26029.36	1021.38	25.48450136
3186.818	149.76	21.27950053
5611.607	299.52	18.7353332
11179.641	599.04	18.66259515
S-32, 48 wt%+SNP, 10 wt%		
1271.505	51.069	24.89778535
2360.01	102.138	23.10609176
3596.9475	153.207	23.47769684
7258.2825	306.414	23.68782921

232.4775	10.2138	22.76111731
4141.2	170.23	24.32708688
7950.9675	340.46	23.35360248
12057.6	510.69	23.61040945
24229.065	1021.38	23.72189097
84.045	3.06414	27.42857702
28117.36	1021.38	27.52879438
3276.625	149.76	21.87917334
6240.256	299.52	20.83418803
11808.29	599.04	19.71202257
S-32, 50 wt%+SNP, 10 wt%		
1568.37	51.069	30.71080303
3052.695	102.138	29.88794572
4487.5425	153.207	29.29071452
8643.6525	306.414	28.20906519
4932.84	170.23	28.97750103
9484.77	340.46	27.85869118
14135.655	510.69	27.67952182
27692.49	1021.38	27.11281795
30205.36	1021.38	29.57308739
3815.467	149.76	25.4772102
6958.712	299.52	23.23287927
13514.623	599.04	22.56046842
3186.818	119.808	26.59937567
S-32, 52 wt%+SNP, 10 wt%		
2013.6675	51.069	39.43032955
3547.47	102.138	34.73212712
5130.75	153.207	33.48900507
9880.59	306.414	32.24588302
5971.8675	170.23	35.08116959
10870.14	340.46	31.92780356
16114.755	510.69	31.55486694
19765.36	510.69	38.70324463
34381.36	1021.38	33.66167342
4354.309	149.76	29.07524706
7946.589	299.52	26.53107973
15580.184	599.04	26.00858707
48180.125	1198.08	40.21444728
3501.1425	119.808	29.22294421

S-32, 54 wt%+SNP, 10 wt%		
2458.965	51.069	48.14985608
4635.975	102.138	45.38932621
6714.03	153.207	43.82325873
12651.33	306.414	41.28835497
183	5.1069	35.83387182
479.865	10.2138	46.98202432
7307.76	170.23	42.92874346
14135.655	340.46	41.51928274
20864.595	510.69	40.85569524
17677.36	340.46	51.9219879
24985.36	510.69	48.92470971
45865.36	1021.38	44.90528501
3097.011	74.88	41.35965545
5072.765	149.76	33.87262954
9203.887	299.52	30.7287894
18723.429	599.04	31.25572416
54915.65	1198.08	45.83637987
4354.309	119.808	36.34405883
S-32, 56 wt%+SNP, 10 wt%		
183	3.06414	59.7231197
2607.3975	51.069	51.05636492
4833.885	102.138	47.32699877
7109.85	153.207	46.40682214
15125.205	306.414	49.36199064
281.955	5.1069	55.21059743
8891.04	170.23	52.22957176
17401.17	340.46	51.11076191
24624.885	510.69	48.21885097
19765.36	340.46	58.05486694
29161.36	510.69	57.10188177
51085.36	1021.38	50.01601754
3680.7565	74.88	49.15540198
6689.291	149.76	44.66674012
12257.325	299.52	40.92322716
24291.463	599.04	40.55065271
55364.685	1198.08	46.21117538
2917.397	59.904	48.70120526
5162.572	119.808	43.09037794

S-32, 58 wt%+SNP, 10 wt%		
3844.335	51.069	75.27727193
7307.76	102.138	71.54790577
10870.14	153.207	70.95067458
21458.325	306.414	70.03049795
331.4325	5.1069	64.89896023
776.73	10.2138	76.04711273
12057.6	170.23	70.83122834
24031.155	340.46	70.58437114
27073.36	340.46	79.51994361
39601.36	510.69	77.54481192
73009.36	1021.38	71.48109421
5701.414	74.88	76.14067842
10371.378	149.76	69.25332532
19890.92	299.52	66.40932158
38750.39	599.04	64.68748331
4938.0545	59.904	82.43280081
8665.045	119.808	72.32442742
S-32, 60 wt%+SNP, 10 wt%		
331.4325	1.53207	216.3298674
479.865	3.06414	156.6067477
5724.48	51.069	112.0930506
10771.185	102.138	105.4571756
15619.98	153.207	101.9534355
628.2975	5.1069	123.029137
1271.505	10.2138	124.4889267
16906.395	170.23	99.31501498
20809.36	170.23	122.2426129
36469.36	340.46	107.1178993
51085.36	510.69	100.0320351
95977.36	1021.38	93.96831737
4174.695	37.44	111.5036058
7407.747	74.88	98.92824519
13963.658	149.76	93.24023771
26985.673	299.52	90.09639757
53568.545	599.04	89.42398671
3456.239	29.952	115.3925948
6150.449	59.904	102.6717581
11628.676	119.808	97.06093082

S-32, 63 wt%+SNP, 10 wt%		
430.3875	1.53207	280.9189528
7208.805	51.069	141.158139
11364.915	102.138	111.2701933
21804.6675	153.207	142.3216139
1419.9375	5.1069	278.0429419
2360.01	10.2138	231.0609176
34381.36	170.23	201.9700405
61525.36	340.46	180.7124479
86581.36	510.69	169.5379976
3815.467	18.72	203.8176816
6509.677	37.44	173.869578
13514.623	74.88	180.4837473
26087.603	149.76	174.196067
51053.949	299.52	170.4525541
3186.818	14.976	212.7950053
6060.642	29.952	202.3451522
10910.22	59.904	182.1284054
21597.253	119.808	180.2655332
2917.397	11.9808	243.5060263
S-32, 66 wt%+SNP, 10 wt%		
479.865	1.53207	313.2134955
974.64	3.06414	318.0794611
9385.815	51.069	183.7869353
17302.215	102.138	169.4003701
24822.795	153.207	162.0212849
1419.9375	5.1069	278.0429419
2458.965	10.2138	240.7492804
34381.36	170.23	201.9700405
55261.36	340.46	162.3138107
79273.36	510.69	155.2279465
145045.36	1021.38	142.0092032
3546.046	18.72	189.4255342
6330.063	37.44	169.0721955
11179.641	74.88	149.3007612
21327.832	149.76	142.4134081
41085.372	299.52	137.1707131
79522.768	599.04	132.7503472
3007.204	14.976	200.8015491

5162.572	29.952	172.3615118
9203.887	59.904	153.643947
18184.587	119.808	151.7810747
S-32, 69 wt%+SNP, 10 wt%		
974.64	1.53207	636.1589222
1617.8475	3.06414	527.9939885
18885.495	51.069	369.8035011
2310.5325	5.1069	452.4334724
4190.6775	10.2138	410.2956294
7237.36	10.2138	708.5864223
59437.36	170.23	349.1591376
3815.467	9.36	407.6353632
6779.098	18.72	362.1313034
12616.553	37.44	336.9805823
24291.463	74.88	324.4052217
45934.95	149.76	306.723758
84551.96	299.52	282.2915331
3366.432	7.488	449.5769231
5791.221	14.976	386.7001202
10281.571	29.952	343.2682626
19980.727	59.904	333.5457899
37942.127	119.808	316.6910974
4623.73	11.9808	385.9283186
S-32, 72 wt%+SNP, 10 wt%		
1518.8925	1.53207	991.3988917
2805.3075	3.06414	915.5285007
4240.155	5.1069	830.2796217
8148.8775	10.2138	797.8301416
7237.36	5.1069	1417.172845
12457.36	10.2138	1219.659676
125209.36	170.23	735.5305175
3546.046	4.68	757.7021368
6330.063	9.36	676.2887821
12885.974	18.72	688.353312
23842.428	37.44	636.8169872
48539.353	74.88	648.228539
3366.432	3.744	899.1538462
6150.449	7.488	821.3740652
11179.641	14.976	746.5038061

20699.183	29.952	691.0784923
40546.53	59.904	676.8584736
77367.4	119.808	645.7615518
2917.397	2.9952	974.0241052
4803.344	5.9904	801.8402778
8754.852	11.9808	730.7401843
S-32, 75 wt%+SNP, 10 wt%		
3745.38	1.53207	2444.653312
8792.085	3.06414	2869.348333
14135.655	5.1069	2767.952182
26406.075	10.2138	2585.333079
12457.36	5.1069	2439.319352
26029.36	10.2138	2548.450136
6240.256	2.34	2666.776068
11000.027	4.68	2350.43312
20968.604	9.36	2240.23547
40187.302	18.72	2146.757585
74673.19	37.44	1994.476229
3456.239	0.936	3692.563034
5791.221	1.872	3093.600962
9922.343	3.744	2650.198451
18004.973	7.488	2404.510283
33900.812	14.976	2263.676015
62639.052	29.952	2091.314503
3276.625	0.7488	4375.834669
5252.379	1.4976	3507.197516
9024.273	2.9952	3012.911659
15939.412	5.9904	2660.825988
27883.743	11.9808	2327.36904
S-32, 77 wt%+SNP, 10 wt%		
21062.505	1.53207	13747.74325
37513.36	5.1069	7345.622589
62569.36	10.2138	6125.962913
34798.882	2.34	14871.31709
55813.72	4.68	11926.00855
8844.659	0.234	37797.68803
13514.623	0.468	28877.39957
20968.604	0.936	22402.3547
32463.9	1.872	17341.82692

50335.493	3.744	13444.30903
80151.417	7.488	10703.98197
7335.9014	0.0234	313500.0598
9742.729	0.0468	208177.9701
12975.781	0.0936	138630.1389
16208.833	0.1872	86585.64637
21417.639	0.3744	57205.23237
26806.059	0.7488	35798.6899
35158.11	1.4976	23476.30208
50425.3	2.9952	16835.36993
71080.91	5.9904	11865.80362

Table 13 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 15 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 15wt%		
974.64	51.069	19.08476767
1964.19	102.138	19.23074664
3151.65	153.207	20.571188
5625.525	306.414	18.35922967
84.045	5.1069	16.45714621
3250.605	170.23	19.09537097
6417.165	340.46	18.84851378
8495.22	510.69	16.63478823
16708.485	1021.38	16.35873524
20809.36	1021.38	20.37376882
4848.2475	299.52	16.18672376
9563.115	599.04	15.96406751
S-32, 5 wt%+ SNP, 15 wt%		
1024.1175	51.069	20.05360395
1964.19	102.138	19.23074664
3151.65	153.207	20.571188
5724.48	306.414	18.6821751
84.045	5.1069	16.45714621
3250.605	170.23	19.09537097
6219.255	340.46	18.26721201
8693.13	510.69	17.02232274
18093.855	1021.38	17.71510603

21853.36	1021.38	21.39591533
3007.204	149.76	20.08015491
5342.186	299.52	17.83582399
10281.571	599.04	17.16341313
S-32, 10 wt%+ SNP, 15 wt%		
1073.595	51.069	21.02244023
2162.1	102.138	21.1684192
3052.695	153.207	19.92529715
6070.8225	306.414	19.81248409
84.045	5.1069	16.45714621
3448.515	170.23	20.25797451
6714.03	340.46	19.72046643
9088.95	510.69	17.79739176
18588.63	1021.38	18.19952417
22897.36	1021.38	22.41806184
3186.818	149.76	21.27950053
5611.607	299.52	18.7353332
11000.027	599.04	18.36275875
S-32, 15 wt%+ SNP, 15 wt%		
1123.0725	51.069	21.99127651
2112.6225	102.138	20.68400106
3102.1725	153.207	20.24824257
6219.255	306.414	20.29690223
3448.515	170.23	20.25797451
6812.985	340.46	20.01111731
10375.365	510.69	20.31636609
20963.55	1021.38	20.52473125
26029.36	1021.38	25.48450136
3007.204	149.76	20.08015491
5701.414	299.52	19.0351696
11179.641	599.04	18.66259515
S-32, 20 wt%+ SNP, 15 wt%		
1419.9375	51.069	27.80429419
2656.875	102.138	26.0126006
3844.335	153.207	25.09242398
7208.805	306.414	23.5263565
4240.155	170.23	24.90838865
7950.9675	340.46	23.35360248
11018.5725	510.69	21.57585326

22348.92	1021.38	21.88110204
27073.36	1021.38	26.50664787
3186.818	149.76	21.27950053
6060.642	299.52	20.23451522
11359.255	599.04	18.96243156
S-32, 25 wt%+ SNP, 15 wt%		
1419.9375	51.069	27.80429419
2656.875	102.138	26.0126006
3844.335	153.207	25.09242398
7555.1475	306.414	24.65666549
4141.2	170.23	24.32708688
8346.7875	340.46	24.51620602
12651.33	510.69	24.77301298
25416.525	1021.38	24.88449451
30205.36	1021.38	29.57308739
3815.467	149.76	25.4772102
6958.712	299.52	23.23287927
13784.044	599.04	23.01022302
2917.397	119.808	24.35060263
S-32, 30 wt%+ SNP, 15 wt%		
1469.415	51.069	28.77313047
2904.2625	102.138	28.4346913
4388.5875	153.207	28.64482367
8841.5625	306.414	28.85495604
4833.885	170.23	28.39619926
9781.635	340.46	28.73064383
14877.8175	510.69	29.13277624
34381.36	1021.38	33.66167342
4444.116	149.76	29.67491987
8305.817	299.52	27.73042535
16657.868	599.04	27.8076055
3456.239	119.808	28.8481487
S-32, 35 wt%+ SNP, 15 wt%		
1815.7575	51.069	35.55498443
3547.47	102.138	34.73212712
5229.705	153.207	34.13489593
10672.23	306.414	34.82944644
5922.39	170.23	34.79051871
11711.2575	340.46	34.39833607

17846.4675	510.69	34.94579393
40645.36	1021.38	39.79455247
4623.73	149.76	30.87426549
9114.08	299.52	30.42895299
17825.359	599.04	29.75654213
3635.853	119.808	30.34733073
S-32, 40 wt%+ SNP, 15 wt%		
133.5225	3.06414	43.57584836
2409.4875	51.069	47.1810198
4537.02	102.138	44.42048993
6812.985	153.207	44.46914958
13492.4475	306.414	44.0333911
529.3425	10.2138	51.82620572
7802.535	170.23	45.83525231
14828.34	340.46	43.55383892
22299.4425	510.69	43.66532045
26029.36	510.69	50.96900272
46909.36	1021.38	45.92743151
3007.204	74.88	40.16030983
5701.414	149.76	38.07033921
11718.483	299.52	39.12420873
21687.06	599.04	36.20302484
54915.65	1198.08	45.83637987
4533.923	119.808	37.84324085
S-32, 45 wt%+ SNP, 15 wt%		
133.5225	3.06414	43.57584836
2904.2625	51.069	56.8693826
5576.0475	102.138	54.59327087
8297.31	153.207	54.15751239
16461.0975	306.414	53.7217539
529.3425	10.2138	51.82620572
9138.4275	170.23	53.68282618
18341.2425	340.46	53.87194531
27643.0125	510.69	54.12875228
31249.36	510.69	61.1904678
58393.36	1021.38	57.1710431
4174.695	74.88	55.75180288
7766.975	149.76	51.86281384
14861.728	299.52	49.61848291

29859.497	599.04	49.84558126
53837.966	1198.08	44.93687066
3366.432	59.904	56.19711538
6150.449	119.808	51.33587907
S-32, 50 wt%+ SNP, 15 wt%		
183	1.53207	119.4462394
281.955	3.06414	92.01766238
4042.245	51.069	79.15261705
7802.535	102.138	76.39208718
11562.825	153.207	75.47191055
23041.605	306.414	75.19762478
479.865	5.1069	93.96404864
875.685	10.2138	85.73547553
13096.6275	170.23	76.9348969
25663.9125	340.46	75.38011073
16633.36	170.23	97.71109675
29161.36	340.46	85.65282265
40645.36	510.69	79.58910494
78229.36	1021.38	76.59182674
3007.204	37.44	80.32061966
5431.993	74.88	72.54264156
10191.764	149.76	68.0539797
20070.534	299.52	67.00899439
40187.302	599.04	67.08617455
66410.946	1198.08	55.43114483
4489.0195	59.904	74.93689069
8485.431	119.808	70.82524539
S-32, 55 wt%+ SNP, 15 wt%		
281.955	1.53207	184.0353248
529.3425	3.06414	172.7540191
6812.985	51.069	133.4074487
13146.105	102.138	128.7092463
19281.315	153.207	125.8513971
677.775	5.1069	132.7174999
1469.415	10.2138	143.8656524
20666.685	170.23	121.4044822
24985.36	170.23	146.7741291
43777.36	340.46	128.582976
63613.36	510.69	124.5635513

109549.36	1021.38	107.256222
4354.309	37.44	116.3009882
8395.624	74.88	112.121047
16029.219	149.76	107.0327123
32149.5755	299.52	107.3369909
64165.771	599.04	107.1143346
3411.3355	29.952	113.8934128
6958.712	59.904	116.1643964
13155.395	119.808	109.803978
S-32, 58 wt%+ SNP, 15 wt%		
430.3875	1.53207	280.9189528
677.775	3.06414	221.1958331
9286.86	51.069	181.8492628
17846.4675	102.138	174.7289696
25861.8225	153.207	168.8031389
1123.0725	5.1069	219.9127651
1914.7125	10.2138	187.463285
27791.445	170.23	163.2582095
31249.36	170.23	183.5714034
57349.36	340.46	168.4466898
81361.36	510.69	159.3165325
153397.36	1021.38	150.1863753
3231.7215	18.72	172.6346955
5791.221	37.44	154.6800481
11089.834	74.88	148.1014156
21956.481	149.76	146.6111178
43150.933	299.52	144.0669505
83564.083	599.04	139.4966663
4938.0545	29.952	164.8656016
9383.501	59.904	156.642311
17825.359	119.808	148.7827107
S-32, 61 wt%+ SNP, 15 wt%		
430.3875	1.53207	280.9189528
727.2525	3.06414	237.3431044
10771.185	51.069	210.9143512
20914.0725	102.138	204.7628943
1123.0725	5.1069	219.9127651
2211.5775	10.2138	216.5283734
36469.36	170.23	214.2357986

65701.36	340.46	192.978206
94933.36	510.69	185.8923417
177409.36	1021.38	173.695745
4084.888	18.72	218.2098291
7497.554	37.44	200.2551816
14233.079	74.88	190.0785123
27075.48	149.76	180.7924679
51772.405	299.52	172.8512453
3366.432	14.976	224.7884615
6015.7385	29.952	200.8459702
11404.1585	59.904	190.3739066
21956.481	119.808	183.2638972
S-32, 64 wt%+ SNP, 15 wt%		
529.3425	1.53207	345.5080381
925.1625	3.06414	301.9321898
10969.095	51.069	214.7896963
21062.505	102.138	206.2161487
1222.0275	5.1069	239.2894907
2261.055	10.2138	221.3725548
38557.36	170.23	226.5015567
69877.36	340.46	205.243964
99109.36	510.69	194.0695138
3860.3705	18.72	206.2163729
7677.168	37.44	205.0525641
13873.851	74.88	185.2811298
27883.743	149.76	186.1895232
52221.44	299.52	174.3504274
3456.239	14.976	230.7851896
6060.642	29.952	202.3451522
11628.676	59.904	194.1218616
22495.323	119.808	187.7614433
2917.397	11.9808	243.5060263
S-32, 67 wt%+ SNP, 15 wt%		
529.3425	1.53207	345.5080381
925.1625	3.06414	301.9321898
11117.5275	51.069	217.6962051
21656.235	102.138	212.0291664
1419.9375	5.1069	278.0429419
2557.92	10.2138	250.4376432

41689.36	170.23	244.9001939
76141.36	340.46	223.6426012
110593.36	510.69	216.556737
4399.2125	18.72	235.0006677
8485.431	37.44	226.6407853
16298.64	74.88	217.6634615
31476.023	149.76	210.1764356
61202.14	299.52	204.3340678
3995.081	14.976	266.7655582
6644.3875	29.952	221.8345186
13155.395	59.904	219.6079561
26087.603	119.808	217.7450838
3231.7215	11.9808	269.7417117
S-32, 69 wt%+ SNP, 15 wt%		
529.3425	1.53207	345.5080381
1024.1175	3.06414	334.2267325
16114.755	51.069	315.5486694
2112.6225	5.1069	413.6800211
3794.8575	10.2138	371.5421782
45865.36	170.23	269.43171
86581.36	340.46	254.3069964
121033.36	510.69	236.9996671
3321.5285	9.36	354.864156
5611.607	18.72	299.7653312
11179.641	37.44	298.6015224
20429.762	74.88	272.83336
40456.723	149.76	270.1437166
77547.014	299.52	258.9042935
2872.4935	7.488	383.612914
4938.0545	14.976	329.7312033
9114.08	29.952	304.2895299
17376.324	59.904	290.0695112
33272.163	119.808	277.7123648
3995.081	11.9808	333.4569478
S-32, 71 wt%+ SNP, 15 wt%		
3250.605	1.53207	2121.707885
7406.715	3.06414	2417.224735
12750.285	5.1069	2496.678024
22942.65	10.2138	2246.240381

14545.36	5.1069	2848.177955
23941.36	10.2138	2344.020835
267193.36	170.23	1569.602068
495829.36	340.46	1456.351289
5791.221	2.34	2474.880769
10281.571	4.68	2196.91688
18903.043	9.36	2019.555876
33631.391	18.72	1796.548665
63896.35	37.44	1706.63328
2827.59	0.936	3020.929487
4803.344	1.872	2565.888889
8440.5275	3.744	2254.414396
15580.184	7.488	2080.686966
29051.234	14.976	1939.852698
54017.58	29.952	1803.471554
2872.4935	0.7488	3836.12914
4533.923	1.4976	3027.459268
7497.554	2.9952	2503.18977
13424.816	5.9904	2241.055021
23393.393	11.9808	1952.573534
S-32, 73 wt%+ SNP, 15 wt%		
9831.1125	1.53207	6416.882062
16807.44	3.06414	5485.20629
26010.255	5.1069	5093.159255
21853.36	5.1069	4279.183066
41689.36	10.2138	4081.669898
11269.448	2.34	4816.003419
18813.236	4.68	4019.922222
33721.198	9.36	3602.692094
65692.49	18.72	3509.214209
3276.625	0.468	7001.33547
5252.379	0.936	5611.516026
9293.694	1.872	4964.580128
16478.254	3.744	4401.243056
29365.5585	7.488	3921.682492
52580.668	14.976	3510.995459
3141.9145	0.3744	8391.865652
4713.537	0.7488	6294.78766
7677.168	1.4976	5126.314103
13065.588	2.9952	4362.175481

22136.095	5.9904	3695.261585
43959.196	11.9808	3669.136952
S-32, 75 wt%+ SNP, 15 wt%		
17698.035	1.53207	11551.71435
31249.36	5.1069	6119.04678
74053.36	10.2138	7250.324071
21956.481	2.34	9383.111538
38391.162	4.68	8203.239744
71889.173	9.36	7680.467201
4803.344	0.234	20527.11111
7003.6155	0.468	14964.99038
10820.413	0.936	11560.2703
19262.271	1.872	10289.67468
34260.04	3.744	9150.651709
60393.877	7.488	8065.421608
3186.818	0.1872	17023.60043
5117.6685	0.3744	13668.98638
8305.817	0.7488	11092.17014
14592.307	1.4976	9743.794738
26087.603	2.9952	8709.803352
48629.16	5.9904	8117.848558
88952.503	11.9808	7424.587924
S-32, 77 wt%+ SNP, 15 wt%		
48629.16	2.34	20781.69231
80959.68	4.68	17299.07692
8754.852	0.234	37413.89744
14502.5	0.468	30988.24786
25189.533	0.936	26911.89423
43150.933	1.872	23050.71207
73775.12	3.744	19704.89316
4084.888	0.0468	87283.93162
6150.449	0.0936	65709.92521
9338.5975	0.1872	49885.67041
15131.149	0.3744	40414.3937
23932.235	0.7488	31960.78392
39379.039	1.4976	26294.76429
64794.42	2.9952	21632.7524

Table 14 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 20 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 20wt%		
2607.3975	51.069	51.05636492
5031.795	102.138	49.26467133
7406.715	153.207	48.3444947
13987.2225	306.414	45.64811823
430.3875	10.2138	42.13784292
7703.58	170.23	45.25395054
15422.07	340.46	45.29774423
22942.65	510.69	44.92480761
19765.36	340.46	58.05486694
28117.36	510.69	55.05758875
48997.36	1021.38	47.97172453
3815.467	74.88	50.95442041
6689.291	149.76	44.66674012
12796.167	299.52	42.72224559
25009.919	599.04	41.74999833
48898.581	1198.08	40.81412009
2917.397	59.904	48.70120526
5252.379	119.808	43.83996895
S-32, 5 wt%+ SNP, 20 wt%		
2854.785	51.069	55.90054632
5427.615	102.138	53.14001645
7950.9675	153.207	51.8968944
15471.5475	306.414	50.49229963
677.775	10.2138	66.35874993
8792.085	170.23	51.64826999
17104.305	340.46	50.23880926
25317.57	510.69	49.57522176
20809.36	340.46	61.12130647
29161.36	510.69	57.10188177
51085.36	1021.38	50.01601754
3815.467	74.88	50.95442041
6958.712	149.76	46.46575855
13514.623	299.52	45.12093683
26716.252	599.04	44.59844418
53119.51	1198.08	44.33719785

2962.3005	59.904	49.45079627
5701.414	119.808	47.58792401
S-32, 10 wt%+ SNP, 20 wt%		
3102.1725	51.069	60.74472772
5922.39	102.138	57.98419785
8693.13	153.207	56.7410758
16906.395	306.414	55.17500832
430.3875	5.1069	84.27568584
727.2525	10.2138	71.20293133
9484.77	170.23	55.71738237
18737.0625	340.46	55.03454885
27692.49	510.69	54.2256359
21853.36	340.46	64.18774599
30205.36	510.69	59.14617478
56305.36	1021.38	55.12675008
3995.081	74.88	53.35311165
7856.782	149.76	52.46248665
15086.2455	299.52	50.36807392
30218.725	599.04	50.44525407
53568.545	1198.08	44.71199336
3276.625	59.904	54.69793336
6150.449	119.808	51.33587907
S-32, 15 wt%+ SNP, 20 wt%		
3399.0375	51.069	66.5577454
6466.6425	102.138	63.31279739
9484.77	153.207	61.90820263
18588.63	306.414	60.66508058
430.3875	5.1069	84.27568584
776.73	10.2138	76.04711273
10474.32	170.23	61.53040005
20567.73	340.46	60.4115902
23941.36	340.46	70.32062504
34381.36	510.69	67.32334684
61525.36	1021.38	60.23748262
4174.695	74.88	55.75180288
7946.589	149.76	53.06215946
15490.377	299.52	51.71733774
31565.83	599.04	52.69402711
55813.72	1198.08	46.58597089

3456.239	59.904	57.69629741
6330.063	119.808	52.8350611
S-32, 20 wt%+ SNP, 20 wt%		
3745.38	51.069	73.33959937
6961.4175	102.138	68.15697879
10325.8875	153.207	67.39827488
20369.82	306.414	66.47809826
479.865	5.1069	93.96404864
875.685	10.2138	85.73547553
11562.825	170.23	67.9247195
22546.83	340.46	66.22460788
26029.36	340.46	76.45350408
36469.36	510.69	71.41193288
64657.36	1021.38	63.30392214
4803.344	74.88	64.14722222
9338.5975	149.76	62.35708801
17915.166	299.52	59.81292067
35966.373	599.04	60.04001903
59675.421	1198.08	49.80921224
3950.1775	59.904	65.94179854
7497.554	119.808	62.57974426
S-32, 25 wt%+ SNP, 20 wt%		
3794.8575	51.069	74.30843565
7010.895	102.138	68.64139693
10523.7975	153.207	68.69005659
21062.505	306.414	68.73871625
1024.1175	10.2138	100.2680197
11711.2575	170.23	68.79667215
22794.2175	340.46	66.95123509
15589.36	170.23	91.57821771
27073.36	340.46	79.51994361
37513.36	510.69	73.45622589
66745.36	1021.38	65.34821516
3097.011	37.44	82.7193109
5431.993	74.88	72.54264156
10550.992	149.76	70.45267094
20564.4725	299.52	68.65809462
41803.828	599.04	69.78470219
68835.735	1198.08	57.45504056

4533.923	59.904	75.6864817
8575.238	119.808	71.5748364
S-32, 30 wt%+ SNP, 20 wt%		
4487.5425	51.069	87.87214357
9039.4725	102.138	88.50254068
13344.015	153.207	87.09794592
26307.12	306.414	85.85482387
1073.595	10.2138	105.1122011
14729.385	170.23	86.52637608
28682.04	340.46	84.2449627
18721.36	170.23	109.9768548
32293.36	340.46	94.85214122
45865.36	510.69	89.81057001
84493.36	1021.38	82.72470579
3231.7215	37.44	86.31734776
6150.449	74.88	82.13740652
12077.711	149.76	80.64710871
23573.007	299.52	78.70261418
47641.283	599.04	79.52938535
80869.873	1198.08	67.49956013
4982.958	59.904	83.18239183
9652.922	119.808	80.56992855
S-32, 35 wt%+ SNP, 20 wt%		
4635.975	51.069	90.77865241
9088.95	102.138	88.98695882
13640.88	153.207	89.03561848
27692.49	306.414	90.37605984
15817.89	170.23	92.92069553
18721.36	170.23	109.9768548
34381.36	340.46	100.9850203
47953.36	510.69	93.89915604
88669.36	1021.38	86.81329182
3546.046	37.44	94.71276709
6419.87	74.88	85.73544338
12706.36	149.76	84.84481838
25009.919	299.52	83.49999666
50335.493	599.04	84.02693142
89042.31	1198.08	74.32083834
2827.59	29.952	94.40404647

5342.186	59.904	89.17911993
10191.764	119.808	85.06747463
S-32, 40 wt%+ SNP, 20 wt%		
5378.1375	51.069	105.3111966
10672.23	102.138	104.4883393
16312.665	153.207	106.4746715
19182.36	170.23	112.6849556
19765.36	170.23	116.1097339
36469.36	340.46	107.1178993
57349.36	510.69	112.2977932
109549.36	1021.38	107.256222
3995.081	37.44	106.7062233
7407.747	74.88	98.92824519
13963.658	149.76	93.24023771
27165.287	299.52	90.69607038
53658.352	599.04	89.57390491
2917.397	29.952	97.40241052
5746.3175	59.904	95.92543904
11359.255	119.808	94.81215779
S-32, 45 wt%+ SNP, 20 wt%		
7456.1925	51.069	146.0023204
15026.25	102.138	147.1171356
23190.0375	153.207	151.3640858
776.73	5.1069	152.0942255
1617.8475	10.2138	158.3981966
27692.49	170.23	162.6769077
28117.36	170.23	165.1727663
52129.36	340.46	153.1144922
80317.36	510.69	157.2722395
155485.36	1021.38	152.2306683
2962.3005	18.72	158.2425481
5297.2825	37.44	141.4872463
9922.343	74.88	132.5099225
19801.113	149.76	132.2189704
38750.39	299.52	129.3749666
76738.751	599.04	128.1028829
4084.888	29.952	136.3811432
8485.431	59.904	141.6504908
16208.833	119.808	135.2900724

S-32, 50 wt%+ SNP, 20 wt%		
7456.1925	51.069	146.0023204
15422.07	102.138	150.9924808
24031.155	153.207	156.8541581
826.2075	5.1069	161.7825883
1667.325	10.2138	163.242378
28484.13	170.23	167.3273219
31249.36	170.23	183.5714034
61525.36	340.46	180.7124479
92845.36	510.69	181.8037557
178453.36	1021.38	174.7178915
3007.204	18.72	160.6412393
5342.186	37.44	142.6865919
9922.343	74.88	132.5099225
18184.587	149.76	121.4248598
39648.46	299.52	132.3733307
76738.751	599.04	128.1028829
4129.7915	29.952	137.8803252
7407.747	59.904	123.6603065
15041.342	119.808	125.5453893
S-32, 55 wt%+ SNP, 20 wt%		
529.3425	1.53207	345.5080381
925.1625	3.06414	301.9321898
13096.6275	51.069	256.4496563
25911.3	102.138	253.6891265
1716.8025	5.1069	336.1731187
3052.695	10.2138	298.8794572
48997.36	170.23	287.8303472
89713.36	340.46	263.506315
130429.36	510.69	255.3983043
3097.011	9.36	330.8772436
5252.379	18.72	280.5758013
10506.0885	37.44	280.6113381
19531.692	74.88	260.8399038
38121.741	149.76	254.5522236
74358.8655	299.52	248.2601012
4803.344	14.976	320.7361111
8440.5275	29.952	281.8017995
15669.991	59.904	261.5850528

31476.023	119.808	262.7205445
3950.1775	11.9808	329.7089927
S-32, 58 wt%+ SNP, 20 wt%		
529.3425	1.53207	345.5080381
974.64	3.06414	318.0794611
15916.845	51.069	311.6733243
1815.7575	5.1069	355.5498443
3547.47	10.2138	347.3212712
57349.36	170.23	336.8933795
105373.36	340.46	309.5029078
155485.36	510.69	304.4613366
3725.66	9.36	398.0405983
6509.677	18.72	347.739156
13335.009	37.44	356.1701122
25099.726	74.88	335.1993323
49527.23	149.76	330.7106704
3546.046	7.488	473.5638355
5701.414	14.976	380.7033921
11000.027	29.952	367.2551749
20699.183	59.904	345.5392461
41085.372	119.808	342.9267829
2917.397	5.9904	487.0120526
4713.537	11.9808	393.4242288
S-32, 61 wt%+ SNP, 20 wt%		
628.2975	1.53207	410.0971235
1271.505	3.06414	414.9630892
18291.765	51.069	358.1774658
2013.6675	5.1069	394.3032955
4091.7225	10.2138	400.6072666
75097.36	170.23	441.1523233
137737.36	340.46	404.562533
4533.923	9.36	484.3934829
7991.4925	18.72	426.8959669
15759.798	37.44	420.9347756
30667.76	74.88	409.5587607
61112.333	149.76	408.0684629
3635.853	7.488	485.5572917
6868.905	14.976	458.6608574
12616.553	29.952	421.2257278

22585.13	59.904	377.0220686
49437.423	119.808	412.638747
3097.011	5.9904	516.9956931
5701.414	11.9808	475.8792401
S-32, 64 wt%+ SNP, 20 wt%		
5229.705	1.53207	3413.489593
8693.13	3.06414	2837.05379
13640.88	5.1069	2671.068554
24426.975	10.2138	2391.565823
15589.36	5.1069	3052.607257
26029.36	10.2138	2548.450136
282853.36	170.23	1661.595253
6509.677	2.34	2781.913248
11000.027	4.68	2350.43312
19352.078	9.36	2067.529701
39558.653	18.72	2113.175908
71978.98	37.44	1922.515491
3456.239	0.936	3692.563034
5611.607	1.872	2997.653312
9383.501	3.744	2506.276976
16478.254	7.488	2200.621528
32104.672	14.976	2143.741453
58507.93	29.952	1953.389757
2917.397	0.7488	3896.096421
4623.73	1.4976	3087.426549
7766.975	2.9952	2593.140692
13963.658	5.9904	2331.005943
26626.445	11.9808	2222.426299
S-32, 66 wt%+ SNP, 20 wt%		
8544.6975	1.53207	5577.223952
14531.475	3.06414	4742.431808
22052.055	5.1069	4318.090231
22897.36	5.1069	4483.612368
38557.36	10.2138	3775.025945
9652.922	2.34	4125.180342
17735.552	4.68	3789.647863
32598.6105	9.36	3482.757532
57340.439	18.72	3063.057639
3635.853	0.468	7768.916667

5297.2825	0.936	5659.48985
8754.852	1.872	4676.737179
14951.535	3.744	3993.465545
26357.024	7.488	3519.901709
49527.23	14.976	3307.106704
3141.9145	0.3744	8391.865652
4668.6335	0.7488	6234.820379
7273.0365	1.4976	4856.461338
12392.0355	2.9952	4137.298177
21327.832	5.9904	3560.335203
41444.6	11.9808	3459.251469
S-32, 68 wt%+ SNP, 20 wt%		
17599.08	1.53207	11487.12526
34381.36	5.1069	6732.334684
64657.36	10.2138	6330.392214
20699.183	2.34	8845.804701
34888.689	4.68	7454.848077
62459.438	9.36	6673.01688
5881.028	0.468	12566.29915
10012.15	0.936	10696.74145
18004.973	1.872	9618.041132
31925.058	3.744	8526.991987
57250.632	7.488	7645.650641
2827.59	0.0468	60418.58974
3546.046	0.0936	37885.10684
4893.151	0.1872	26138.62714
6689.291	0.3744	17866.69605
9922.343	0.7488	13250.99225
15759.798	1.4976	10523.36939
26087.603	2.9952	8709.803352
45575.722	5.9904	7608.126669
78265.47	11.9808	6532.574619
S-32, 70 wt%+ SNP, 20 wt%		
63613.36	5.1069	12456.35513
126253.36	10.2138	12361.05661
56711.79	2.34	24235.80769
9563.115	0.234	40868.01282
16478.254	0.468	35209.94444
28153.164	0.936	30078.16667

47641.283	1.872	25449.40331
80690.259	3.744	21551.88542
3097.011	0.0234	132350.8974
4623.73	0.0468	98797.64957
6868.905	0.0936	73385.73718
9832.536	0.1872	52524.23077
15669.991	0.3744	41853.60844
24560.884	0.7488	32800.32585
41264.986	1.4976	27554.07719
68656.121	2.9952	22922.04894

Table 15 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 25 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 25 wt%		
281.955	1.53207	184.0353248
578.82	3.06414	188.9012904
7357.2375	51.069	144.0646478
14333.565	102.138	140.3352817
20914.0725	153.207	136.5085962
628.2975	5.1069	123.029137
1320.9825	10.2138	129.3331081
22744.74	170.23	133.6118193
26029.36	170.23	152.9070082
46909.36	340.46	137.7822945
67789.36	510.69	132.7407233
124165.36	1021.38	121.5662731
5297.2825	37.44	141.4872463
10191.764	74.88	136.1079594
19352.078	149.76	129.2206063
38211.548	299.52	127.5759482
74224.155	599.04	123.9051733
4399.2125	29.952	146.8754173
7991.4925	59.904	133.4049897
15849.605	119.808	132.2917084
S-32, 5 wt%+ SNP, 25 wt%		
578.82	3.06414	188.9012904
7604.625	51.069	148.9088292

14778.8625	102.138	144.6950449
21953.1	153.207	143.2904502
677.775	5.1069	132.7174999
1568.37	10.2138	153.5540152
24031.155	170.23	141.1687423
28117.36	170.23	165.1727663
50041.36	340.46	146.9816131
73009.36	510.69	142.9621884
135649.36	1021.38	132.8098847
3007.204	18.72	160.6412393
5521.8	37.44	147.4839744
10371.378	74.88	138.5066506
20070.534	149.76	134.0179888
40546.53	299.52	135.3716947
80780.066	599.04	134.8492021
4444.116	29.952	148.3745994
8126.203	59.904	135.6537627
16298.64	119.808	136.0396635
S-32, 10 wt%+ SNP, 25 wt%		
578.82	3.06414	188.9012904
8396.265	51.069	164.4102097
16609.53	102.138	162.6185161
24525.93	153.207	160.0836124
727.2525	5.1069	142.4058627
1667.325	10.2138	163.242378
26950.3275	170.23	158.3171445
30205.36	170.23	177.4385243
54217.36	340.46	159.2473712
78229.36	510.69	153.1836535
146089.36	1021.38	143.0313497
2827.59	18.72	151.0464744
5566.7035	37.44	148.68332
10371.378	74.88	138.5066506
20160.341	149.76	134.6176616
40815.951	299.52	136.2712039
81408.715	599.04	135.8986295
4444.116	29.952	148.3745994
8216.01	59.904	137.1529447
16388.447	119.808	136.7892545

S-32, 15 wt%+ SNP, 25 wt%		
578.82	3.06414	188.9012904
8643.6525	51.069	169.2543911
17153.7825	102.138	167.9471157
25416.525	153.207	165.89663
776.73	5.1069	152.0942255
1766.28	10.2138	172.9307408
27692.49	170.23	162.6769077
32293.36	170.23	189.7042824
57349.36	340.46	168.4466898
82405.36	510.69	161.3608255
153397.36	1021.38	150.1863753
3276.625	18.72	175.0333868
6150.449	37.44	164.274813
11628.676	74.88	155.2974893
23123.972	149.76	154.4068643
46114.564	299.52	153.9615518
4848.2475	29.952	161.8672376
9114.08	59.904	152.144765
18723.429	119.808	156.2786208
S-32, 20 wt%+ SNP, 25 wt%		
578.82	3.06414	188.9012904
9187.905	51.069	179.9115902
18341.2425	102.138	179.573151
27395.625	153.207	178.8144471
826.2075	5.1069	161.7825883
1815.7575	10.2138	177.7749222
34381.36	170.23	201.9700405
62569.36	340.46	183.7788874
90757.36	510.69	177.7151697
171145.36	1021.38	167.5628659
3411.3355	18.72	182.2294605
6330.063	37.44	169.0721955
12616.553	74.88	168.4902911
25099.726	149.76	167.5996661
49976.265	299.52	166.8545172
2917.397	14.976	194.804821
5162.572	29.952	172.3615118
10012.15	59.904	167.1365852

19801.113	119.808	165.2737129
S-32, 25 wt%+ SNP, 25 wt%		
776.73	3.06414	253.4903758
10672.23	51.069	208.9766786
21260.415	102.138	208.1538213
1172.55	5.1069	229.6011279
2112.6225	10.2138	206.8400106
37513.36	170.23	220.3686777
69877.36	340.46	205.243964
100153.36	510.69	196.1138068
3635.853	18.72	194.2229167
6958.712	37.44	185.8630342
13873.851	74.88	185.2811298
27883.743	149.76	186.1895232
55723.913	299.52	186.0440471
3231.7215	14.976	215.7933694
5656.5105	29.952	188.852514
11628.676	59.904	194.1218616
22764.744	119.808	190.0102163
S-32, 30 wt%+ SNP, 25 wt%		
380.91	1.53207	248.6244101
578.82	3.06414	188.9012904
9682.68	51.069	189.599953
19380.27	102.138	189.745932
29077.86	153.207	189.7945916
974.64	5.1069	190.8476767
1964.19	10.2138	192.3074664
37513.36	170.23	220.3686777
69877.36	340.46	205.243964
103285.36	510.69	202.2466859
3905.274	18.72	208.6150641
7587.361	37.44	202.6538729
15310.763	74.88	204.4706597
29051.234	149.76	193.9852698
57520.053	299.52	192.0407752
3546.046	14.976	236.7819177
6419.87	29.952	214.3386084
12436.939	59.904	207.6144999
23662.814	119.808	197.5061265

2827.59	11.9808	236.0101162
S-32, 35 wt%+ SNP, 25 wt%		
578.82	1.53207	377.8025808
1123.0725	3.06414	366.5212751
15174.6825	51.069	297.1407801
1716.8025	5.1069	336.1731187
3201.1275	10.2138	313.4120014
53173.36	170.23	312.3618634
99109.36	340.46	291.1042707
140869.36	510.69	275.8412344
3007.204	9.36	321.2824786
5791.221	18.72	309.3600962
11089.834	37.44	296.2028312
21597.253	74.88	288.4248531
42342.67	149.76	282.7368456
83025.241	299.52	277.1943142
4713.537	14.976	314.739383
9203.887	29.952	307.287894
17196.71	59.904	287.0711472
35068.303	119.808	292.704185
4084.888	11.9808	340.9528579
S-32, 40 wt%+ SNP, 25 wt%		
628.2975	1.53207	410.0971235
1222.0275	3.06414	398.8158178
18192.81	51.069	356.2397932
1914.7125	5.1069	374.9265699
3745.38	10.2138	366.6979968
63404.56	170.23	372.464078
117901.36	340.46	346.3001821
174277.36	510.69	341.2586109
3635.853	9.36	388.4458333
7228.133	18.72	386.1182158
13424.816	37.44	358.5688034
27344.901	74.88	365.1829728
53029.703	149.76	354.09791
3141.9145	7.488	419.5932826
6240.256	14.976	416.6837607
10550.992	29.952	352.2633547
21417.639	59.904	357.5327023

43150.933	119.808	360.1673761
4758.4405	11.9808	397.1721838
S-32, 45 wt%+ SNP, 25 wt%		
677.775	1.53207	442.3916662
1568.37	3.06414	511.8467172
26702.94	51.069	522.8796334
2706.3525	5.1069	529.9403748
4438.065	10.2138	434.5165365
92845.36	170.23	545.4112671
172189.36	340.46	505.7550373
2827.59	4.68	604.1858974
5252.379	9.36	561.1516026
9922.343	18.72	530.0396902
19890.92	37.44	531.2745726
37942.127	74.88	506.7057559
74583.383	149.76	498.0193843
4309.4055	7.488	575.5082131
8081.2995	14.976	539.6166867
16119.026	29.952	538.1619257
30667.76	59.904	511.9484509
61112.333	119.808	510.0855786
3546.046	5.9904	591.9547943
6958.712	11.9808	580.8219818
S-32, 50 wt%+ SNP, 25 wt%		
1222.0275	1.53207	797.6316356
2458.965	3.06414	802.4976013
3844.335	5.1069	752.7727193
7753.0575	10.2138	759.0766904
107461.36	170.23	631.2715738
3725.66	4.68	796.0811966
7183.2295	9.36	767.4390491
13514.623	18.72	721.9349893
26626.445	37.44	711.1764156
52939.896	74.88	706.9964744
3456.239	3.744	923.1407585
5836.1245	7.488	779.3969685
11538.869	14.976	770.4907185
21597.253	29.952	721.0621327
42252.863	59.904	705.342932

82666.013	119.808	689.9874215
2827.59	2.9952	944.0404647
4713.537	5.9904	786.8484575
9383.501	11.9808	783.2115552
4281.35	7.2	594.6319444
8318.24	14.4	577.6555556
16392.02	28.8	569.1673611
32050.26	57.6	556.428125
62755.09	115.2	544.7490451
118659.9	230.4	515.0169271
3547.37	5.76	615.8628472
6605.62	11.52	573.4045139
13089.11	23.04	568.1037326
26056.09	46.08	565.453342
10369.36	10.2138	1015.230375
S-32, 55 wt%+ SNP, 25 wt%		
1469.415	1.53207	959.104349
2953.74	3.06414	963.9703147
4784.4075	5.1069	936.8516125
9187.905	10.2138	899.557951
13501.36	10.2138	1321.874327
151309.36	170.23	888.8524937
3007.204	2.34	1285.129915
5387.0895	4.68	1151.0875
9652.922	9.36	1031.295085
17825.359	18.72	952.2093483
36056.18	37.44	963.0389957
70182.84	74.88	937.2708333
4444.116	3.744	1186.996795
8036.396	7.488	1073.236645
14861.728	14.976	992.3696581
30667.76	29.952	1023.896902
57609.86	59.904	961.7030582
3680.7565	2.9952	1228.885049
6644.3875	5.9904	1109.172593
12975.781	11.9808	1083.04796
5137.66	7.2	713.5638889
10520.18	14.4	730.5680556
20306.58	28.8	705.0895833
40124.04	57.6	696.5979167

77434.69	115.2	672.1761285
4403.68	5.76	764.5277778
8440.57	11.52	732.6883681
16392.02	23.04	711.4592014
32661.91	46.08	708.8088108
3425.04	4.608	743.28125
S-32, 58 wt%+ SNP, 25 wt%		
3745.38	1.53207	2444.653312
7010.895	3.06414	2288.046564
11068.05	5.1069	2167.273689
21309.8925	10.2138	2086.382394
11413.36	5.1069	2234.890051
21853.36	10.2138	2139.591533
5342.186	2.34	2282.98547
9203.887	4.68	1966.642521
16657.868	9.36	1779.686752
35158.11	18.72	1878.104167
66590.56	37.44	1778.594017
4444.116	1.872	2373.99359
7856.782	3.744	2098.499466
14143.272	7.488	1888.791667
28871.62	14.976	1927.859241
54017.58	29.952	1803.471554
3905.274	1.4976	2607.688301
6689.291	2.9952	2233.337006
11808.29	5.9904	1971.202257
22585.13	11.9808	1885.110343
3547.37	1.8	1970.761111
6605.62	3.6	1834.894444
13272.605	7.2	1843.417361
26056.09	14.4	1809.450694
49910.44	28.8	1733.001389
94560.89	57.6	1641.682118
3058.05	1.44	2123.645833
5932.805	2.88	2060.001736
10948.335	5.76	1900.752604
21040.56	11.52	1826.4375
40491.03	23.04	1757.423177
77924.01	46.08	1691.059245
4648.34	2.304	2017.508681

8807.56	4.608	1911.362847
S-32, 61 wt%+ SNP, 25 wt%		
7555.1475	1.53207	4931.333098
14333.565	3.06414	4677.842723
23239.515	5.1069	4550.610938
16633.36	5.1069	3257.036558
37513.36	10.2138	3672.811295
11269.448	2.34	4816.003419
19621.499	4.68	4192.627991
35607.145	9.36	3804.182158
72787.243	18.72	3888.207425
3725.66	0.468	7960.811966
5611.607	0.936	5995.306624
9383.501	1.872	5012.553953
16837.482	3.744	4497.190705
30218.725	7.488	4035.620326
58507.93	14.976	3906.779514
2917.397	0.3744	7792.192842
4623.73	0.7488	6174.853098
7677.168	1.4976	5126.314103
13514.623	2.9952	4512.093683
25548.761	5.9904	4264.950755
49976.265	11.9808	4171.362931
5137.66	1.8	2854.255556
9725.035	3.6	2701.398611
18471.63	7.2	2565.504167
35475.5	14.4	2463.576389
66302.66	28.8	2302.175694
4526.01	1.44	3143.0625
8318.24	2.88	2888.277778
15658.04	5.76	2718.409722
28747.35	11.52	2495.429688
54069.66	23.04	2346.773438
102145.35	46.08	2216.695964
3669.7	1.152	3185.503472
6850.28	2.304	2973.211806
12844.45	4.608	2787.424045
S-32, 64 wt%+ SNP, 25 wt%		
15521.025	1.53207	10130.75447

34381.36	5.1069	6732.334684
61525.36	10.2138	6023.748262
20609.376	2.34	8807.425641
36684.829	4.68	7838.638675
64704.613	9.36	6912.886004
3276.625	0.234	14002.67094
5611.607	0.468	11990.61325
9563.115	0.936	10217.00321
17196.71	1.872	9186.276709
31206.602	3.744	8335.096688
58148.702	7.488	7765.585203
3097.011	0.0936	33087.72436
4354.309	0.1872	23260.19765
6015.7385	0.3744	16067.67762
9293.694	0.7488	12411.45032
15580.184	1.4976	10403.43483
27075.48	2.9952	9039.623397
48449.546	5.9904	8087.864917
85450.03	11.9808	7132.247429
5137.66	0.9	5708.511111
9786.2	1.8	5436.777778
18043.475	3.6	5012.076389
33885.21	7.2	4706.279167
62877.42	14.4	4366.4875
112543.4	28.8	3907.756944
4464.845	0.72	6201.173611
8379.405	1.44	5819.03125
15780.37	2.88	5479.295139
28502.69	5.76	4948.383681
52357.04	11.52	4544.881944
94560.89	23.04	4104.205295
4036.69	0.576	7008.142361
7094.94	1.152	6158.802083
12660.955	2.304	5495.206163
23364.83	4.608	5070.492622
S-32, 66 wt%+ SNP, 25 wt%		
53173.36	5.1069	10412.06211
103285.36	10.2138	10112.33429
45036.88	2.34	19246.52991
77367.4	4.68	16531.49573

8754.852	0.234	37413.89744
13604.43	0.468	29069.29487
22495.323	0.936	24033.46474
40366.916	1.872	21563.5235
69913.419	3.744	18673.45593
3007.204	0.0234	128512.9915
4084.888	0.0468	87283.93162
5611.607	0.0936	59953.06624
8305.817	0.1872	44368.68056
12257.325	0.3744	32738.58173
19441.885	0.7488	25964.05582
32463.9	1.4976	21677.28365
55813.72	2.9952	18634.38835
11988.14	0.9	13320.15556
21774.54	1.8	12096.96667
37065.79	3.6	10296.05278
67892.95	7.2	9429.576389
116090.97	14.4	8061.872917
3180.38	0.18	17668.77778
5871.64	0.36	16310.11111
10397.85	0.72	14441.45833
18349.3	1.44	12742.56944
32784.24	2.88	11383.41667
57250.24	5.76	9939.277778
97863.8	11.52	8495.121528
5137.66	0.288	17839.09722
8807.56	0.576	15290.90278
15291.05	1.152	13273.4809
26790.07	2.304	11627.63455
47341.51	4.608	10273.76519
S-32, 68 wt%+ SNP, 25 wt%		
77185.36	5.1069	15113.93605
75232.75	0.9	83591.94444
118659.9	1.8	65922.16667
13945.42	0.09	154949.1111
22997.84	0.18	127765.7778
37310.45	0.36	103640.1389
62755.09	0.72	87159.84722
106671.56	1.44	74077.47222
3914.36	0.018	217464.4444

6605.62	0.036	183489.4444
11009.5	0.072	152909.7222
18471.63	0.144	128275.2083
30949.29	0.288	107462.8125
51623.06	0.576	89623.36806
87465.75	1.152	75925.13021

Table 16 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 30 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 30%		
578.82	1.53207	377.8025808
1222.0275	3.06414	398.8158178
19677.135	51.069	385.3048816
2013.6675	5.1069	394.3032955
3992.7675	10.2138	390.9189038
63613.36	170.23	373.6906538
116857.36	340.46	343.2337426
168013.36	510.69	328.9928528
312085.36	1021.38	305.5526445
3501.1425	9.36	374.0536859
7228.133	18.72	386.1182158
13514.623	37.44	360.9674947
26267.217	74.88	350.7908253
51862.212	149.76	346.3021635
3186.818	7.488	425.5900107
5611.607	14.976	374.706664
11359.255	29.952	379.2486311
21956.481	59.904	366.5277945
42252.863	119.808	352.671466
4623.73	11.9808	385.9283186
S-32, 5 wt%+ SNP, 30 wt%		
677.775	1.53207	442.3916662
1518.8925	3.06414	495.6994458
20270.865	51.069	396.930917
2211.5775	5.1069	433.0567468
4438.065	10.2138	434.5165365
67789.36	170.23	398.22217

125209.36	340.46	367.7652588
3905.274	9.36	417.2301282
7317.94	18.72	390.9155983
15310.763	37.44	408.9413194
28781.813	74.88	384.3725027
55993.334	149.76	373.8871127
3321.5285	7.488	443.580195
6689.291	14.976	446.6674012
11628.676	29.952	388.2437233
23034.165	59.904	384.5179788
46473.792	119.808	387.9022436
4982.958	11.9808	415.9119591
S-32, 10 wt%+ SNP, 30 wt%		
727.2525	1.53207	474.6862089
1419.9375	3.06414	463.4049032
22249.965	51.069	435.6843682
2310.5325	5.1069	452.4334724
4537.02	10.2138	444.2048993
69877.36	170.23	410.4879281
134605.36	340.46	395.3632145
4084.888	9.36	436.4196581
8126.203	18.72	434.0920406
15580.184	37.44	416.1373932
29769.69	74.88	397.5653045
59316.193	149.76	396.0750067
3366.432	7.488	449.5769231
6958.712	14.976	464.6575855
12257.325	29.952	409.2322716
25189.533	59.904	420.4983474
49437.423	119.808	412.638747
3007.204	5.9904	502.0038729
5431.993	11.9808	453.3915097
S-32, 15 wt%+ SNP, 30 wt%		
776.73	1.53207	506.9807515
1617.8475	3.06414	527.9939885
24229.065	51.069	474.4378194
2607.3975	5.1069	510.5636492
4982.3175	10.2138	487.8025319
70921.36	170.23	416.6208071

136693.36	340.46	401.4960935
4084.888	9.36	436.4196581
8395.624	18.72	448.484188
16029.219	37.44	428.1308494
31476.023	74.88	420.3528713
62010.403	149.76	414.065191
3546.046	7.488	473.5638355
7317.94	14.976	488.6444979
12436.939	29.952	415.2289997
25279.34	59.904	421.9975294
51233.563	119.808	427.6305672
3231.7215	5.9904	539.4834235
5611.607	11.9808	468.38333
5137.66	14.4	356.7819444
10397.85	28.8	361.0364583
20428.91	57.6	354.6685764
40124.04	115.2	348.2989583
78413.33	230.4	340.3356337
3914.36	11.52	339.7881944
8073.58	23.04	350.4157986
16269.69	46.08	353.0748698
S-32, 20 wt%+ SNP, 30 wt%		
776.73	1.53207	506.9807515
1667.325	3.06414	544.1412599
25466.0025	51.069	498.6587264
2656.875	5.1069	520.252012
5081.2725	10.2138	497.4908947
79273.36	170.23	465.6838395
4982.958	9.36	532.3673077
9293.694	18.72	496.4580128
17196.71	37.44	459.3138355
35427.531	74.88	473.1240785
68745.928	149.76	459.0406517
3995.081	7.488	533.5311165
7317.94	14.976	488.6444979
15131.149	29.952	505.1799212
28781.813	59.904	480.4656283
55813.72	119.808	465.8597089
3366.432	5.9904	561.9711538
6419.87	11.9808	535.8465211

5871.64	14.4	407.7527778
11621.15	28.8	403.5121528
22630.85	57.6	392.8967014
43426.95	115.2	376.9700521
87465.75	230.4	379.625651
4464.845	11.52	387.5733507
9174.55	23.04	398.2009549
17982.31	46.08	390.2411024
S-32, 25 wt%+ SNP, 30 wt%		
875.685	1.53207	571.5698369
1716.8025	3.06414	560.2885312
26158.6875	51.069	512.2224344
2805.3075	5.1069	549.3171004
5328.66	10.2138	521.7118017
88669.36	170.23	520.8797509
5431.993	9.36	580.3411325
9832.536	18.72	525.2423077
20070.534	37.44	536.0719551
38660.583	74.88	516.3005208
75122.225	149.76	501.6174212
4444.116	7.488	593.4983974
8036.396	14.976	536.6183226
16568.061	29.952	553.153746
30667.76	59.904	511.9484509
61202.14	119.808	510.8351696
3546.046	5.9904	591.9547943
7048.519	11.9808	588.317892
3180.38	7.2	441.7194444
6238.63	14.4	433.2381944
12599.79	28.8	437.4927083
24710.46	57.6	429.0010417
48564.81	115.2	421.5695313
94683.22	230.4	410.9514757
5137.66	11.52	445.9774306
10153.19	23.04	440.6766493
19939.59	46.08	432.7167969
S-32, 30 wt%+ SNP, 30 wt%		
974.64	1.53207	636.1589222
2063.145	3.06414	673.3194306

3151.65	5.1069	617.13564
6169.7775	10.2138	604.0628855
10369.36	10.2138	1015.230375
99109.36	170.23	582.2085414
3097.011	4.68	661.7544872
5521.8	9.36	589.9358974
10191.764	18.72	544.4318376
21327.832	37.44	569.6536325
40546.53	74.88	541.4867788
79343.154	149.76	529.8020433
4444.116	7.488	593.4983974
8575.238	14.976	572.5986912
17286.517	29.952	577.1406584
33182.356	59.904	553.9255475
65602.683	119.808	547.5651292
4084.888	5.9904	681.9057158
7317.94	11.9808	610.8056223
3669.7	7.2	509.6805556
7339.6	14.4	509.6944444
15046.39	28.8	522.4440972
29359	57.6	509.7048611
57861.89	115.2	502.2733507
111687.09	230.4	484.7529948
5993.97	11.52	520.3098958
11988.14	23.04	520.3185764
23731.82	46.08	515.0134549
S-32, 35 wt%+ SNP, 30 wt%		
1617.8475	1.53207	1055.987977
2854.785	3.06414	931.675772
4388.5875	5.1069	859.3447101
8544.6975	10.2138	836.5835928
10369.36	10.2138	1015.230375
113725.36	170.23	668.068848
3815.467	4.68	815.2707265
6824.0015	9.36	729.0599893
14771.921	18.72	789.098344
27883.743	37.44	744.7580929
55813.72	74.88	745.3755342
3097.011	3.744	827.193109
6240.256	7.488	833.3675214

12347.132	14.976	824.4612714
21866.674	29.952	730.0572249
45036.88	59.904	751.8175748
88952.503	119.808	742.4587924
4803.344	5.9904	801.8402778
9024.273	11.9808	753.2279147
3058.05	7.2	424.7291667
6483.29	14.4	450.2284722
13089.11	28.8	454.4829861
25322.11	57.6	439.6199653
49910.44	115.2	433.2503472
96885.16	230.4	420.5085069
5015.33	11.52	435.3585069
10153.19	23.04	440.6766493
20551.24	46.08	445.9904514
S-32, 40 wt%+ SNP, 30 wt%		
1865.235	1.53207	1217.46069
3646.425	3.06414	1190.032113
5625.525	5.1069	1101.55378
11117.5275	10.2138	1088.481026
13501.36	10.2138	1321.874327
4489.0195	4.68	959.1922009
7946.589	9.36	848.9945513
16478.254	18.72	880.2486111
32463.9	37.44	867.0913462
63896.35	74.88	853.31664
3635.853	3.744	971.1145833
7228.133	7.488	965.2955395
14367.7895	14.976	959.3876536
26087.603	29.952	870.9803352
51772.405	59.904	864.2562266
3186.818	2.9952	1063.975027
5970.835	5.9904	996.733941
11000.027	11.9808	918.1379374
3302.71	3.6	917.4194444
6850.28	7.2	951.4277778
14128.915	14.4	981.1746528
28258.03	28.8	981.1815972
55904.61	57.6	970.5661458
107283.21	115.2	931.2778646

5626.98	5.76	976.90625
11559.985	11.52	1003.47092
22997.84	23.04	998.1701389
45506.56	46.08	987.5555556
4526.01	4.608	982.2070313
S-32, 45 wt%+ SNP, 30 wt%		
2656.875	1.53207	1734.173373
5180.2275	3.06414	1690.597525
8445.7425	5.1069	1653.79046
16263.1875	10.2138	1592.275891
10369.36	5.1069	2030.460749
17677.36	10.2138	1730.73293
3995.081	2.34	1707.299573
7048.519	4.68	1506.093803
12167.518	9.36	1299.948504
24201.656	18.72	1292.823504
51952.019	37.44	1387.607345
3007.204	1.872	1606.412393
5611.607	3.744	1498.826656
10191.764	7.488	1361.079594
19711.306	14.976	1316.192975
39648.46	29.952	1323.733307
79163.54	59.904	1321.506744
4354.309	2.9952	1453.762353
8799.7555	5.9904	1468.976279
18543.815	11.9808	1547.794388
3547.37	3.6	985.3805556
6972.61	7.2	968.4180556
14373.575	14.4	998.1649306
28258.03	28.8	981.1815972
55415.29	57.6	962.0710069
105815.25	115.2	918.5351563
5871.64	5.76	1019.381944
11743.48	11.52	1019.399306
22997.84	23.04	998.1701389
45506.56	46.08	987.5555556
4893	4.608	1061.848958
S-32, 50 wt%+ SNP, 30 wt%		
4487.5425	1.53207	2929.071452

8693.13	3.06414	2837.05379
14333.565	5.1069	2806.705634
27890.4	10.2138	2730.658521
13501.36	5.1069	2643.748654
26029.36	10.2138	2548.450136
6419.87	2.34	2743.534188
12257.325	4.68	2619.086538
22854.551	9.36	2441.725534
41983.442	18.72	2242.705235
85539.837	37.44	2284.717869
3007.204	0.936	3212.824786
5342.186	1.872	2853.731838
9922.343	3.744	2650.198451
18094.78	7.488	2416.503739
34978.496	14.976	2335.636752
70182.84	29.952	2343.177083
4264.502	1.4976	2847.557425
8126.203	2.9952	2713.075254
15759.798	5.9904	2630.842348
27524.515	11.9808	2297.3854
3180.38	1.8	1766.877778
6116.3	3.6	1698.972222
12477.46	7.2	1732.980556
24832.79	14.4	1724.499306
47586.17	28.8	1652.297569
92481.28	57.6	1605.577778
4893	2.88	1698.958333
9786.2	5.76	1698.993056
19083.28	11.52	1656.534722
37432.78	23.04	1624.686632
73520.13	46.08	1595.488932
3914.36	2.304	1698.940972
7584.26	4.608	1645.889757
S-32, 55 wt%+ SNP, 30 wt%		
9682.68	1.53207	6319.998433
19974	3.06414	6518.631655
17677.36	5.1069	3461.46586
31249.36	10.2138	3059.52339
12616.553	2.34	5391.689316
22585.13	4.68	4825.882479

44138.81	9.36	4715.684829
89042.31	18.72	4756.533654
3186.818	0.468	6809.440171
5162.572	0.936	5515.568376
9922.343	1.872	5300.396902
19352.078	3.744	5168.824252
37313.478	7.488	4983.103365
72877.05	14.976	4866.25601
5072.765	0.7488	6774.525908
8844.659	1.4976	5905.888755
16478.254	2.9952	5501.553819
31116.795	5.9904	5194.44361
56711.79	11.9808	4733.55619
4403.68	0.9	4892.977778
8073.58	1.8	4485.322222
15780.37	3.6	4383.436111
32294.92	7.2	4485.405556
61776.45	14.4	4290.03125
116702.62	28.8	4052.174306
3180.38	0.72	4417.194444
6605.62	1.44	4587.236111
13578.43	2.88	4714.732639
26423.08	5.76	4587.340278
50766.75	11.52	4406.835938
95417.2	23.04	4141.371528
5626.98	1.152	4884.53125
10887.17	2.304	4725.334201
21040.56	4.608	4566.09375
S-32, 58 wt%+ SNP, 30 wt%		
19974	1.53207	13037.26331
33337.36	5.1069	6527.905383
66745.36	10.2138	6534.821516
25189.533	2.34	10764.75769
47641.283	4.68	10179.76132
5701.414	0.234	24365.01709
7766.975	0.468	16596.10043
12257.325	0.936	13095.43269
22046.288	1.872	11776.86325
41354.793	3.744	11045.61779
75571.26	7.488	10092.31571

3456.239	0.1872	18462.81517
5611.607	0.3744	14988.26656
10281.571	0.7488	13730.7305
18184.587	1.4976	12142.48598
33721.198	2.9952	11258.41279
64075.964	5.9904	10696.44164
6238.63	0.9	6931.811111
11009.5	1.8	6116.388889
19939.59	3.6	5538.775
39267.73	7.2	5453.851389
74254.11	14.4	5156.535417
4526.01	0.72	6286.125
8807.56	1.44	6116.361111
16881.34	2.88	5861.576389
32417.25	5.76	5627.994792
60920.14	11.52	5288.206597
111687.09	23.04	4847.529948
3669.7	0.576	6371.006944
7094.94	1.152	6158.802083
13761.925	2.304	5973.057726
26300.75	4.608	5707.628038
S-32, 61 wt%+ SNP, 30 wt%		
40124.04	0.9	44582.26667
69605.57	1.8	38669.76111
6483.29	0.09	72036.55556
10214.355	0.18	56746.41667
18838.62	0.36	52329.5
34619.19	0.72	48082.20833
61287.13	1.44	42560.50694
106059.91	2.88	36826.35764
3425.04	0.036	95140
5626.98	0.072	78152.5
9419.21	0.144	65411.18056
15658.04	0.288	54368.19444
29114.34	0.576	50545.72917
50766.75	1.152	44068.35938
89423.03	2.304	38812.07899

Table 17 Rheological Data for Suspensions of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 35 wt%.

Shear Stress (mPa)	Shear Rate (s^{-1})	Viscosity (mPa.s)
SNP, 35 wt%		
2557.92	1.53207	1669.584288
5031.795	3.06414	1642.155711
8247.8325	5.1069	1615.037009
15570.5025	10.2138	1524.457352
8281.36	5.1069	1621.602146
16633.36	10.2138	1628.518279
3815.467	2.34	1630.541453
6689.291	4.68	1429.335684
12347.132	9.36	1319.138034
26806.059	18.72	1431.947596
48269.932	37.44	1289.261004
3276.625	1.872	1750.333868
6105.5455	3.744	1630.754674
11808.29	7.488	1576.961806
21597.253	14.976	1442.124265
40187.302	29.952	1341.723491
76469.33	59.904	1276.531283
4848.2475	2.9952	1618.672376
8844.659	5.9904	1476.472189
16568.061	11.9808	1382.884365
3180.38	1.8	1766.877778
6238.63	3.6	1732.952778
13089.11	7.2	1817.931944
25444.44	14.4	1766.975
49421.12	28.8	1716.011111
93459.92	57.6	1622.568056
5259.99	2.88	1826.385417
11009.5	5.76	1911.371528
20673.57	11.52	1794.580729
41347.34	23.04	1794.58941
77679.35	46.08	1685.749783
4342.515	2.304	1884.772135
8562.9	4.608	1858.268229
S-32, 5 wt%+ SNP, 35 wt%		
2805.3075	1.53207	1831.057001

5477.0925	3.06414	1787.481153
8989.995	5.1069	1760.362451
17351.6925	10.2138	1698.847882
10369.36	5.1069	2030.460749
18721.36	10.2138	1832.947581
4623.73	2.34	1975.952991
8126.203	4.68	1736.368162
14771.921	9.36	1578.196688
31476.023	18.72	1681.411485
58507.93	37.44	1562.711806
3411.3355	1.872	1822.294605
6419.87	3.744	1714.708868
12616.553	7.488	1684.902911
26716.252	14.976	1783.937767
47731.09	29.952	1593.586071
2962.3005	1.4976	1978.031851
5521.8	2.9952	1843.549679
10281.571	5.9904	1716.341313
21597.253	11.9808	1802.655332
3914.36	3.6	1087.322222
8318.24	7.2	1155.311111
16881.34	14.4	1172.315278
32417.25	28.8	1125.598958
62021.11	57.6	1076.755382
113889.03	115.2	988.6200521
3241.545	2.88	1125.536458
7033.775	5.76	1221.141493
13456.1	11.52	1168.064236
26545.41	23.04	1152.144531
50766.75	46.08	1101.708984
5504.65	4.608	1194.585503
S-32, 10 wt%+ SNP, 35 wt%		
2904.2625	1.53207	1895.646087
5625.525	3.06414	1835.922967
9286.86	5.1069	1818.492628
18390.72	10.2138	1800.575692
11413.36	5.1069	2234.890051
19765.36	10.2138	1935.162231
4354.309	2.34	1860.815812
7946.589	4.68	1697.989103

15310.763	9.36	1635.765278
32284.286	18.72	1724.587927
61112.333	37.44	1632.273851
3770.5635	1.872	2014.189904
7183.2295	3.744	1918.597623
13694.237	7.488	1828.824386
24471.077	14.976	1634.019565
49078.195	29.952	1638.561532
3456.239	1.4976	2307.851896
6150.449	2.9952	2053.435163
11359.255	5.9904	1896.243156
19890.92	11.9808	1660.23304
6972.61	7.2	968.4180556
13823.09	14.4	959.9368056
27646.38	28.8	959.94375
52112.38	57.6	904.7288194
5626.98	5.76	976.90625
11192.995	11.52	971.6141493
22263.86	23.04	966.3133681
43243.455	46.08	938.4430339
4403.68	4.608	955.6597222
S-32, 15 wt%+ SNP, 35 wt%		
3448.515	1.53207	2250.886056
6565.5975	3.06414	2142.721122
10721.7075	5.1069	2099.455149
21161.46	10.2138	2071.84985
13501.36	5.1069	2643.748654
21853.36	10.2138	2139.591533
4893.151	2.34	2091.090171
9473.308	4.68	2024.211111
18633.622	9.36	1990.771581
34709.075	18.72	1854.117254
68566.314	37.44	1831.365224
3815.467	1.872	2038.176816
7497.554	3.744	2002.551816
15310.763	7.488	2044.706597
30128.918	14.976	2011.813435
57609.86	29.952	1923.406116
3501.1425	1.4976	2337.835537
6240.256	2.9952	2083.418803

12077.711	5.9904	2016.177718
23483.2	11.9808	1960.069444
5015.33	3.6	1393.147222
10397.85	7.2	1444.145833
21652.21	14.4	1503.625694
40980.35	28.8	1422.928819
78780.32	57.6	1367.713889
4159.02	2.88	1444.104167
8562.9	5.76	1486.614583
17248.33	11.52	1497.250868
34007.54	23.04	1476.021701
66669.65	46.08	1446.824002
3180.38	2.304	1380.373264
6850.28	4.608	1486.605903
S-32, 20 wt%+ SNP, 35 wt%		
3547.47	1.53207	2315.475141
6763.5075	3.06414	2207.310208
11117.5275	5.1069	2176.962051
21804.6675	10.2138	2134.824208
13501.36	5.1069	2643.748654
22897.36	10.2138	2241.806184
5611.607	2.34	2398.12265
9563.115	4.68	2043.400641
18274.394	9.36	1952.392521
39019.811	18.72	2084.391613
72877.05	37.44	1946.502404
4444.116	1.872	2373.99359
7722.0715	3.744	2062.519097
14682.114	7.488	1960.752404
31116.795	14.976	2077.777444
58507.93	29.952	1953.389757
3770.5635	1.4976	2517.73738
6689.291	2.9952	2233.337006
12167.518	5.9904	2031.169538
25099.726	11.9808	2094.995827
5259.99	3.6	1461.108333
10275.52	7.2	1427.155556
21040.56	14.4	1461.15
41225.01	28.8	1431.423958
79024.98	57.6	1371.961458

4464.845	2.88	1550.293403
8562.9	5.76	1486.614583
16759.01	11.52	1454.775174
33151.23	23.04	1438.855469
64223.05	46.08	1393.729384
3302.71	2.304	1433.467882
6972.61	4.608	1513.153212
S-32, 25 wt%+ SNP, 35 wt%		
3695.9025	1.53207	2412.35877
7060.3725	3.06414	2304.193836
11711.2575	5.1069	2293.222405
22794.2175	10.2138	2231.707836
14545.36	5.1069	2848.177955
23941.36	10.2138	2344.020835
5701.414	2.34	2436.501709
10550.992	4.68	2254.48547
21238.025	9.36	2269.019765
42252.863	18.72	2257.097382
80959.68	37.44	2162.384615
4668.6335	1.872	2493.928152
8665.045	3.744	2314.381677
17017.096	7.488	2272.582265
35696.952	14.976	2383.610577
64794.42	29.952	2163.27524
4084.888	1.4976	2727.622863
7497.554	2.9952	2503.18977
14008.5615	5.9904	2338.501853
27524.515	11.9808	2297.3854
3058.05	1.8	1698.916667
6360.96	3.6	1766.933333
12722.12	7.2	1766.961111
26056.09	14.4	1809.450694
51133.74	28.8	1775.477083
98597.78	57.6	1711.767014
5259.99	2.88	1826.385417
10581.345	5.76	1837.039063
21162.89	11.52	1837.056424
41714.33	23.04	1810.517795
80859.93	46.08	1754.772786
4281.35	2.304	1858.224826

8440.57	4.608	1831.72092
S-32, 30 wt%+ SNP, 35 wt%		
15589.36	5.1069	3052.607257
24985.36	10.2138	2446.235485
6958.712	2.34	2973.808547
11269.448	4.68	2408.001709
20250.148	9.36	2163.47735
41085.372	18.72	2194.73141
80061.61	37.44	2138.397703
4982.958	1.872	2661.836538
9652.922	3.744	2578.237714
18813.236	7.488	2512.451389
33721.198	14.976	2251.682559
66590.56	29.952	2223.242521
4174.695	1.4976	2787.590144
7677.168	2.9952	2563.157051
15041.342	5.9904	2510.907786
28422.585	11.9808	2372.344501
5137.66	3.6	1427.127778
9908.53	7.2	1376.184722
19694.93	14.4	1367.703472
38411.42	28.8	1333.729861
74743.43	57.6	1297.628993
4159.02	2.88	1444.104167
8318.24	5.76	1444.138889
15902.7	11.52	1380.442708
31316.28	23.04	1359.213542
60675.48	46.08	1316.742188
3302.71	2.304	1433.467882
6483.29	4.608	1406.963976
S-32, 35 wt%+ SNP, 35 wt%		
18721.36	5.1069	3665.895161
35425.36	10.2138	3468.381993
8126.203	2.34	3472.736325
14816.8245	4.68	3165.988141
29051.234	9.36	3103.764316
60304.07	18.72	3221.371261
3950.1775	0.936	4220.275107
7138.326	1.872	3813.208333

13784.044	3.744	3681.635684
26357.024	7.488	3519.901709
48269.932	14.976	3223.152511
3905.274	0.7488	5215.376603
6330.063	1.4976	4226.804888
11044.9305	2.9952	3687.54357
20474.6655	5.9904	3417.912911
38121.741	11.9808	3181.902794
4036.69	1.8	2242.605556
7951.25	3.6	2208.680556
16636.68	7.2	2310.65
33151.23	14.4	2302.16875
64100.72	28.8	2225.719444
120984.17	57.6	2100.419618
3425.04	1.44	2378.5
6911.445	2.88	2399.807292
14067.75	5.76	2442.317708
26912.4	11.52	2336.145833
52724.03	23.04	2288.369358
100310.4	46.08	2176.875
5504.65	2.304	2389.171007
11192.995	4.608	2429.035373
S-32, 40 wt%+ SNP, 35 wt%		
27073.36	5.1069	5301.329574
48997.36	10.2138	4797.172453
13604.43	2.34	5813.858974
26267.217	4.68	5612.653205
49257.809	9.36	5262.586432
3501.1425	0.468	7481.073718
6150.449	0.936	6570.992521
11628.676	1.872	6211.899573
22495.323	3.744	6008.366186
42612.091	7.488	5690.717281
75481.453	14.976	5040.161124
3501.1425	0.3744	9351.342147
5925.9315	0.7488	7913.904247
10191.764	1.4976	6805.39797
18633.622	2.9952	6221.161191
34080.426	5.9904	5689.173678
61471.561	11.9808	5130.839426

3547.37	0.9	3941.522222
7033.775	1.8	3907.652778
14067.75	3.6	3907.708333
27891.04	7.2	3873.755556
54069.66	14.4	3754.8375
100799.72	28.8	3499.990278
5993.97	1.44	4162.479167
11926.975	2.88	4141.310764
23854.15	5.76	4141.345486
44283.26	11.52	3844.032986
83795.85	23.04	3636.972656
4893	1.152	4247.395833
9847.365	2.304	4274.029948
19144.445	4.608	4154.61046
S-32, 45 wt%+ SNP, 35 wt%		
84493.36	5.1069	16544.94116
23854.15	0.9	26504.61111
38166.76	1.8	21203.75556
54191.99	3.6	15053.33056
74865.76	7.2	10398.02222
98475.45	14.4	6838.572917
8685.23	0.09	96502.55556
13700.76	0.18	76115.33333
21285.22	0.36	59125.61111
31438.61	0.72	43664.73611
43304.62	1.44	30072.65278
55292.96	2.88	19198.94444
73520.13	5.76	12763.91146
94805.55	11.52	8229.648438
5137.66	0.072	71356.38889
9174.55	0.144	63712.15278
16392.02	0.288	56916.73611
25689.1	0.576	44599.13194
37065.79	1.152	32175.16493
50522.09	2.304	21927.99045
66547.32	4.608	14441.69271

Appendix B: Power Law Variable Values and Actual Concentrations of Solid Particles in Each SNP Dispersion

This appendix contains data on the Power-Law Variable Values for Weight Percent (wt%) Concentrations and Volume Fractions of Solid Particles in Each SNP Dispersion.

Appendix B.1: Power Law Variable Values and Actual Concentrations of SG Solid Particles in Each SNP Dispersion

Table 18 Power Law Variable Values and Actual Concentrations of SG Solid Particles in SNP Dispersion with SNP Concentration of 9.89 wt%.

SNP, 9.89 wt%				
SG Particle Concentration in Suspension (wt%)	**SG Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	7	1	1
5.000038	0.067843786	7.614714401	1	1.087816343
10.00055558	0.133192153	8.712833711	1	1.24469053
15.00053971	0.196167763	12.90612261	1	1.843731801
20.00040781	0.256902523	15.76323207	1	2.251890295
25.00068503	0.315519993	39.6007415	1	5.657248785
28.00097638	0.349718952	42.67970305	1	6.097100436
31.00090846	0.383211656	60.52748315	1	8.646783307
34.00077441	0.41602293	68.39177576	1	9.77025368
37.00054015	0.448172999	305.94	0.694	43.70571429
39.00061354	0.469251834	480.84	0.663	68.69142857
41.00061791	0.490050947	529.72	0.667	75.67428571
42.9993974	0.510564085	626.29	0.689	89.47
44.99920203	0.530819736	1566	0.644	223.7142857
46.99837091	0.550806213	8730.9	0.361	1247.271429

Table 19 Power Law Variable Values and Actual Concentrations of SG Solid Particles in SNP Dispersion with SNP Concentration of 14.83 wt%.

SNP, 14.83 wt%				
SG Particle Concentration in Suspension (wt%)	**SG Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	23.85925134	1	1.000000056
5.001104052	0.069031447	27.44238702	1	1.150178108
10.00047555	0.135330373	33.38672215	1	1.399319851
15.00077724	0.19908916	51.78151848	1	2.170291123
20.00037217	0.26043134	61.18420789	1	2.564381021
25.00070176	0.319508462	76.42339038	1	3.203092737
28.00019772	0.353907165	125.3092	1	5.252017561
30.99986277	0.387559483	254.5912175	1	10.6705457
33.99966544	0.420489105	309.9367719	1	12.99021436
36.99959348	0.452718935	1215.4	0.773	50.94041095
39.99961284	0.48427069	2132.5	0.728	89.37833335
41.99952918	0.504937468	6635	0.5	278.0892107
43.99951881	0.525318738	16674	0.345	698.848455
45.99939785	0.545418541	37470	0.078	1570.460094

Table 20 Power Law Variable Values and Actual Concentrations of SG Solid Particles in SNP Dispersion with SNP Concentration of 19.75 wt%.

SNP, 19.75 wt%				
SG Particle Concentration in Suspension (wt%)	**SG Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	56.72693	1	1
4.999728571	0.070219352	68.47995911	1	1.20718606
10.00032537	0.137523029	95.3945404	1	1.681644686
14.99972195	0.202062777	106.7029826	1	1.88099343
20.00022596	0.264033449	159.8155161	1	2.817277722
25.00021184	0.323566469	262.5369691	1	4.628083506
29.99878587	0.380792857	635.45	0.877	11.20191063
34.99881798	0.435875136	1378.933	0.725	24.30826064
37.99880278	0.467937138	5739	0.609	101.1688805
40.99905625	0.499291744	11868	0.55	209.2128025

43.9989644	0.529955901	36010	0.379	634.7955019
46.99857242	0.559952614	58665	0.18	1034.164902

Table 21 Power Law Variable Values and Actual Concentrations of SG Solid Particles in SNP Dispersion with SNP Concentration of 24.71 wt%.

SNP, 24.71 wt%				
SG Particle Concentration in Suspension (wt%)	**SG Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	163.7088	1	1
5.000489247	0.071491862	205.3732	1	1.254502581
9.999392407	0.139800056	316.2976273	1	1.932073853
14.95686572	0.204622881	686.7192679	1	4.194759074
19.95963809	0.26727773	981.9012314	1	5.997849911
24.96218893	0.327329251	1356.282821	1	8.284724102
27.9638929	0.36218044	1969.7	0.851	12.03172437
30.96566415	0.396185485	2931.7	0.851	17.9080095
33.96741899	0.429373917	4819.9	0.823	29.4418989
36.96931055	0.461776435	8044.2	0.778	49.13722757
39.97204692	0.493428005	26916	0.501	164.4138158
41.97135323	0.514094011	33842	0.581	206.7206255
43.97066101	0.534442271	53134	0.535	324.5639653

Table 22 Power Law Variable Values and Actual Concentrations of SG Solid Particles in SNP Dispersion with SNP Concentration of 29.67 wt%.

SNP, 29.67 wt%				
SG Particle Concentration in Suspension (wt%)	**SG Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	485.1720268	1	1.000000055
4.999986429	0.072789959	575.8564314	1	1.186911923
9.999528921	0.142163321	923.7540964	1	1.903972398
14.99969151	0.208368886	1129.478124	1	2.327995276
20.00035606	0.271617326	1926.891014	1	3.97156269
25.00072508	0.332093002	4176.2	0.848	8.607669033
28.00042997	0.367118028	7053.8	0.838	14.53876151
31.00039584	0.401249619	11872	0.839	24.46967261

34.00011429	0.434515961	22806	0.766	47.00601024
37.0000154	0.466954138	37523	0.646	77.33958266
40.00001467	0.498593813	94126	0.666	194.0054249
42.00048099	0.519261984	134961	0.439	278.1714526

Table 23 Power Law Variable Values and Actual Concentrations of SG Solid Particles in SNP Dispersion with SNP Concentration of 34.60 wt%.

SNP, 34.60 wt%				
SG Particle Concentration in Suspension (wt%)	SG Particle Concentration in Suspension (Volume fraction)	consistency index (K), $mPa.s^n$	flow behavior index (n)	relative viscosity (K_r)
0	0	1823.835104	1	1
5.000308749	0.074142183	3170.2	0.885	1.738205485
10.0002925	0.144605413	4970.5	0.876	2.725301357
15.00227714	0.211687323	6617.8	0.855	3.628508061
20.00200341	0.275572447	8597.8	0.86	4.714132583
25.00233489	0.336518061	14966	0.651	8.205786159
27.99958264	0.37172016	21904	0.684	12.00985835
30.99797074	0.405987928	31842	0.667	17.45881618
33.99923614	0.439377134	62915	0.662	34.49599333
37.00115194	0.471897288	88411	0.655	48.47532809
40.0093178	0.503640203	167971	0.613	92.09769524

Appendix B.2: Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in Each SNP Dispersion

Table 24 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 5 wt%.

SNP, 5 wt%				
S-32 Particle Concentration in Suspension (wt%)	S-32 Particle Concentration in Suspension (Volume fraction)	consistency index (K), $mPa.s^n$	flow behavior index (n)	relative viscosity (K_r)
0	0	3.346	1	1
5.00028913	0.02302642	4.746	1	1.418487642

10.00068385	0.047399324	5.299	1	1.583785322
15.00060535	0.073237291	5.784	1	1.728711561
20.00056974	0.100679434	6.094	1	1.821379274
25.00053413	0.129879676	6.406	1	1.914870657
30.00042006	0.161012053	7.077	1	2.115225845
35.00046733	0.194276548	7.420	1	2.217867122
40.00043138	0.229898149	7.840	1	2.343458829
45.00021245	0.268135805	13.237	1	3.95660737
50.00019314	0.309291955	13.926	1	4.16263073
55.00005337	0.353711032	19.317	1	5.773760009
60.00004744	0.401799633	27.412	1	8.193441177
62.00000299	0.422165285	34.319	1	10.25791358
63.99982737	0.443225247	43.851	1	13.10719371
65.99976782	0.465018382	100.780	0.925	30.12329164
67.99968407	0.487582042	109.640	0.974	32.77155879
70.99978875	0.522967436	279.810	0.963	83.63562446
72.99966993	0.547646603	550.890	0.988	164.661839
74.99969438	0.573258087	1042.700	0.903	311.6645782

Table 25 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 10 wt%.

SNP, 10 wt%				
S-32 Particle Concentration in Suspension (wt%)	S-32 Particle Concentration in Suspension (Volume fraction)	consistency index (K), $mPa.s^n$	flow behavior index (n)	relative viscosity (K_r)
0	0	6.48	1	1
5.000083125	0.022270578	6.91	1	1.067318626
10.00005492	0.045719376	7.11	1	1.097940426
15.00003674	0.070443053	8.23	1	1.270318856
20.00000995	0.096548382	8.64	1	1.33346295
25.0000409	0.124154889	8.94	1	1.379672597
28.00001458	0.141493743	9.97	1	1.538634748
30.99999045	0.159452086	11.40	1	1.759008727
34.00000932	0.178063978	12.46	1	1.922779507
37.00003637	0.19736553	13.28	1	2.049861969
40.00015158	0.217396341	14.43	1	2.227858455
42.0004192	0.23117702	18.43	1	2.844624621
44.00051394	0.245312287	18.99	1	2.931392776

46.00052066	0.25981663	21.03	1	3.246340698
48.00075641	0.274707088	23.59	1	3.642137378
50.00072732	0.289995458	27.47	1	4.241045888
52.00062202	0.305699409	32.99	1	5.092615363
54.00051385	0.321836719	41.77	1	6.448224819
56.00147758	0.338434616	49.43	1	7.629695031
58.001921	0.355499323	72.35	1	11.1682208
60.00205119	0.373052655	168.97	0.901	26.08259844
63.00173677	0.400346462	284.00	0.895	43.83889422
66.00001669	0.428858376	308.01	0.87	47.54513313
68.99999045	0.458703339	608.62	0.862	93.94798521
71.99998545	0.489959224	1042.20	0.898	160.8763928
74.99998701	0.52272834	3411.40	0.843	526.5915625
77.0003212	0.545474069	26915.00	0.387	4154.661401

Table 26 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 15 wt%.

SNP, 15 wt%				
S-32 Particle Concentration in Suspension (wt%)	**S-32 Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	18.097	1	1
4.999975123	0.021372924	18.736	1	1.035313993
10.00010067	0.043846988	19.627	1	1.084563818
15.00196653	0.06751726	20.633	1	1.140114565
20.00193357	0.092463203	23.428	1	1.294580879
25.00191242	0.118801135	25.209	1	1.392960193
30.00203727	0.146651681	29.057	1	1.605645104
35.00173429	0.176145514	33.716	1	1.863042663
40.00160089	0.207436348	43.688	1	2.414085126
45.00142024	0.240692086	53.019	1	2.929684342
50.00129112	0.276104529	104.630	0.937	5.781593402
55.00118254	0.313890268	164.710	0.936	9.101464678
58.00115156	0.337802377	237.880	0.921	13.14465678
61.00103461	0.362715522	256.630	0.941	14.18073511
64.00095503	0.388694997	295.840	0.915	16.34738213
67.00087544	0.415810416	314.100	0.926	17.35638428

69.00082584	0.43455581	408.250	0.919	22.55887897
71.00077256	0.453864	2891.000	0.869	159.749465
73.00067479	0.473760305	6036.000	0.795	333.5343379
75.00072933	0.49427406	11809.000	0.772	652.5359504
77.0006297	0.515431168	28404.000	0.674	1569.53435

Table 27 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 20 wt%.

SNP, 20 wt%				
S-32 Particle Concentration in Suspension (wt%)	**S-32 Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	47.026	1	1
5.0001327	0.026806393	51.445	1	1.093973178
10.00012572	0.054953736	57.207	1	1.216511524
15.00024701	0.084546856	61.274	1	1.302993157
20.00004148	0.115697172	68.060	1	1.447295682
24.99988228	0.148533431	73.430	1	1.561490799
29.99964443	0.183195422	86.377	1	1.836805649
34.99976009	0.219843027	89.976	1	1.913335625
39.99975518	0.258648107	102.439	1	2.178368482
44.99963477	0.299807002	146.353	1	3.112191791
49.99966797	0.343543003	151.149	1	3.214185851
54.9995734	0.390103269	349.060	0.943	7.422764828
57.99961708	0.419512744	407.690	0.959	8.669532438
60.99965944	0.450108156	454.280	0.979	9.660269312
63.9998397	0.481964222	3349.700	0.843	71.2314082
65.99991486	0.503939621	5861.400	0.768	124.642737
67.99989161	0.526533852	13496.000	0.629	286.9925919
69.99997589	0.549775855	29834.000	0.629	634.4203457

Table 28 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 25 wt%.

SNP, 25 wt%				
S-32 Particle Concentration in Suspension (wt%)	S-32 Particle Concentration in Suspension (Volume fraction)	consistency index (K), $mPa.s^n$	flow behavior index (n)	relative viscosity (K_r)
0	0	139.7842277	1	1
5.000158333	0.027454395	145.605055	1	1.041641517
9.999990564	0.056241751	152.0110325	1	1.087469131
15.00019137	0.086465861	164.3507475	1	1.175746007
19.99985229	0.118231119	176.400406	1	1.261947853
25.00006726	0.151665994	203.2451221	1	1.453991809
29.99989764	0.186898878	205.5848779	1	1.470730148
34.99998759	0.224083738	366.59	0.952	2.622541943
40.00040573	0.263387965	415.5	0.969	2.972438357
45.00026747	0.304990491	534.47	0.995	3.823535809
50.00024315	0.349105065	880.52	0.918	6.299136996
55.00035162	0.395966479	1115.2	0.925	7.978010242
58.00032818	0.425509038	2339.6	0.915	16.7372245
61.00054909	0.456200119	4992.3	0.799	35.71432974
64.00050686	0.488102522	9603.5	0.727	68.70231471
66.00014045	0.510077494	19414	0.638	138.8854832
68.00001964	0.532650388	65639	0.646	469.5737216

Table 29 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 30 wt%.

SNP, 30 wt%				
S-32 Particle Concentration in Suspension (wt%)	S-32 Particle Concentration in Suspension (Volume fraction)	consistency index (K), $mPa.s^n$	flow behavior index (n)	relative viscosity (K_r)
0	0	370.076	1	1
4.999611362	0.028098251	411.708	1	1.112497052
9.99964968	0.057524981	435.187	1	1.175939528
14.99915883	0.088370647	426.396	1	1.152183757
19.99930539	0.120748153	467.761	1	1.263958838
24.99985321	0.154772867	609.360	0.946	1.646580559

30.00007262	0.190568412	684.260	0.943	1.848971402
34.99995815	0.228276686	1007.100	0.864	2.721332679
39.99950189	0.268055141	1159.500	0.939	3.133139947
45.00025465	0.310092472	1690.200	0.886	4.56716959
50.0002315	0.354568539	2660.500	0.902	7.189063243
55.00153378	0.401722305	5450.500	0.913	14.72805458
57.99901949	0.431362712	10340.000	0.763	27.94020445
60.99944207	0.462138153	44466.000	0.797	120.1536877

Table 30 Power Law Variable Values and Actual Concentrations of S-32 Solid Particles in SNP Dispersion with SNP Concentration of 35 wt%.

SNP, 35 wt%				
S-32 Particle Concentration in Suspension (wt%)	**S-32 Particle Concentration in Suspension (Volume fraction)**	**consistency index (K), $mPa.s^n$**	**flow behavior index (n)**	**relative viscosity (K_r)**
0	0	1620.517	1	1
5.000021591	0.028746732	1530.778	1	0.944623336
10.00029355	0.058810687	1573.312	1	0.970870099
15.00032569	0.090281367	1840.854	1	1.135966739
20.00030654	0.123261144	1902.322	1	1.173897852
24.99976187	0.157857869	2335.600	0.95	1.441268171
29.99966536	0.1942007	2460.300	0.884	1.518218908
34.99945086	0.232420809	3577.900	0.885	2.207875231
39.99961817	0.272671637	5922.400	0.87	3.654635476
44.99984863	0.315116668	30017.000	0.522	18.52309758

Appendix C: Samples of Suspensions of Solid Particles in SNP dispersions

In this section, images of samples of suspensions containing solid particles in SNP dispersions at each concentration of SNP are provided.

Appendix C.1: Samples of Suspensions of SG Solid Particles in SNP dispersions

Figure 40 Samples of suspensions of SG hollow spheres in SNP dispersion, with SNP concentration of approximately 10 wt%

Figure 41 Samples of suspensions of SG hollow spheres in SNP dispersion, with SNP concentration of approximately 15 wt%

Figure 42 Samples of suspensions of SG hollow spheres in SNP dispersion, with SNP concentration of approximately 20 wt%

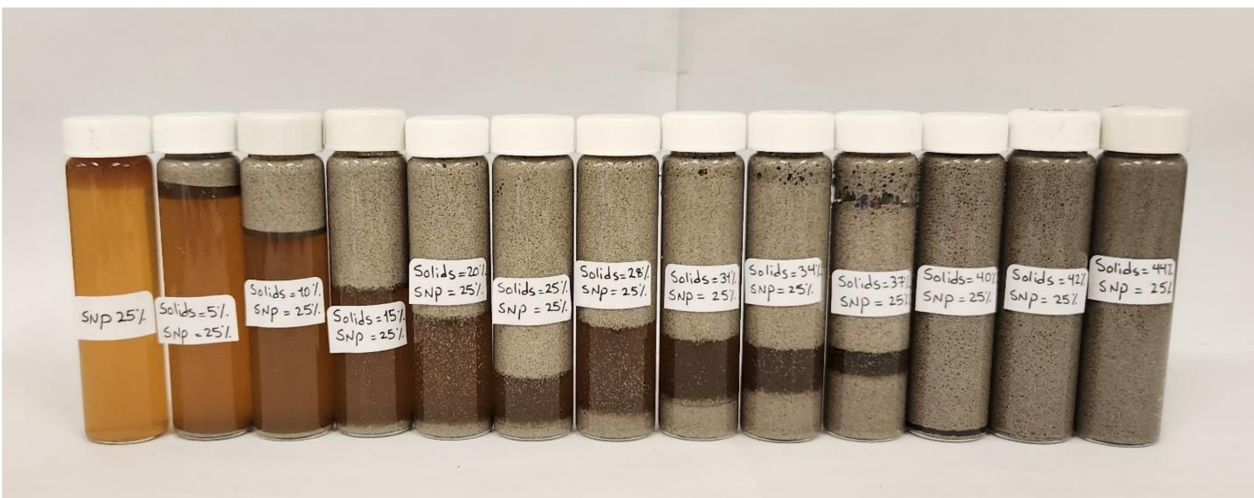

Figure 43 Samples of suspensions of SG hollow spheres in SNP dispersion, with SNP concentration of approximately 25 wt%

Figure 44 Samples of suspensions of SG hollow spheres in SNP dispersion, with SNP concentration of approximately 30 wt%

Figure 45 Samples of suspensions of SG hollow spheres in SNP dispersion, with SNP concentration of approximately 35 wt%

Appendix C.2: Samples of Suspensions of S-32 Solid Particles in SNP dispersions

Figure 46 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 5 wt%

Figure 47 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 10 wt%

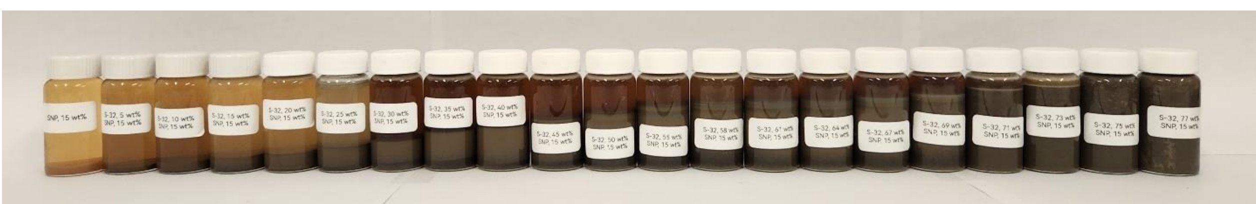

Figure 48 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 15 wt%

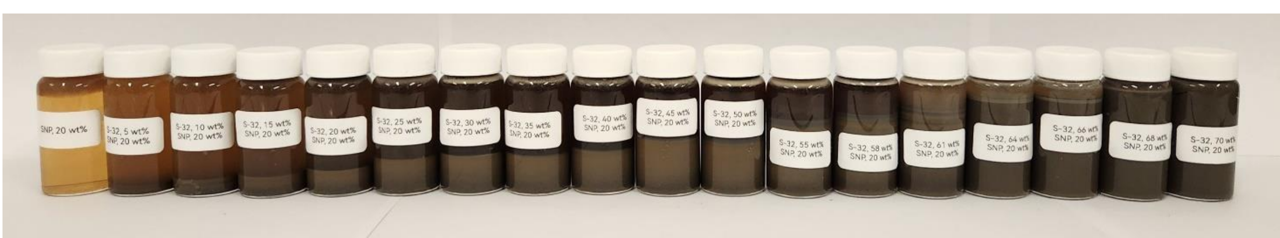

Figure 49 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 20 wt%

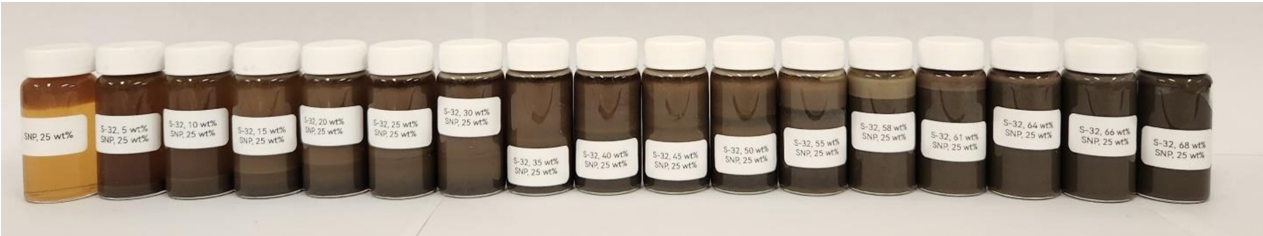

Figure 50 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 25 wt%

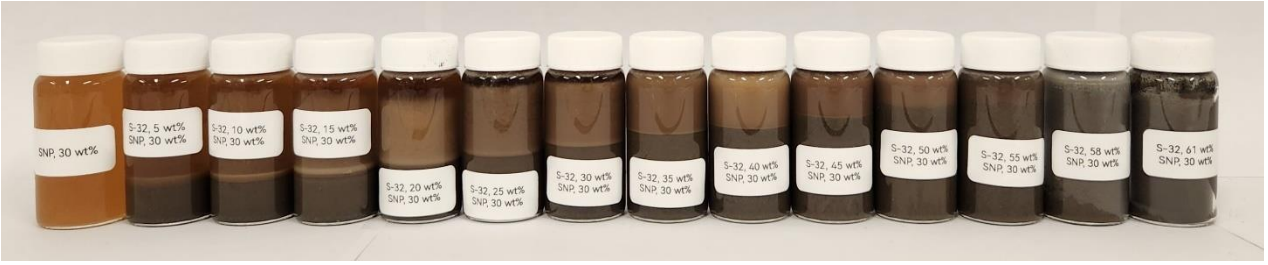

Figure 51 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 30 wt%

Figure 52 Samples of suspensions of S-32 solo spheres in SNP dispersion, with SNP concentration of 35 wt%

Appendix D: Physical and Chemical Properties of Materials Used in This Research

Appendix D.1: Microbicide

Label# 018-1 V001 08/14/2013

ENVIRONMENTAL HAZARDS

This pesticide is toxic to fish and wildlife. Do not discharge effluent containing this product into lakes, streams, ponds, estuaries, oceans or other waters unless in accordance with the requirements of a National Pollutant Discharge Elimination System (NPDES) permit and the permitting authority has been notified in writing prior to discharge. Do not discharge effluent containing this product to sewer systems without previously notifying the treatment plant authority. For guidance contact your State Water Board or Regional Office of the EPA.

STORAGE AND DISPOSAL

PROHIBITIONS: This product (pH 3.5) is corrosive to mild steel. Do not store in unlined containers. Do not contaminate food or feed by storage, disposal or cleaning of equipment.

PESTICIDE DISPOSAL: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

CONTAINER DISPOSAL: Non-refillable container. Do not reuse or refill this container. Triple rinse container promptly after emptying. Triple rinse as follows: [For containers < 5 gallons in size] – Empty the remaining contents into application equipment or a mix tank and drain for 10 seconds after the flow begins to drip. Fill the container ¼ full with water and recap. Shake for 10 seconds. Pour rinsate into application equipment or a mix tank or store rinsate for later use or disposal. Drain for 10 seconds after the flow begins to drip. Repeat this procedure two more times. [For containers > 5 gallons in size] - Empty the remaining contents into application equipment or a mix tank. Fill the container ¼ full with water. Replace and tighten closures. Tip container on its side and roll it back and forth, ensuring at least one complete revolution, for 30 seconds. Stand the container on its end and tip it back and forth several times. Turn the container over onto its other end and tip it back and forth several times. Empty the rinsate into application equipment or a mix tank or store rinsate for later use or disposal. Repeat this procedure two more times. Then offer for recycling if available or puncture and dispose of in a sanitary landfill, or by other procedures approved by state and local authorities. ***GENERAL: CONSULT FEDERAL, STATE OR LOCAL DISPOSAL AUTHORITIES FOR APPROVED ALTERNATIVE PROCEDURES.***

CONDITIONS OF SALE AND WARRANTY

Thor GmbH warrants that the product conforms to its chemical description and is reasonably fit for the purpose stated on the label only when used in accordance with label directions under normal conditions of use. THOR GMBH MAKES NO OTHER EXPRESS OR IMPLIED WARRANTIES EITHER OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR USE. Handling, storage and use of the product by Buyer or User are beyond the control of Thor GmbH and Seller. Risks such as ineffectiveness or other unintended consequences resulting from, but not limited to, failure to follow label directions will be assumed by the Buyer or User. IN NO CASE WILL THOR GMBH OR SELLER BE HELD LIABLE FOR CONSEQUENTIAL, SPECIAL OR INDIRECT DAMAGES RESULTING FROM THE HANDLING, STORAGE OR USE OF THIS PRODUCT.

ACTICIDE® GA

Active Ingredients:

2-Bromo-2-nitropropane-1, 3-diol	5.20%
5-Chloro-2-methyl-4-isothiazolin-3-one	0.85%
2-Methyl-4-isothiazolin-3-one	0.28%
Inert Ingredients:	93.67%
Total:	100.0%

KEEP OUT OF REACH OF CHILDREN

DANGER

See Side panel for additional precautionary statements

FIRST AID

IF SWALLOWED:

- Call a poison control center or doctor immediately for treatment advice.
- Have person sip a glass of water if able to swallow.
- Do not induce vomiting unless told to do so by a poison control center or doctor.
- Do not give anything by mouth to an unconscious person.

IF ON SKIN OR CLOTHING:

- Take off contaminated clothing.
- Rinse skin immediately with plenty of water for 15-20 minutes.
- Call a poison control center or doctor for treatment advice.

IF IN EYES:

- Hold eye open and rinse slowly and gently with water for 15-20 minutes.
- Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye.
- Call a poison control center or doctor for treatment advice.

IF INHALED:

- Move person to fresh air.
- If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably mouth-to- mouth, if possible.
- Call a poison control center or doctor for further treatment advice.

HOT LINE NUMBER: Have the product container or label with you when calling a poison control center or doctor, or going for treatment. You may also contact 1-800-424-9300 for emergency medical treatment information.

NOTE TO PHYSICIAN: Probable mucosal damage may contraindicate the use of gastric lavage. Measures against circulatory shock, respiratory depression and convulsions may be needed.

For Transportation / Spills Emergency call Chemtrec at 1-800-424-9300

THOR

Precautionary Statements:

Hazards to Humans and Domestic Animals

DANGER

CORROSIVE. CAUSES EYE DAMAGE AND SKIN BURNS. MAY CAUSE ALLERGIC SKIN REACTION. MAY BE HARMFUL IF INHALED OR ABSORBED THROUGH THE SKIN. DO NOT GET IN EYES, ON SKIN, ON CLOTHING. WEAR GOGGLES OR FACE SHIELD WHEN HANDLING. HARMFUL IF SWALLOWED. AVOID BREATHING VAPOR OR SPRAY MIST. AVOID CONTAMINATION OF FOOD. WASH THOROUGHLY WITH SOAP AND WATER AFTER HANDLING. REMOVE CONTAMINATED CLOTHING, AND WASH CLOTHING BEFORE REUSE.

DIRECTIONS FOR USE

It is a violation of Federal Law to use this product in a manner inconsistent with its labeling.

Industrial microbiocide for use in adhesives, tackifiers, paints, coatings, building materials, polymer latices, printing inks, *metal working, *metal cleaning fluids, *fuels/oil/storage tank bottom water/crude, dispersions/emulsions/solutions/suspensions, aqueous compositions, *pulp and paper mills, * Industrial Water Systems, and other cleaners including liquid soaps, cleaners, detergents, carpet shampoos for industrial and household uses and in polishes and waxes. READ AND FOLLOW THE DIRECTIONS FOR USE ON THE ACCOMPANYING INFORMATION SHEET.

*** Not approved for use in the State of California**

EPA Reg. No. 67071-18 EPA Est. No 67071-DEU-001

Manufactured By/For: Thor GmbH
U.S. Office: Thor Specialties, Inc.
50 Waterview Drive, Shelton, CT
06484 USA
Tel. (203) 516-6980

UN 3265, CORROSIVE LIQUID, ACIDIC, ORGANIC, N.O.S. [mixture containing 5-Chloro-2-methyl-4-isothiazolin-3-one and 2-Methyl-4-isothiazolin-3-one (3:1)], 8, PG-II

Batch:	Mfg Date:	Net Contents (pounds):

Appendix D.2: Starch Nanoparticle

MSDS

I. CHEMICAL PRODUCT & COMPANY IDENTIFICATION

PRODUCT NAME: ECOSPHERE® 2202 Biolatex® binder

CHEMICAL NAME: Engineered Biopolymer Particles

MANUFACTURER AND MSDS PREPARER:

ECOSYNTHETIX CORP.

3365 Mainway Drive
Burlington, ON L7M 1A6
Canada
Phone: +1 289 245 4000 or +1 289 288 4731
ChemTrec: 703-253-4249
Fax: +1 289 288 4731

MSDS PREPARATION DATE: 8/5/2005 **REVISION DATE:** 06/11/2015

II. COMPOSITION / INFORMATION ON INGREDIENTS

COMPONENT:		CASRN	Weight %
1.	Engineered Biopolymer	Confidential	90-99
2.	Water	7732-18-5	1-10

III. HAZARDS IDENTIFICATION

PRIMARY ROUTES OF EXPOSURE: Inhalation, Eye Contact, Skin Contact.

EMERGENCY OVERVIEW:

Warning! May form combustible dust concentrations in air (during processing)

Avoid inhalation, skin and eye contact. Inhalation may cause irritation of respiratory tract. Prolonged contact with eyes and skin may produce irritation.

OSHA & WHMIS CLASSIFICATION:

This product is considered hazardous as defined under the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard 29 C.F.R. § 1910.1200 (Combustible dust).

IV. FIRST AID MEASURES

Exposure to this product is unlikely to require first aid measures or treatment.

EYE CONTACT: Flush eyes with water. If irritation occurs and persists, get medical attention.

SKIN CONTACT: Wash exposed area with soap and water. If irritation occurs and persists, get medical attention. Wash heavily contaminated clothes before reuse.

INHALATION: If adverse symptoms occur, move to fresh air. If adverse symptoms persist, get medical attention.

INGESTION: Get medical attention if adverse reactions occur and persist.

V. FIRE FIGHTING MEASURES

FLAMMABLE: No data available.

EXTINGUISHING MEDIA: In case of fire, use water spray, foam, dry chemical or carbon dioxide.

FLASH POINT: >200º F (93º C) Method: Pensky-Martens, Closed Cup.

UPPER FLAMMABLE LIMIT: No data available.

LOWER FLAMMABLE LIMIT: No data available.

AUTOIGNITION TERMPERATURE: No data available.

EXPLOSION: Avoid generating dust; fine dust dispersed in air in sufficient concentrations, and in the presence of an ignition source is a potential dust explosion hazard.

FIRE FIGHTING EQUIPMENT: Fire fighters or others who may be exposed to products of combustion should wear full protective clothing including self-contained breathing apparatus. Equipment should be thoroughly decontaminated after use.

HAZARDOUS COMBUSION PRODUCTS: Carbon Monoxide, Carbon Dioxide.

VI. ACCIDENTAL RELEASE MEASURES

Minimize dust generation. Dust deposits should not be allowed to accumulate on surfaces, as these may form an explosive mixture if they are released into the atmosphere in sufficient concentration. Avoid dispersal of dust in the air (i.e., clearing dust surfaces with compressed air). Flush residual spill area with water.

VII. HANDLING & STORAGE

HANDLING: Minimize dust build-up by using good housekeeping techniques (do not use compressed air to remove dust from surfaces). Minimize airborne dust generation and eliminate potential sources of ignition, and include electrical grounding and bonding, or inert atmospheres. Dry powders can build static electricity charges when subject to the friction of transfer and mixing operations.

STORAGE: To maximize shelf life, store between 50º to 90º F. Expected shelf life is twelve months. Do not store outside or in high humidity or damp conditions. Provide adequate precautions for static electrical charges such as electrical grounding and bonding or inert atmospheres. Refer to NFPA 654 "Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, for safe handling methods.

VIII. EXPOSURE CONTROLS/PERSONAL PROTECTION

OCCUPATIONAL EXPOSURE LIMITS: None established for product.

It is recommended that all dust control equipment such as local exhaust ventilation and material transport systems involved in handling of this product contain explosion relief vents or an explosion suppression system or an oxygen deficient environment.

Ensure that dust-handling systems (such as exhaust ducts, dust collectors, vessels, and processing equipment) are designed in a manner to prevent the escape of dust into the work area (i.e., there is no leakage from the equipment).

COMPONENT OCCUPATIONAL EXPOSURE LIMITS:

	OSHA (TWA,STEL)	ACGIH (TWA,STEL)
Engineered Biopolymer	None established	None established
Water	None established	None established

ENGINEERING CONTROLS: Provide natural or mechanical ventilation to minimize exposure and match process conditions. Maintain airborne levels to minimal levels. It is recommended that all dust control equipment such as local exhaust ventilation and material transport systems involved in handling of this product contain explosion relief vents or an explosion suppression system or an oxygen-deficient environment if required to meet standards. Ensure that dust-handling systems (such as exhaust ducts, dust collectors, vessels, and processing equipment) are designed in a manner to prevent the escape of dust into the work area (i.e., there is no leakage from the equipment). Use only appropriately classified electrical equipment and powered industrial trucks.

PERSONAL PROTECTION EQUIPMENT:

EYE PROTECTION: Use of safety glasses or goggles may be appropriate if potential for eye contact exists when handling this product

SKIN PROTECTION: Use of gloves may be appropriate if potential for prolonged skin contact exists when handling this product.

RESPIRATORY PROTECTION: Avoid breathing dust. Avoid creating dust clouds. Use NIOSH approved respiratory protection equipment if airborne exposure approaches permissible exposure limits. Consult respirator manufacturer to determine appropriate type equipment for given application. Observe respirator use limitation specified by NIOSH or the manufacturer. Respirator protection programs must comply with 29 CFR 1910.134.

IX. PHYSICAL & CHEMICAL PROPERTIES

Appearance: off-white to light beige colored powder
Odor: faint mealy odor; contains no Volatile Organic Compounds (VOC's)
Boiling Point: N/A
Vapor Pressure: N/A
Bulk Density in Pounds per Cubic Foot: 25-32
Bulk Density in Kg per Liter: 0.4-0.5
Particle size upon dispersion, nanometers: 50-150
pH: 3-6 (1% solution in water)

NOTE: These physical data are typical values based on material tested but may vary from sample to sample. Typical values should not be construed as a guaranteed analysis of any specific lot or as specifications for the product.

X. STABILITY & REACTIVITY

STABILITY: Product is stable under normal conditions of storage & handling.

CONDITIONS TO AVOID: Minimize dust generation and accumulation

MATERIALS TO AVOID: Strong oxidizing agents

HAZARDOUS DECOMPOSITION PRODUCTS: None known.

HAZARDOUS POLYMERIZATION: Does not occur.

XI. TOXICOLOGICAL INFORMATION

EFFECTS OF ACUTE EXPOSURE: May produce slight irritation to respiratory tract. Prolonged exposure to eyes and skin may cause slight irritation.

EFFECTS OF CHRONIC EXPOSURE: None known.

CARCINOGENICITY: Product and components are not listed as IARC, ACGIH or OSHA carcinogens.

TOXICITY DATA: Product LD_{50} >10.6 g/kg

XII. ECOLOGICAL INFORMATION

No data available.

XIII. DISPOSAL CONSIDERATIONS

Dispose of material in an approved solid waste disposal area according to federal, state and local laws. Emptied container may retain vapor and product residue. Observe all labeled safeguards until container is cleaned, reconditioned or destroyed.

XIV. TRANSPORT INFORMATION

PIN: None: Not considered a dangerous good.
TDG: None: Not considered a dangerous good.
DOT: None: Not regulated as a hazardous material.

XV. REGULATORY INFORMATION

UNITED STATES:

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION: This product is considered hazardous as defined in 29 CFR 1910.1200.

TOXIC SUBSTANCES CONTROL ACT: All components have suitable status under the TSCA Chemical Substance Inventory.

CANADA:

DOMESTIC SUBSTANCE LIST: All components are listed on the DSL.

CONTROLLED PRODUCT REGULATIONS: This product is not classified as a controlled product as defined by the hazard criteria of the *CPR.*

XVI. OTHER INFORMATION

Refer to NFPA 654, Standard for the prevention of Fire and Dust Explosions from the Manufacturing, Processing, and handling of Combustible Particulate Solids, for safe handling

Abbreviations:

ACGIH = American Conference of Governmental Industrial Hygienists
OSHA = Occupational Safety & Health Administration
TLV = Threshold Limit Value
PEL = Permissible Exposure Limit
TWA = Time Weighted Average
STEL = Short-Term Exposure Limit

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Appendix D.3: SG Hollow Sphere

SPHERE ONE

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	**Extendospheres (all grades)**
Synonyms:	Hollow ceramic spheres, ceramic microspheres, cenospheres

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Recommend Uses:	Low density, heat/fire resistant filler
Uses Advised Against:	None known

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Sphere One, Inc.
Street Address:	601 Cumberland, Ste. C
City, State and Zip Code:	Chattanooga, TN 37404
Telephone Number:	423.629.7160

1.4 Emergency Telephone Number

Emergency Phone Number:	1-800-424-9300 (ChemTrec)
Hours Available:	24 hr 7 days/week

Section 2
Hazards Identification

2.1 Classification of the Substance

- **GHS Classification according to Directive 67/548/EEC (DSD) and Regulation (EC) No1272/2008 (CLP)- Does not meet the criteria for hazardous classification.**

- **GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):**
  - STOT-SE Category 3
  - STOT-RE Category 2

Note: The level of respirable crystalline silica (RCS) present in this product has not been determined; however, a conservative classification for STOT-RE, Category 2 has been assigned.

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	 
Signal word:	Danger
Hazard Statement(s):	• May cause respiratory irritation. • May cause damage to lungs after repeated/prolonged exposure via inhalation.
Precautionary Statement(s):	• Do not breath dust. • Use outdoors or in a well ventilated area. • If inhaled: Remove to fresh air and keep comfortable for breathing. • Get medical advice/attention if you feel unwell. • Store in secure area. • Dispose of product in accourance with local/national regulations.

** Extendospheres and other coal combustion products (CCPs) are UVCB substances (substance of unknown or variable composition or biological material). The following elements may be present as oxides: Aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium. The exact composition of Extendospheres is dependent on the fuel source and flue additives composed of a large number of constituents. The classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.*

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [No] **Other:** [No]

Section 3
Composition/Information on Ingredients

Substance	*CAS No.*	*Percentage (%)*	*GHS Classification*
Fly ash; Cenospheres	*68131-74-8*	*100%*	*Single Exposure STOT, Category 3*
Crystalline Silica	*14808-60-7*	*< 1.5%*	*Repeat Dose STOT, Category 2*

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.
Chronic effects: Chronic exposure may cause lung damage from repeated exposure. Chronic inhalation of dusts containing respirable crystalline silica may result in silicosis.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising From the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.3 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for safe storage, including any incompatibilities

Minimize dust produced during loading and unloading.

Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS

SUBSTANCE		OSHA PEL TWA (mg/m³)	NIOSH REL TWA (mg/m³)	ACGIH TLV TWA (mg/m³)	CA - OSHA PEL (mg/m³)
Particulates Not Otherwise Regulated	Total	15	15	-	10
	Respirable	5	5	-	5
Crystalline Silica	Total Quartz	30 ÷ (%SiO_2+2) (Total Quartz)	-	-	0.3
	Respirable Crystalline Silica	10 ÷ (%SiO_2+2)	0.05	0.025 (α-quartz & cristobalite)	0.1
	Cristobalite	-	0.05	0.025 (α-quartz & cristobalite)	0.05 (respirable)

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C): Not applicable	**Specific gravity or relative density:** 0.60-0.95 [Ref Std water=1.0]
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point and boiling range (°C): Not applicable	**Partition coefficient: n-octane/water:** Not applicable
Flash point (°C): Not applicable	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

Section 10
Stability and Reactivity

10.1 Reactivity:	The material is non-reactive.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is inert; polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Not irritating to skin
Eye damage/irritation	Slight, but reversible eye irritation
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer
Germ cell mutagenicity	Not mutagenic in in vitro and in vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by NTP and IARC.
Reproductive toxicity	An animal study with coal combustion product (CCP) has indicated some effects on male and female reproductive organs and parameters without a clear dose response while studies

Endpoint	Data
	with other CCPs have not shown reproductive effects. Therefore, there is not enough evidence available to classify according to reproductive toxicity. No developmental toxicity has been observed in available animal studies.
Specific Target Organ Toxicity-Single Exposure STOT-SE	No specific target organ toxicity after a single exposure to the substance is expected; however, presence as a nuisance dust may result in respiratory irritation.
Specific Target Organ Toxicity-Repeated Exposure STOT-RE	NOAEC=4.2 mg/m^3 dust; as no effects were observed at the highest dose tested during the 180 day inhalation study, it is not possible to assess the level at which toxicologically significant effects may occur.
Aspiration hazard	Not applicable based on product form.

Section 12
Ecological Information

12.1 Toxicity

No data available on final product.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulative Potential

No data available.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

No data available.

12.6 Other Adverse Effects

None known.

Section 13
Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate hygienic practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated
Regulatory entity: International	IMDG - International Maritime Dangerous Goods	Not Regulated
	IATA DGR - IATA Dangerous Goods Regulations (DGR)	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65

  The following substance is known to the State of California to be a carcinogen and/or reproductive toxicant:

  - Respirable crystalline silica

Chemical Inventory Lists	Included Y/N
AICS-Australia Inventory of Chemical Substances	Yes
DSL-Canada Domestic Substances List	Yes
NDSL-Canada Non-Domestic Substances List	No
IECSC-China-Inventory of Existing Chemical Substances Produced or Imported in China	Yes
KECI-Korea-Existing Chemicals List	Yes
PICCA-Philippine Inventory of Chemicals and Chemical Substances	Yes
NZIoC-New Zealand Inventory	Yes
TCSI-Taiwan Chemical Substance Inventory	Yes
TSCA-Toxic Substances Control Act Inventory	Yes

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Silica-crystalline (SiO_2), quartz	14808-60-7	Yes	Yes	Yes	No

[1] Massachusetts Department of Public Health, no date
[2] 189th General Court of The Commonwealth of Massachusetts, no date
[3] New Jersey Department of Health and Senior Services, 2010a
[4] New Jersey Department of Health, 2010b
[5] Pennsylvania Code, 1986
[6] Rhode Island Department of Labor and Training, no date

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: September 23, 2022

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- ANSI: American National Standards Institute
- CA: California
- CAA: Clean Air Act
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFB: Circulating Fluidized Bed
- CFR: Code of Federal Regulations
- CWA: Clean Water Act
- EPA: Environmental Protection Agency
- GHS: Globally Harmonized System of Classification and Labelling
- HMIS: Hazardous Materials Identification System
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- LEL: Lower explosive limit
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides

- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- Pa: Paschal
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SARA: Superfund Amendments and Reauthorization Act
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit

- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological Material
- U.S.: United States
- U.S. DOT: United States of Department of Transportation
- vPvB: Very Persistent and Very Bioaccumulative

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	1*	**Flammability:**	**0**	**Reactivity:**	**0**	**Personal protection:**	

** Chronic Health Effects*

DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

Appendix D.4: S-32 Solosphere

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	**Solospheres (all grades)**
Synonyms:	Fly Ash/Ceramic microspheres
Product Code:	
Formula:	UVCB Substance

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Recommend Uses:	Filler
Uses Advised Against:	None known

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Sphere One Inc.
Street Address:	601 Cumberland, Ste C
City, State and Zip Code:	Chattanooga, TN 37404
Customer Service Telephone:	423.629.7160

1.4 Emergency Telephone Number

Emergency Phone Number:	1-800-424-9300 (ChemTrec)
Hours Available:	24 hr. 7 days/week

Section 2
Hazards Identification

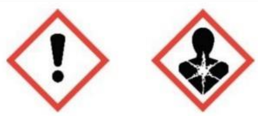
2.1 Classification of the Substance

- **GHS Classification according to Directive 67/548/EEC (DSD) and Regulation (EC) No1272/2008 (CLP)- Does not meet the criteria for hazardous classification.**

- **GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):**
  - STOT-SE Category 3
  - STOT-RE Category 2

Note: The level of respirable crystalline silica (RCS) present in this product has not been determined; however, a conservative classification for STOT-RE, Category 2 has been assigned.

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	
Signal word:	Danger
Hazard Statement(s):	• May cause respiratory irritation. • May cause damage to lungs after repeated/prolonged exposure via inhalation.
Precautionary Statement(s):	• Do not breath dust. • Use outdoors or in a well ventilated area. • If inhaled: Remove to fresh air and keep comfortable for breathing. • Get medical advice/attention if you feel unwell. • Store in secure area. • Dispose of product in accordance with local/national regulations.

** Solospheres and other coal combustion products (CCPs) are UVCB substances (substance of unknown or variable composition or biological material). The following elements may be present as oxides: aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium." The exact composition of Solospheres is dependent on the fuel source and flue additives composed of a large number of constituents. The classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.*

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [No] **Other:** [No]

Section 3
Composition/Information on Ingredients

Substance	*CAS No.*	*Percentage (%)*	*GHS Classification*
Fly ash	*68131-74-8*	*100%*	*Single Exposure STOT, Category 3*
Crystalline Silica	*14808-60-7*	*< 1.5%*	*Repeat Dose STOT, Category 2*

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.
Chronic effects: Chronic exposure may cause lung damage from repeated exposure. Chronic inhalation of dusts containing respirable crystalline silica may result in silicosis.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising From the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.3 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for safe storage, including any incompatibilities

Minimize dust produced during loading and unloading.

Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS					
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Particulates Not Otherwise Regulated	Total	15	15	-	10
	Respirable	5	5	-	5
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Crystalline Silica	Total Quartz	30 ÷ (%SiO_2+2) (Total Quartz)	-	-	0.3
	Respirable Crystalline Silica	10 ÷ (%SiO_2+2)	0.05	0.025 (α-quartz & cristobalite)	0.1
	Cristobalite	-	0.05	0.025 (α-quartz & cristobalite)	0.05 (respirable)

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C): Not applicable	**Specific gravity or relative density:** 2.10 – 2.40 [Ref Std water=1.0]
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point and boiling range (°C): Not applicable	**Partition coefficient: n-octane/water:** Not applicable
Flash point (°C): Not applicable	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

9.2 Other Information

Section 10
Stability and Reactivity

10.1 Reactivity:	The material is non-reactive.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is inert; polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Not irritating to skin
Eye damage/irritation	Slight, but reversible eye irritation
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer
Germ cell mutagenicity	Not mutagenic in in vitro and in vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by NTP and IARC.
Reproductive toxicity	An animal study with coal combustion product (CCP) has indicated some effects on male and female reproductive organs

Endpoint	Data
	and parameters without a clear dose response while studies with other CCPs have not shown reproductive effects. Therefore, there is not enough evidence available to classify according to reproductive toxicity. No developmental toxicity has been observed in available animal studies.
Specific Target Organ Toxicity-Single Exposure STOT-SE	No specific target organ toxicity after a single exposure to the substance is expected; however, presence as a nuisance dust may result in respiratory irritation.
Specific Target Organ Toxicity-Repeated Exposure STOT-RE	NOAEC=4.2 mg/m^3 fly ash dust; as no effects were observed at the highest dose tested during the 180 day inhalation study, it is not possible to assess the level at which toxicologically significant effects may occur.
Aspiration hazard	Not applicable based on product form.

Section 12
Ecological Information

12.1 Toxicity

No data available on final product.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulate Potential

No data available.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

No data available.

12.6 Other Adverse Effects

None known.

Section 13
Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate hygienic practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65

  The following substance is known to the State of California to be a carcinogen and/or reproductive toxicant:

  - Respirable crystalline silica

Chemical Inventory Lists	Included Y/N
AICS-Australia Inventory of Chemical Substances	Yes
DSL-Canada Domestic Substances List	Yes
NDSL-Canada Non-Domestic Substances List	No
IECSC-China-Inventory of Existing Chemical Substances Produced or Imported in China	Yes
KECI-Korea-Existing Chemicals List	Yes
PICCA-Philippine Inventory of Chemicals and Chemical Substances	Yes
NZIoC-New Zealand Inventory	Yes
TCSI-Taiwan Chemical Substance Inventory	Yes
TSCA-Toxic Substances Control Act Inventory	Yes

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Silica-crystalline (SiO2), quartz	14808-60-7	Yes	Yes	Yes	No

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: March 7, 2023

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- ANSI: American National Standards Institute
- CA: California
- CAA: Clean Air Act
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFB: Circulating Fluidized Bed
- CFR: Code of Federal Regulations
- CWA: Clean Water Act
- EPA: Environmental Protection Agency
- GHS: Globally Harmonized System of Classification and Labelling
- HMIS: Hazardous Materials Identification System
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- LEL: Lower explosive limit
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides
- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- Pa: Paschal
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SARA: Superfund Amendments and Reauthorization Act
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit

- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological Material
- U.S.: United States
- U.S. DOT: United States of Department of Transportation
- vPvB: Very Persistent and Very Bioaccumulative

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	1*	**Flammability:**	**0**	**Reactivity:**	**0**	**Personal protection:**	

** Chronic Health Effects*

DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

Appendix E: Apparatus Specification

Appendix E.1 Fann Viscometer Model 35

Model 35 Viscometer

Instruction Manual

Manual No. 208878, Revision P

Instruction No. 207198 (35A)
207199 (35SA)
207200 (35A/SR-12)
207201 (35SA/SR-12)

fann
Fann Instrument Company

1 Introduction

Fann Model 35 viscometers are direct-reading instruments which are available in six- speed and twelve- speed designs for use on either 50 Hz or 60 Hz electrical power. The standard power source is 115 volts, but all models may be fitted with a transformer, making operation with 220/230 volts possible.

Fann Model 35 viscometers are used in research and production. These viscometers are recommended for evaluating the rheological properties of fluids, Newtonian and non-Newtonian. The design includes a R1 Rotor Sleeve, B1 Bob, F1 Torsion Spring, and a stainless steel sample cup for testing according to American Petroleum Institute Recommended Practice for Field Testing Water Based Drilling Fluids, API RP 13B-1/ISO 10414-1 Specification.

1.1 Background

Fann Model 35 viscometers are Couette rotational viscometers. In this viscometer, the test fluid is contained in the annular space (shear gap) between an outer cylinder and the bob (inner cylinder). Viscosity measurements are made when the outer cylinder, rotating at a known velocity, causes a viscous drag exerted by the fluid. This drag creates a torque on the bob, which is transmitted to a precision spring where its deflection is measured.

Viscosity measured by a Couette viscometer, such as the Model 35, is a measure of the shear stress caused by a given shear rate. This relationship is a linear function for Newtonian fluids (i.e., a plot of shear stress vs. shear rate is a straight line).

The instrument is designed so that the viscosity in centipoise (or millipascal second) of a Newtonian fluid is indicated on the dial with the standard rotor R1, bob B1, and torsion spring F1 operating at 300 rpm. Viscosities at other test speeds may be measured by using multipliers of the dial reading. A simple calculation that closely approximates the viscosity of a pseudo-plastic fluid, such as a drilling fluid is described in Section 7.

The shear rate may be changed by changing the rotor speed and rotor-bob combination. Various torsion springs are available and are easily interchanged in order to broaden shear stress ranges and allow viscosity measurements in a variety of fluids.

2.2 Standard B1 Bob

The standard B1 bob (furnished with the Model 35 series viscometers) is a hollow bob that must not be used to test samples hotter than 200°F (93°C).

Solid bobs are available for testing at higher temperatures.

2.3 Heated Sample Cup

When testing heated samples using the heated sample cups wear the proper hand protection to avoid getting burned.

When using heated sample cups, do NOT exceed 200°F (93°C).

3 Features and Specifications

The Fann direct-indicating viscometers are equipped with the standard R1 rotor sleeve, B1 bob, F1 torsion spring, and a stainless steel sample cup. Other rotor-bob combinations and/or torsion springs can be substituted to extend the torque measuring range or increase the sensitivity of the torque measurement.

Each viscometer is supplied with a 115 volt motor. For operation on 230 volts, a step-down transformer is required.

The viscometers are available in six-speed and twelve-speed models.
See Table 3-1, Table 3-2, Table 3-3 and Table 3-4for specifications. Table 3-5 lists the recommended environmental conditions for use.

The photo in Figure 3-1 shows the viscometer and the detailed drawing in Figure 3-2 identifies the individual parts.

Figure 3-1 Model 35SA Viscometer

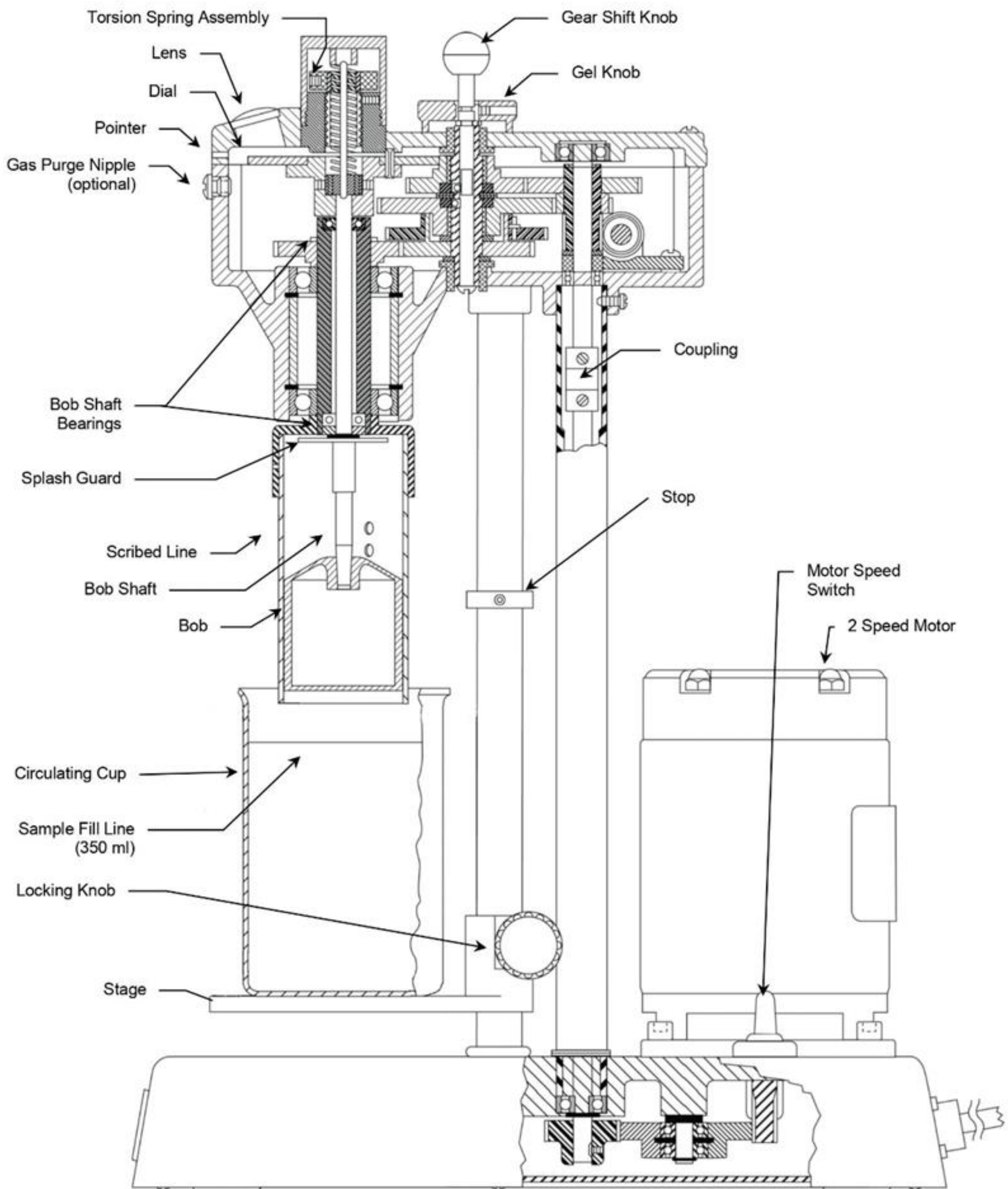


Figure 3-2 Model 35 Viscometer Schematic

Table 3-1 Model 35 Viscometer Specifications

Model No.	Part No.	Electrical	No. of Speeds	Speeds
35A	207198	115V, 60 Hz, 90W	6	600, 300, 200, 100, 6, 3
35SA	207199	115V, 50 Hz, 90W	6	600, 300, 200, 100, 6, 3
35A/SR-12	207200	115V, 60 Hz, 90W	12	600, 300, 200, 180, 100, 90, 60, 30, 6, 3, 1.8, 0.9
35SA/SR-12	207201	115V, 50 Hz, 90W	12	600, 300, 200, 180, 100, 90, 60, 30, 6, 3, 1.8, 0.9

Table 3-2 Model 35 Viscometer Sizes

Model No.	Part No.	Dimensions (LxDxH)	Weight
35A	207198	15.2 x 6 x 10.5 in. 39 x 15 x 27 cm	15 lb 6.8 kg
35SA	207199	15.2 x 6 x 10.5 in. 39 x 15 x 27 cm	15 lb 6.8 kg
35A/SR-12	207200	15.2 x 6 x 10.5 in. 39 x 15 x 27 cm	15 lb 6.8 kg
35SA/SR-12	207201	15.2 x 6 x 10.5 in. 39 x 15 x 27 cm	15 lb 6.8 kg
35A w/ case	101671768	8 x 16 x 19 in. 20.3 x 40.6 x 48.3 cm	26 lb 11.8 kg
35SA w/ case	101671770	8 x 16 x 19 in. 20.3 x 40.6 x 48.3 cm	26 lb 11.8 kg

Table 3-3 Rotor and Bob Dimensions

Unit	Radius (cm)	Length (cm)	Cylinder Area (cm^2) x Radius (cm)
B1	1.7245	3.8	71.005
B2	1.2276	3.8	35.981
B3	0.86225	3.8	17.751
B4	0.86225	1.9	8.876
R1	1.8415	n/a	n/a
R2	1.7589	n/a	n/a
R3	2.5867	n/a	n/a

Table 3-4 Rotor-Bob Specifications

ROTOR-BOB	R1 B1	R2 B1	R3 B1	R1 B2	R1 B3	R1 B4
Rotor Radius, R_0 (cm)	1.8415	1.7588	2.5866	1.8415	1.8415	1.8415
Bob Radius, R_i (cm)	1.7245	1.7245	1.7245	1.2276	0.8622	0.8622
Bob Height, L (cm)	3.8	3.8	3.8	3.8	3.8	1.9
Shear Gap in Annulus (cm)	0.117	0.0343	0.8261	0.6139	0.9793	0.9793
Radii Ratio, R_i/R_0	0.9365	0.9805	0.667	0.666	0.468	0.468
Maximum Use Temperature (°C)	93	93	93	93	93	93
Minimum Use Temperature (°C)	0	0	0	0	0	0

Table 3-5 Range of Environmental Conditions

Maximum Altitude	6562 ft (2000 m)
Temperature Range	41°F to 104°F (5°C to 40°C)
Maximum Relative Humidity (RH)	80% RH at 87.8°F (31°C) or less 50% RH at 104°F (40°C)

4 Installation

The Model 35 should be placed in a position where there is easy access to the power cord plug for disconnection.

Consideration should be given to the location where samples are prepared and equipment is cleaned when the test is completed. There should be sufficient storage area nearby for commonly used tools, as well as consumables.

⚠ The viscometer base cover has vents to help prevent heat build-up. Do not block the vents.

5 Operation

This section describes the operating instructions for the Model 35 series viscometers. It also includes instructions for measuring gel strength and changing rotors, bobs, and torsion springs.

To start the test, add 350 ml of pre-stirred sample to the stainless steel sample cup. The sample cup has a line that marks 350 ml as shown in Figure 3-2.

A scribed line on the rotor indicates proper immersion depth. Refer to Figure 3-2. Damage to the bob shaft bearings may occur if this immersion depth is exceeded. If other sample holders are used, the space between the bottom of the rotor and the bottom of the sample holder should be one-half inch (1.27cm) or greater.

The standard B1 Bob is hollow and should never be used to test samples hotter than 200°F (93°C).

The viscometer base cover has vents to help prevent heat build-up. Do not block the vents.

During operation, the motor surface may get hot and there is risk of getting burned if the surface is touched.

5.1 Operating the Model 35A and 35SA

The Model 35A and 35SA viscometers operate at six speeds, ranging from 3 rpm to 600 rpm. To select the desired speed, set the speed switch (located on the right side of the base) to the high or low speed position as desired. Then turn the motor on and move the gear shift knob (located on the top of the instrument) to the position that corresponds to the desired speed.

Table 5-1 lists the positions for the viscometer switch and the gear knob combinations to obtain the desired speed. The viscometer gear shift knob may be engaged while the motor is running. Read the dial for shear stress values.

Table 5-1 Six-Speed Testing Combinations for Models 35A and 35SA

Speed RPM	Viscometer Switch	Gear Shift Knob
600	High	Down
300	Low	Down
200	High	Up
100	Low	Up
6	High	Center
3	Low	Center

5.2 Operating the Model 35A/SR-12 and 35SA/SR-12

The Model 35A/SR-12 and 35SA/SR-12 have twelve speeds for testing capabilities. To achieve this broader testing range from 0.9 rpm to 600 rpm, an additional gear box shift lever is used; it is located on the right side of the gear box. See Figure 5-1. Move this lever to the left or right as determined from Table 5-2.

Never change the gear box shift lever while the motor is running. Changing it while the motor is running will result in gear damage.

Only the viscometer gear shift knob (on top of the instrument) can be changed while the motor is running.

5.4 Changing the Rotors, Bobs, and Torsion Springs

The R1-B1-F1 rotor-bob-torsion spring combination is standard for all Fann viscometers. Other rotor-bob combinations may be used, provided shear rates are calculated for the fluid being tested. Rotor-bob combinations other than R1-B1 have large gap sizes; as a result, the shear stress dial readings are not consistent with readings from a smaller gap.

The following instructions explain how to remove and replace the rotors, bobs, and torsion springs.

Calibration is required when torsion springs are changed.

Changing the rotors and bobs only reconfigures the geometry of the shear gap. These changes do not affect the torsion springs, bearings, or shaft. Therefore, calibration is not required when changing rotors or bobs.

6 Instrument Calibration Check

A calibration check only verifies the instrument's correct mechanical operation — its torsion springs, bearings, and shaft.

Changing the rotors and bobs only reconfigures the geometry of the shear gap. These changes do not affect the torsion springs, bearings, or shaft. Therefore, calibration is not required when changing rotors or bobs.

Periodically, the Model 35 viscometer should be checked for proper calibration. If the measurements do not meet the specified accuracy, then the viscometer should be calibrated or repaired. For continuous accurate measurements, the instrument must be properly calibrated.

In accordance with API 13B-1 and 13B-2, Fann recommends calibrating the Model 35 before it is placed in service and at least monthly while it is in service. However, calibration frequency depends on your usage and laboratory quality assurance program.

The calibration is checked by applying known torques to the bob shaft. For any applied torque, within the torque range of the spring, there should be a specific dial reading (plus or minus a small tolerance). There are two methods of calibration check — 1) dead weight calibration check, and 2) standard fluid calibration check.

If the spring requires adjustment, the proper setting can be easily verified.

The standard fluid calibration check verifies that the complete instrument is operating properly. This calibration method will identify a bent bob shaft, rotor eccentricity, and/or runout of the rotor or bob more effectively than the dead weight method.

6.1 Dead Weight Calibration

This procedure uses the Model DW3 Calibration Kit (P/N 207853). Refer to Figure 6-1.

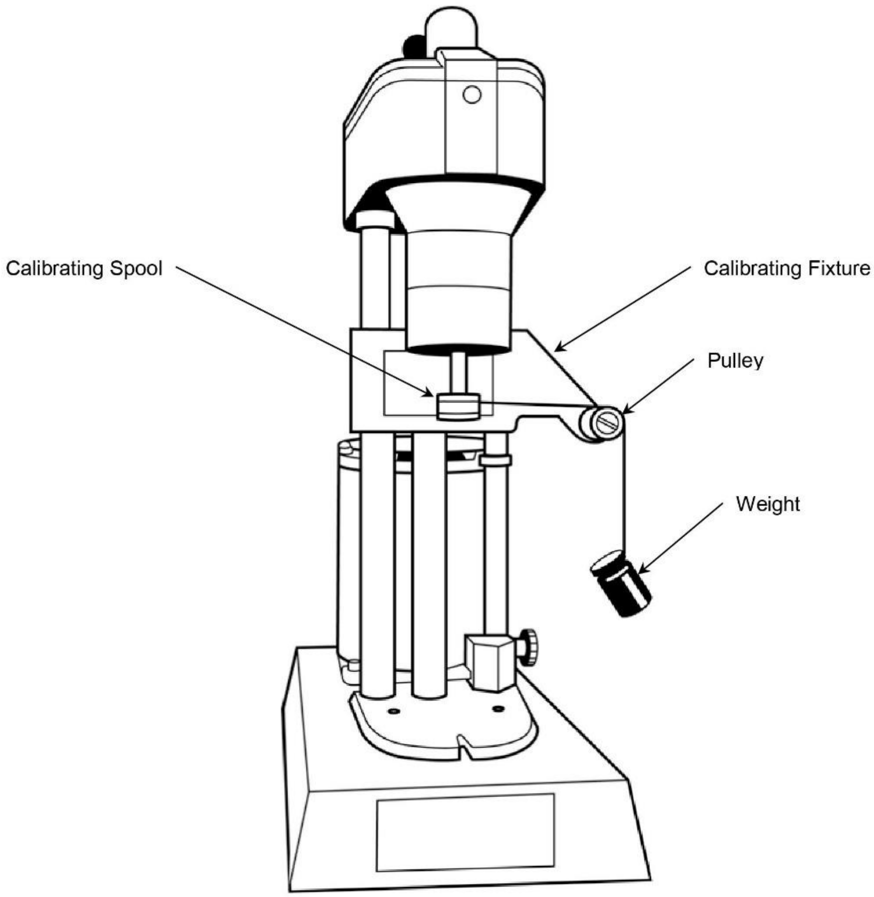


Figure 6-1 DW3 Calibration Fixture

1. Remove rotor and bob. Refer to Section 6. Be sure that the tapered end of the bob shaft is clean, and then install the calibrating spool.
2. Install the DW3 calibrating fixture by clamping it onto the upper portion of the viscometer support legs.
3. Select a weight according to Table 6-1. Insert the bead at the end of the thread into the recess in the top of the calibrating spool. Wrap the thread a little more than once around the spool and then drape the thread over the pulley.
4. Hang the selected weight on the thread, and then adjust the calibrating fixture up or down until the thread from the spool to the pulley is horizontal. Compare the dial reading with the reading on Table 6-1.
5. If necessary, adjust the torsion spring as specified in Section 6.3.

From Table 6-1, the factory tolerances for F1 spring only are 127 ± 1/2° for 50 grams and 254 ± 1/2° for 100 grams. A movement of ± 1/2° is permissible when the main shaft is turning. This movement will generally be dampened out when a fluid is being tested.

Check the linearity of the dial reading with at least three weights. If the spring appears to be non-linear, then bob shaft is probably bent. An instrument with these characteristics needs additional service and/or repair.

Table 6-1 Dial Deflection for Calibration Weights and Torsion Spring Assemblies

Torsion Spring Assembly (with R1-B1 combination)	Torsion Spring Constant, k_1 Dynes/cm/degree deflection	Weight in Grams				
		10	20	50	100	200
		Dial Reading				
F-0.2	77.2	127.0	254.0	-	-	-
F-0.5	193.0	50.8	101.6	254.0	-	-
F-1	386.0	25.4	50.8	127.0	254.0	-
F-2	772.0	-	25.4	63.5	127.0	254.0
F-3	1158.0	-	-	43.0	84.7	169.4
F-4	1544.0	-	-	-	63.5	127.0
F-5	1930.0	-	-	-	50.8	101.6
F-10	3860.0	-	-	-	-	50.8

6.2 Fluid Calibration Check

This procedure describes the calibration check using only certified Newtonian calibration fluids. Fann calibration fluids are available for separate purchase (Table 9-1). All calibration standards are certified by methods traceable to the United States National Institute of Standards and Technology (NIST).

1. Make sure that the instrument is clean before immersing the rotor and bob into the calibration fluid. If necessary, remove the rotor and thoroughly clean the bob, bob shaft, and rotor. Make sure the bob shaft and rotor are straight and have not been damaged.

The batch number on the label of the calibration fluid must match the number on the viscosity/temperature chart.

2. Fill the sample cup to the scribed line with calibration fluid and place it on the instrument stage. Elevate the stage so that the rotor is immersed to the proper immersion depth. Refer to Figure 3-2.
3. Place a thermometer into the sample cup until it touches the bottom, and then secure it to the side of the viscometer to prevent breakage.
4. Operate the instrument at 100 rpm for approximately three minutes. This will equalize the temperature of the bob, rotor, and the fluid.
5. Read the dial at 300 rpm and 600 rpm. Record these numbers and the temperature from the thermometer to the nearest 0.1° C (0.15° F).

The viscosity at the 300 rpm reading should be within ±1.5 cP of the viscosity from the temperature chart at the recorded temperature.

Divide the 600 rpm reading by 1.98; compare this value to the value on the chart.

The viscosity at the 600 rpm reading should be within ±1.5 cP of this viscosity value.

Plot the 300 rpm reading and the 600 rpm reading then draw a straight line from zero through these two points. If the 300 and 600 points do not fall in a straight line, it is possible that the either rotor, bob, or bob shaft is bent or that other eccentricity exists.

Points at 100 rpm and 200 rpm can be plotted if verification is needed.

Readings outside the specified limits are indications that the instrument should be either calibrated or repaired. (See Section 6.3 for the procedure to calibrate the spring.)

After completion of the calibration check, carefully wipe clean the rotor surfaces (inner and outer), bob, thermometer, sample cup, and work area.

6.3 Torsion Spring Calibration

Refer to Figure 5-4 for identification of parts.

Make sure that the bob shaft is not bent before adjusting the torsion spring.

1. Remove dust cap [A], and then loosen set screw [C] about one-half turn.

2. Insert the calibration tool into the spring and rotate the adjustable mandrel (inside the spring) slightly. Turn the mandrel counterclockwise if the dial reading is too low, or turn the mandrel clockwise if the dial reading is too high.

Before tightening set screw [C], check the top of the center mandrel and be sure that it is flush with the top of the clamp [E]. To accomplish this, it may be necessary to adjust the spring by slightly compressing or stretching the spring.

3. Tighten the set screw [C]. The slot in the top of the adjustable mandrel should line up with clamping set screw [C].

4. Loosen the set screw [F] to zero dial under index, then rotate knob [G] as required for alignment, then adjust knob [G] vertically to allow the spring to be clamped in a "free" position, neither stretched nor compressed.

5. Tighten the set screw [F] and replace the dust cap [A].

Appendix E.2 Haake Rotovisco RV12

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Sensor System MV

Application:

The MV is primarily used for viscosity measurements of medium viscous liquids such as heavy oils, paints, varnishes, resins, emulsions, etc. working in the medium shear rate range. Small yield points can be determined.

This coaxial cylinder sensor system consists of an MV cup used with three different rotors to provide different viscosity measuring ranges. MV I and MV II are both available in plastic (phenolic thermoset) and in stainless steel, 18/8. The plastic rotors are low weight and allow higher rates of rotor acceleration. They are mechanically and chemically safe for temperatures up to 100°C.

This sensor system requires the temperature vessel.

The rotors are positively mechanically centered. The top and the bottom surfaces of the rotors are recessed to minimize "end effects", i.e. their influence on torque. An air bubble is retained in the bottom recess, while the upper recess accomodates any excess sample.

The required amount of sample depends on the type of rotor used. For the purpose of reference there are two ring marks on the inside wall of the cup. The lower mark indicates the approximate sample volume required when the MV I and the MV II rotors are used in the cup MV. The upper ring mark is used for the MV III rotor.

Decreasing the temperature of a sample which just fills the annular gap between cup and rotor up to the upper rim of the rotor will cause the sample volume to shrink. This will lead to an only partly filled sensor system, to a reduced torque and to an erroneous viscosity value being below the true viscosity level.

When a sample must be measured at various temperatures, it is advisable to begin at the lowest temperature. When this is not possible, the sensor system MV should be overfilled to such an extent that the sample will be slightly above the rim of the rotor even at the lowest temperature. Rotor alternative: MV DIN (see G.6).

During a test the liquid level of the sample must just overflow into the upper recess of the rotor. The liquid level must not surpass the upper rim of the rotor by more than 1 or 2 mm. Excess sample may be removed by sucking it back by means of a syringe.

Cleaning: To remove the bottom of the cup, first loosen the knurled screw and remove the cross-bar. (Order no. of sealing 807-0458)

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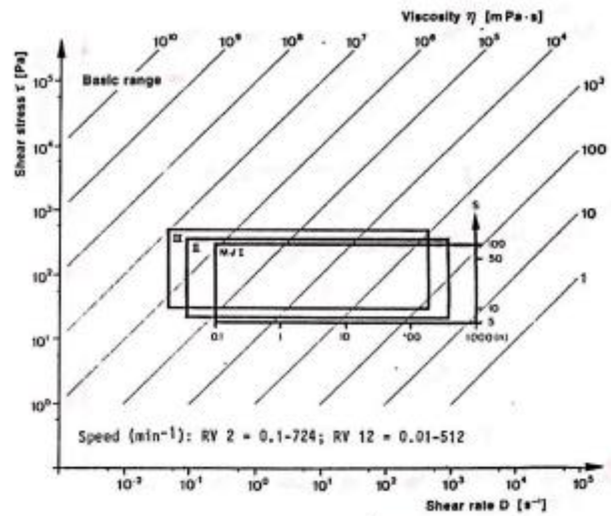
Sensor System	MV I	MV II	MV III
Inner Cylinder (rotor) radius R_i (mm)	20.04	18.4	15.2
height L (mm)	60	60	60
Outer Cylinder (cup) radius R_a (mm)	21	21	21
Radii Ratio R_a/R_i	1.05	1.14	1.38
Sample Volume V (cm^3)	40	55	70
Temperature: max. (°C)	100	100	100
min. (°C)	-30	-30	-30
Calculation Factors			
A (Pa/scale grad.)	3.22	3.76	5.44
M (min/s)	2.34	0.9	0.44
G (mPa·s/scale grad.·min)	1374	4171	12375



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Evaluation

Principle: preset test speed "n" ⟶ read off torque "S".

The list of calculation factors (test certificate) shows the factors M, A and G. These factors are needed to calculate shear rate, shear stress and viscosity.

1) Shear rate D:

$D = M \cdot n\ (s^{-1})$

is calculated with "n"
M = "shear rate factor", depending on sensor system.
n = actual test speed
The actual test speed is calculated:

$n = \frac{\text{set test speed}}{\text{reduction factor R}}$

i.e. 64 min^{-1} on knob "R", position 10:

$n = \frac{64}{10} = 6.4\ min^{-1}$

2) Shear stress τ:

$\tau = A \cdot S\ (Pa)$

is calculated with scale value "S".
A = "shear stress factor", depending on type of measuring drive unit and sensor system.

S = measuring value (scale grad)·sensitivity E.
The value to be obtained from this calculation is arrived at by multiplying the scale value by the set step "E", i.e. 57 scale grad on E = 0.3; S = 57·1/3 = 19 scale grad.

3) Viscosity η:

$\eta = \frac{G \cdot S}{n}\ (mPa \cdot s)$

Calculated with shear stress and shear rate.
G = "instrument factor", depending on the type of measuring drive unit and sensor system.

$G = 10^3 \cdot A/M$ (mPa·s/scale grad·min)

Conversion of viscosity data from SI to CGS units:
Viscosity η : Pascal seconds (Pa·s); 1 Pa·s = 10 Poise; 1 mPa·s = 1 cp.
Shear stress τ : Pascal (Pa); 1 Pa = 10 dyne/cm^2
Shear rate D : Reciprocal second (1/s).

Thus the equation (11a) is changed to:

$\eta = \frac{G \cdot S}{n}$ (mPa·s) (11)

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8.1 Equations for the evaluation

The designations used are:

M_d = torque at the rotor (Ncm)	f = shape factor
L = height of the rotor (cm)	A = shear factor
R_i = radius of the rotor (cm)	a = torque-signal factor
R_a = radius of the cup (cm)	M = shear rate factor
n = speed of the rotor (min^{-1})	S = scale units on ordinate
α = opening angle of the cone (rad)	
R_k = radius of the cone (cm)	

Shear stress τ

The shear stress τ is linearly linked to the torque M_d:

$$\tau = f \cdot M_d \quad (1)$$

The proportionality factor f recognizes the characteristic geometry of the rotor. One might call f the 'shape factor'. The shear stress τ can be calculated easily using the value 'S' measured in scale graduations:

$$\tau = A \cdot S$$

Combining (1) and (2) defines the shear stress factor A:

$$A = f \cdot a \quad \text{with } a = \text{torque/reading} = M_d/S \quad (3)$$

The "a" value is a constant correlation factor to correlate the torque applied at the shaft of the measuring-drive-unit to the value "S" indicated. The value "a" depends on the constant of the torsional measuring spring and the electrical specifications of both the basic unit and the measuring-drive-unit. The true value of "a" is given in the list of calculation factors supplied with each measuring-drive-unit.

The shape factor "f" can be calculated for the range of sensor systems offered using the following equations:

C y l i n d e r   S e n s o r   S y s t e m s

$$f = \frac{1}{2 \cdot \pi \cdot L \cdot R_i^2} \quad (4)$$

It is common procedure to add to this value "f" a correction factor which originates from the unavoidable torque caused by the cylinder end faces (end-effects) and which is added to the real torque created by the mass sheared in the coaxial cylinder gap. Thus instead of the real rotor height L a corrected height L* takes place in equation (4).

$$L^* = L + \Delta L \quad (5)$$

This value ΔL is defined by means of the procedure as stated in the German standard DIN 53 018, page 2.

C o n e - a n d - P l a t e   S e n s o r   S y s t e m s

$$f = \frac{3}{2 \cdot \pi \cdot R_k^3} \quad (6)$$

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Shear rate D

The shear rate 'D' is linearly linked to speed 'n':

$$D = M \cdot n \quad (7)$$

The proportionality factor M recognizes the characteristic geometry of the sensor system. It is defined as the shear rate per speed unit. The following equations define this M factor:

Cylinder Sensor Systems

$$M = \frac{\pi}{15} \cdot \frac{R_a^2}{R_a^2 - R_i^2} \quad (8)$$

Cone-and-Plate Sensor Systems

$$M = \frac{\pi}{30 \cdot \alpha} \quad (9)$$

Note: The new SI-unit of an angle is the "radiant" rad. This correlates to the normally used "degree angle" (°):

$$1° = \frac{\pi}{180} \text{ rad} = 0.0174 \text{ rad}$$

Viscosity η:

The equation to calculate the viscosity of Newtonian liquids is:

$$\tau = \eta \cdot D \quad (10)$$

When using the equations for τ (2) and D (7) this leads to:

$$A \cdot S = \eta \cdot M \cdot n$$

or with η:

$$\eta = \frac{A \cdot S}{M \cdot n} \quad (11)$$

It is common practice to give viscosity in values of "milli Pascal seconds". Then (11) becomes:

$$\eta = 10^3 \cdot \frac{A \cdot S}{M \cdot n} \quad (11a)$$

To simplify the equation a part of it is combined to a constant G being typical for each sensor system: it can change with time, the specifications given ... a period of 3 months after delivery.

$$G = 10^3 \cdot \frac{A}{M} \quad (12)$$

Thus the equation (11a) is changed to:

$$\eta = \frac{G \cdot S}{n} \text{ (mPa·s)} \quad (13)$$

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8.2 Determination of instrument constants

Shear rate D, shear stress τ, and viscosity η, are computed from test results of 'n' and 'S' with the sensor factors 'M' (shear rate factor), 'A' (shear stress factor), and 'G' (viscosity factor). These factors are found in the list of calculation factors delivered with each instrument. They were established by means of an absolute test of 'weighing torques' or they are, as for instance 'M' and 'f', calculated by using the geometrical dimensions of the sensor systems:

Sensor system	$f \cdot 10^{-4}$ (cm^{-3})	M (min/s)
NV	36.3	5.41
MV I / T I	65.7	2.34
MV II / T II	76.8	0.90
MV III	111	0.44
MV I P	65.8	2.0
MV II P	76.8	0.88
MV SP	87.8	11 *
SV I	253	0.89
SV II	768	0.89
SV II P	768	0.78
SV II FL	572	----
SV SP	253	4.4
MV DIN	55.8	1.29
SV DIN	369.4	1.29
MV-E	61.43	1.29
SV-E	322.1	1.29
HS I	1172	40 *
HS II	1142	10 *
PK V, 1°	305.6	6 *
PK I, 1°	1740	6 *
PKII, 1°	4775	6 *
PK V, 0.5°	305.6	12 *
PK I, 0.5°	1740	12 *
PKII, 0.5°	4775	12 *
PK V, 0.3°	305.6	20 *
PK I, 0.3°	1740	20 *
PKII, 0.3°	4775	20 *

* the factors given are values for reference only; for exact values, see list of calculation factors.

In case that an instrument is expanded by further measuring-drive-units the relevant values A for the range of sensor systems must be calculated:

Example - you need 'A', 'M' for RV 12 with M 150 and MV I.

The value 'a' of the measuring-drive-unit M 150 is 0.0147 Ncm/scale grad.
" " " M 500 is 0.049 Ncm/scale grad.
" " " M 1500 is 0.147 Ncm/scale grad.

Calculation of shear stress factor 'A':

$A = f \cdot a = f(MV\ I) \cdot a(M\ 150)$

$A = 65.7 \cdot 10^{-4}\ cm^3 \cdot 0.0147$ Ncm/scale grad. $A = 0.966 \cdot 10^{-4}\ N/cm^2 \cdot$ scale gr

A = 0.966 (Pa/scale grad.)

Calculation of shear stress factor 'M':

Taken from the above table.

Calculation of viscosity factor 'G':

$$G = \frac{A}{M} \cdot 1000 = \frac{0.966}{2.34} \cdot 1000 = 413$$

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ROTOVISCO RV 12

Berechnungsfaktoren
Calculation factors
Facteurs de calcul

Nr. 850195
Datum 26.4.1985
Kontr.

M 150
Nr. 840805
a= 0.0147 $\left(\frac{N\cdot cm}{Skt}\right)$

System	Rotor	D/L (mm)	Nr.	M (min/s)	A $\left(\frac{Pa}{Skt}\right)$	G $\left(\frac{mPa\cdot s}{Skt\cdot min}\right)$
NV	NV	40.2 /60		5.41	0,533	98,6
MV T/MV	MV I	40.08/60		2.34	0,966	412
	MV II	36.8 /60		0.9	1,13	1250
	MV III	30.4 /60		0.44	1,63	3710
SV T/SV	SV I	20.2 /61.4		0.89	3,72	4175
	SV II	20.2 /19.6		0.89	11,3	12670
P	MV I P	40.08/60		2.0	0,966	483
	MV II P	36.8 /60		0.88	1,13	1282
	SV II P	20.2 /19.6		0.78	11,3	14460
DIN 53019	MV	38.7 /58.1		1.29	0,9	700
	SV	21.3 /32		1.29	5,43	4210
HS	HS I	19.95/15				
[redacted]	HS II	19.8 /15				
	PK V,.........°	50 /—				
	PK I,.........°	28 /—				
	PK II,.........°	20 /—				
	MV SP	41.6/40				
	SV SP	20.2 /61.4				

[redacted]KE Mess-Technik GmbH u. Co. · Dieselstraße 6 · D-7500 Karlsruhe 41 · Telefon (07 21) 40 94-1