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A NOVEL METHOD OF ATOMIZING COAL-WATER SLURRY FUELS

Final Report

By
P. E. Sojka
A. H. Lefebvre

May 1990

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For
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

By
Purdue University
West Lafayette, Indiana

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DE-FG22-87PC79913
U.S. Department of Energy
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by

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May 1990

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1 INTRODUCTION

The need for cheap and plentiful energy has brought the United States to depend heavily on imports of petroleum products that are of limited supply and may soon be scarce and expensive. One energy source that is still plentiful in the United States, however, is coal but its use is severely limited since transport can be accomplished only by barge, train or truck. This eliminates the vast infrastructure of pipelines and tankers that already exist to transport liquid fuels such as petroleum. Another limitation is the difficulty in injecting coal into the gas turbine and internal combustion engines that provide a large percentage of the power used in this country.

One development with potential for making coal easier to use is coal-water slurry (CWS). By suspending microscopic coal particles in water or some other fluid the coal is "liquified" and can be easily transported thereby facilitating its use in pipelines, tankers and the combustion zones of gas turbine and internal combustion engines.

Unfortunately, the properties of CWS introduce another set of problems. Coal-water slurry is a highly viscous, non-Newtonian, two-phase fluid that sometimes contains polymers in order to maintain suspension of the coal particles. The rheological properties and polymers make slurries hard to atomize, and the coal particles make it abrasive and prone to clogging orifices.

The difficulty in atomizing CWS exacerbates the problem of efficiently burning the fuel. Efficiency can be increased by exposing more surface area of the fuel to the hot combustion gases, but it is necessary to produce small drop sizes in order to accomplish that goal.

The majority of atomizers are incapable of efficiently atomizing CWS since they are sensitive to slurry rheological properties. In order to overcome rheological effects, some atomizers require that the injection velocity be increased. This is often accomplished by raising injection pressure and decreasing orifice diameter. Increasing exit velocity is detrimental to nozzle operation since the abrasive effect of CWS increases. In addition, the probability of clogging increases with decreasing nozzle diameter. Other nozzles attempt to produce small drops by increasing the air liquid ratio (ALR). Increasing ALR is undesirable due to the increase in cost associated with pumping large volumes of air at high pressure.

In recent years, several techniques have been developed that have met with limited success when atomizing CWS. One technique, termed air assist atomization, uses high velocity air streams to shear the liquid and transform it into small drops. Another technique, termed flashing atomization, uses superheated liquid to generate bubbles that rapidly expand immediately outside the nozzle. In both methods, energy in a high pressure or high velocity gas is used to break the liquid into small droplets.

Air assist and flashing atomization do have drawbacks. Air assist atomization requires a substantial flow of high pressure air, often necessitating costly pumping equipment. Flashing atomization requires that nuclei be present in the liquid to ensure bubble formation and, in addition, the rate of bubble expansion is limited by mass transfer from the surrounding liquid. An alternative method of producing small mean drop size sprays is obviously desirable. Effervescent atomization is such a method.

Effervescent atomization is being developed at Purdue University. An effervescent atomizer combines air and a liquid inside a mixing tube such that a bubbly flow is created within the nozzle body. The two-phase flow exits the nozzle final orifice where the bubbles rapidly expand and shatter the liquid. The process is unique in that the nozzle creates and maintains a mixture such that the air is always in intimate contact with the liquid.

Previous works have shown that effervescent atomization is not affected by changes in orifice diameter, solving the dilemma of clogging. They have also shown that quality atomization can be achieved with low injection pressures and low ALR thereby minimizing the energy required. Effervescent atomization possesses these advantages because the sonic velocity of the mixture decreases dramatically as air is bubbled into the liquid with the result that choking occurs at the final exit orifice. Once the nozzle is choked a nearly instantaneous pressure drop occurs across the orifice which in turn produces a rapid expansion of the gas and results in break up of the liquid. Fortunately, choking is not a function of the orifice diameter; therefore, spray quality is not a function of orifice diameter either. As a result, the nozzle final exit orifice can be made as large as necessary to eliminate clogging with no reduction in atomizer performance.

Despite the body of work describing the performance of effervescent atomizers, its potential for use with CWS had not been evaluated prior to this study. This program was therefor undertaken

- **to demonstrate that effervescent atomization can produce CWS sprays with mean drop sizes below 50 μm**
- **to determine a lower size limit for effervescent atomizer produced CWS sprays**
- **to determine the mechanism(s) responsible for the formation of effervescent atomizer produced sprays.**

Application of effervescent atomization to coal slurries requires an analysis of the effects of slurry rheological properties (as indicated by the consistency index and the flow behavior index) and formulation (in terms of loading and coal particle top size) on the spray formation process. This was accomplished in three steps. First, Newtonian liquids, derived from solutions of glycerine and water, were sprayed with Sauter mean diameter (SMD) measurements obtained at various nozzle pressures and ALR values. This provided information on the effect of consistency index (or viscosity). Next, SMD measurements of non-Newtonian liquids consisting of glycerine, water and polymer were acquired to assess the effect of flow behavior index. Finally, spray data for five coal water slurry mixtures was collected, again at varying nozzle pressures and ALR values. This provided information on the relationship between drop size and coal loading and top size.

The experimental data reported were then analyzed to explain the physical processes responsible for spray formation. The analysis began by considering an energy balance across a control volume that extended from the nozzle exit plane to the line of spray measurement. The inlet conditions were calculated using two-phase flow techniques and the outlet conditions were calculated by using conservation of momentum and assuming that the final velocities of the air and liquid were equal. Entrainment was considered negligible and losses were accounted for by realizing that only a small fraction of the atomizing air participated in the spray formation process with the remainder passing through the control volume unperturbed.

The results showed that effervescent nozzles effectively atomized CWS, as well as Newtonian and non-Newtonian fluids, while eliminating clogging and erosion problems. In addition, effervescent atomization produced small CWS drop sizes at low discharge pressures and low values of ALR and was insensitive to changes in consistency index, flow behavior index, and loading and particle top size. The report ends with suggestions for future work.

2 LITERATURE REVIEW

2.1 Introduction

The technique of effervescent atomization has been influenced by two methods of forming sprays, internal mixing atomization and flashing atomization. In each of these methods, a gas assists the liquid break up process with the energy stored in the gas used to increase the surface energy of the liquid, thereby transforming it into drops. Internal mixing atomizers commonly inject gas and liquid into a chamber where a two-phase bubbly or separated flow is produced. Flashing atomization uses bubbles generated by either flashing a superheated liquid or nucleation of a dissolved gas in the liquid.

Mixing of the two phases is critical for achieving good atomization. An even distribution of bubbles squeezes the liquid into a matrix of thin films or fragments that are easily broken apart. Flashing atomization accomplishes this goal through formation of numerous tiny bubbles. The small bubble size and high number density provide intimate contact between the vapor and the liquid, an arrangement important during the bubble expansion process if small drops are to be formed. In contrast, internal mixing atomizers do not provide good mixing and, as a result, alternating slugs of liquid and gas often exit the nozzle along with the air. The alternating slug geometry is less efficient at transforming the liquid into small drops.

Despite the potential for forming numerous small bubbles distributed uniformly throughout the fluid, flashing atomization also has disadvantages. In particular, it requires heating of the liquid thereby consuming large amounts of energy. In addition, it can cause plugging problems if the substance to be sprayed is prone to thermally induced decomposition. Heating is not required with internal mixing atomization.

Effervescent atomization incorporates the virtues of both methods; it gives particular consideration to how the phases are mixed, but does not require heating to generate bubbles. Instead air is injected into the liquid as in an internal mixing atomizer, but the bubbles are made as small as possible and are maintained such that they spread the liquid matrix into numerous thin films as in a flashing atomizer. The resulting bubbly mixture exits the orifice where the expanding gas shatters the liquid in the same fashion as in flashing atomization. The advantages of effervescent atomization are that it needs no nucleation sites to form bubbles and the flow at the exit orifice is choked. The latter leads to a nozzle whose performance is independent of its geometry.

2.2 Internal Mixing Atomization

Sakai et al. [1978] describe a nozzle where air and water are ducted into a large diameter mixing chamber in order to enhance the atomization quality. The two fluids enter parallel and on axis with the exit orifice and impinge on the wall over the orifice where churning mixes them. A portion of the mixed fluid exits through the orifice and the remainder circulates inside the chamber. Sakai et al. suggest that internal mixing atomization can be used to atomize high viscosity fluids and slurries over a wide turn down ratio and suggest that the major obstacle in this technique is the mixing of the two phases.

The data of Sakai et al. is summarized by the correlation

$$D_{32} = 14.0 \cdot D_n^{0.75} \cdot ALR^{-0.75} \tag{1}$$

where D_{32} is the Sauter mean diameter, in microns, D_n is the nozzle diameter, in mm, and ALR is the air-liquid ratio. Equation (1) indicates SMD decreases with increasing ALR and decreasing nozzle diameter. If the nozzle diameter is fixed at 2 *mm* and

ALR varied, it is found that SMD = 740 μm when ALR = 0.01 and SMD = 80 μm when ALR increases to 0.2. Obviously, while SMD does decrease with increasing ALR, spray quality is very poor at low ALR. Surprisingly, the low ALR reported corresponds to the bubbly flow regime for this nozzle where mixing should be at its best and drop sizes should be small. In contrast, an effervescent atomizer operating under identical conditions does a much better job of breaking up the spray at low ALR. For example, Roesler [1988] showed effervescent atomization produces a spray of 35 μm at an ALR of 0.01 using the same flow conditions and orifice geometry as Sakai et al. This discrepancy may result from the manner in which the internal mixing nozzle mixes the two fluids. According to Sakai et al., bubbly flow is generated in the mixing chamber at low ALR and a swirling action is generated on the sides of the mixing chamber; pockets form at the top of the mixing chamber as ALR is increased and the turbulent swirl eventually grows into large voids. It is possible that these voids, along with the swirl, produce areas of low velocity that cause small bubbles to coalesce into large bubbles, which are in turn less efficient in breaking up the liquid. Sakai et. al. made no mention of the size of the bubbles and do not clarify whether bubbly, slug or separated flow exits the nozzle. Bubble coalescence and impingement of the two streams on the orifice would inhibit the formation of the liquid matrix and resulting thin films that are important for producing quality atomization.

Another property of the design employed by Sakai et al. is the strong dependence of SMD on nozzle diameter. Sauter mean diameter changes by 300 μm when orifice diameter is changed from 1 to 2 *mm* and ALR is held constant at 0.01. In flashing atomization studies under conditions of bubbly flow similar to those of Sakai et al., there was no dependence on nozzle diameter. The same is true for effervescent atomizers. The dependence of SMD on nozzle geometry is an obvious disadvantage of internal mixing atomizers when spraying fluids such as CWS that are prone to clogging small orifices.

Chawla [1985], described a two-phase atomizer that had limited success in atomizing water and coal-water slurry. The design incorporated a mixing chamber with a liquid inlet parallel and on axis with the nozzle exit orifice. The air was injected perpendicular to the axis of the nozzle and the two fluids were allowed to mix within the nozzle body.

Although the atomizer could spray slurries, it contained design flaws that prevented it from achieving the small mean drop sizes necessary for efficient coal burnout. The major flaw was swirl, introduced into the mixing chamber because the gas was injected tangential to the liquid flow. Swirl results in separated flow, a condition that is detrimental to the formation of the liquid matrix and resulting small mean drop sizes. A lesser flaw was the large quantity of air the nozzle consumed, a requirement that made it less efficient than an effervescent nozzle. For instance, ALR values as low as 0.004 produce drop sizes lower than 50 μm when atomizing water with an effervescent atomizer while Chawla's design required an ALR of 0.016 to obtain the same mean drop size.

Regardless of the merits of Chawla's design, his paper did provide an important contribution: the realization that choking could occur at the nozzle exit when spraying a two-phase mixture since addition of even small amounts of gas to a liquid stream dramatically reduce the sonic velocity. Chawla recognized that this occurred and attributed the break up process to the pressure jump experienced at the choked orifice.

There is uncertainty as to the two-phase flow pattern existing in Chawla's nozzle. The most desirable situation is, of course, bubbly flow. However, calculation of void fraction values indicates they were above the limiting value of 0.8 for transition to annular flow. Further evidence for the existence of annular flow was supplied by Whitlow [1990], who studied a design similar to Chawla's where air was injected perpendicular to the axis to intentionally produce swirl. Under all flow conditions the swirling action produced a centrifuge effect that caused the air to migrate to the center line of the nozzle. The bubbly flow was transformed to annular flow with a jet of air flowing through the nozzle core. As a result of these two analyses, the flow in Chawla's nozzle was almost surely separated, and therefor outside the regime employed by effervescent atomizers.

Lefebvre et al. [1988] studied an internal mixing nozzle that was the preliminary work to effervescent atomization. The concept arose from an attempt to imitate flashing atomization by mixing nitrogen and water in a chamber that creates the bubbly flow found by Solomon et al. [1985], but without having to heat the fluid. The design used a drilled tube suspended in a mixing chamber to inject air outward into the liquid. The liquid was supposed to shear bubbles from the surface of the tube and form a two-phase flow.

Results of the study of Lefebvre et al. showed that SMD values as low as 42 μm could be achieved at pressure differentials as low as 35 kPa. The effect of pressure was illustrated when SMD decreased to 20 μm while the pressure increased to 635 kPa. This result is expected since the energy available for atomization increases with pressure.

Air-liquid ratio had a strong influence on atomization as well. Sauter mean diameters as low as 35 μm were reported at ALR values above 0.10 and by decreasing ALR to 0.015, an SMD of 70 μm was achieved.

One weakness of the study of Lefebvre et al. was that the nozzle was opaque and the flow regime could not be ascertained. Unfortunately, subsequent work by Roesler and Lefebvre [1987] using a transparent nozzle demonstrated that some of the ALR values employed by Lefebvre et al. [1988] did indeed result in annular flow. This does not detract from the results of their study, however, which showed that excellent atomization could be obtained at very low pressures and ALR values when using effervescent atomization.

A study similar to that of Lefebvre et al. was reported by Wang et al. [1987] who modified the air injector to feed air from a single hole located on the axis of the nozzle final orifice. Their results demonstrated that the method of injecting gas had no significant effect on SMD.

2.3 Flashing Atomization

Flashing atomization is a technique where a spray is produced by transforming a portion of the liquid into vapor. The rapid expansion of the vapor imparts kinetic energy to the remaining liquid and shatters it into droplets. Flashing occurs when a superheated liquid suddenly experiences a drop in pressure to a value below saturation. This creates a non-equilibrium situation, and in order for the liquid to stabilize itself it gives off latent heat which forms vapor bubbles. Flashing also occurs when a gas and a liquid are mixed under great pressure allowing the gas to dissolve into the liquid. Subsequently, the gas comes out of solution after undergoing rapid decompression at the nozzle exit.

Several studies have been published describing flashing atomization. One of the first was by Brown and York [1962] where the authors atomized superheated water. Their results demonstrated that drop sizes smaller than 40 μm could be achieved at pressures below those required to operate a pressure swirl nozzle. Photographs showed the liquid jet exiting the nozzle and suddenly bursting into droplets a short distance downstream of the final orifice, revealing the sudden and violent effect the expanding bubbles have on the jet.

Sher and Elata [1977] reported a flashing atomization study where a Freon-22 propellant and toluene mixture was atomized. The Freon propellant flashed and atomized the liquid toluene when the mixture passed through the final orifice. Sher and Elata noted the same explosive atomization process as Brown and York. In addition, their results showed that the spray mean diameter decreased with an increase in discharge pressure, but that this effect diminished with pressure until it disappeared completely. They also found that nozzle orifice size had no effect on mean drop size.

Solomon et al. [1985] discussed a design where air was dissolved into Jet-A fuel under high pressure. The resulting mixture was fed to a nozzle where it passed through an orifice and into an expansion chamber. As the air came out of solution, it formed a two-phase flow in the expansion chamber with the result that the mixture atomized upon exiting the final orifice. Solomon et al. found that the effect of dissolved air was negligible when the bubbles were not allowed to diffuse out of solution in the expansion chamber, but as more air diffused out, mean diameter decreased. This gave the nozzle the peculiar property that as discharge pressure decreased mean diameter decreased since more air diffused out as the pressure was lowered. Solomon et al. also found that SMD values as low as 20 μm could be achieved with a dissolved air content of 15% mole fraction and found that there was no dependence of SMD on nozzle diameter.

Consideration of the flashing atomization studies shows that drop sizes less than 50 μm could be achieved using this technique. Its drawbacks are the requirements of either a heating source or premixing of the gas with the liquid in order to generate the gas bubbles. Heating adds the additional problem of clogging since some fuels break down and coat supply lines and orifices; premixing gases with the liquid can be cumbersome and time consuming. As a result, neither flashing nor dissolved gas atomization has attracted much interest.

2.4 Effervescent Atomization

Roesler and Lefebvre [1987] were the first to investigate effervescent atomization. They employed a design similar to that of Lefebvre et al. [1988] except that a sintered plastic aerator tube was used in place of the aerator tube containing drilled holes, water flowed inside the porous tube rather than outside, and air was injected toward the axis of the nozzle instead of away from it. The air was injected at low velocity, therefore requiring very little pressure drop in order to generate the bubbly flow. The results were very similar to those of Lefebvre et al. [1988] except that Roesler studied a lower range of ALR values, which corresponded to the bubbly flow region of operation.

The results showed that SMD was a strong function of pressure and ALR. Mean drop sizes of 80 μm, achievable at a pressure drop of 173 kPa and an ALR of 0.01, were reduced to 35 μm when the pressure drop was increased to 690 kPa. Quality atomization was achieved over an ALR range of 0.001 to 0.025 with SMD changing from 100 to 25 μm over this range.

2.5 Correlations

Many correlations describing SMD have been proposed with most investigators approaching the process by describing the break up of a viscous jet or sheet in a viscous medium. In such a model, shearing forces between the liquid and the surrounding air cause the liquid to become unstable and break up into ligaments which are then pulled into droplets by surface tension forces. This approach could not be applied to effervescent atomization, however, since it is not affected by fluid rheology, as will be shown in Section 4. Instead, the spray formation process was analyzed following Lefebvre [1990].

Lefebvre [1990] suggests an alternative approach to predicting SMD. He considers the break up of a liquid stream, either sheet or jet, to be caused by impingement of an air jet on the liquid at some angle in order to impart a significant normal force on it. He argues that the break up mechanism shifts from wavy sheet to a momentum transfer due to collision of the air and liquid jets as the air jet impinges normal to the liquid stream. The break up process is then considered to be controlled by the normal component of the air velocity, the air-liquid ratio and the surface tension of the liquid.

The analysis begins by considering the energy required to overcome surface tension forces while transforming the liquid stream into droplets. The change in energy of the liquid is the product of its surface tension and the change in surface area, as represented by Equation (2):

$$E_L = 2 \cdot \sigma \cdot \frac{m_l}{\rho_l} \cdot \left(\frac{3}{D} - \frac{1}{t} \right) \tag{2}$$

where A_{L1} is the surface area of the liquid sheet and A_{L2} is the surface area of the droplets as given by

$$A_{L1} = 2 \frac{m_L}{\rho_L t} \tag{3}$$

$$A_{L2} = 6 \frac{m_L}{\rho_L D} \tag{4}$$

Here, t is the liquid sheet thickness, m_L is the liquid mass, D is the droplet mean diameter, E_L is the change in surface energy of the liquid, ρ_L is the liquid density, and σ is the liquid surface tension. The energy of the air is now taken into consideration and is equal to

$$E_a = m_A \cdot \frac{V_a^2}{2} \tag{5}$$

where V_A is the air velocity, E_A is the air kinetic energy, and m_A is the air mass.

By equating the energy required for atomization and the energy of the air times the efficiency of the atomization process

$$E_L = C \cdot E_A \tag{6}$$

it is found that

$$SMD = 3 \cdot \left(\frac{1}{t} + \frac{C \rho_L V_a^2 ALR}{4\sigma} \right)^{-1} \tag{7}$$

where C represents the efficiency of the process. Lefebvre [1990] altered this expression by first substituting $\left(1 + \frac{1}{ALR}\right)^{-1}$ for ALR, since studies have shown that SMD for prefilming air blast atomizers is proportional to (1+1/ALR), and then substituting C' for C. This suggests that C is a function of ALR and can be expressed as

$$C = \frac{C'}{ALR + 1} \tag{8}$$

The resulting expression

$$SMD = 3 \cdot \left(\frac{1}{t} + \frac{C' \rho_L V_a^2}{4\sigma\left(1 + \frac{1}{ALR}\right)} \right)^{-1} \tag{9}$$

fits his data very well and shows great promise when correlating data for various types of atomizers.

2.6 Summary

In summary, flashing atomization has the detrimental quality of requiring a heat source or a mixing tank where a gas can be dissolved into the liquid. Heating the liquid not only consumes energy but can cause clogging problems. Furthermore, the mixing tank is cumbersome and requires high pressures, often for extended periods of time.

Internal mixing atomization circumvents these problems by mixing the air and liquid in a region just prior to the orifice so that dissolution is not necessary. But internal mixing atomizers have the disadvantage of poor mixing such that separated or annular flow is often the result.

Effervescent atomization incorporates the beneficial qualities of flashing atomization, where a matrix of bubbles under pressure is used to spread the liquid into thin sheets and then blast it into droplets in an explosive expansion process. The force on the liquid created by the expansion is responsible for the atomization quality; therefore, it is imperative that the flow not be separated. Effervescent atomization mixes a gas and liquid in such a manner as to sustain a well mixed flow that atomizes in the same manner as flashing atomization, but without the need for a heat source or a mixing tank.

Finally, effervescent atomization allows SMD values of 40 μm to be achieved at

ALR values lower than 0.01 and pressures under 100 kPa. In addition, spray quality is unaffected by nozzle diameter and liquid viscosity making it an attractive method of atomizing CWS.

3 EXPERIMENTAL APPARATUS AND INSTRUMENTATION

3.1 Introduction

This section explains in detail the design and operation of the atomizer and experimental apparatus as well as the operation and calibration of the instrumentation used to acquire data. The description of the nozzle begins at the liquid and air inlets and proceeds to the final orifice. It includes descriptions of the various components and the flow path of the fluids. The description of the experimental apparatus begins with the air and liquid supply systems and ends at the nozzle inlets. The systems used to analyze the spray are then described and the theory behind their operation summarized. This is followed by a description of the equipment used to determine the properties of the test liquids. Equipment calibration procedures are also included.

3.2 Atomizer Design

The effervescent atomizer employed in this study is illustrated in Figure 1. Two primary requirements were established that constrained the design: the nozzle had to withstand 3.4 MPa in order to achieve the maximum flow rates allowable, and the two-phase flow within the nozzle had to be observable and photographable. Both requirements were met by using glass and acrylic to construct portions of the nozzle.

The acrylic containment tube, with a wall thickness of 6.4 mm, inner diameter of 25 mm and length of 300 mm, served a dual role: it acted as a reservoir for the liquid and carried the pressure load produced by the 3.4 MPa air supply. By pressurizing the liquid within the acrylic shell, the internal parts were relieved of the pressure load. O-ring groves cut into the top and bottom provided high pressure seals at the joints.

The mixing chamber was the most significant nozzle element. It consisted of a plenum, termed the aerator shell, surrounding a porous plastic aerator tube which in turn served as the mixing zone. The aerator shell was made of brass since it had to

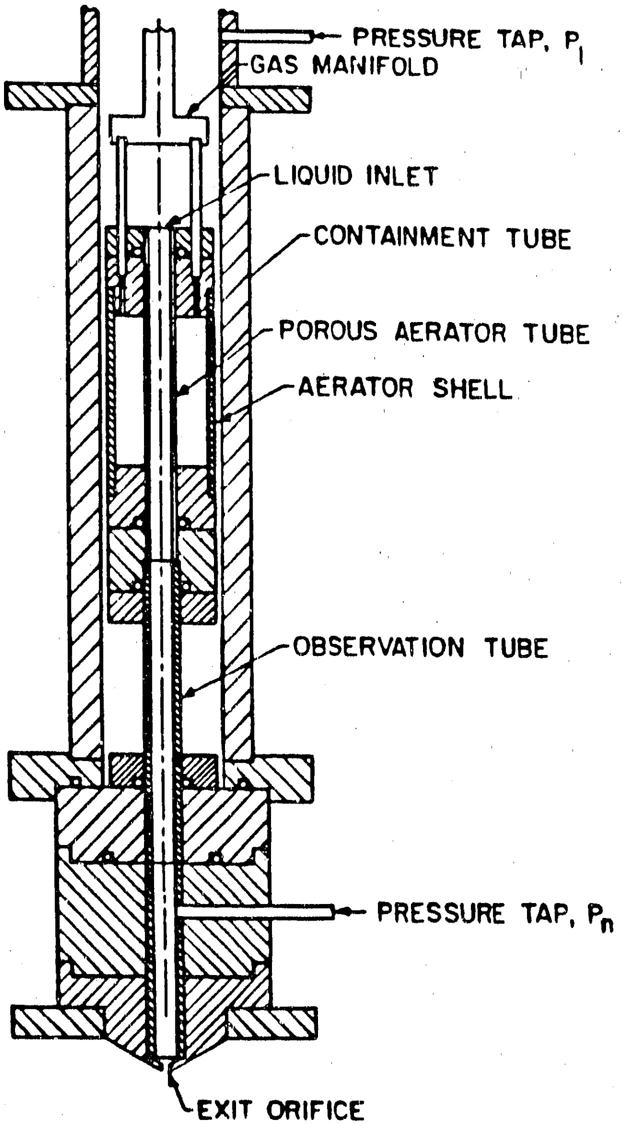

Figure 1. Effervescent atomizer.

withstand the sudden shock of high pressure air entering the mixing chamber during start up. Air was supplied to the plenum through a stainless steel tee-shaped gas manifold and two short lines.

A glass observation tube followed the mixing zone to provide easy viewing of the two-phase flow. The tube was 5 mm in diameter and 82 mm long. The glass tube was replaced with one made of stainless steel when spraying coal-water slurry.

A multipurpose spool section, made of brass, was located between the observation tube and the exit orifice. This component was originally designed to position an electronic bubble probe within the flow. The bubble probe was omitted during this study so the attachment served instead as a pressure tap, allowing accurate measurement of the static pressure immediately upstream of the exit orifice.

Two brass nozzle final orifices were used in this study. Both were of the sharp edged plain orifice type, one having an inner diameter of 1.5 mm and the other an inner diameter of 2.5 mm. The 1.5 mm orifice was used exclusively with the Newtonian fluids and the single phase non-Newtonian fluids. The 2.5 mm orifice was used when atomizing coal-water slurries in order to avoid plugging.

The nozzle operated by spilling liquid into the acrylic containment tube through a port 430 mm upstream. As shown in Figure 2, the liquid collected in the containment tube, filling it until it reached a level such that it would flow into the inlet of the porous aerator tube. The air flowed into the aerator shell, then through the porous plastic aerator tube where it mixed with the liquid flow. Finally, the two-phase mixture flowed through the clear glass observation tube, shown in Figure 1, and then through the exit orifice where it formed the spray.

During operation, it was often important to determine the two-phase flow pattern exiting the nozzle. As a result, an acrylic exit orifice was substituted for the brass exit orifice shown in Figure 1. The channel leading to this orifice consisted of a 5 mm diameter bore that was 25 mm long and terminated with a 1.5 mm diameter orifice. Two parallel outer surfaces were milled flat to minimize visual distortion of the flow inside the channel.

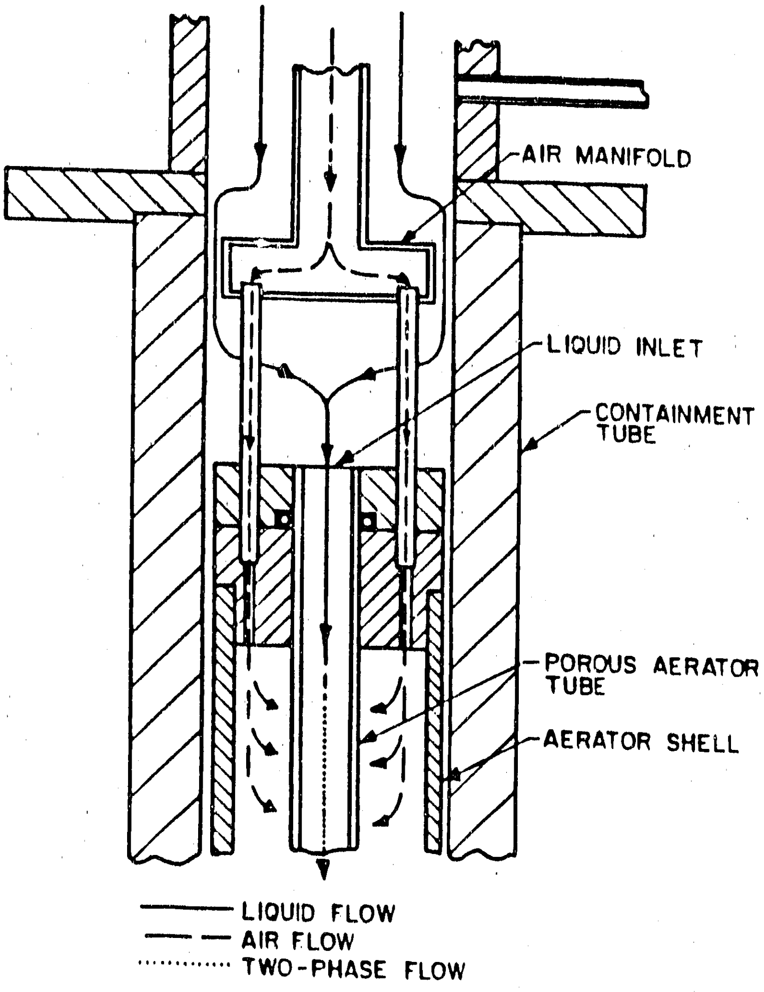

Figure 2. Effervescent atomizer cutaway view.

3.3 Air and Liquid Supply Systems

The separate air and liquid supply systems are shown in Figure 3. Stainless steel tubing and flex line were used throughout. Air from the 13.7 MPa facility supply was regulated to 3.4 MPa and provided atomizing air plus air to pressurize the free surface of the liquid storage reservoir that was used during the single phase Newtonian and non-Newtonian fluid studies. The atomizing air passed through a three-way valve which diverted it through one of two rotameter mass flow rate monitors (Brooks).

The configuration of the rotameters was chosen to allow accurate flow measurements in a low flow regime (0 to 1.44 g/s) and a high flow regime (1.22 to 7.6 g/s). The low range flow meter incorporated a tube (Brooks model R-2-15-C) with a tantalum ball while the high range meter incorporated a tube (Brooks model 8M-25-3) with a stainless steel float. Air exited the rotameters past a dial pressure gauge (Duragauge) and flowed through a pair of needle valves arranged in parallel. These valves controlled the atomizing air mass flow rate and were located downstream of the rotameters to eliminate errors due to changes in air pressure and temperature. Air flowed through the needle valves and then passed through a ball type shut off valve before finally entering the tee-shaped manifold located in the nozzle body.

Liquid was stored in an 83 liter stainless steel pressure vessel when atomizing the Newtonian and the single phase non-Newtonian fluids. As mentioned in the previous paragraph, the liquid free surface was pressurized to 3.4 MPa which forced it through the liquid delivery system. This configuration also had the advantage that unsteady flows and vibrations associated with mechanical pumps were eliminated. After leaving the reservoir, the liquid flowed through two parallel needle valves which served to control the flow rate. Liquid then passed though a Micromotion mass flow meter (model D-25) and a ball type shut off valve before finally entering the nozzle via the liquid supply tube.

When coal-water slurry was sprayed, the 83 liter stainless steel sphere shown in Figure 3 was removed and replaced with a standard 208 liter storage drum whose outlet was connected to a nine-stage progressive cavity pump (Moyno model 9P3CDQ). The pump drew slurry from the drum and forced it through a pair of ball valves arranged in parallel, one serving the nozzle and the other serving a closed loop return to the pump inlet. Small changes in mass flow rate were realized by manipulating these valves. Large changes in flow rate were realized by increasing the pump drive speed. The flow rate was measured by a Micromotion flow meter (model D-25) positioned upstream of the nozzle liquid supply tube.

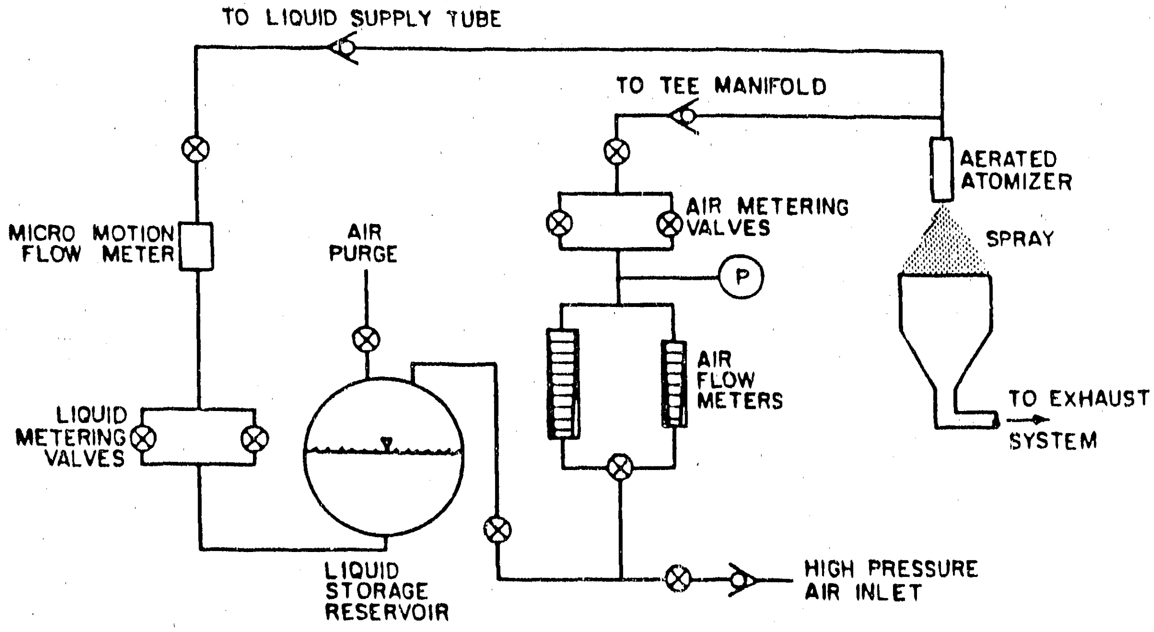

Figure 3. Air and liquid supply systems.

When spraying single phase liquids, spent fluid was removed via an evacuation system consisting of a 270 mm diameter conical collection funnel, a section of 100 mm diameter PVC tubing and a pair of 1.7 kW (Craftsman) vacuum cleaners. The flow rate through the evacuation system was approximately the volume flow rate exiting the nozzle, thus reducing droplet recirculation.

The nozzle assembly during the coal slurry part of this study was suspended over a 102 cm wide, 65 cm high, 153 cm long aluminum spray box by a frame (Unistrut). The box served as a collection vessel. Spray recirculation was minimized by exhausting the atomized fluid via a 61 cm by 63 cm rectangular duct and a centrifugal blower whose volume flow rate was sufficient to draw all the atomizing air out of the laboratory.

3.4 Calibration of Instrumentation

Calibrations were performed on the Micromotion flow meter and the rotameters. The Micromotion flow meter operates on the principle of Coriolis effects as noted in the Micromotion operations manual. To summarize, as fluid flows through the U shaped tubing, Coriolis forces cause the tubing to twist. The magnitude of the displacement caused by the twisting motion is determined via Newton's second law and is insensitive to changes in temperature, pressure, and viscosity. The insensitivity of the device to fluid properties allows fluids other than those employed in the experiment to be used during calibration. This was verified by calibrating first with water, then recalibrating with air.

Calibration of the Micromotion was performed by collecting and timing tap water as it flowed through the device. The accumulated water was then weighed on a beam balance (Fairbanks Morse model 532) and the flow rate determined. Adjustment of the span and zero on the Micromotion A/D converter allowed the measured and predicted flow rates to be matched at high, moderate and low values. After calibration, the Micromotion measured the flow rate with an accuracy of ± 0.1 g/s.

The rotameters measure flow rate in terms of the drag produced by the flow of a fluid past a float located in a tapered tube. Since drag depends on the density and viscosity of the fluid flowing past the float, it is sensitive to temperature and pressure; therefore, the rotameter must be calibrated at the temperature and pressure at which it is to be used. In addition, since viscosity is fluid dependent, rotameters must also be calibrated using fluid that is to be employed in the experiment.

The rotameter was calibrated by connecting it in series with a dry gas volume flow meter (American Meter DTM 115). Air pressurized to 3.4 MPa was passed through the rotameter and then through the gas flow meter where time and volume displaced were measured. This procedure was performed on both rotameters for high, intermediate and low flow rates. The calibration proved to be linear and was fitted to the equation

$$\dot{m} = A \cdot R + B \tag{10}$$

where A and B are coefficients and R is the scale reading. For the large flow meter A = 0.145 g/s and B = 0.35 g/s and for the small rotameter A = 0.15 g/s and B = 0.0 g/s. In order to correct for errors in the measured flow rate due to slight changes in the system pressure, the flow rate was multiplied by the square root of the ratio of actual pressure to calibration pressure, as recommended by the rotameter manufacturer and verified by Roesler [1987].

All pressure gauges were dial type and were calibrated using a portable gauge tester (Ashcroft model 1305).

3.5 Particle Sizing Systems

Droplets of CWS consist of a multitude of coal particles suspended in water. When heated, the water evaporates leaving a non-spherical, opaque particle. The non-sphericity precludes the use of several types of particle sizing instruments, including the Phase-Doppler Particle Analyzer. Fortunately, forward diffraction instruments circumvent this problem since they do not require spherical particles in order to provide a measure of mean drop size and drop size distribution [Hirleman and Wittig, 1977]. Details of the theory underlying these instruments are outlined by Van de Hulst [1981] with a practical application discussed by Swithenbank et al. [1976].

This study employed two particle sizing systems: the Malvern Particle Analyzing System and a second system that was developed at the Purdue Thermal Sciences and Propulsion Center. Both are described in this section.

3.5.1 Purdue Laser Diffraction System

The diffraction based particle sizing instrument shown in Figure 4 was used to obtain spray drop sizes and is based on the Fraunhofer diffraction technique. This particular system was developed by Rizk and Lefebvre [1984] and modified by Roesler [1988]. It provided line-of-sight measurements of mean drop size and drop size distribution.

The instrument consisted of a He-Ne laser (Melles-Griot 05-LHR-151), whose output was mechanically chopped (Stanford Research SR540) and then spatially filtered (Newport Research 900 assembly, 25 μm pin-hole and 10X microscope objective). The beam was then collimated using a 25 mm diameter f/4 lens. The resulting 12 mm beam traversed the spray along a diameter where some of it was scattered. Scattered and unscattered light was collected by a 50 mm diameter f/10 lens and focused on a 5 μm pin-hole. The collecting lens was located not more than 500 mm from the most distant edge of the spray.

The scattered light energy profile collected by the lens was scanned horizontally in its Fourier transform plane using a photo-multiplier tube (EMI 9658R) that was attached to the 5 μm pin-hole. The photo-multiplier tube (PMT) and

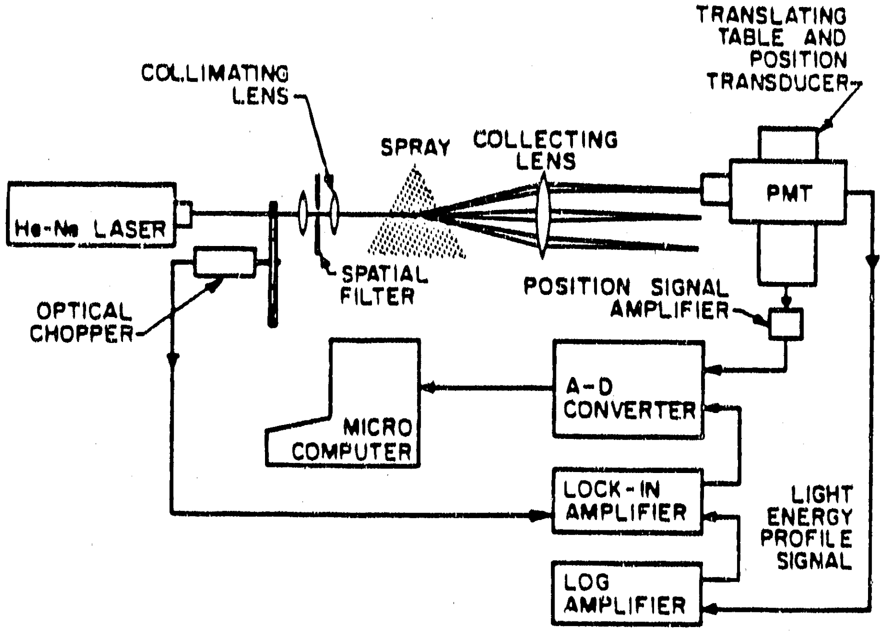

Figure 4. Purdue drop size measurement system.

pin-hole were mounted on a translation stage (Newport 430) whose position was monitored by a linear potentiometer. The PMT output signal was then amplified by an analog signal processor (Stanford Research SR235), with phase sensitive detection (Stanford Research SR510 lockin amplifier) employed to improve the signal-to-noise ratio. The amplified signal was processed using an A/D converter (located in a Hewlett-Packard HP7090A Measurement Plotting System) and fed to a dedicated micro-computer (Zenith Z-158). The output from the position sensitive linear potentiometer located on the translation stage was also fed to the microcomputer. The computer reduced the data and determined Rosin-Rammler parameters using software developed by Roesler [1988].

A comparison of the diffraction system performance with that of the Malvern was made by Roesler and is outlined in his thesis [Roesler 1988]. Roesler's procedure was as follows. First, the Purdue instrument was used to obtain drop size data from a water spray produced by a pressure swirl atomizer (Hago 15-80). The data was compared to drop size measurements made using the Malvern Spray Analyzer with the result that the Malvern consistently over predicted the value returned by the Purdue instrument by approximately 10 μm. Second, theoretical light intensity profiles were generated and then reduced using the Purdue instrument software. Repeatability for the Purdue instrument was within 2 % of the theoretical SMD and within 4 % of the two Rosin-Rammler size distribution parameters. The Malvern, in contrast, could not approach the 2 % repeatability of the Purdue system and repeatability became worse as the theoretical SMD exceeded 100 μm.

Instrument repeatability and day-to-day variation was determined using a standard calibration reticle [Hirleman 1983]. Repeatability and day-to-day variation were both ±3 μm.

3.5.2 Malvern Particle Sizing System

As the study progressed, it became evident that scatter associated with the Purdue instrument was unacceptable in too many cases. The Malvern Spray Analyzer (model 2600D), being able to provide more repeatable results, was thus employed to alleviate this problem.

The Malvern, shown in Figure 5, operates on the same principle as the Purdue system with the most significant difference being that the Malvern incorporates a circular photo-detector containing 32 diode rings to record the scattered light distribution. The Malvern also uses an additional diode, located at the center of the detector, to measure the amount of light being scattered thus providing an indication of when multiple scattering is occurring. The existence of multiple scattering is important, as shown by Dodge [1986], since the measured value of the mean drop size begins to deviate substantially from the actual mean drop size when multiple scattering is present. A correlation was derived by Dodge to correct for this deviation. A similar correction scheme has been incorporated into the Malvern software, but its details are obscure since the software is proprietary.

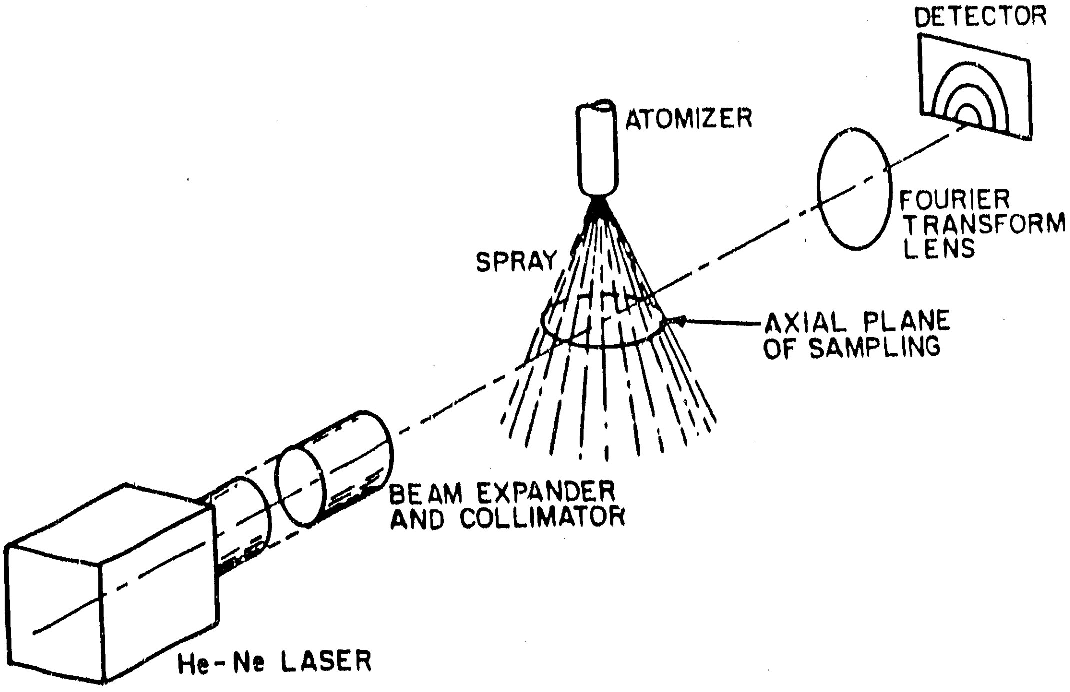

Figure 5. Schematic of the Malvern Particle Size Analyzer, Knoll [1989].

3.6 Photographs

A photographic study was undertaken to determine the flow structure in the nozzle and to photograph the formation of the spray in order to better understand the atomization process. Photographs of the flow structure in the nozzle were taken 30 mm upstream of the final orifice. Photographs of the spray formation process were taken immediately downstream of the final orifice, 150 mm downstream of the final orifice and 250 mm downstream of the final orifice.

Photographs were obtained using a 35 mm single lens reflex camera (Nikon F2) and a 135 mm lens (Nikkor-Q) mounted on a bellows (Nikon II). This combination of lens and camera allowed photographs to be made at a magnification of 2. Images were recorded on black-and-white film (Kodak Tmax 400), push processed to ASA 3200. Illumination was provided by a micro-flash (EG&G model 549) which had a flash duration of 0.5 μs. Further details are provided in Roesler's thesis [Roesler 1988].

3.7 Shadowgraphs

Shadowgraphs of the spray immediately downstream of the nozzle were obtained in order to record the density gradients produced when the flow underwent rapid expansion after exiting through the final orifice. The objective of these photographs was to verify the premise that supersonic flow was being generated at the nozzle exit, the information being necessary to determine if choked flow existed.

Shadow photographs were obtained using a pair of 2.03 m radius of curvature, 254 mm diameter, parabolic, front silvered mirrors to collimate and then refocus the output from a high pressure mercury arc lamp. Images were recorded using the 35 mm single lens reflex camera mentioned above with film normally processed. Further details of this system are provided by Richards [1987].

3.8 Viscosity Measurements

Newtonian liquids of high viscosity were formulated for use in this study by decanting a known volume of 99.5% pure natural glycerine (Van Waters & Rogers, Industrial Grade USP) into a 114 liter drum and then diluting it with tap water until the desired composition was obtained. Homogeneity was insured by agitating the mixture with a three fin stirrer (Neptune Mixer Co. D-1.4 with MP1 11x11 propeller driven by a Gast Manufacturing. Corp. 4AM-NRV-50C air motor). After complete mixing was obtained, the viscosity and surface tension were evaluated.

Non-Newtonian fluids were formulated from mixtures of glycerine, tap water, and Xanthan gum. The consistency index and the flow behavior index were altered by manipulating the glycerine and polymer levels. Experience indicated that the flow behavior index was relatively insensitive to the glycerine level, so this parameter was successfully altered by adding polymer. Conversely, the consistency index was sensitive to both polymer and glycerine content. By starting with a base mixture whose consistency index was significantly below the desired value, the target value was achieved by first adding polymer until the desired flow behavior index was reached and then adding glycerine until the consistency index rose to its target value.

An attempt was made to establish a protocol for formulating the non-Newtonian liquids, but large variations in the rheological properties were found with mixtures of the same polymer and glycerine content. As a result, the development of each mixture was more art than science, but each mixture was repeatedly tested before it was spayed in order to determine its rheological properties.

The coal-water slurries used consisted of three commercially available slurries of varying grinds and loadings. The effects of reduced coal loading and polymer addition were analyzed by diluting one slurry with glycerine and later diluting this same slurry with glycerine and polymer. A total of five separate fluids were thus employed.

Viscosity measurements were made using a rotary viscometer (Haake-Buchler RV20 with PG242 controller, PT100 digital thermometer, F3 temperature controller and associated constant temperature bath). A cup and rotor measuring system (Haake-Buchler MV SP) was employed. Three silicon based oils (polyDIMETHYLSILOXANE, Petrarch Systems Inc.) having viscosities of 10, 100, and 1000 cS were used to calibrate the rheological instrumentation. The procedure used was to calibrate the instrument over the entire strain rate range that was allowed by the fluid. The measured values fell within 20 % of the standard with the percent error being constant for each fluid. After calibration, the viscosity of each fluid being sprayed was determined by fitting the measured shear stress-strain rate curve to an assumed power law expression. This was accomplished by routing the analog output of the rheometer controller to the A/D converter with the resulting digitized signal input into the microcomputer for analysis.

The rheological data were reduced from 1000 to 200 points by combining them in groups of five and averaging. The data were then transformed into a pair of column vectors and analyzed using a curve fit analysis outlined in Chapra and Canale [1985]. The analysis fitted the data to the Herschel-Bulkley viscosity model

$$\tau = \tau_s + K\dot{\gamma}^n \tag{11}$$

where τ is the shear stress in Pa, τ_y is the yield stress in Pa, $\dot{\gamma}$ is the shear rate in 1/s, K is the consistency index in $Pa \cdot s^{(1-n)}$, and n is the dimensionless flow behavior index. The advantage of using this model was that it accurately represented the rheological properties of the three classes of fluids used in this study.

The incorporation of the yield stress term in Equation (11) was necessary to minimize the error when curve-fitting the equation to the data. When the yield stress was not included, the curve-fit was forced to predict a zero shear stress at a zero strain rate which produced a poor fit. Unfortunately, the magnitude of the yield stress varied from one mixture to the next with no consistency between fluids. It was therefore concluded that the instrumentation could not accurately measure the yield stress, but that the analysis could not accurately predict n and K without it. As a result, yield stress values were used to facilitate curve fitting but were considered unreliable for analyzing the spray data.

3.9 Surface Tension Measurements

Surface tension was measured using a du-Nuoy type ring tensiometer (Cenco 70535). The tensiometer was calibrated by placing known weights (as determined by a Mettler P1200 balance) on the instrument's Pt-Ir ring and measuring the resulting gravitational force. The instrument's performance was verified by determining the surface tension of deionized water. Excellent agreement was observed as long as care was taken to keep the equipment clean. The following procedure proved satisfactory. After each measurement, the ring was washed in a water bath, dipped in alcohol, and heated thoroughly over a Bunsen burner flame and the vessel containing the test fluid was washed thoroughly with water and alcohol.

4 RESULTS

4.1 Introduction

The goals of this research were to demonstrate that effervescent atomization can produce CWS sprays with mean drop sizes below 50 μm, to determine a lower size limit for effervescent atomizer produced CWS sprays, and to determine the mechanism(s) responsible for the formation of effervescent atomizer produced sprays. Accomplishment of these goals required an analysis of the effect of coal-water slurry fluid properties and nozzle operating parameters on spray quality, specifically on the Sauter mean diameter (SMD). The liquid properties necessary for the analysis consisted of flow behavior index (n), consistency index (K), slurry coal loading, coal particle top size, the addition of polymers, surface tension and density. The flow behavior index and the consistency index were derived from the Herschel-Bulkley expression shown in Equation (11), and their effect on SMD was analyzed by manipulating them and observing changes in SMD. Coal loading was studied by diluting CWS with glycerine and top size was studied by analyzing three mixtures containing particles with maximum sizes of 15, 45 and 100 μm. Polymer addition effects were observed by analyzing a CWS mixture containing glycerine and polymer. Surface tension and density were measured for each test; however, they were not systematically changed in order to observe their influence on SMD.

The operating parameters of significance included the air-liquid ratio (ALR) and the nozzle discharge pressure. These parameters were systematically varied and their effects observed.

The study began with mixtures of glycerine and water to simplify the analysis, minimize the number of variables and facilitate data collection. Glycerine-water mixtures are highly viscous Newtonian fluids that have densities and surface tensions near those of CWS. By using these mixtures, the influence of flow behavior index and particle suspension were removed while viscosity (or consistency index) was widely varied.

Polymer was added to the glycerine-water mixtures in order to form non-Newtonian fluids and investigate the effects of n and K on SMD. The use of glycerine-water-polymer mixtures is a common practice among those who study the atomization of CWS; note Knoll [1989] and Rosfjord [1985]. By dissolving Xanthan gum into the glycerine-water mixture, the flow behavior index was decreased thereby simulating the non-Newtonian behavior of CWS. These results completed the analysis of rheological effects on SMD while eliminating effects associated with coal particles.

Addition of polymer to the glycerine-water mixtures also provided insight into the effects of varying slurry additive packages since stabilizers such as "Flocon" contain substantial concentrations of polymer. The glycerine-water data is of special interest in this respect since it indicates how additives affect effervescent atomization in the absence of complicating effects such as slurry loading and coal particle top size.

The program concluded with the spraying of five coal-water slurries. Included were three commercially available slurries, each possessing a different coal loading and coal particle top size, plus two additional slurry mixtures formulated by adding glycerine, then glycerine plus polymer to one of the neat slurries. In this way, large changes in consistency index, flow behavior index, loading, and coal particle size were achieved and their effects on SMD determined.

The results obtained are presented in the graphs below, with all raw data tabulated in the Appendix. In each figure, Sauter mean diameter is plotted versus one of the parameters mentioned above with the remaining parameters held within a defined range represented by a nominal value (values listed in subheadings and legends represent this nominal value). The ordinate of a plot represents actual values to provide a true representation of the data and an accurate determination of trends.

4.2 Fluid Physical Properties

Data describing the physical properties of the 24 different liquids sprayed during this study are reported in Tables 1 to 3. These liquids consisted of glycerine-water solutions used to investigate Newtonian fluid behavior, glycerine-water-polymer (Xanthan gum) solutions used to investigate non-Newtonian fluid behavior and coal-water slurries used to investigate two-phase fluid behavior. The properties of relevance to this study were: consistency index, flow behavior index, particle top size, coal loading, surface tension and density.

4.2.1 Single Phase Liquids

Ten Newtonian liquids were tested. Their properties are listed in Table 1 and a marker is provided that denotes the test series each fluid was associated with. Viscosities for the Newtonian liquids varied from 384 to 968 cP. They were divided into 3 groups: 400 cP, 520 cP and 800 cP. These are nominal values used mainly to designate low, medium and high viscosity. Surface tension and density for all of the liquids was approximately 64 dynes/cm and 1.26 g/cm^3, respectively, since glycerine content dominated these properties.

Table 2 lists the properties of the non-Newtonian liquids. Flow behavior indices varied from 0.85 to 0.95. Consistency indices were approximately matched with the viscosities of the Newtonian mixtures and ranged from 400 to 930 $cP - s^{n-1}$.

Table 1: Glycerine-Water Mixture Physical Properties

Mixture	K, $cP-\sec^{n-1}$	n,	σ, dynes/cm	ρ, g/cm^3
1 (test 1)	384	1.0	64	1.26
2 (test 1)	420	1.0	64	1.26
3 (test 1)	520	1.0	64	1.26
4 (test 1)	537	1.0	64	1.26
5 (test 1)	874	1.0	64	1.26
6 (test 1)	968	1.0	64	1.26
7 (test 2)	487	1.0	64	1.26
8 (test 2)	586	1.0	64	1.26
9 (test 2)	800	1.0	64	1.26
10 (test 2)	852	1.0	64	1.26

Table 2: Glycerine-Water-Polymer Mixture Physical Properties

Mixture	K, $cP-\sec^{n-1}$	n,	σ, dynes/cm	ρ, g/cm^3
1	400	0.85	68	1.13
2	510	0.85	68	1.13
3	930	0.86	68	1.13
4	420	0.90	66	1.20
5	570	0.90	66	1.20
6	780	0.90	66	1.20
7	450	0.95	65	1.22
8	520	0.94	65	1.22
9	840	0.94	65	1.22

4.2.2 Coal-Water Slurries

A total of five coal-water slurries were sprayed during this study. Three of the slurries were commercially available and had varying grinds and loadings. They were identified as slurry 1 (45 μm top size), slurry 2 (100 μm top size) and slurry 3 (15 μm top size). The other two slurries were derived from slurry 3 by either diluting it with 99.5% pure USP glycerine or with glycerine plus a polymer (Xanthan gum). The rheology of all five slurries, in terms of the consistency index, K, which ranged from 133 to 1964 $cP - \sec^{n-1}$, and the flow behavior index, n, which ranged from 0.603 to 1.03, is reported in Table 3. Slurry surface tension was measured and varied from 54 to 78 dyne/cm as shown. Yield stresses were not reported since they were not used in any analysis and were therefore unimportant to the study.

Table 3: Coal-Water Slurry Physical Properties

Slurry	Top Size, μm	Loading, wt-%	K, $cP - \sec^{n-1}$	n,	σ, dyne/cm	ρ, g/cm^3
1	45	65	181	1.03	54	1.2
2	100	57	1777	0.603	78	1.2
3	15	58	1964	0.763	72	1.2
3+gly	15	49	133	0.961	70	1.2
3+gly+ply	15	49	630	0.878	71	1.2

4.3 Newtonian Liquid Spray Data

Two studies were undertaken using glycerine and water solutions. In the first study, six fluids were sprayed and drop size data were collected using the instrumentation described in Section 3.5.1. In the second study, the drop sizing instrumentation was changed to the Malvern and four additional fluids were sprayed with viscosities and flow conditions similar to those of the first study.

Spray data for the Newtonian fluids is shown below in Figures 6 through 9. Figure 6 shows air-liquid ratio has a significant effect on SMD over the range 0.04 to 0.15. The influence diminishes, however, as ALR increases from 0.15 to 0.34. This result is supported by the findings of Roesler [1988] and of Wang et al. [1987] and is explained by recognizing that entrainment losses become more severe as ALR is increased.

Figure 7 depicts the lack of an effect of consistency index (or viscosity for Newtonian fluids) on SMD where no correlation is observed for a two fold increase in μ. This behavior is unique to effervescent atomization since most spray nozzles exhibit a significant dependence of SMD on viscosity. The absence of a relationship between SMD and viscosity is explained by considering the two mechanisms of liquid break up: shearing interaction between the liquid and the air, known as primary atomization, and competition between droplet surface tension and pressure forces caused by the velocity of the droplet relative to the air, known as secondary atomization. In general, liquid break up due to shearing action between fluids is a function of liquid viscosity. Effervescent atomization demonstrates no dependence of SMD on liquid viscosity; therefore, it is concluded that shearing action has no effect on the atomization process. However, the relative velocity between the droplets and air is very high which would produce large pressure forces on the droplets. This suggests that secondary atomization has a strong effect on the atomization process and is the controlling factor. This conclusion is supported by Brown and York [1962] who observed that the rapid expansion of vapor bubbles in flashing atomization tears the liquid into shreds much like the air bubbies of effervescent atomization.

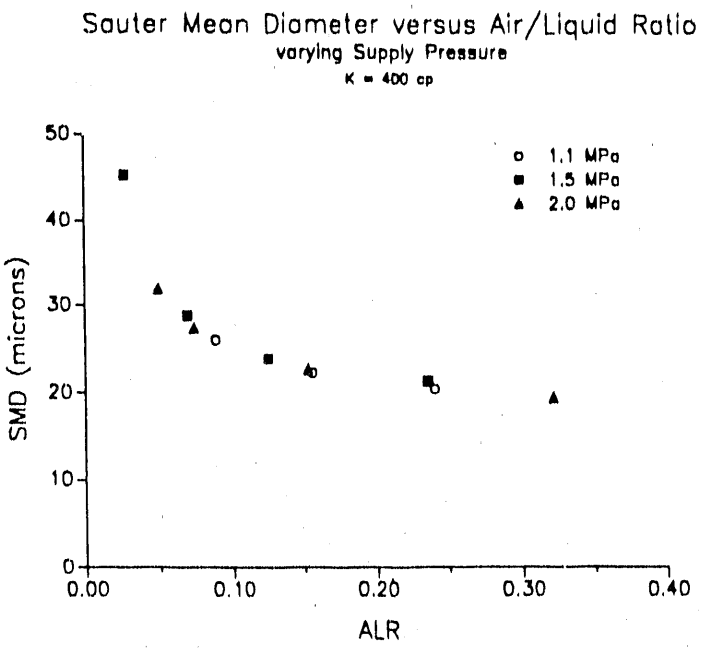

Figure 6. Sauter mean diameter versus air-liquid ratio for glycerine-water mixture 6, K = 400 cP.

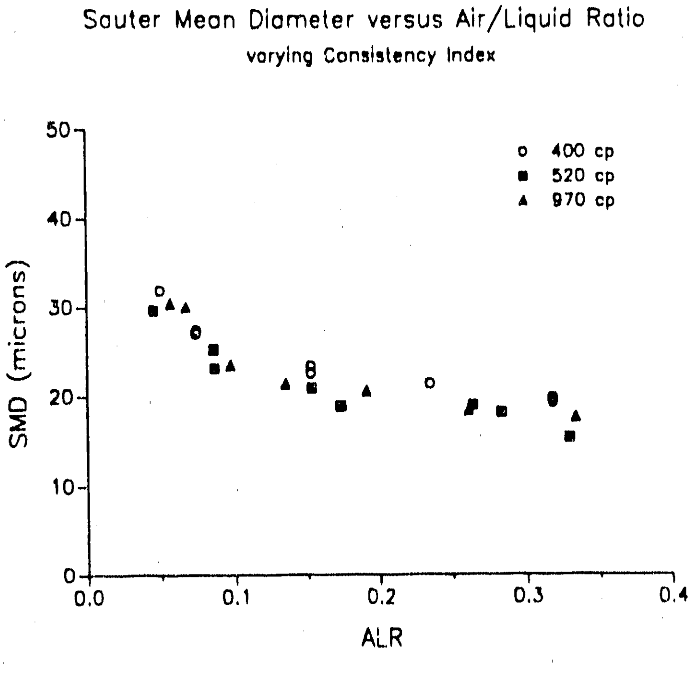

Figure 7. Sauter mean diameter versus air-liquid ratio for glycerine-water mixtures 2, 4, and 6, varying K.

The effect of discharge pressure on SMD is shown in Figures 8 and 9. When ALR is as high as 0.34, the effect of discharge pressure is very small. Notice that the profile in Figure 8 is flat over a pressure range of 1.1 to 2.4 MPa. This behavior changes when ALR is small; at an ALR of 0.085, a change of 50 μm is observed in Figure 9 when pressure changes from 0.75 to 1.5 MPa. The diminishing influence of pressure on SMD as ALR is increased was also observed by Roesler [1988] and Lefebvre et al. [1988] and can be explained by recognizing that at high ALR, energy losses associated with entrainment become so large that any increase in available energy associated with an increase in pressure is quickly lost to the ambient and has no effect on SMD. On the other hand, when ALR is low, a liquid shroud surrounds the expanding gas shielding it from entrainment and associated losses; therefore, increased energy input due to an increase in pressure is not lost to the ambient but contributes to liquid break up.

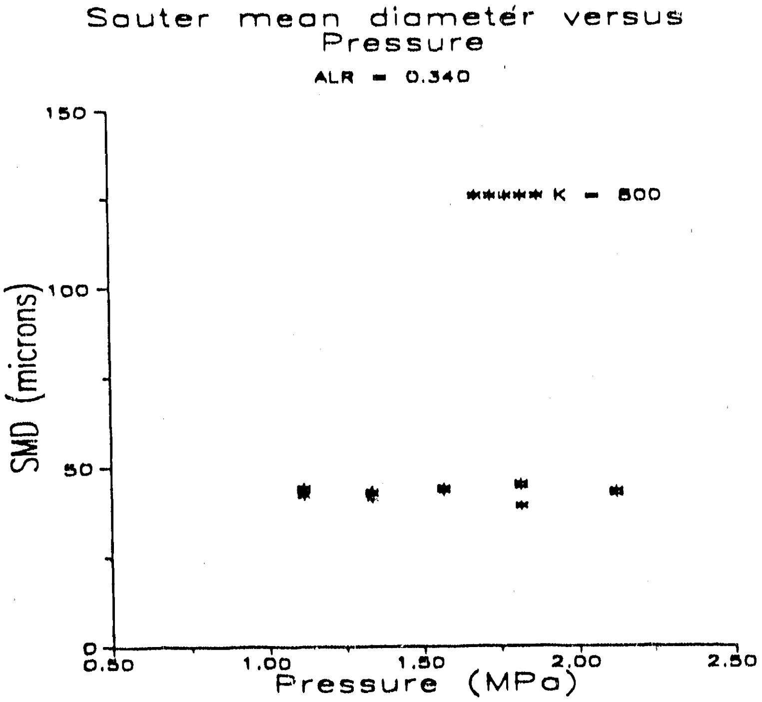

Figure 8. Sauter mean diameter versus pressure for glycerine-water mixture 9, ALR = 0.340.

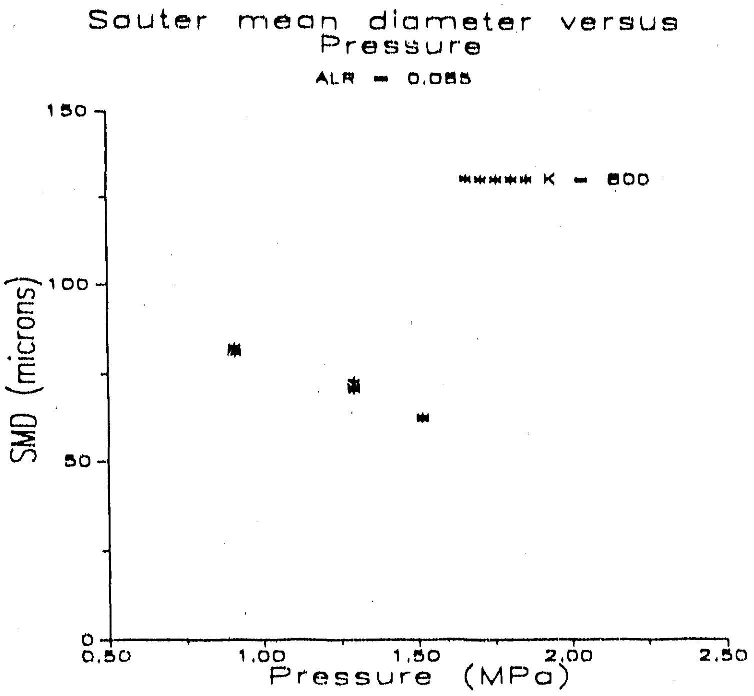

Figure 9. Sauter mean diameter versus pressure for glycerine-water mixture 9, ALR = 0.085.

4.4 Non-Newtonian Spray Data

Figures 10 through 12 show data obtained when atomizing nine non-Newtonian glycerine-water-polymer solutions. The results of this study were similar to the Newtonian results previously shown.

The effect of ALR on SMD is shown in Figures 10 and 11 for K values of 850 and 420 $cP - \sec^{n-1}$. There are only slight differences between these results and those shown in the preceding section: when atomizing solutions containing polymer, SMD increased, especially in the low ALR region. A change in ALR had a smaller effect on SMD in the low ALR range than for fluids containing no polymer, changing the slope of the SMD versus ALR curve, while at high ALR the polymer solutions atomize in the same manner as the non-polymer solutions.

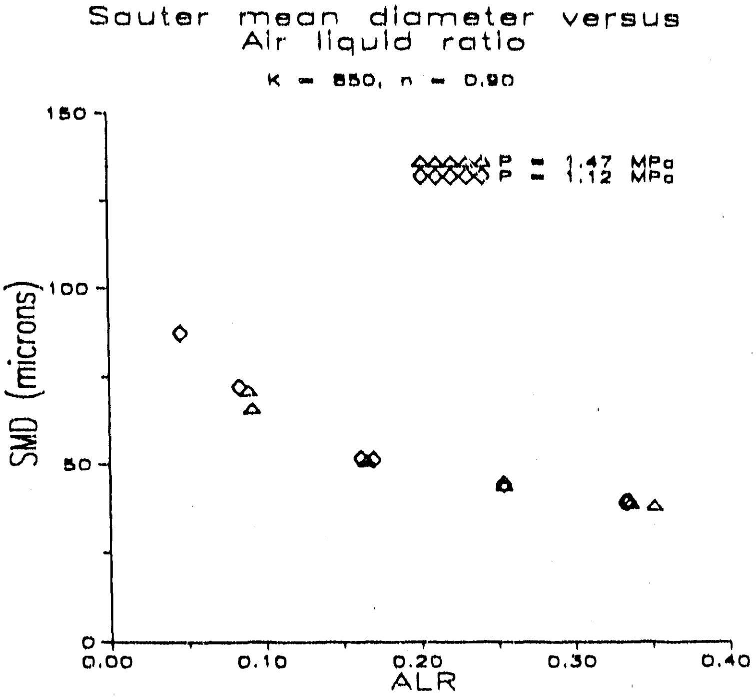

Figure 10. Sauter mean diameter versus air-liquid ratio for glycerine-water-polymer mixture 6, K = 850 $cP - \sec^{n-1}$.

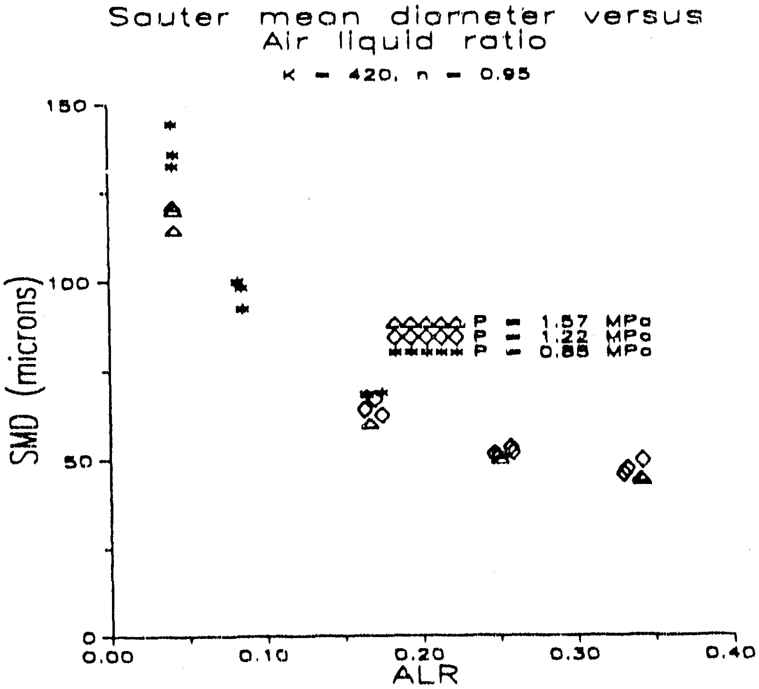

Figure 11. Sauter mean diameter versus air-liquid ratio for glycerine-water-polymer mixture 7, K = 420 $cP - \sec^{n-1}$.

Figures 12 through 15 show SMD versus consistency index and indicate no consistent change in SMD for a two fold increase in K. Similarly, no consistent effect of flow behavior index could be found as n changed from 0.85 to 0.95, as shown in Figures 16 and 17. These results conclusively demonstrate that non-Newtonian rheology, as characterized by n and K, has no effect on the quality of effervescent atomization. This is evidence that effervescent atomization is not controlled by fluid mechanic instabilities, but is instead dominated by secondary atomization.

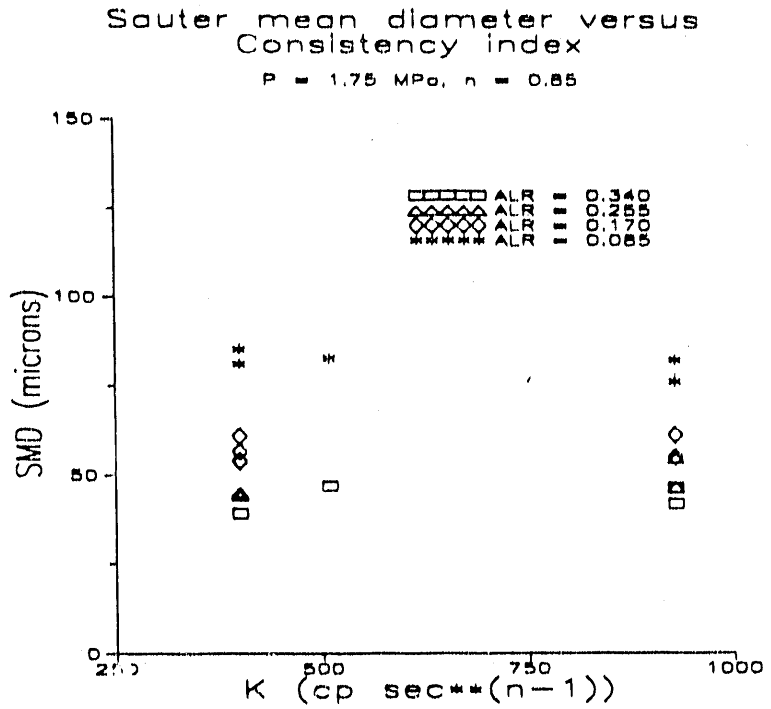

Figure 12. Sauter mean diameter versus consistency index for mixtures 1, 2, and 3, P = 1.75 MPa.

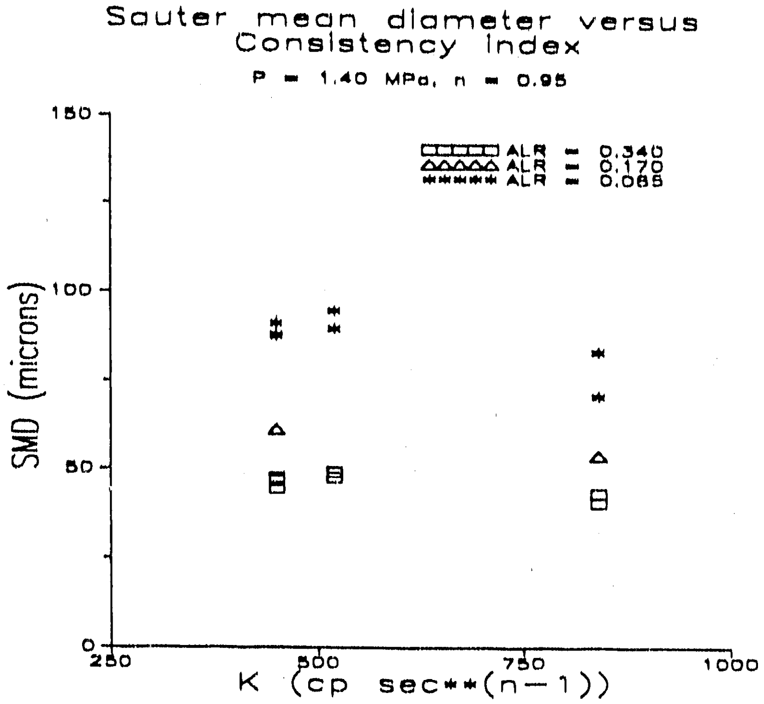

Figure 13. Sauter mean diameter versus consistency index for mixtures 7, 8, and 9, P = 1.4 MPa.

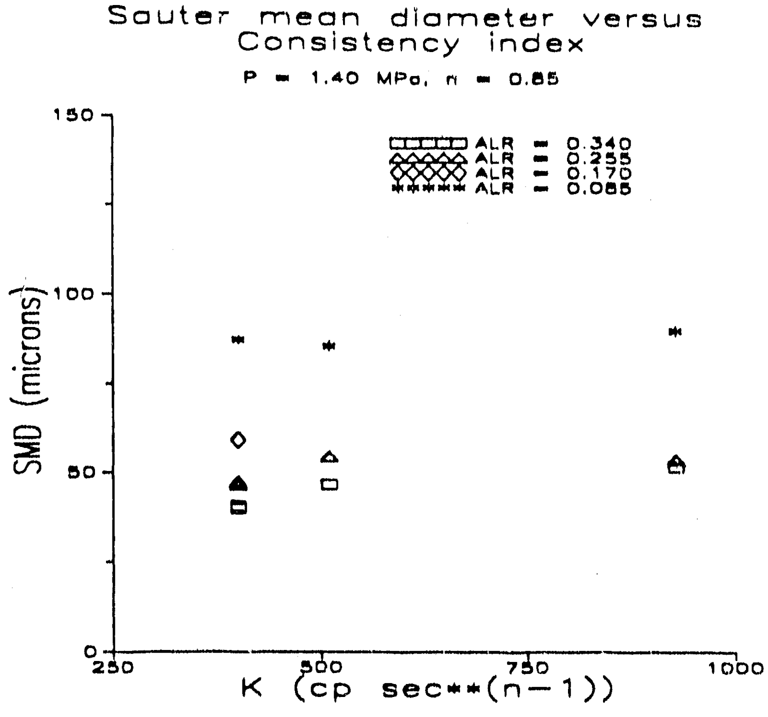

Figure 14. Sauter mean diameter versus consistency index for mixtures 1, 2, and 3, P = 1.4 MPa.

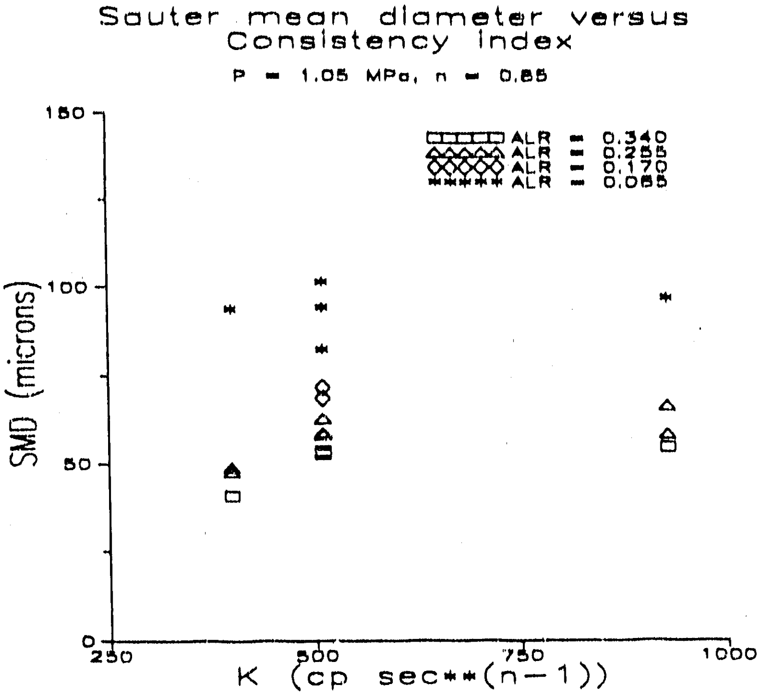

Figure 15. Sauter mean diameter versus consistency index for mixtures 1, 2, and 3, P = 1.05 MPa.

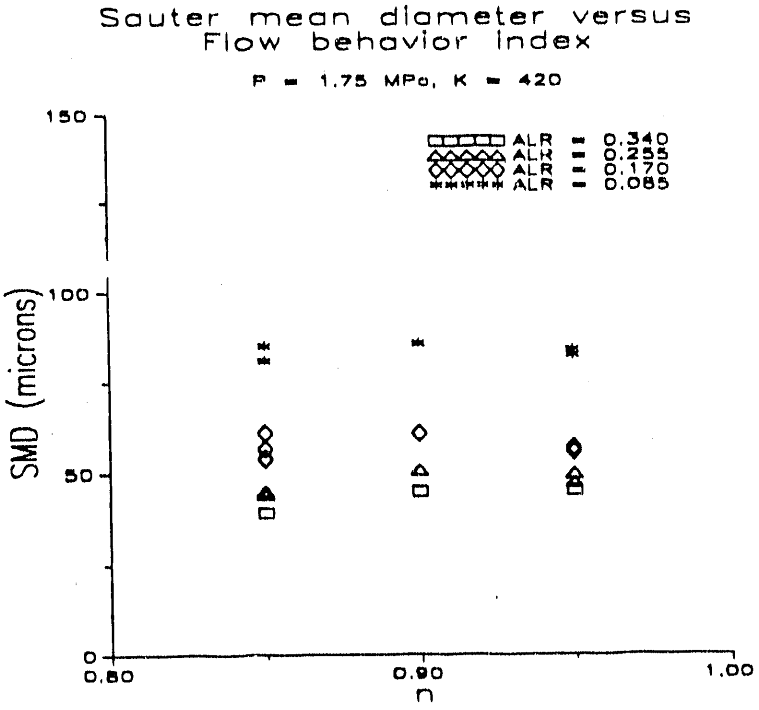

Figure 16. Sauter mean diameter versus flow behavior index for mixtures 1, 4, and 7, P = 1.75 MPa.

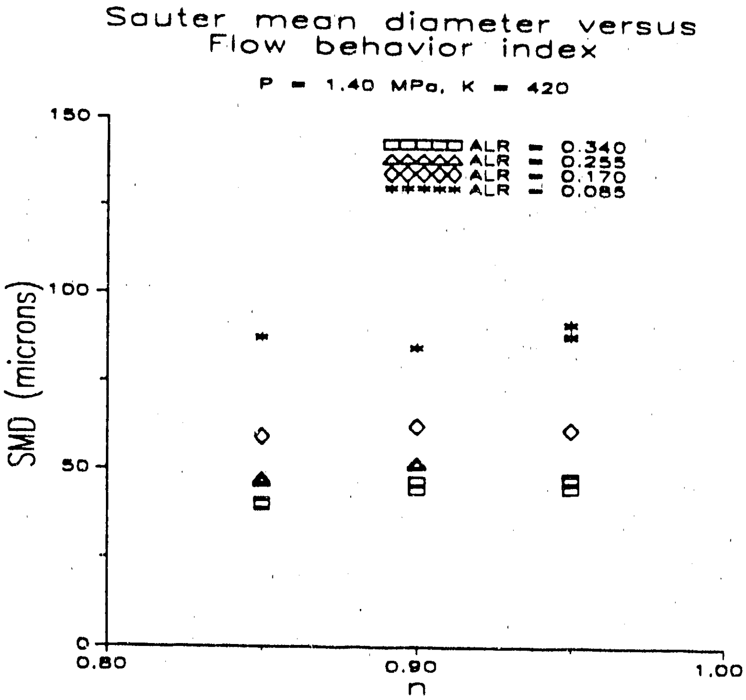

Figure 17. Sauter mean diameter versus flow behavior index for mixtures 1, 4, and 7, P = 1.4 MPa.

The effect of discharge pressure on SMD is shown in Figures 18 through 22, where SMD versus pressure is presented for decreasing values of ALR. The results are the same as in the Newtonian study showing that changes in pressure at high ALR (above about 0.2) have no effect on SMD, while an increase in pressure at low ALR (below about 0.2) leads to a slight decrease in SMD. When comparing these results with those of Figures 8 and 9, it is obvious that non-Newtonian flow behavior does not change the influence of pressure on SMD. It is therefore concluded from the Newtonian data describing the effect of consistency index and discharge pressure on SMD, plus the non-Newtonian data describing the effects of consistency index, flow behavior index and discharge pressure on SMD, that the dominant mechanism of atomization is the same for both Newtonian and non-Newtonian fluids.

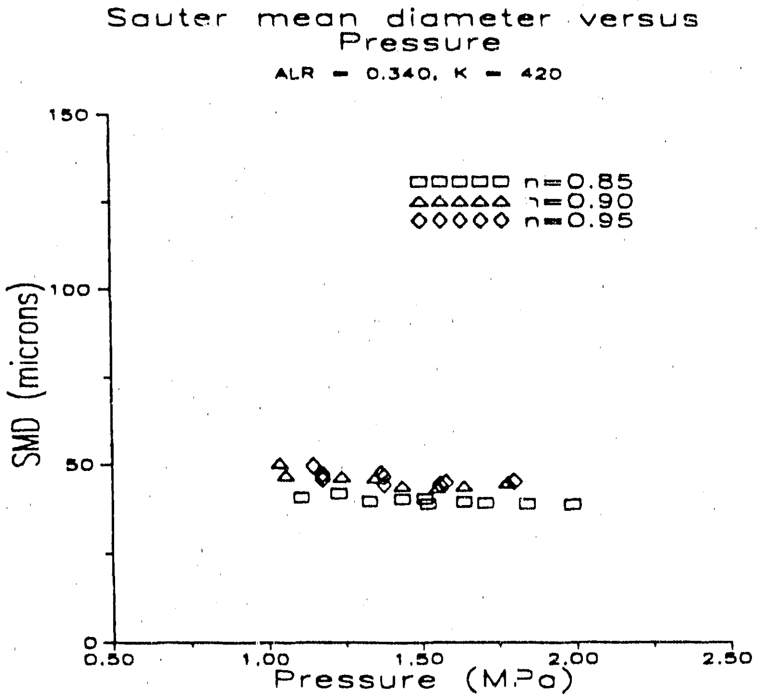

Figure 18. Sauter mean diameter versus discharge pressure for mixtures 1, 4, and 7, ALR = 0.344.

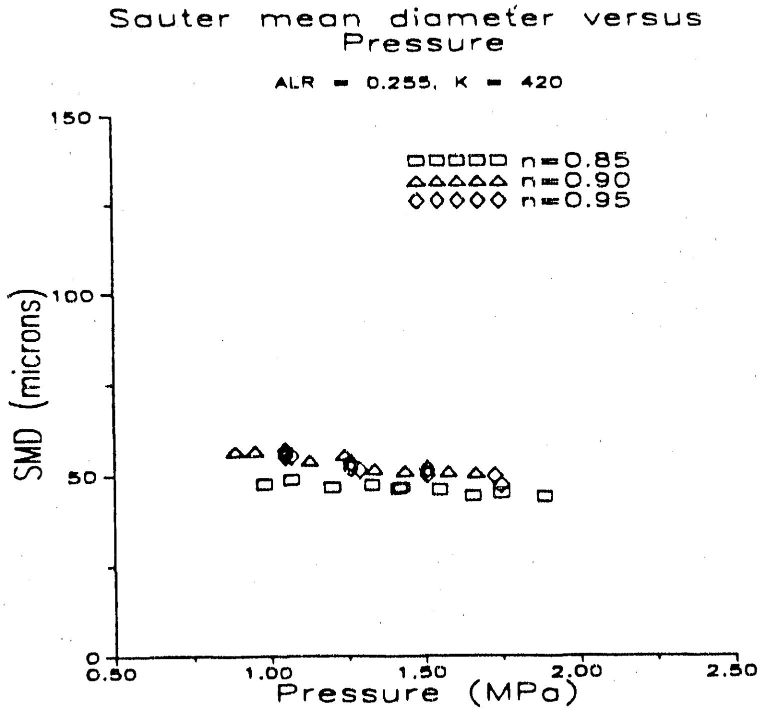

Figure 19. Sauter mean diameter versus discharge pressure for mixtures 1, 4, and 7, ALR = 0.255.

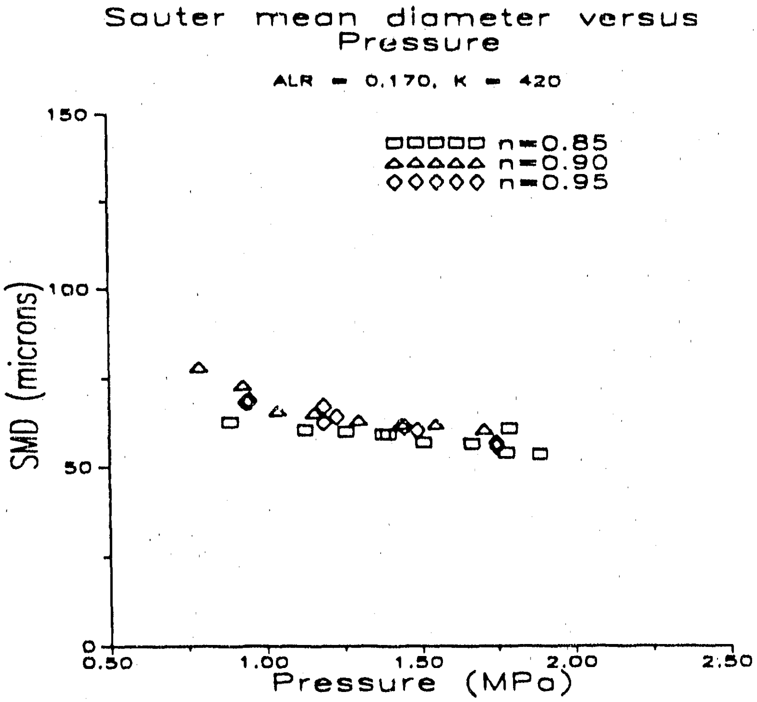

Figure 20. Sauter mean diameter versus discharge pressure for mixtures 1, 4, and 7, ALR = 0.170.

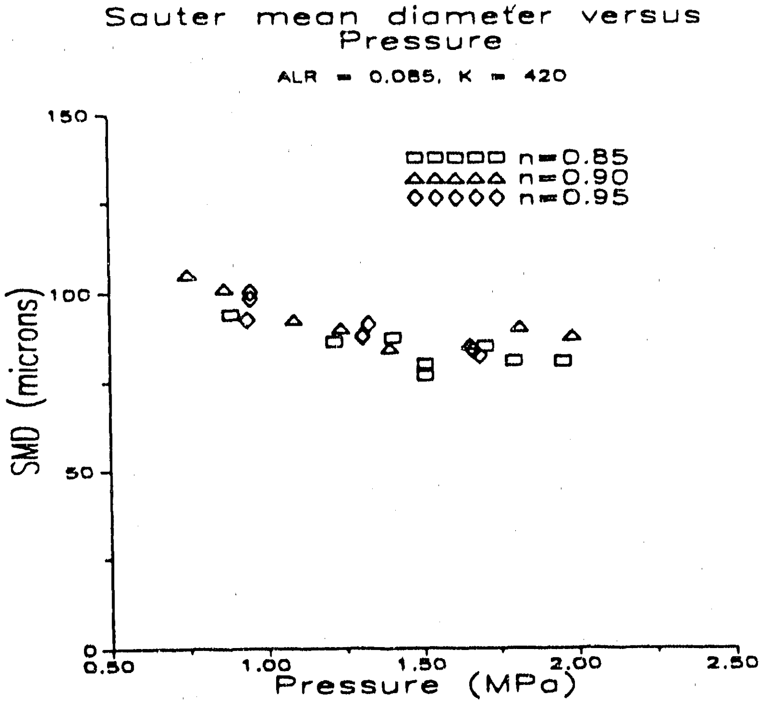

Figure 21. Sauter mean diameter versus discharge pressure for mixtures 1, 4, and 7, ALR = 0.085.

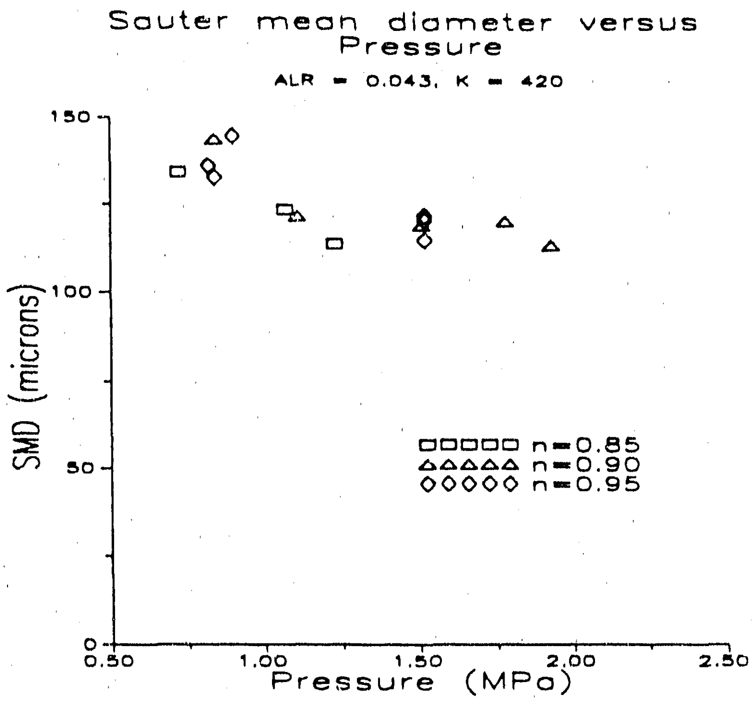

Figure 22. Sauter mean diameter versus discharge pressure for mixtures 1, 4, and 7, ALR = 0.043.

The data of Figures 10 through 22 show how operating parameters and liquid properties affect atomization quality, but they do not show why SMD increased in the low ALR region when polymer was added to the glycerine-water solutions. One possible explanation is that the viscoelastic and yield stress characteristics of Xanthan gum solutions have an effect on the atomization quality. Assuming this hypothesis is true, more energy would be required to overcome the forces associated with viscoelasticity and yield stress and therefore an increase in SMD would be observed. At low ALR, the effect of the fluid properties predominates, but as ALR increases, the energy associated with the large mass of air is able to dominate the atomization process and overcome the effect of the polymer. As a result, mean drop sizes at high ALR are smaller and resemble those of the Newtonian data.

Unfortunately, it was not possible to test this hypothesis since the available rheological instrumentation was incapable of providing the necessary data. This topic should, however, be pursued in future studies because of the relationship between polymers and stabilizers and the necessity of adding stabilizers to CWS.

4.5 Coal-Water Slurry Spray Data

Five coal-water slurries were sprayed using the Malvern for drop size measurements. During the coal-water slurry study, some equipment changes were made in order to eliminate problems associated with flowing CWS in small diameter tubing. The glass observation tube in the atomizer was replaced with an equivalent stainless steel model and the diameter of the final orifice was increased to 2.5 mm. In addition, the spray collection system was changed to a spray box and the slurry was driven by a 9 stage positive displacement pump as described in Section 3.3.

The drop size data obtained when spraying coal-water slurry are presented in Figures 23 through 29. Figures 23 and 24 show the effect of ALR on SMD. The results are the same as in the single phase fluid studies: there was a diminishing effect of ALR on SMD as ALR was increased. Notice, that with ALR as low as 0.045, SMD was as low as 55 μm. It would take an ALR of approximately unity to achieve similar SMD values using a conventional air-assist nozzle. Furthermore, an increase in ALR to 0.15 decreases SMD to about 33 μm. Sauter mean diameters this low cannot be readily achieved using even advanced design air-assist nozzles. The data also suggest that mean drop sizes below 25 μm are obtainable using effervescent atomization. Equipment limitations precluded attaining this value, however, because the minimum liquid flow rate increased from 10 g/s during the single phase fluid tests to 40 g/s during the CWS tests; therefore, an ALR greater than 0.17 could not be achieved when spraying CWS. It is exciting to note that when sub-25 μm mean drop sizes are obtained, substantial increases in coal burnout will result, along with increased combustion efficiency and smaller heat engines for a fixed power rating.

In summary, the results of Figures 23 and 24 demonstrate that (1) effervescent atomizers can achieve quality coal-water slurry atomization even at low values of ALR, and (2) the performance of even a prototype effervescent atomizer is superior to that of advanced design air-assist nozzles.

In addition to illustrating the excellent SMD values achievable using effervescent atomization, Figures 23 and 24 also demonstrate that slurry formulation had little effect on atomizer performance. See Figure 23 where the loading of the 45 and 100 μm slurries differed by 14 %, yet no change in SMD was observed, and Figure 24 where coal loading varied by 19 % between undiluted slurry 3 and slurry 3 diluted with glycerine while SMD changed only slightly. The change in SMD resulting from changes in particle top size was also slight. No change in SMD was observed between the 45 and 100 μm top size slurries, as shown in Figure 23, while the change in SMD between the 100 and 15 μm top size slurries was less than 15 μm.

Figures 25 through 29 show discharge pressure had the same effect on CWS mean drop size as shown in Sections 4.2 and 4.3: a slight decrease in SMD with discharge pressure at low ALR values and no dependence of SMD on ALR at air-liquid ratios. Figures 28 and 29 show the dependence at low ALR to be more pronounced in the slurry mixtures containing glycerine and glycerine with polymer. The reasons for these differences are not entirely understood at the present time; however, based on single phase fluid results, it is concluded that yield stress or viscoelasticity are the source of the observed variations since all fluid properties were recorded with the exception of these.

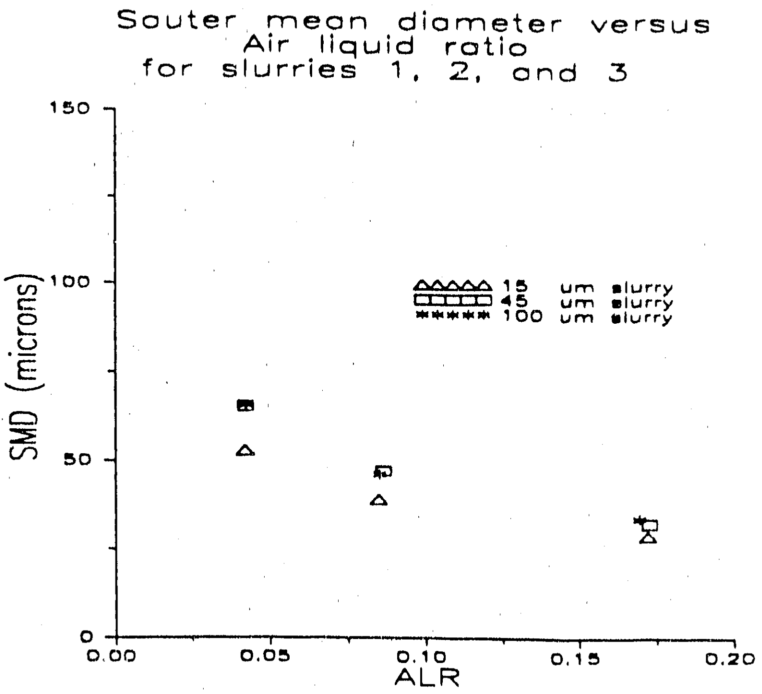

Figure 23. Sauter mean diameter versus air-liquid ratio for slurries 1, 2, and 3.

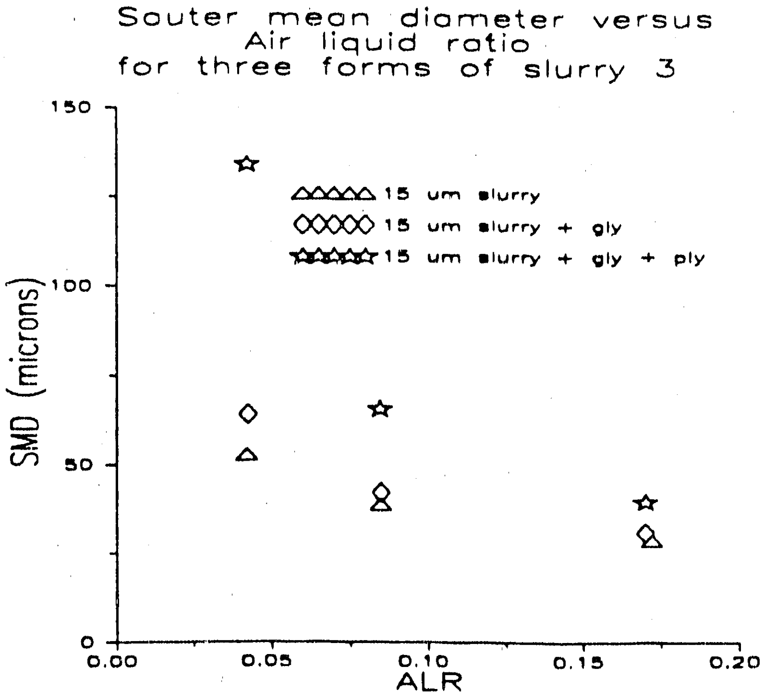

Figure 24. Sauter mean diameter versus air-liquid ratio for slurry 3 undiluted, diluted with glycerine, and diluted with glycerine and polymer.

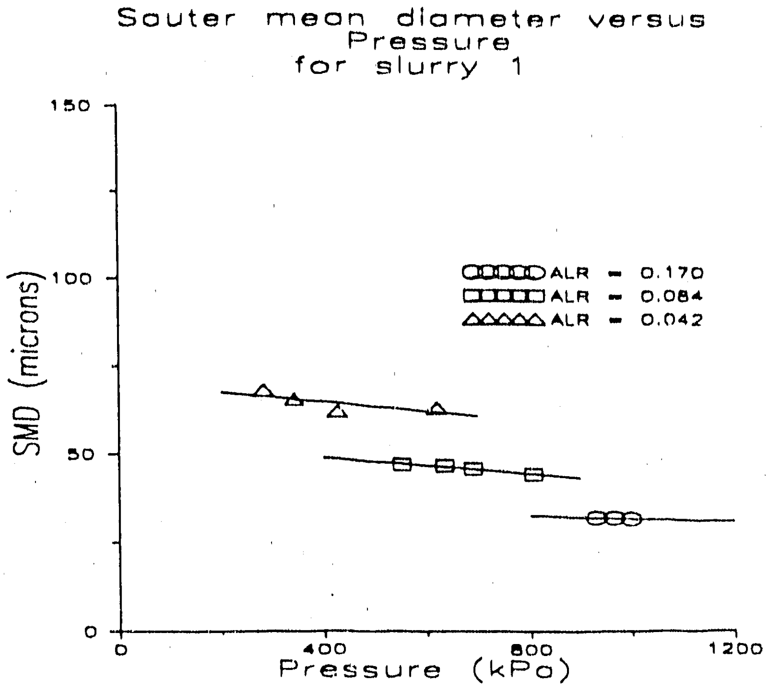

Figure 25. Sauter mean diameter versus discharge pressure for slurry 1.

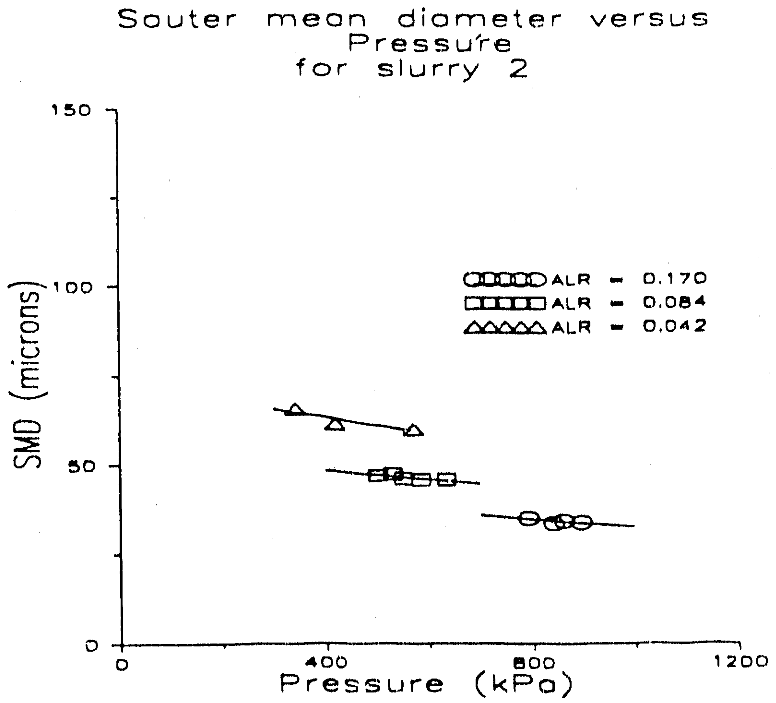

Figure 26. Sauter mean diameter versus discharge pressure for slurry 2.

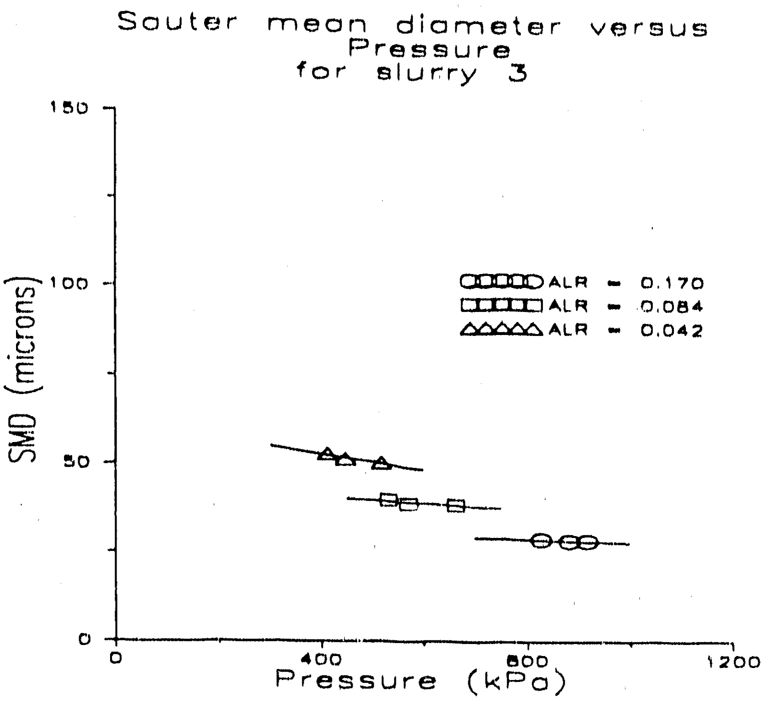

Figure 27. Sauter mean diameter versus discharge pressure for slurry 3.

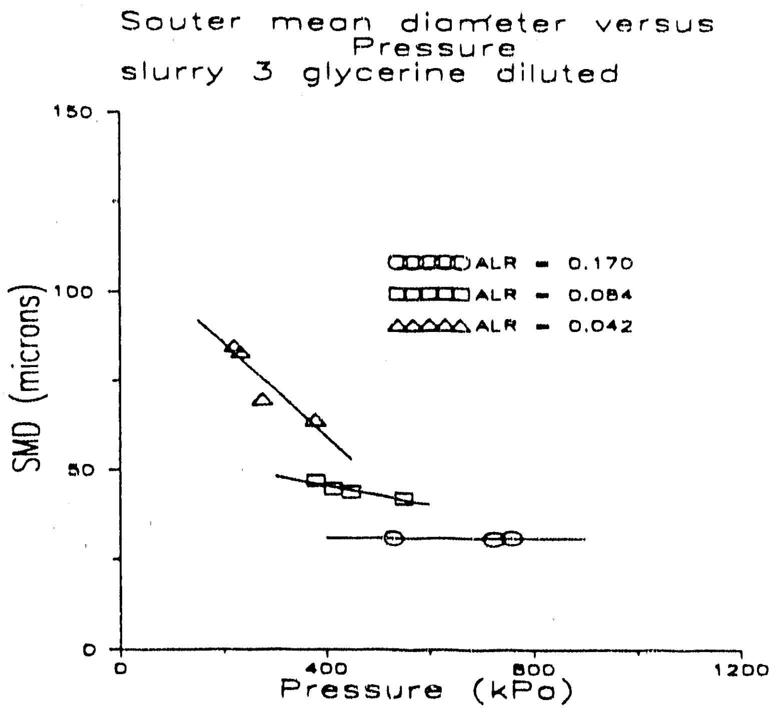

Figure 28. Sauter mean diameter versus discharge pressure for slurry 3 diluted with glycerine.

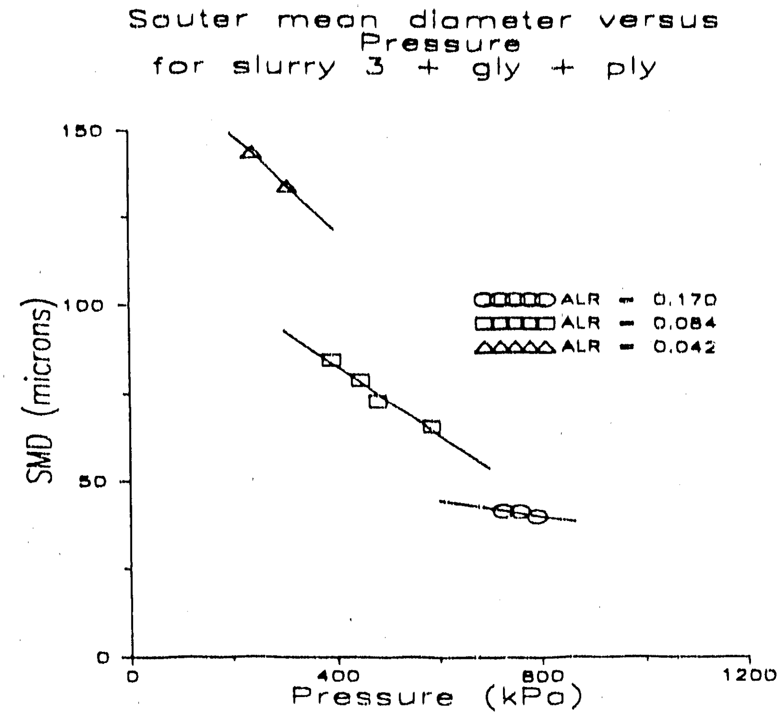

Figure 29. Sauter mean diameter versus discharge pressure for slurry 3 diluted with glycerine and polymer.

4.6 Summary

The results of all tests show that ALR has the strongest influence on atomization with the largest effect occurring at low ALR. This influence diminishes as ALR is increased and is explained by considering the losses associated with entrainment. When ALR is small, a liquid shroud encases the expanding air, reducing entrainment losses. As ALR is increased, the shroud is ineffectual or nonexistent and entrainment losses become more severe.

There was no change in mean drop size as consistency index was changed two fold. The flow behavior index had no effect either; therefore, Newtonian and non-Newtonian rheological properties, as indicated by n and K, have no effect on the atomization process. This result is explained by considering the two mechanisms of liquid break up: the shearing interaction between the liquid and the air and the competition between droplet surface tension and pressure forces caused by the relative velocity. Liquid break up due to shearing action is a function of the liquid viscosity, but for effervescent atomization fluid viscosity has no influence on SMD; therefore, atomization is not influenced by shear. However, the relative velocity between the droplets and air is very high suggesting that the spray formation process is controlled by secondary atomization.

Pressure had little effect on SMD at high ALR values (above about 0.20). High values of ALR increase losses to the ambient; therefore, any increase in available energy due to an increase in pressure is dissipated. The situation changes at low ALR values (below about 0.20) since a liquid shroud encompasses the expanding gas protecting it from losses to the ambient air. Here, an increase in pressure assists break up since the energy is not lost to the entrained air.

When atomizing solutions containing polymer, SMD increases, especially in the low ALR region. A change in ALR has a smaller effect on SMD in the low ALR range when spraying fluids containing polymers, as compared to fluids containing no polymer. This changes the slope of the SMD versus ALR curve. At high ALR, the polymer solutions atomize in the same manner as the non-polymer solutions. It is believed that these effects are caused by either viscoelastic properties or the yield stress of the polymer solutions.

No effect of slurry formulation on SMD was found for three slurries whose particle top size changed by a factor of 6 and whose loading varied from 49 to 65 %. The only change in SMD between the different slurries occurred when atomizing CWS with added polymer. Sauter mean diameter increased with polymer addition similar to the manner in which SMD increased when polymer was added to glycerine-water solutions.

In conclusion, the data substantiates the effectiveness of effervescent atomization in forming low SMD sprays from highly viscous Newtonian and non-Newtonian fluids. Most importantly, the ultimate goal of this study, to successfully atomize coal-water slurry using an effervescent nozzle, was achieved.

5 ANALYSIS

5.1 Introduction

An analysis of the effervescent atomization process was performed to better understand the physical mechanisms responsible for the results reported in Section 4. To that end, an expression for SMD was developed using the techniques of two-phase separated flow plus mass, momentum, and energy conservation. It embodies the physics of effervescent atomization, adequately representing the dynamics of this process.

Previous models describing atomization processes using two-phase flows have been divided into two areas. Internal mixing atomization models describe the mixing of air and liquid within the nozzle in order to form a two-phase bubbly or slug flow. The gas expands upon exiting the nozzle and produces a spray. Flashing atomization models incorporate either dissolution of gas into a liquid or superheating a liquid such that gas comes out of solution during the atomization process thus breaking the liquid into drops. Both types of models are summarized in the following paragraphs.

Chawla [1985] investigated internal mixing atomization and developed an expression for the maximum droplet diameter as a function of the pressure jump experienced at the throat of a choked converging nozzle. He noted that a two-phase mixture possesses a very low velocity for sonic flow thereby making the pressure jump required for choking easily attainable. However, Chawla erred when developing his model by oversimplifying the atomization process and incorrectly postulating that the maximum droplet diameter is proportional solely to the inverse of the pressure jump. Thus, Chawla ignored the fact that maximum drop size is a function of the relative velocity between the liquid and the air, and as a result the thermodynamic process by which the gas expands must be considered. Furthermore, Chawla's model is of only limited utility since it attempts to predict only the maximum drop size when drop size distribution or Sauter Mean Diameter is a more useful parameter for describing a spray.

Sher and Elata [1977] developed an expression for the mean diameter of a flashing spray. Their analysis began by considering the nucleation of minute bubbles caused by the surface roughness of the nozzle wall. The bubbles increased in volume through evaporation of the Freon propellant due to a drop in the pressure of the liquid, growing until their outer edges touched and caused the film between them to rupture. The remaining energy of the bubble accelerated the vapor past the liquid shredding it into droplets.

Sher and Elata's correlation incorporated assumptions that give the solution many degrees of freedom. First, a factor expressing the number of nucleation sights was assumed. Second, a bubble growth rate was assumed in order to predict the number and size of the bubbles at the time they burst. Third, a close-packed cubic array of bubbles was assumed in order to calculate the mass of liquid at bursting per unit volume of two-phase fluid. Fourth, the mean drop size was assumed to follow the log normal size distribution. Finally, an efficiency term was determined by dividing the surface energy of the drops by the energy in the bubbles just prior to bursting. These assumptions provided a good correlation to their data but restricted its applicability to other systems.

Solomon et al. [1985] considered dissolved gas atomization, a second type of flashing atomization. They analyzed their system by incorporating a correlation developed by Lefebvre [1980] for prefilming air blast injectors. The expression was empirical in nature and was developed by considering the operating parameters and physical properties of the fluids that most strongly influenced spray formation. In order to generalize the expression, two experimentally determined constants were inserted into the equation. The weakness of their expression was its empirical nature and the number of degrees of freedom it possessed.

Dissolved gas and flashing atomization are similar to aerated atomization in that all use the expansion of gas bubbles to increase the liquid surface energy, thereby forming droplets. Both dissolved gas and flashing atomization, however, require the presence of nucleation sites for the formation and subsequent growth of bubbles. Aerated atomization, in contrast, requires no nucleation sites because bubbles are formed automatically when gas enters the liquid via the aeration tube. As a result, the present analysis is not limited by the assumption that the number of droplets formed in the spray is directly proportional to the number of nuclei, as proposed by Sher and Elata [1977], nor does it require the assumption of a bubble packing geometry or a drop size distribution.

This analysis also differs from that of Solomon et al. [1982] in two significant respects. First, the current analysis is developed from first principles instead of being based on a correlation developed from dimensional arguments. Second, it is not restricted to sprays controlled by sheet or jet break up processes, although it has been extended to such processes by Lefebvre [1990].

The expression derived in this report relates spray mean drop size, in terms of the Sauter mean diameter, to the liquid surface tension and density, the initial air and liquid velocities, and the air-liquid mass ratio. It was applied to both the aerated atomization data presented in Section 4 and the data of Roesler [1988] in order to illustrate the relative importance of the physical mechanisms responsible for aerated atomization. The analysis was inspired by Lefebvre [1990] and follows his basic premise that a simple energy balance can be applied to the spray.

5.2 Analysis

The analysis begins by considering conservation of energy for the two phases. The region of interest extends from the nozzle exit plane to the line of spray measurements

(See Figure 30). The flow is assumed to be one-dimensional and steady, and evaporation is ignored. The latter assumption may provide a source of error when analyzing the water data of Roesler [1988], but is acceptable when analyzing the data of Section 4 because of the low vapor pressures associated with mixtures containing water and glycerine.

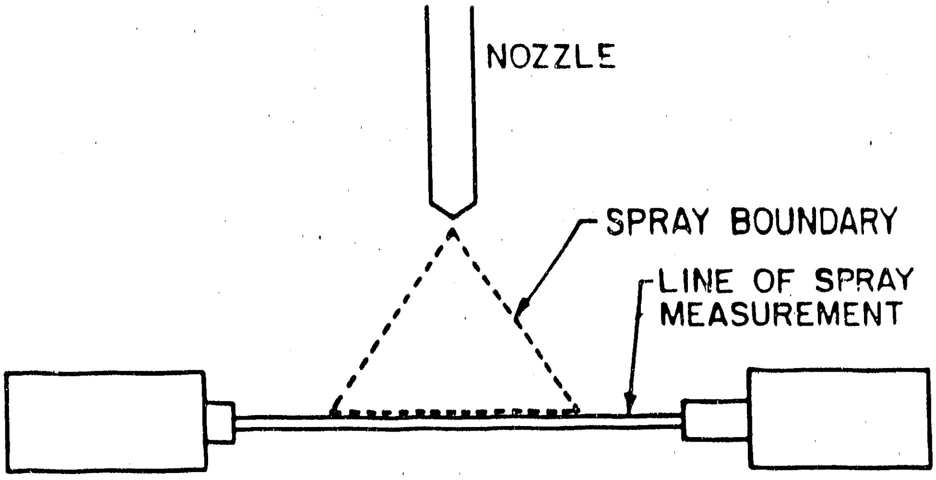

Figure 30. Illustration of the control volume considered in the analysis.

The mixture is modeled as a two-phase separated flow with the liquid treated as an isentropic incompressible substance and the air assumed to be an ideal gas. The thermodynamic process describing the expansion of the air must lie between the limiting isothermal and isentropic cases. Elliot [1960] derived an expression for the temperature of the two-phase mixture during an expansion where infinite heat transfer occurs between the fluids

$$\frac{T_a}{T_n} = \left(\frac{P_a}{P_n}\right)^{ALR\frac{R}{(C_l + C_p ALR)}} \tag{12}$$

where T_a is the mixture temperature after expansion, T_n is the initial mixture temperature, P_a is the mixture pressure after expansion, P_n is the initial mixture pressure, R is the ideal gas constant, C_l is the liquid specific heat, and C_p is the gas constant pressure specific heat.

Equation (12) indicates the change in mixture temperature ranges from 3 to 16° K for the conditions under which this study was performed. As a result, the velocity of the gas is no more than 10 to 25% higher for the infinite heat transfer case than for the isothermal case. However, based on the work of Elliot [1960] and Netzer [1962], and because of the small errors noted above, the gas will be assumed to undergo an isothermal expansion. (Note that regardless of the exact thermodynamic path traveled by the expanding air, the experimental results of Eddington, Elliot and Netzer show that actual velocities deviate only slightly from the isothermal case for ALR values up to 0.22.)

After undergoing expansion, the air and liquid are assumed to reach a common velocity before crossing the line of spray measurement. Losses due to entrainment, viscous dissipation, and irreversibilities during the expansion of the air are incorporated by defining ε to be the fraction of air directly participating in the atomization process. The remaining air (1-ε) passes through the control volume undisturbed such that its energy is lost to the ambient and thus need not be considered in the analysis.

Under these assumptions, the energy flowing into the control volume includes the initial air and liquid kinetic energies, plus the initial surface energy of the bubbles. The energy flowing out of the control volume includes the final air and liquid kinetic energies, plus the surface energy of the drops. Equating the energy fluxes results in

$$\frac{\varepsilon \dot{m}_A V_{A1}^2}{2} + \frac{\dot{m}_L V_{L1}^2}{2} + \frac{6\sigma \dot{m}_L}{\rho_L SMD_b} = \frac{\varepsilon \dot{m}_A V_{A2}^2}{2} + \frac{\dot{m}_L V_{L2}^2}{2} + \frac{6\sigma \dot{m}_L}{\rho_L SMD_d} \tag{13}$$

where $\dot{m}_L$ is the liquid mass flow rate, $\dot{m}_A$ is the air mass flow rate, V_{A1} is the initial air velocity, V_{L1} is the initial liquid velocity, V_{A2} is the final air velocity, V_{L2} is the final liquid velocity, ρ_L is the liquid density, σ_L is the liquid surface tension, SMD_b is the Sauter mean diameter for the bubbles, and SMD_d is the Sauter mean diameter for the droplets.

Conservation of momentum is then used to determine the final air and liquid velocity

$$V_{A2} = V_{L2} = \frac{(\varepsilon \dot{m}_A V_{A1} + \dot{m}_L V_{L1})}{\varepsilon \dot{m}_A + \dot{m}_L} \tag{14}$$

An order of magnitude analysis allows elimination of the bubble surface energy term. The resulting equation can be rewritten using the air-liquid ratio to yield

$$SMD_d = \frac{12\sigma}{\rho_L \left(V_{L1}^2 + \varepsilon ALR\, V_{A1}^2 - \frac{(V_{L1} + \varepsilon ALR\, V_{A1})^2}{1 + \varepsilon ALR} \right)} \tag{15}$$

Equation (15) indicates that SMD depends on ALR, liquid surface tension and density, the air and liquid velocities at the control volume inlet, plus the parameter ε. The determination of V_{A1} and V_{L1} is discussed in the following paragraphs. An expression for ε is presented in Section 5.3.

The initial air and liquid velocities are calculated using a separated flow analysis. According to Wallis [1969], the velocity of the air within the flow tube is

$$V_{A0} = C_1 j \tag{16}$$

where C_1 is an empirical coefficient that expresses the degree of slip between the gas and liquid and j is the volumetric flux of the two-phase flow. The velocity of the liquid in the flow tube is

$$V_{L0} = \frac{j_L}{1-\alpha} \tag{17}$$

where j_L is the volumetric flux of the liquid and α is the void fraction.

The velocities V_{A0} and V_{L0} are determined at the point upstream of the converging section of the nozzle where the static pressure is known. Knowing the velocities and the static pressure allows the stagnation pressure of each constituent to be computed. This information is used to calculate the inlet velocities to the control volume.

The velocity of the air at the control volume inlet is found from the isothermal relationship

$$V_{A1} = \left(2RT_a \ln\frac{P_{A0}}{P_{atm}}\right)^{1/2} \tag{18}$$

The velocity of the liquid at the control volume inlet is

$$V_{L1} = \left[\frac{2(P_{Lo} - P_{atm})}{\rho_l}\right]^{1/2} \tag{19}$$

It is important to note that Equation (15) is similar in form to other published expressions such as Equation (2.9) proposed by Lefebvre [1990]. For instance, it indicates that an increase in surface tension increases SMD by requiring a larger portion of the available energy to go into droplet surface energy. It also indicates that SMD decreases with ALR according to the relationship $[1+1/(\varepsilon ALR)]$ which is similar to the 1+1/ALR dependence of Lefebvre [1990], Solomon [1982], and Knoll [1989]. In addition, there is an efficiency associated with the energy transfer between the expanding gas and the droplets as proposed by Sher and Elata [1977] and Lefebvre [1990].

5.3 Results

The model developed in Section 5.2 was applied to the data of Section 4 to further the understanding of the effervescent atomization process. The first step was to determine ε. The resulting ε values were then used to calculate SMD with the calculated values compared with experimental results. As will be shown, the agreement obtained demonstrates the ability of the model to describe the effervescent atomization process. The final step was to use the model to explain the process of effervescent atomization.

Calculation of SMD requires the fraction of air participating in the atomization process. This quantity is not expected to remain constant over the entire test matrix. Consideration of the spray mean drop size at the limiting ALR values of 0 and ∞ indicates that ε must decrease with ALR. As a result, a power law form for ε was chosen and determined by fitting Equation (20) to the experimental data in Section 4. The resulting dependence of ε on ALR for CWS is illustrated in Figure 31. The coefficients A and B are tabulated in Table 4 for the various fluids sprayed.

$$\varepsilon = 10^{A} \cdot ALR^{B} \qquad (20)$$

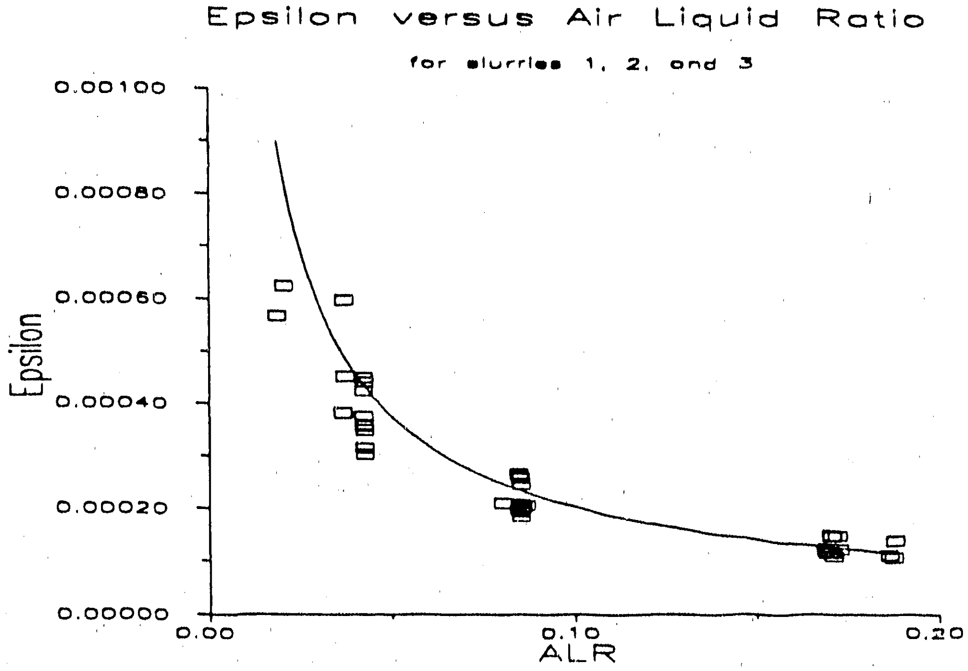

Figure 31. Epsilon versus air-liquid ratio for undiluted coal-water slurries 1, 2, and 3.

Table 4: Coefficients A and B for all fluids

Fluid	A	B
glycerine and water test 1	-3.89	-0.78
glycerine and water test 2	-4.33	-0.67
glycerine, water and polymer	-4.21	-0.56
CWS undiluted	-4.50	-0.78
CWS and glycerine	-4.34	-0.64
CWS, glycerine and polymer	-4.34	-0.44
CWS undiluted and CWS diluted with glycerine	-4.46	-0.74
water, Roesler [1988]	-3.18	-0.46
glycerine and water of test 1 plus water of Roesler	-3.83	-0.74

Figure 32 shows SMD calculated using Equations (15) and (20) versus measured SMD where the glycerine water data of test 1 was used. Notice that viscosity varies from 487 to 852 cP, as shown in Table 1, and that the correlation is able to accurately predict SMD. This indicates that the expression for SMD is accurate with no consideration given to changes in viscosity.

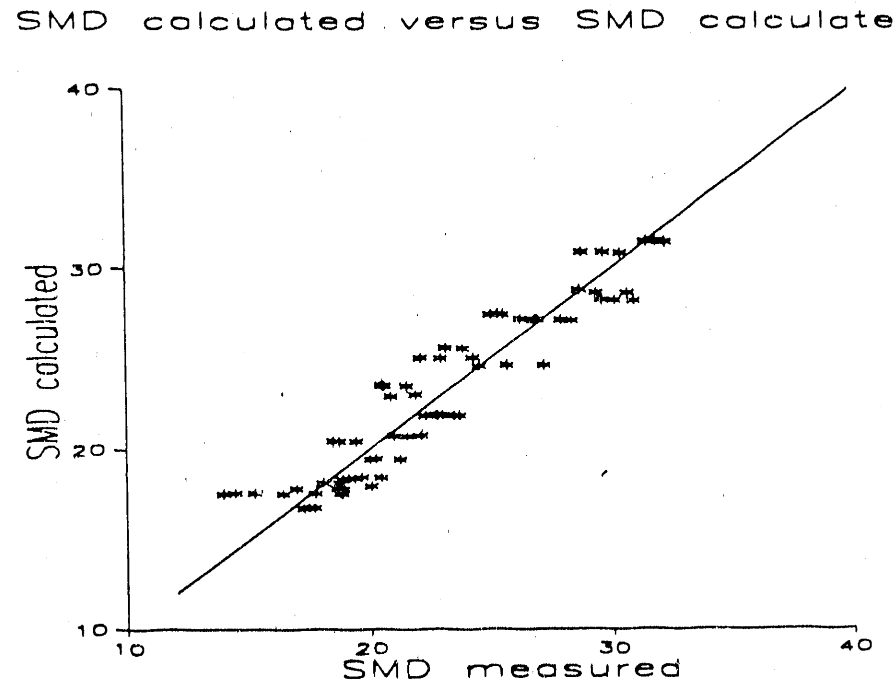

Figure 32. Calculated Sauter mean diameter versus measured Sauter mean diameter for glycerine-water test 1.

Figure 33 shows calculated SMD versus measured SMD using data taken from the non-Newtonian study. No variation is seen as consistency index varied from 400 to 930 cP-s^{n-1} and flow behavior index changed from 0.85 to 0.95. This verifies that the expression for SMD need no correction for non-Newtonian rheological properties.

Figures 34 through 37 show calculated SMD versus measured SMD using data taken from the coal-water slurry portion of this study. Flow behavior index and consis-

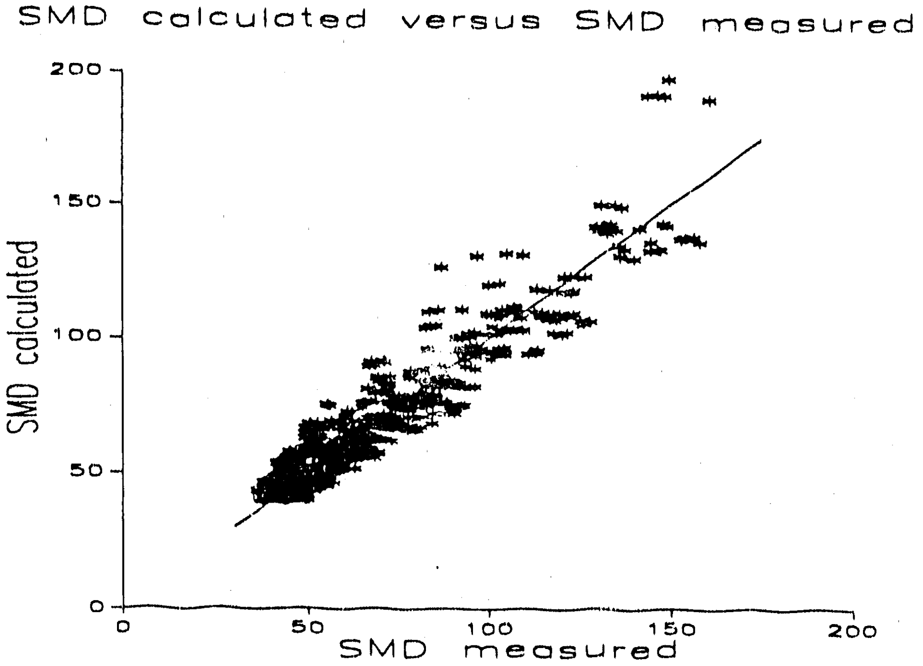

Figure 33. Calculated Sauter mean diameter versus measured Sauter mean diameter for the glycerine-water-polymer fluids.

tency index varied from 0.603 to 1.03 and 133 to 1964 cP-s^{n-1}, respectively, and no adjustment to the equations was necessary in order to obtain a good fit, thus supporting the conclusions drawn in the non-Newtonian single phase fluid portion of the study. This data also contained variations of 19 % in coal loading, and variations of 85 μm in particle top size yet the equations were able to accurately predict SMD with no adjustments necessary.

Figure 38 shows calculated SMD versus measured SMD using Roesler's water data. This figure indicates the expressions accurately predict SMD in a region of ALR much lower than that of this study and in a flow regime different from that of this study.

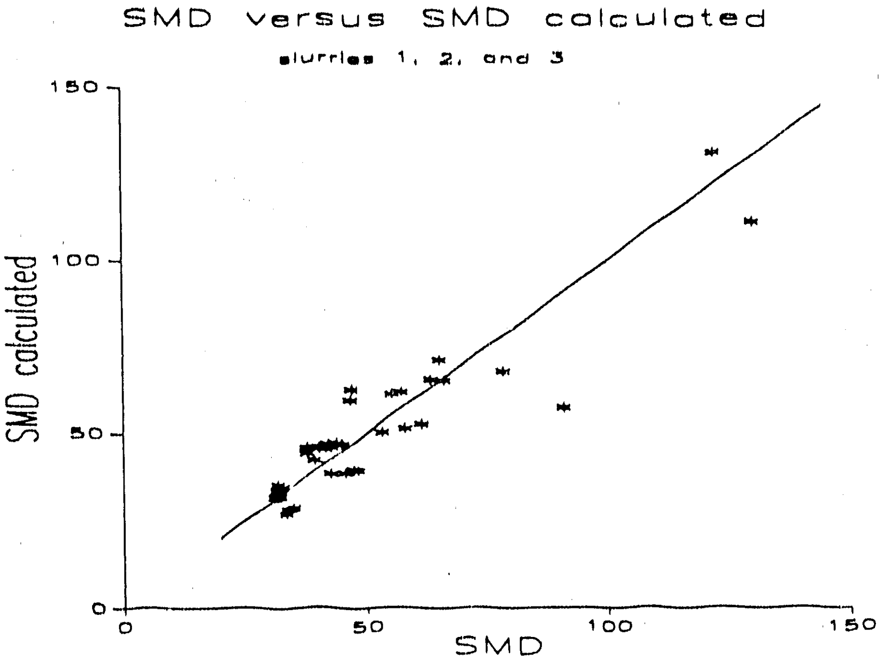

Figure 34. Calculated Sauter mean diameter versus measured Sauter mean diameter for the undiluted coal-water slurries.

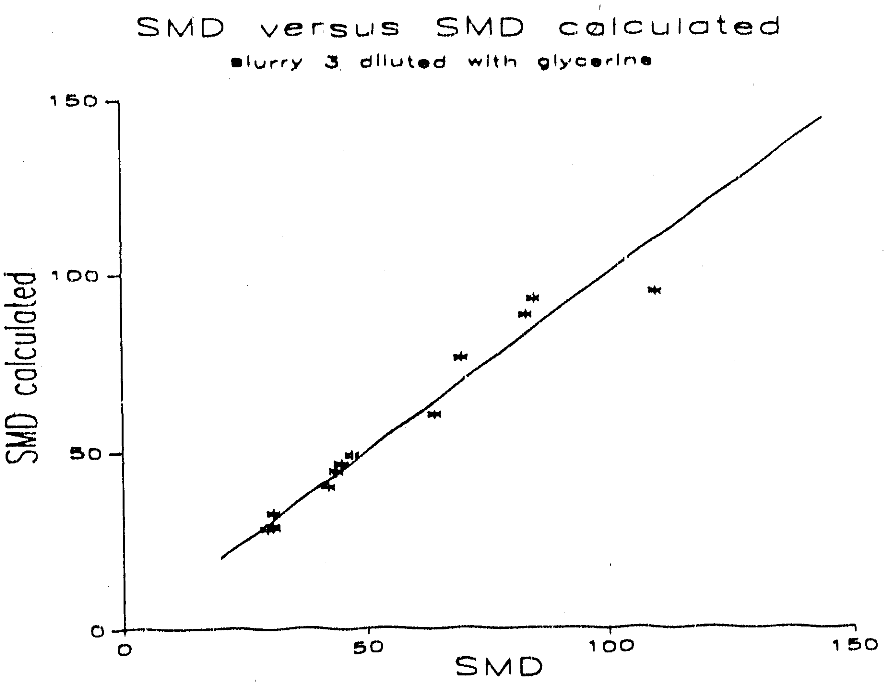

Figure 35. Calculated Sauter mean diameter versus measured Sauter mean diameter for the coal-water slurry diluted with glycerine.

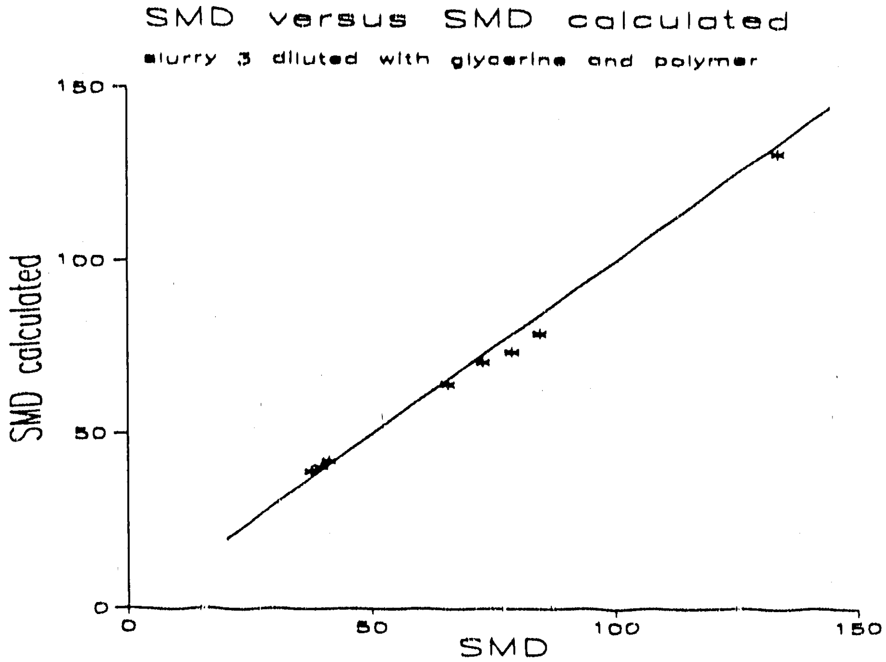

Figure 36. Calculated Sauter mean diameter versus measured Sauter mean diameter for coal-water slurry diluted with glycerine and polymer.

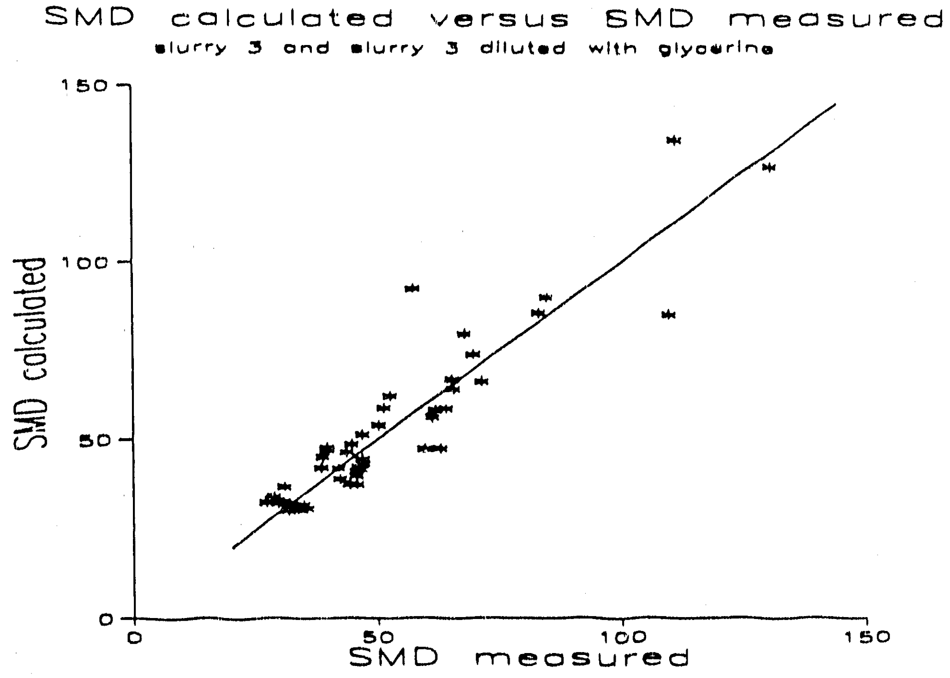

Figure 37. Calculated Sauter mean diameter versus measured Sauter mean diameter for coal-water slurry undiluted and diluted with glycerine.

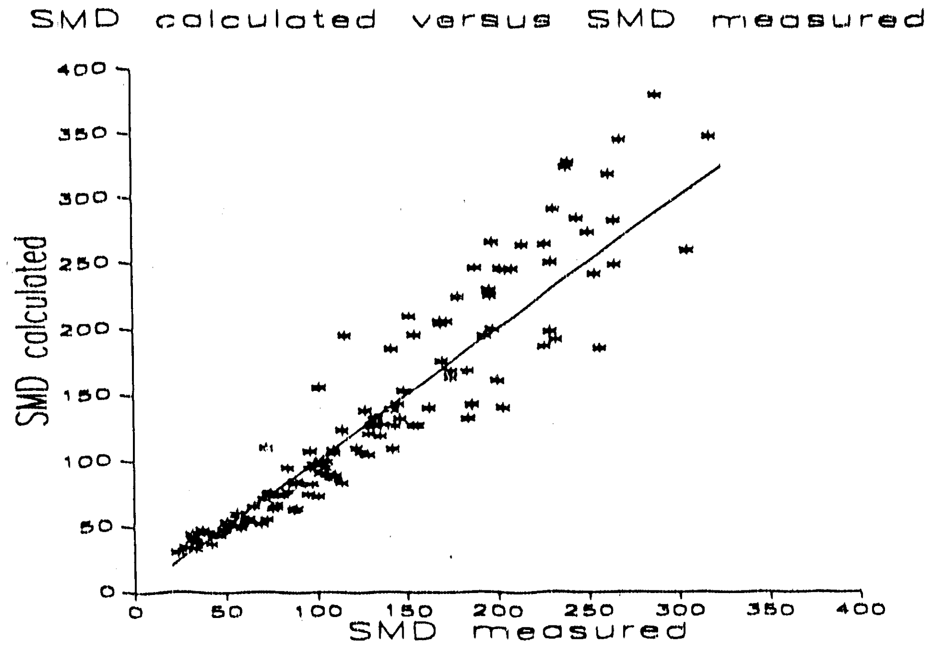

Figure 38. Calculated Sauter mean diameter versus measured Sauter mean diameter for water, Roesler [1988].

A comparison of the experimental data from glycerine and water test 1 with Roesler's water data correlation indicated a close match. A curve fit was performed on the combined data and is reported in Table 4. Figures 39 and 40 show ε versus ALR and a curve fit for the glycerine and water test 1 data and for Roesler's data, respectively. Figure 41 shows ε versus ALR for the combined data. A common correlation for the two sets together matches well with either data set even though viscosity changes by three orders of magnitude and the flow structure changes from bubbly to slug flow.

In summary, Figures 31 through 41 demonstrate that Equations (15) and (20) do indeed describe the data of Section 4. These equations, and the assumptions employed in their development, provide the following picture of effervescent atomization.

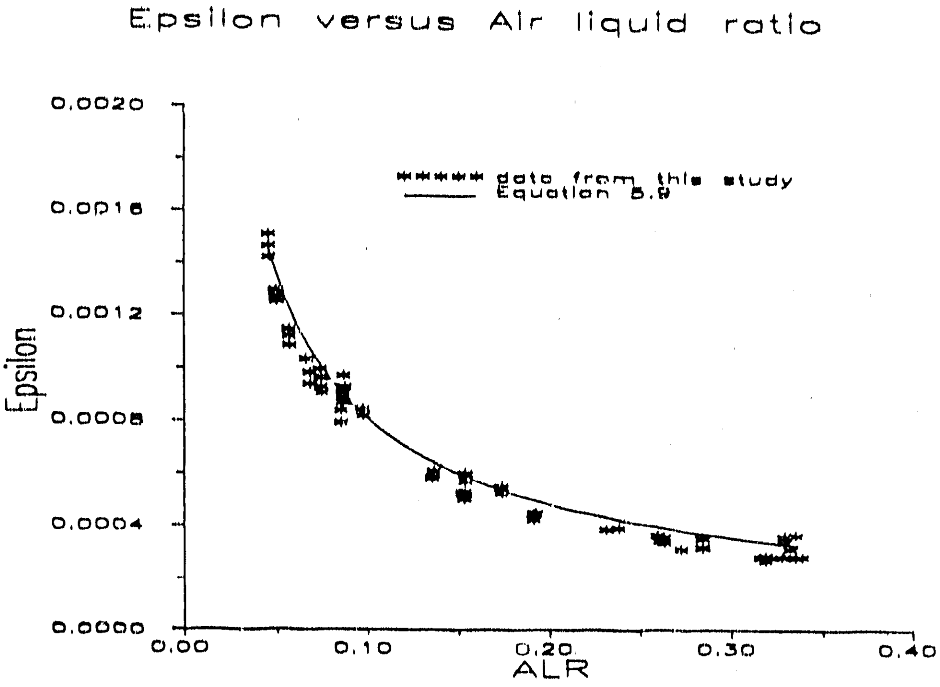

Figure 39. Epsilon versus air-liquid ratio for data extracted from glycerine and water test 1.

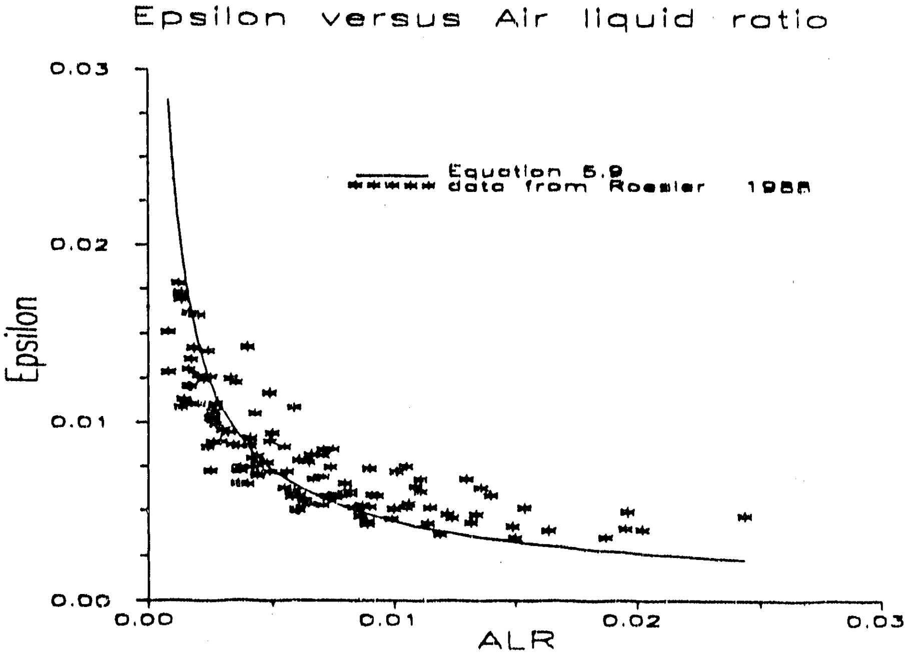

Figure 40. Epsilon versus air-liquid ratio for water data extracted from Roesler [1988].

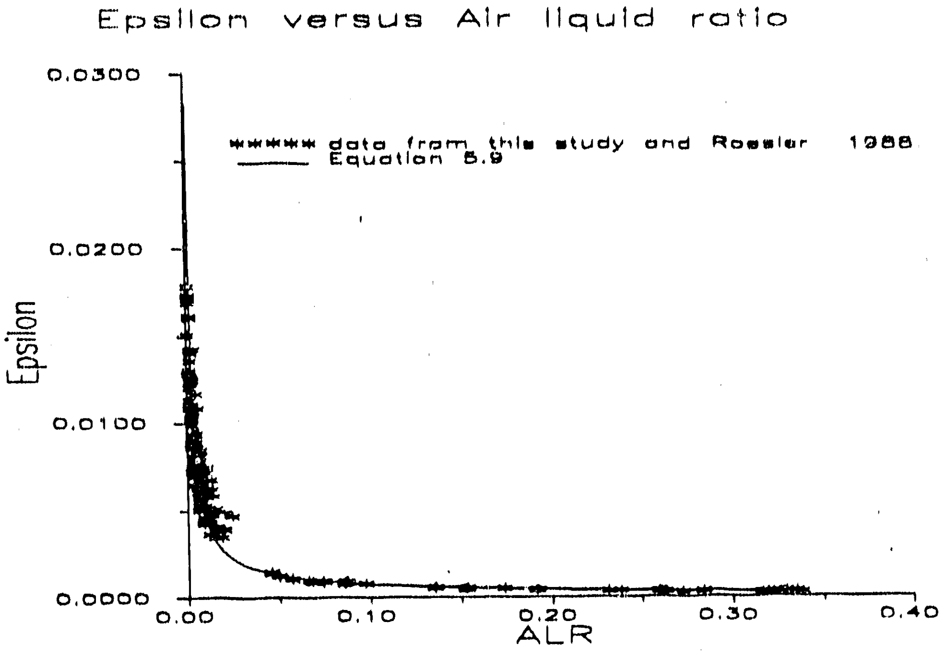

Figure 41. Epsilon versus air-liquid ratio for combined glycerine and water test 1 data, and that of Roesler [1988].

- The low values of ε indicated in Figures 31 and 39 through 41 demonstrate that only a small portion of the air bubbled into the liquid actually participates in the atomization process. The rest simply passes through the control volume, neither helping nor hindering the droplet formation process. As a result, the process is inefficient, even though it produces very small mean drop sizes when spraying a wide variety of highly viscous fluids. Obviously, the cause for this inefficiency should be investigated. But it should not cause alarm for two reasons. First, atomizers in general have low efficiencies, with ε values generally estimated to be below 1 %. Second, the effervescent nozzle employed in this investigation was designed to facilitate research into the spray formation process with no effort expended to optimize its performance. As a result, a commercial device is expected to exhibit a significantly greater efficiency.

- The efficiency of the nozzle, as indicated by the parameter ε, decreases with ALR.

  The cause for this behavior is at present unknown, but two hypotheses must be considered.

  First, the increase in ALR is leading to a coalescence of bubbles within the nozzle body because of the length of observation tube located between the aerator tube and the final orifice and because of the increase in bubble number density. A consequence is the formation of slugs within the nozzle. Bubbly flow is expected to be more efficient since it results in more intimate contact between the gas and the liquid, thus ensuring that more of the energy available during expansion goes into increasing the liquid surface energy.

  Second, the increase in ALR will reduce the sheathing effect of the liquid, even in the absence of bubble coalescence. The reduction in sheathing will lead directly to a decrease in efficiency since the air will expand more freely, encounter less liquid during that expansion, and therefor contribute less of its energy to increasing the surface energy of the liquid.

- The efficiency of the nozzle, again as indicated by ε, decreases when polymer is added to a fluid. Note that this effect should not be attributed to a change in fluid rheology, as indicated by the power law parameters n and K, since the data of Section 4.4 exhibit no systematic correlation between SMD and either n or K. Instead, two alternative explanations must be considered.

  First, the addition of polymer could result in a rheological effect we are presently unable to determine. Viscoelasticity and yield stress are two examples. Both are energy loss mechanisms and are expected to affect the spray formation process in much the same manner as surface tension. For instance, a yield stress results in a force that must be overcome by air flowing past a droplet before it will deform and break apart. As a result, a velocity difference that leads to droplet disintegration in the absence of a yield stress may not do so when the yield stress is present. Since droplets undergo rapid acceleration upon leaving the nozzle while the air is undergoing rapid deceleration, it is clear that the limited time during which a droplet is subject to relative velocities large enough to break it apart is decreased. The result is droplets of larger size. Viscoelastic effects are similar in that the restoring force must be overcome before a droplet can break up. Viscoelasticity can therefor reduce the interval during which a droplet is exposed to relative velocities large enough to break it apart with the result that larger droplets remain in the spray. Second, the addition of polymer may act to increase the surface tension with the obvious result that SMD increases. Support for this hypothesis is provided by investigations into the two-phase flow of mixtures of air and non-Newtonian liquids. Mahalingam and Valle [1972], for instance, suggest that fluids of increasing pseudoplasticity have lessened interaction between the phases. This would result in a decrease in the transfer of energy from the air to the liquid with a corresponding increase in mean drop size. Oliver and Young-Hoon [1968] also note that viscoelasticity damps waves that occur in air-Newtonian liquid flow suggesting a decrease in energy transfer upon addition of polymers.

- The process commonly referred to as secondary atomization dominates sprays formed using effervescent atomizers. This conclusion is supported by the lack of a relationship between liquid rheology (or viscosity) and SMD, and by the form of the expression that describes the data of Section 4, namely Equation (15). This expression can be rewritten as

$$SMD_d = \frac{12\sigma}{\rho_L (V_{L1} - V_{A1})^2}\left(1 + \frac{1}{\varepsilon ALR}\right) \tag{21}$$

which is simply 12 times the quantity $\left(1 + \frac{1}{\varepsilon ALR}\right)$ divided by the Weber number.

5.4 Summary

The analysis developed here showed that effervescent atomization can be described using two-phase separated flow theory, energy conservation, momentum conservation, and mass conservation, if ALR, σ_l, ρ_l, and the air and liquid velocities are known. Atomization was also shown to be insensitive to changes in viscosity, consistency index, and flow behavior index. The efficiency of the process, in terms of the parameter ε, is low, but consistent with other spray nozzles. The efficiency decreases with ALR and with the addition of polymers. Explanations were proposed for both effects. Finally, secondary atomization was shown to dominate the spray formation process, based on the absence of a dependence of SMD on fluid rheology and the reduction of the expression for SMD to a function of the Weber number.

6 SUMMARY AND CONCLUSIONS

6.1 Summary

A rigorous study of the effervescent atomization of high viscosity Newtonian fluids has been completed. The emphasis was on the formation of CWS sprays using the effervescent technique. The unique feature of effervescent atomization, injection of gas bubbles into the liquid while still within the nozzle body, was introduced. The effect of gas injection, choking the flow at the nozzle exit and the resulting production of a pressure jump that ruptures the bubbles as they cross the exit plane, was noted.

The study was performed in three steps: first, Newtonian fluids were sprayed with viscosities varying from 300 to 1000 cP; second, non-Newtonian fluids were sprayed with consistency indices ranging from 400 - 968 $cp - s^{1-n}$ and flow behavior indices ranging form 0.85 to 0.95; finally, coal water slurries were sprayed with varying consistency index, flow behavior index, coal loading and top size. In each study, pressure and air-liquid ratio (ALR) were varied from 0.6 MPa to 2.1 MPa and 0.043 to 0.34, respectively, with exception of the CWS portion where ALR varied from 0.043 to 0.17.

Three goals were to be met during this study. They were

- to demonstrate that effervescent atomization can produce CWS sprays with mean drop sizes below 50 μm
- to determine a lower size limit for effervescent atomizer produced CWS sprays
- to determine the mechanism(s) responsible for the formation of effervescent atomizer produced sprays

The first goal was accomplished using a three step approach, where single phase non-Newtonian and coal-water slurry sprays were formed using an effervescent atomizer. The results were presented in Section 4 and clearly demonstrated that the effervescent technique successfully atomized each of the fluids. Several qualitative features were also evident upon inspection of the data.

First, ALR was shown to have the greatest impact on atomization quality, SMD dropping dramatically between ALR values of 0.043 and about 0.20. Beyond an ALR of about 0.20 SMD dropped very little. Pressure had a significant effect on SMD in the ALR region below about 0.20. However this effect diminished dramatically as ALR increased beyond about 0.20.

The mechanism responsible for the influence of ALR is evident when one considers that to effectively transfer the energy of the air to the liquid, the two fluids must be in intimate contact. Therefor, at low ALR the atomizing air is surrounded with liquid that shields it from losses to the ambient so that a larger portion of the atomizing air energy goes into increasing the liquid surface energy. As ALR increases, however, the liquid film surrounding each bubble becomes thinner producing smaller droplets when the bubbles expand downstream of the final orifice. In addition, losses to the ambient increase since the liquid shield is less effective in insulating the expanding bubbles from the ambient at higher ALR. Eventually, the effect of ALR disappears since ambient losses dominate as ALR increases.

The effect of pressure on SMD is less substantial than that of ALR, but its effects are similar. At low ALR, the air is protected by a shroud of liquid as it expands. By increasing the pressure, the energy of the air is increased and the air is able to do more work on the liquid, therefor producing smaller droplets. As ALR is increased, however, the liquid shroud becomes less effective and losses to the ambient air become more substantial; therefore, a greater portion of the increase in energy of the air, due to an increase in its pressure, is lost to the ambient. The losses to the ambient at high ALR eventually dominate the process such that an increase in pressure has no observable effect on SMD.

Second, fluid rheology, as characterized by n and K, had little to no effect on SMD. For the Newtonian study, viscosity changed two fold with no change in SMD observed. The non-Newtonian fluids showed no consistent change in SMD even though flow behavior index varied between 0.85 and 0.95 and consistency index varied between 400 and 968 $cp - s^{1-n}$. These results were repeated when spraying CWS.

The lack of an effect of n and K is explained by considering the two mechanisms of droplet formation. Primary atomization results from the shearing action between the liquid and air with liquid viscosity the controlling property. Secondary atomization results from pressure forces that arise from high velocity air passing over a ligament or drop. Surface tension resists this latter force. In effervescent atomization, the fluid rheological properties had no effect on the drop size; therefore, it was concluded that primary atomization was not the controlling process. However, the air velocities were very high, thus it was also concluded that secondary atomization was the mechanism controlling atomization.

Third, SMD increased when atomizing solutions that contained polymer, especially in the low ALR region. This effect is not to be attributed to a variation in either n or K since no consistent relationship between SMD and either parameter was observed. Instead, the increase is believed to result from either the viscoelastic properties or yield stresses characteristic of the polymer solutions. This hypothesis could not be tested, however, since the available rheological instrumentation was incapable of providing the necessary data.

The second goal was not accomplished, since the lower limit for effervescent atomization produced sprays has yet to be observed. It is likely that one does exist, but it must be below 25 μm since such sprays were routinely produced during this study.

The third goal was accomplished by developing a model of the effervescent spray formation process and then using that model to determine the physical processes important to effervescent atomization. Several conclusions were reached.

The low values of ε observed in Section 5 demonstrate that only a small portion of the air bubbled into the liquid actually participated in the atomization process. As a result, the process was inefficient, even though it produced very small mean drop sizes when spraying a wide variety of highly viscous fluids.

The efficiency of the nozzle, as indicated by the parameter ε, decreased with ALR. There are two possible explanations. First, the increase in ALR may have lead to a coalescence of bubbles within the nozzle body, the subsequent formation of slugs, and thus a decrease in efficiency because the less intimate contact between the gas and the liquid ensured less of the energy available during expansion went into increasing the liquid surface energy. Second, the increase in ALR may have reduced the sheathing effect of the liquid, even in the absence of bubble coalescence, leading directly to a decrease in efficiency since the air expanded more freely, encountered less liquid during that expansion, and therefor contributed less of its energy to increasing the surface energy of the liquid.

The efficiency of the nozzle, again as indicated by ε, decreased when polymer is added to a fluid. Note that this effect should not be attributed to a change in fluid rheology, as indicated by the power law parameters n and K, since the data of Section 4.4 exhibited no systematic correlation between SMD and either n or K. Instead, two alternative explanations were considered. First, the addition of polymer could have resulted in a rheological effect we are presently unable to determine. Viscoelasticity and yield stress are two examples. Both are energy loss mechanisms and are expected to affect the spray formation process in much the same manner as surface tension. Second, the addition of polymer may have acted to increase the surface tension with the obvious result that SMD increased. Support for this hypothesis is provided by investigations into the two-phase flow of mixtures of air and non-Newtonian liquids, notably Mahalingam and Valle [1972] and Oliver and Young-Hoon [1968], who noted that fluids of increasing pseudoplasticity have lessened interaction between the phases and that viscoelasticity damps waves that occur in air-Newtonian liquid flow, therefor suggesting a decrease in energy transfer upon addition of polymers.

Finally, the process commonly referred to as secondary atomization dominated sprays formed using effervescent atomizers. This conclusion is supported by the lack of a relationship between liquid rheology (or viscosity) and SMD, and by the form of the expression that describes the data of Section 4, namely Equation (15), which can be rewritten as 12 times the quantity $\left(1+\frac{1}{\epsilon ALR}\right)$ divided by the Weber number.

6.2 Conclusions and Recommendations for Future Work

In conclusion, effervescent atomization is an effective means of atomizing highly viscous Newtonian and non-Newtonian fluids and can be applied in areas where orifice diameter must be large to circumvent clogging. It produces sprays using low pressures and low air-liquid ratios (ALR) making it attractive in many applications including the atomization of coal-water slurry in gas turbines and internal combustion engines.

Effervescent atomization can be commercialized upon solution of the following problems.

First, the efficiency must be improved. Such an improvement will yield two benefits: smaller mean drop sizes at fixed ALR, or an equivalent mean drop size at a lower value of ALR. The former would improve combustion efficiency while the latter would reduce the cost associated with operating an effervescent injection system. Improvement of the efficiency can most easily be accomplished by a systematic investigation of the physical processes occurring immediately downstream of the nozzle final orifice.

Second, the effects of polymer addition must be understood. At present, the best that can be offered is that an as yet undetermined rheological property is responsible for the increase in SMD that occurs when spraying polymeric fluids at low ALR values. That property must be identified so slurry manufacturers can formulate additive packages which minimize its effect. Identification can be accomplished by more detailed rheological characterization of the test fluids in concert with test fluid selection which emphasizes differences in viscoelastic and yield stress behavior.

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Glycerine-Water Mixture Data From Test 1

K $cp-s^{(n-1)}$	ALR	Pd MPa	SMD μm	Liquid Mass g/s	Air Mass g/s	Surface Tension dyn/cm	Ta C	Density g/cm^3
384	0.0493	0.7928	31.85	28.6	1.41	64	20	1.26
384	0.0500	0.7928	31.48	28.2	1.41	64	20	1.26
384	0.0500	0.7928	32.31	28.2	1.41	64	20	1.26
384	0.0741	0.8962	26.86	24.3	1.80	64	20	1.26
384	0.0741	0.8962	26.98	24.3	1.80	64	20	1.26
384	0.0747	0.8962	28.40	24.1	1.80	64	20	1.26
384	0.1517	1.0341	22.78	17.6	2.67	64	20	1.26
384	0.1534	1.0341	22.85	17.4	2.67	64	20	1.26
384	0.1534	1.0341	22.36	17.4	2.67	64	20	1.26
384	0.2311	0.8273	21.95	10.3	2.38	64	20	1.26
384	0.2380	0.8273	20.90	10.0	2.38	64	20	1.26
384	0.3161	1.1030	19.68	11.2	3.54	64	20	1.26
384	0.3218	1.1030	19.41	11.0	3.54	64	20	1.26
384	0.3218	1.1030	19.41	11.0	3.54	64	20	1.26
384	0.3278	1.1030	18.86	10.8	3.54	64	20	1.26
420	0.0496	0.7928	31.47	28.4	1.41	64	20	1.26
420	0.0498	0.7928	32.26	28.3	1.41	64	20	1.26
420	0.0498	0.7928	31.87	28.3	1.41	64	20	1.26
420	0.0735	0.8962	26.29	24.5	1.80	64	20	1.26
420	0.0741	0.8962	27.96	24.3	1.80	64	20	1.26
420	0.0741	0.8962	27.00	24.3	1.80	64	20	1.26
420	0.1526	1.0341	23.75	17.5	2.67	64	20	1.26
420	0.1526	1.0341	23.02	17.5	2.67	64	20	1.26
420	0.1534	1.0341	23.52	17.4	2.67	64	20	1.26
420	0.3189	1.1030	20.46	11.1	3.54	64	20	1.26
420	0.3189	1.1030	19.14	11.1	3.54	64	20	1.26
520	0.0858	0.8273	25.35	17.6	1.51	64	20	1.26
520	0.0863	0.8273	25.05	17.5	1.51	64	20	1.26
520	0.0863	0.8273	25.55	17.5	1.51	64	20	1.26
520	0.1537	0.8962	20.64	13.6	2.09	64	20	1.26
520	0.1537	0.8962	21.59	13.6	2.09	64	20	1.26
520	0.1537	0.8962	20.51	13.6	2.09	64	20	1.26
520	0.2592	1.2065	18.06	10.3	2.67	64	20	1.26
520	0.2618	1.2065	18.75	10.2	2.67	64	20	1.26
520	0.2724	1.2065	20.06	9.8	2.67	64	20	1.26
520	0.2840	1.2065	16.96	9.4	2.67	64	20	1.26
520	0.2840	1.2065	18.63	9.4	2.67	64	20	1.26
520	0.2840	1.2065	18.94	9.4	2.67	64	20	1.26

Glycerine-Water Mixture Data For Test 1 (continued)

537	0.0454	0.8273	28.82	26.3	1.19	64	20	1.26
537	0.0454	0.8273	29.70	26.3	1.19	64	20	1.26
537	0.0456	0.8273	30.43	26.2	1.19	64	20	1.26
537	0.0861	0.9652	24.32	20.8	1.79	64	20	1.26
537	0.0865	0.9652	22.16	20.7	1.79	64	20	1.26
537	0.0873	0.9652	22.97	20.5	1.79	64	20	1.26
537	0.1736	1.1030	18.50	15.3	2.66	64	20	1.26
537	0.1736	1.1030	18.74	15.3	2.66	64	20	1.26
537	0.1736	1.1030	19.45	15.3	2.66	64	20	1.26
537	0.3291	1.1720	14.41	10.7	3.52	64	20	1.26
537	0.3291	1.1720	15.21	10.7	3.52	64	20	1.26
537	0.3322	1.1720	16.40	10.6	3.52	64	20	1.26
537	0.3354	1.1720	13.94	10.5	3.52	64	20	1.26
874	0.0662	0.8273	28.74	21.2	1.40	64	20	1.26
874	0.0681	0.8273	29.40	20.6	1.40	64	20	1.26
874	0.0681	0.8273	30.71	20.6	1.40	64	20	1.26
874	0.0973	0.8962	23.17	18.4	1.79	64	20	1.26
874	0.0973	0.8962	23.91	18.4	1.79	64	20	1.26
874	0.1911	1.1720	21.29	13.9	2.66	64	20	1.26
874	0.1911	1.1720	20.25	13.9	2.66	64	20	1.26
874	0.1925	1.1720	20.02	13.8	2.66	64	20	1.26
874	0.3322	1.2754	17.49	10.6	3.52	64	20	1.26
874	0.3354	1.2754	17.70	10.5	3.52	64	20	1.26
874	0.3386	1.2754	17.26	10.4	3.52	64	20	1.26
968	0.0566	0.8962	29.62	21.1	1.19	64	20	1.26
968	0.0568	0.8962	30.17	21.0	1.19	64	20	1.26
968	0.0571	0.8962	30.97	20.9	1.19	64	20	1.26
968	0.0853	0.9996	25.72	17.6	1.50	64	20	1.26
968	0.0853	0.9996	27.23	17.6	1.50	64	20	1.26
968	0.0863	0.9996	24.58	17.4	1.50	64	20	1.26
968	0.1350	1.1720	22.16	15.4	2.08	64	20	1.26
968	0.1359	1.1720	21.60	15.3	2.08	64	20	1.26
968	0.1359	1.1720	21.03	15.3	2.08	64	20	1.26
968	0.2606	1.2754	18.77	11.3	2.94	64	20	1.26
968	0.2629	1.2754	18.88	11.2	2.94	64	20	1.26
968	0.2629	1.2754	17.75	11.2	2.94	64	20	1.26

Glycerine-Water Mixture Data From Test 2

K $cp - s^{(n-1)}$	ALR	Pd MPa	SMD μm	Liquid Mass g/s	Air Mass g/s	Surface Tension dyn/cm	Ta C	Density g/cm^3
487	0.0427	0.8205	167.7	25.7	1.10	64	28	1.26
487	0.0432	0.8205	162.1	25.4	1.10	64	28	1.26
487	0.0436	0.8205	157.2	25.2	1.10	64	28	1.26
487	0.0821	0.9791	123.2	21.7	1.78	64	28	1.26
487	0.0825	0.9791	118.2	21.6	1.78	64	28	1.26
487	0.0828	0.9791	118.8	21.5	1.78	64	28	1.26
487	0.1154	1.1583	98.6	20.4	2.36	64	28	1.26
487	0.1166	1.1583	97.6	20.2	2.36	64	28	1.26
487	0.1172	1.1583	100.3	20.1	2.36	64	28	1.26
487	0.1674	1.2411	79.6	17.5	2.93	64	28	1.26
487	0.1682	0.9928	83.3	14.0	2.36	64	28	1.26
487	0.1683	1.2411	84.4	17.4	2.93	64	28	1.26
487	0.1683	1.2411	84.2	17.4	2.93	64	28	1.26
487	0.1694	0.9928	83.1	13.9	2.36	64	28	1.26
487	0.1694	0.9928	86.7	13.9	2.36	64	28	1.26
487	0.2037	1.3927	73.1	17.2	3.50	64	28	1.26
487	0.2061	1.3927	73.2	17.0	3.50	64	28	1.26
487	0.2061	1.3927	72.4	17.0	3.50	64	28	1.26
487	0.2502	1.3100	68.8	14.0	3.50	64	28	1.26
487	0.2502	1.3100	68.5	14.0	3.50	64	28	1.26
487	0.2502	1.3100	68.7	14.0	3.50	64	28	1.26
487	0.2525	1.0618	73.0	11.6	2.93	64	28	1.26
487	0.2525	1.0618	70.7	11.6	2.93	64	28	1.26
487	0.2547	1.0618	70.0	11.5	2.93	64	28	1.26
487	0.2613	1.5168	65.3	15.6	4.08	64	28	1.26
487	0.2613	1.5168	65.1	15.6	4.08	64	28	1.26
487	0.2630	1.5168	63.6	15.5	4.08	64	28	1.26
487	0.3274	1.1170	63.8	10.7	3.50	64	28	1.26
487	0.3305	1.1170	62.6	10.6	3.50	64	28	1.26
487	0.3305	1.1170	63.1	10.6	3.50	64	28	1.26
487	0.3322	1.6547	59.0	14.0	4.65	64	28	1.26
487	0.3369	1.4065	59.7	12.1	4.08	64	28	1.26
487	0.3370	1.6547	59.1	13.8	4.65	64	28	1.26
487	0.3397	1.4065	60.3	12.0	4.08	64	28	1.26
487	0.3397	1.4065	60.8	12.0	4.08	64	28	1.26

Glycerine-Water Mixture Data From Test 2 (continued)

586	0.0423	0.7860	161.6	26.1	1.10	64	25	1.26
586	0.0430	0.7860	137.6	25.7	1.10	64	25	1.26
586	0.0431	0.7860	174.2	25.6	1.10	64	25	1.26
586	0.0829	0.9928	129.8	21.6	1.79	64	25	1.26
586	0.0833	0.9928	132.2	21.5	1.79	64	25	1.26
586	0.0837	0.9928	136.2	21.4	1.79	64	25	1.26
586	0.1196	1.1307	114.7	19.8	2.37	64	25	1.26
586	0.1202	1.1307	107.4	19.7	2.37	64	25	1.26
586	0.1208	1.1307	108.9	19.6	2.37	64	25	1.26
586	0.1667	1.0066	91.8	14.2	2.37	64	25	1.26
586	0.1667	1.0066	90.3	14.2	2.37	64	25	1.26
586	0.1673	1.2686	86.2	17.6	2.94	64	25	1.26
586	0.1683	1.2686	85.8	17.5	2.94	64	25	1.26
586	0.1691	1.0066	87.3	14.0	2.37	64	25	1.26
586	0.1692	1.2686	88.1	17.4	2.94	64	25	1.26
586	0.2106	1.4203	72.8	16.9	3.56	64	25	1.26
586	0.2131	1.4203	75.3	16.7	3.56	64	25	1.26
586	0.2144	1.4203	76.5	16.6	3.56	64	25	1.26
586	0.2480	1.3100	77.9	14.2	3.52	64	25	1.26
586	0.2498	1.3100	79.1	14.1	3.52	64	25	1.26
586	0.2498	1.3100	80.9	14.1	3.52	64	25	1.26
586	0.2538	1.0756	75.5	11.6	2.94	64	25	1.26
586	0.2560	1.0756	71.4	11.5	2.94	64	25	1.26
586	0.2638	1.5444	64.2	15.7	4.14	64	25	1.26
586	0.2638	1.5444	63.9	15.7	4.14	64	25	1.26
586	0.2655	1.5444	62.9	15.6	4.14	64	25	1.26
586	0.3387	1.4065	68.6	12.1	4.10	64	25	1.26
586	0.3387	1.4065	71.1	12.1	4.10	64	25	1.26
586	0.3395	1.4065	67.6	12.2	4.14	64	25	1.26
586	0.3399	1.6823	62.8	13.9	4.72	64	25	1.26
586	0.3423	1.6823	62.4	13.8	4.72	64	25	1.26
586	0.3423	1.6823	64.0	13.8	4.72	64	25	1.26
800	0.0825	0.9101	81.2	21.6	1.78	64	28	1.26
800	0.0831	1.2962	70.8	28.2	2.34	64	25	1.26
800	0.0831	1.2962	70.2	28.2	2.34	64	25	1.26
800	0.0832	0.9101	80.7	21.4	1.78	64	28	1.26
800	0.0837	1.2962	72.5	28.0	2.34	64	25	1.26
800	0.0840	0.9101	82.3	21.2	1.78	64	28	1.26
800	0.1005	1.5168	62.3	29.0	2.91	64	25	1.26
800	0.1008	1.5168	61.9	28.9	2.91	64	25	1.26
800	0.1019	1.5168	61.8	28.6	2.91	64	25	1.26

Glycerine-Water Mixture Data From Test 2 (continued)

800	0.1665	1.1583	52.4	17.5	2.91	64	25	1.26
800	0.1674	1.1583	54.5	17.4	2.91	64	25	1.26
800	0.1674	1.1583	54.8	17.4	2.91	64	25	1.26
800	0.1675	1.4479	50.9	20.8	3.48	64	25	1.26
800	0.1676	1.7237	51.8	24.2	4.06	64	25	1.26
800	0.1682	0.9239	58.3	14.0	2.36	64	28	1.26
800	0.1691	1.4479	50.7	20.6	3.48	64	25	1.26
800	0.1694	0.9239	56.1	13.9	2.36	64	28	1.26
800	0.1694	0.9239	56.9	13.9	2.36	64	28	1.26
800	0.1700	1.4479	51.0	20.5	3.48	64	25	1.26
800	0.1704	1.7237	51.8	23.8	4.06	64	25	1.26
800	0.1711	1.7237	51.9	23.7	4.06	64	25	1.26
800	0.2471	1.2411	46.5	14.1	3.48	64	25	1.26
800	0.2471	1.2411	46.6	14.1	3.48	64	25	1.26
800	0.2487	1.7237	46.8	18.6	4.63	64	25	1.26
800	0.2487	1.7237	47.0	18.6	4.63	64	25	1.26
800	0.2489	1.2411	47.1	14.0	3.48	64	25	1.26
800	0.2503	1.4755	46.0	16.2	4.06	64	25	1.26
800	0.2503	1.4755	46.2	16.2	4.06	64	25	1.26
800	0.2503	0.9928	49.7	11.7	2.93	64	28	1.26
800	0.2514	1.7237	47.4	18.4	4.63	64	25	1.26
800	0.2519	1.4755	45.7	16.1	4.06	64	25	1.26
800	0.2525	0.9928	48.3	11.6	2.93	64	28	1.26
800	0.2525	0.9928	47.9	11.6	2.93	64	28	1.26
800	0.3328	1.5720	43.9	13.9	4.63	64	25	1.26
800	0.3328	1.5720	44.0	13.9	4.63	64	25	1.26
800	0.3351	1.3376	41.2	12.1	4.06	64	25	1.26
800	0.3352	1.5720	43.3	13.8	4.63	64	25	1.26
800	0.3353	1.8202	44.5	15.5	5.20	64	25	1.26
800	0.3368	1.1170	42.2	10.4	3.50	64	28	1.26
800	0.3375	1.8202	45.2	15.4	5.20	64	25	1.26
800	0.3375	1.8202	39.0	15.4	5.20	64	25	1.26
800	0.3379	1.3376	43.0	12.0	4.06	64	25	1.26
800	0.3401	1.1170	44.1	10.3	3.50	64	28	1.26
800	0.3408	1.3376	42.5	11.9	4.06	64	25	1.26
800	0.3434	1.1170	43.4	10.2	3.50	64	28	1.26
800	0.4254	2.1236	42.6	14.9	6.34	64	25	1.26
800	0.4254	2.1236	43.2	14.9	6.34	64	25	1.26
800	0.4254	2.1236	42.5	14.9	6.34	64	25	1.26
852	0.0511	1.3238	59.7	57.3	2.93	64	28	1.26
852	0.0721	1.1859	80.3	28.7	2.07	64	28	1.26
852	0.0723	1.1859	75.7	28.6	2.07	64	28	1.26
852	0.0739	1.1859	82.3	28.0	2.07	64	28	1.26
852	0.0824	0.8274	62.7	21.5	1.77	64	28	1.26
852	0.0829	1.2962	67.6	28.4	2.36	64	28	1.26
852	0.0832	0.8274	62.0	21.3	1.77	64	28	1.26

Glycerine-Water Mixture Data From Test 2 (continued)

852	0.0832	0.8274	62.0	21.3	1.77	64	28	1.26
852	0.0835	1.2962	68.9	28.2	2.36	64	28	1.26
852	0.0841	1.2962	69.7	28.0	2.36	64	28	1.26
852	0.1054	1.4203	58.8	27.8	2.93	64	28	1.26
852	0.1069	1.4203	57.7	27.4	2.93	64	28	1.26
852	0.1077	1.3238	60.3	27.2	2.93	64	28	1.26
852	0.1085	1.4203	61.4	27.0	2.93	64	28	1.26
852	0.1109	1.3238	59.6	26.4	2.93	64	28	1.26
852	0.1673	0.8412	46.1	14.0	2.34	64	28	1.26
852	0.1683	1.1721	53.4	17.4	2.93	64	28	1.26
852	0.1683	1.1583	52.0	17.4	2.93	64	28	1.26
852	0.1684	1.4479	49.7	20.8	3.50	64	28	1.26
852	0.1692	1.4479	57.0	20.7	3.50	64	28	1.26
852	0.1692	1.4479	49.0	20.7	3.50	64	28	1.26
852	0.1703	1.1583	51.3	17.2	2.93	64	28	1.26
852	0.1709	1.4479	52.2	20.5	3.50	64	28	1.26
852	0.1710	0.8412	45.3	13.7	2.34	64	28	1.26
852	0.1713	1.1583	52.0	17.1	2.93	64	28	1.26
852	0.1717	1.4479	51.6	20.4	3.50	64	28	1.26
852	0.1717	1.4479	51.8	20.4	3.50	64	28	1.26
852	0.1735	0.8412	46.5	13.5	2.34	64	28	1.26
852	0.1853	1.6134	48.5	22.0	4.08	64	28	1.26
852	0.1870	1.6134	49.1	21.8	4.08	64	28	1.26
852	0.1870	1.6134	50.4	21.8	4.08	64	28	1.26
852	0.2048	1.1721	55.0	14.3	2.93	64	28	1.26
852	0.2048	1.1721	53.8	14.3	2.93	64	28	1.26
852	0.2502	1.2273	48.5	14.0	3.50	64	28	1.26
852	0.2502	1.2273	45.8	14.0	3.50	64	28	1.26
852	0.2512	0.8963	39.0	11.6	2.91	64	28	1.26
852	0.2514	1.7099	47.8	18.5	4.65	64	28	1.26
852	0.2514	1.7099	47.3	18.5	4.65	64	28	1.26
852	0.2517	1.4755	52.4	16.2	4.08	64	28	1.26
852	0.2517	1.4755	55.7	16.2	4.08	64	28	1.26
852	0.2517	1.4755	55.5	16.2	4.08	64	28	1.26
852	0.2520	1.2273	48.5	13.9	3.50	64	28	1.26
852	0.2528	1.7099	46.7	18.4	4.65	64	28	1.26
852	0.2532	1.4755	55.0	16.1	4.08	64	28	1.26
852	0.2532	1.4755	53.3	16.1	4.08	64	28	1.26
852	0.2548	1.4755	53.6	16.0	4.08	64	28	1.26
852	0.2556	0.8963	39.7	11.4	2.91	64	28	1.26
852	0.2698	0.8963	38.8	10.8	2.91	64	28	1.26
852	0.3350	0.8963	36.0	10.4	3.48	64	28	1.26
852	0.3369	1.3100	43.4	12.1	4.08	64	28	1.26
852	0.3370	1.5444	51.1	13.8	4.65	64	28	1.26
852	0.3370	1.5306	52.4	13.8	4.65	64	28	1.26
852	0.3371	1.8340	45.8	15.5	5.22	64	28	1.26

Glycerine-Water Mixture Data From Test 2 (continued)

852	0.3371	1.8340	44.7	15.5	5.22	64	28	1.26
852	0.3371	1.8340	45.2	15.5	5.22	64	28	1.26
852	0.3397	1.3100	43.8	12.0	4.08	64	28	1.26
852	0.3397	1.3100	43.4	12.0	4.08	64	28	1.26
852	0.3445	1.5444	54.8	13.5	4.65	64	28	1.26
852	0.3445	1.5306	54.1	13.5	4.65	64	28	1.26
852	0.3445	1.5306	52.4	13.5	4.65	64	28	1.26
852	0.3471	1.5444	58.7	13.4	4.65	64	28	1.26
852	0.3484	0.8963	35.9	10.0	3.48	64	28	1.26

Glycerine-Water-Polymer Mixture Data

K $cp-s^{(n-1)}$	n	ALR	Pd MPa	SMD μm	Liq. Mass g/s	Air Mass g/s	Surface Tens. dyn/cm	Ta C	Density g/cm^3
400	0.85	0.0436	0.9652	122.9	34.3	1.49	64	18	1.13
400	0.85	0.0437	0.9652	121.1	34.2	1.49	64	18	1.13
400	0.85	0.0438	0.6205	134.9	25.1	1.10	64	18	1.13
400	0.85	0.0439	0.6205	131.0	25.0	1.10	64	18	1.13
400	0.85	0.0441	0.9652	126.7	33.9	1.49	64	18	1.13
400	0.85	0.0441	0.6205	136.7	24.9	1.10	64	18	1.13
400	0.85	0.0495	1.1307	114.8	36.0	1.78	64	18	1.13
400	0.85	0.0496	1.1307	112.7	35.9	1.78	64	18	1.13
400	0.85	0.0728	2.0408	80.5	47.6	3.47	64	18	1.13
400	0.85	0.0728	2.0408	83.1	47.6	3.47	64	18	1.13
400	0.85	0.0728	1.6133	84.9	39.8	2.90	64	18	1.13
400	0.85	0.0728	1.6133	87.6	39.8	2.90	64	18	1.13
400	0.85	0.0730	1.6133	82.7	39.7	2.90	64	18	1.13
400	0.85	0.0736	2.0408	83.3	47.1	3.47	64	18	1.13
400	0.85	0.0754	1.8615	83.5	42.2	3.18	64	18	1.13
400	0.85	0.0756	1.8615	80.7	42.1	3.18	64	18	1.13
400	0.85	0.0758	1.8615	77.8	42.0	3.18	64	18	1.13
400	0.85	0.0773	2.1373	78.2	48.5	3.75	64	18	1.13
400	0.85	0.0776	2.1373	76.4	48.3	3.75	64	18	1.13
400	0.85	0.0784	2.1373	78.8	47.8	3.75	64	18	1.13
400	0.85	0.0803	1.6961	81.6	39.6	3.18	64	18	1.13
400	0.85	0.0803	1.6961	81.8	39.6	3.18	64	18	1.13
400	0.85	0.0805	1.6961	79.4	39.5	3.18	64	18	1.13
400	0.85	0.0810	0.7860	94.4	22.0	1.78	64	18	1.13
400	0.85	0.0828	0.7860	94.9	21.5	1.78	64	18	1.13
400	0.85	0.0832	0.7860	92.6	21.4	1.78	64	18	1.13
400	0.85	0.0833	1.3100	89.5	31.9	2.66	64	18	1.13
400	0.85	0.0833	1.3100	85.2	31.9	2.66	64	18	1.13
400	0.85	0.0853	1.1169	87.6	27.6	2.36	64	18	1.13
400	0.85	0.0863	1.1169	84.8	27.3	2.36	64	18	1.13
400	0.85	0.0906	1.4065	73.9	32.0	2.90	64	18	1.13
400	0.85	0.0914	1.4065	78.5	31.7	2.90	64	18	1.13
400	0.85	0.0920	1.4065	78.1	31.5	2.90	64	18	1.13
400	0.85	0.0921	1.4065	80.4	31.8	2.93	64	18	1.13
400	0.85	0.0924	1.4065	79.6	31.7	2.93	64	18	1.13
400	0.85	0.1009	0.8549	84.2	20.5	2.07	64	18	1.13
400	0.85	0.1024	0.8549	82.7	20.2	2.07	64	18	1.13
400	0.85	0.1034	0.8549	78.4	20.0	2.07	64	18	1.13
400	0.85	0.1513	1.6892	61.7	22.9	3.47	64	18	1.13
400	0.85	0.1520	1.6892	61.7	22.8	3.47	64	18	1.13
400	0.85	0.1537	1.5720	55.5	24.4	3.75	64	18	1.13
400	0.85	0.1542	1.7926	53.8	28.0	4.32	64	18	1.13
400	0.85	0.1547	1.6892	58.8	22.4	3.47	64	18	1.13
400	0.85	0.1551	1.6823	53.3	26.0	4.03	64	18	1.13

Glycerine-Water-Polymer Mixture Data (continued)

400	0.85	0.1551	1.6823	54.7	26.0	4.03	64	18	1.13
400	0.85	0.1556	1.5720	57.1	24.1	3.75	64	18	1.13
400	0.85	0.1559	1.7926	53.8	27.7	4.32	64	18	1.13
400	0.85	0.1562	1.5720	56.8	24.0	3.75	64	18	1.13
400	0.85	0.1569	1.6823	53.8	25.7	4.03	64	18	1.13
400	0.85	0.1576	1.7926	53.1	27.4	4.32	64	18	1.13
400	0.85	0.1582	1.2824	58.8	21.9	3.47	64	18	1.13
400	0.85	0.1597	1.2824	60.6	21.7	3.47	64	18	1.13
400	0.85	0.1619	1.2824	57.9	21.4	3.47	64	18	1.13
400	0.85	0.1635	0.7860	65.1	14.4	2.36	64	18	1.13
400	0.85	0.1637	1.4065	56.0	22.9	3.75	64	18	1.13
400	0.85	0.1646	1.0342	60.6	17.8	2.93	64	18	1.13
400	0.85	0.1652	1.4065	56.7	22.7	3.75	64	18	1.13
400	0.85	0.1652	1.2962	58.0	21.2	3.50	64	18	1.13
400	0.85	0.1658	1.1583	60.2	19.5	3.23	64	18	1.13
400	0.85	0.1659	1.4065	57.8	22.6	3.75	64	18	1.13
400	0.85	0.1660	1.2962	59.4	21.1	3.50	64	18	1.13
400	0.85	0.1664	1.0342	60.5	17.6	2.93	64	18	1.13
400	0.85	0.1664	1.0342	60.2	17.6	2.93	64	18	1.13
400	0.85	0.1672	0.8963	62.5	15.8	2.64	64	18	1.13
400	0.85	0.1675	1.1583	59.8	19.3	3.23	64	18	1.13
400	0.85	0.1684	1.2962	60.0	20.8	3.50	64	18	1.13
400	0.85	0.1693	1.1583	59.7	19.1	3.23	64	18	1.13
400	0.85	0.1694	0.7860	60.8	13.9	2.36	64	18	1.13
400	0.85	0.1719	0.7860	62.1	13.7	2.36	64	18	1.13
400	0.85	0.1785	0.8963	59.7	14.8	2.64	64	18	1.13
400	0.85	0.1848	0.8963	58.3	14.3	2.64	64	18	1.13
400	0.85	0.2416	1.1031	46.9	14.5	3.50	64	18	1.13
400	0.85	0.2427	1.2272	48.9	15.7	3.81	64	18	1.13
400	0.85	0.2439	1.4478	46.4	17.7	4.32	64	18	1.13
400	0.85	0.2450	1.7926	44.5	21.1	5.17	64	18	1.13
400	0.85	0.2453	1.4478	45.0	17.6	4.32	64	18	1.13
400	0.85	0.2461	1.7926	43.7	21.0	5.17	64	18	1.13
400	0.85	0.2461	1.7926	44.1	21.0	5.17	64	18	1.13
400	0.85	0.2467	1.4478	46.9	17.5	4.32	64	18	1.13
400	0.85	0.2467	1.6547	45.8	19.8	4.88	64	18	1.13
400	0.85	0.2467	1.6547	44.8	19.8	4.88	64	18	1.13
400	0.85	0.2474	1.2272	45.9	15.4	3.81	64	18	1.13
400	0.85	0.2474	1.2272	47.7	15.4	3.81	64	18	1.13
400	0.85	0.2480	1.6547	44.6	19.7	4.88	64	18	1.13
400	0.85	0.2490	1.3237	46.7	16.2	4.03	64	18	1.13
400	0.85	0.2501	1.5582	44.7	18.4	4.60	64	18	1.13
400	0.85	0.2502	1.1031	47.3	14.0	3.50	64	18	1.13
400	0.85	0.2528	1.5582	44.2	18.2	4.60	64	18	1.13
400	0.85	0.2532	1.3237	47.8	16.1	4.08	64	18	1.13
400	0.85	0.2532	0.9652	48.0	12.7	3.22	64	18	1.13
400	0.85	0.2542	1.5582	44.1	18.1	4.60	64	18	1.13
400	0.85	0.2548	1.3237	45.3	16.0	4.08	64	18	1.13
400	0.85	0.2557	1.1031	46.0	13.7	3.50	64	18	1.13

Glycerine-Water-Polymer Mixture Data (continued)

400	0.85	0.2564	1.3237	47.4	15.9	4.08	64	18	1.13
400	0.85	0.2569	1.3237	46.4	15.7	4.03	64	18	1.13
400	0.85	0.2585	1.3237	46.3	15.6	4.03	64	18	1.13
400	0.85	0.2636	0.9652	49.1	12.2	3.22	64	18	1.13
400	0.85	0.2658	0.9652	49.6	12.1	3.22	64	18	1.13
400	0.85	0.2712	0.8825	49.1	10.8	2.93	64	18	1.13
400	0.85	0.2737	0.8825	47.1	10.7	2.93	64	18	1.13
400	0.85	0.2737	0.8825	46.7	10.7	2.93	64	18	1.13
400	0.85	0.3156	1.3375	40.5	13.9	4.39	64	18	1.13
400	0.85	0.3185	1.1307	42.57	11.9	3.79	64	18	1.13
400	0.85	0.3239	1.1307	41.72	11.7	3.79	64	18	1.13
400	0.85	0.3239	1.1307	41.69	11.7	3.79	64	18	1.13
400	0.85	0.3250	1.3375	40.6	13.5	4.39	64	18	1.13
400	0.85	0.3250	1.3375	40.2	13.5	4.39	64	18	1.13
400	0.85	0.3259	1.8891	39.0	17.6	5.74	64	18	1.13
400	0.85	0.3265	1.7374	39.9	16.7	5.45	64	18	1.13
400	0.85	0.3278	1.8891	38.2	17.5	5.74	64	18	1.13
400	0.85	0.3278	1.8891	39.2	17.5	5.74	64	18	1.13
400	0.85	0.3301	1.5444	39.0	14.8	4.88	64	18	1.13
400	0.85	0.3305	1.7374	39.0	16.5	5.45	64	18	1.13
400	0.85	0.3310	1.4065	40.7	13.9	4.60	64	18	1.13
400	0.85	0.3315	1.2272	39.5	12.3	4.08	64	18	1.13
400	0.85	0.3323	1.5444	39.9	14.7	4.88	64	18	1.13
400	0.85	0.3323	1.5444	39.6	14.7	4.88	64	18	1.13
400	0.85	0.3334	1.4203	38.7	13.8	4.60	64	18	1.13
400	0.85	0.3335	1.6133	39.6	15.5	5.17	64	18	1.13
400	0.85	0.3336	1.0066	41.6	10.5	3.50	64	18	1.13
400	0.85	0.3345	1.7374	38.3	16.3	5.45	64	18	1.13
400	0.85	0.3356	1.6133	39.0	15.4	5.17	64	18	1.13
400	0.85	0.3358	1.4065	40.5	13.7	4.60	64	18	1.13
400	0.85	0.3383	1.4065	40.0	13.6	4.60	64	18	1.13
400	0.85	0.3397	1.2272	39.7	12.0	4.08	64	18	1.13
400	0.85	0.3397	1.2272	39.8	12.0	4.08	64	18	1.13
400	0.85	0.3401	1.6133	38.9	15.2	5.17	64	18	1.13
400	0.85	0.3408	1.4203	38.8	13.5	4.60	64	18	1.13
400	0.85	0.3434	1.4203	39.6	13.4	4.60	64	18	1.13
400	0.85	0.3649	1.0066	40.0	9.6	3.50	64	18	1.13
400	0.85	0.3727	1.0066	40.6	9.4	3.50	64	18	1.13
420	0.90	0.0386	0.7446	148.2	28.6	1.10	64	23	1.20
420	0.90	0.0386	0.7446	133.6	28.6	1.10	64	23	1.20
420	0.90	0.0392	0.7446	149.2	28.2	1.10	64	23	1.20
420	0.90	0.0408	1.4065	118.0	43.9	1.79	64	23	1.20
420	0.90	0.0412	1.4065	118.7	43.5	1.79	64	23	1.20
420	0.90	0.0417	1.6823	121.9	49.8	2.08	64	23	1.20
420	0.90	0.0419	0.4136	160.8	17.8	0.75	64	23	1.20

Glycerine-Water-Polymer Mixture Data (continued)

420	0.90	0.0419	1.6823	117.9	49.6	2.08	64	23	1.20
420	0.90	0.0421	1.4065	120.2	42.5	1.79	64	23	1.20
420	0.90	0.0424	1.6823	120.4	49.0	2.08	64	23	1.20
420	0.90	0.0447	1.0066	123.6	33.6	1.50	64	23	1.20
420	0.90	0.0448	1.0066	118.8	33.5	1.50	64	23	1.20
420	0.90	0.0454	1.0066	122.9	33.1	1.50	64	23	1.20
420	0.90	0.0460	1.8340	113.6	51.5	2.37	64	23	1.20
420	0.90	0.0462	1.8340	113.4	51.3	2.37	64	23	1.20
420	0.90	0.0470	1.8340	112.9	50.4	2.37	64	23	1.20
420	0.90	0.0825	1.7236	92.3	39.2	3.23	64	23	1.20
420	0.90	0.0833	1.7236	89.5	38.8	3.23	64	23	1.20
420	0.90	0.0835	0.9928	93.5	24.9	2.08	64	23	1.20
420	0.90	0.0835	1.7236	89.7	38.7	3.23	64	23	1.20
420	0.90	0.0844	1.5582	87.0	34.9	2.94	64	23	1.20
420	0.90	0.0846	1.5582	85.2	34.8	2.94	64	23	1.20
420	0.90	0.0846	1.5582	84.5	34.8	2.94	64	23	1.20
420	0.90	0.0849	1.8891	84.5	41.5	3.52	64	23	1.20
420	0.90	0.0851	1.8891	88.6	41.4	3.52	64	23	1.20
420	0.90	0.0852	0.9928	96.3	24.4	2.08	64	23	1.20
420	0.90	0.0853	1.8891	90.6	41.3	3.52	64	23	1.20
420	0.90	0.0853	0.9928	87.7	24.4	2.08	64	23	1.20
420	0.90	0.0861	1.1445	90.5	27.5	2.37	64	23	1.20
420	0.90	0.0870	1.1445	90.1	27.2	2.37	64	23	1.20
420	0.90	0.0873	0.7722	96.6	20.5	1.79	64	23	1.20
420	0.90	0.0894	0.6481	101.3	16.8	1.50	64	23	1.20
420	0.90	0.0894	1.2962	81.7	29.7	2.66	64	23	1.20
420	0.90	0.0895	0.7722	103.1	20.0	1.79	64	23	1.20
420	0.90	0.0900	0.7722	104.3	19.9	1.79	64	23	1.20
420	0.90	0.0900	1.2962	86.9	29.5	2.66	64	23	1.20
420	0.90	0.0903	1.2962	85.1	29.4	2.66	64	23	1.20
420	0.90	0.0907	1.1445	89.6	26.1	2.37	64	23	1.20
420	0.90	0.1592	1.0617	65.0	18.5	2.94	64	23	1.20
420	0.90	0.1633	0.8273	70.9	14.5	2.37	64	23	1.20
420	0.90	0.1633	1.1996	62.1	19.8	3.23	64	23	1.20
420	0.90	0.1644	0.8273	74.4	14.4	2.37	64	23	1.20
420	0.90	0.1650	1.1996	61.5	19.6	3.23	64	23	1.20
420	0.90	0.1661	1.3375	58.3	21.2	3.52	64	23	1.20
420	0.90	0.1663	0.6894	79.2	12.5	2.08	64	23	1.20
420	0.90	0.1667	1.1996	65.8	19.4	3.23	64	23	1.20
420	0.90	0.1669	1.3375	63.6	21.1	3.52	64	23	1.20
420	0.90	0.1670	0.9376	63.0	15.9	2.66	64	23	1.20
420	0.90	0.1673	1.0617	63.6	17.6	2.94	64	23	1.20
420	0.90	0.1677	0.6894	77.8	12.4	2.08	64	23	1.20
420	0.90	0.1679	0.8273	73.9	14.1	2.37	64	23	1.20
420	0.90	0.1686	1.4478	62.0	22.6	3.81	64	23	1.20

Glycerine-Water-Polymer Mixture Data (continued)

420	0.90	0.1687	1.6133	61.4	24.3	4.10	64	23	1.20
420	0.90	0.1687	1.6133	58.3	24.3	4.10	64	23	1.20
420	0.90	0.1692	0.9376	67.7	15.7	2.66	64	23	1.20
420	0.90	0.1692	0.9376	66.6	15.7	2.66	64	23	1.20
420	0.90	0.1693	1.3375	64.3	20.8	3.52	64	23	1.20
420	0.90	0.1693	1.4478	60.5	22.5	3.81	64	23	1.20
420	0.90	0.1694	1.6133	62.0	24.2	4.10	64	23	1.20
420	0.90	0.1702	1.0617	67.3	17.3	2.94	64	23	1.20
420	0.90	0.1709	1.4478	63.3	22.3	3.81	64	23	1.20
420	0.90	0.1718	0.6894	77.9	12.1	2.08	64	23	1.20
420	0.90	0.2434	0.8549	57.7	12.1	2.94	64	23	1.20
420	0.90	0.2442	1.2410	51.9	15.6	3.81	64	23	1.20
420	0.90	0.2454	0.8549	55.5	12.0	2.94	64	23	1.20
420	0.90	0.2463	1.1445	57.3	14.3	3.52	64	23	1.20
420	0.90	0.2490	1.2410	52.7	15.3	3.81	64	23	1.20
420	0.90	0.2493	1.4754	51.2	17.6	4.39	64	23	1.20
420	0.90	0.2495	0.8549	56.8	11.8	2.94	64	23	1.20
420	0.90	0.2498	1.1445	56.5	14.1	3.52	64	23	1.20
420	0.90	0.2507	1.2410	51.1	15.2	3.81	64	23	1.20
420	0.90	0.2507	1.4754	50.5	17.5	4.39	64	23	1.20
420	0.90	0.2515	1.1445	52.9	14.0	3.52	64	23	1.20
420	0.90	0.2521	1.4754	51.7	17.4	4.39	64	23	1.20
420	0.90	0.2526	1.0342	53.2	12.8	3.23	64	23	1.20
420	0.90	0.2530	1.3375	48.8	16.2	4.10	64	23	1.20
420	0.90	0.2541	1.5720	49.7	18.4	4.68	64	23	1.20
420	0.90	0.2555	1.5720	50.8	18.3	4.68	64	23	1.20
420	0.90	0.2562	1.3375	53.2	16.0	4.10	64	23	1.20
420	0.90	0.2566	1.0342	54.0	12.6	3.23	64	23	1.20
420	0.90	0.2569	1.5720	51.6	18.2	4.68	64	23	1.20
420	0.90	0.2579	0.7860	59.5	10.3	2.66	64	23	1.20
420	0.90	0.2586	1.0342	55.0	12.5	3.23	64	23	1.20
420	0.90	0.2611	1.3375	51.6	15.7	4.10	64	23	1.20
420	0.90	0.2767	0.7860	56.5	9.6	2.66	64	23	1.20
420	0.90	0.2826	0.7860	53.7	9.4	2.66	64	23	1.20
420	0.90	0.3202	1.2548	46.2	12.8	4.10	64	23	1.20
420	0.90	0.3253	1.2548	46.3	12.6	4.10	64	23	1.20
420	0.90	0.3253	1.2548	46.7	12.6	4.10	64	23	1.20
420	0.90	0.3299	0.9376	50.4	9.8	3.23	64	23	1.20
420	0.90	0.3313	1.1445	48.3	11.5	3.81	64	23	1.20
420	0.90	0.3322	1.0480	48.8	10.6	3.52	64	23	1.20
420	0.90	0.3324	1.6823	44.7	15.8	5.25	64	23	1.20
420	0.90	0.3324	1.6823	46.1	15.8	5.25	64	23	1.20
420	0.90	0.3345	1.6823	44.1	15.7	5.25	64	23	1.20
420	0.90	0.3349	1.3375	43.4	13.1	4.39	64	23	1.20
420	0.90	0.3386	1.0480	47.6	10.4	3.52	64	23	1.20
420	0.90	0.3401	1.3375	45.0	12.9	4.39	64	23	1.20
420	0.90	0.3401	1.3375	44.2	12.9	4.39	64	23	1.20
420	0.90	0.3402	1.1445	45.8	11.2	3.81	64	23	1.20
420	0.90	0.3438	1.4478	43.2	13.6	4.68	64	23	1.20

Glycerine-Water-Polymer Mixture Data (continued)

420	0.90	0.3439	0.9376	50.3	9.4	3.23	64	23	1.20
420	0.90	0.3439	0.9376	50.9	9.4	3.23	64	23	1.20
420	0.90	0.3452	1.0480	44.9	10.2	3.52	64	23	1.20
420	0.90	0.3463	1.4478	42.8	13.5	4.68	64	23	1.20
420	0.90	0.3495	1.1445	45.5	10.9	3.81	64	23	1.20
420	0.90	0.3496	1.5444	44.1	14.2	4.96	64	23	1.20
420	0.90	0.3515	1.4478	44.3	13.3	4.68	64	23	1.20
420	0.90	0.3521	1.5444	43.0	14.1	4.96	64	23	1.20
420	0.90	0.3546	1.5444	45.1	14.0	4.96	64	23	1.20
420	0.90	0.0839	0.6481	109.2	17.9	1.50	64	23	1.20
450	0.95	0.0402	0.7997	152.9	27.3	1.10	64	21	1.22
450	0.95	0.0407	0.7446	135.1	27.0	1.10	64	21	1.22
450	0.95	0.0408	0.7997	144.7	26.9	1.10	64	21	1.22
450	0.95	0.0410	0.7446	130.4	26.8	1.10	64	21	1.22
450	0.95	0.0410	1.4203	119.7	43.4	1.78	64	21	1.22
450	0.95	0.0412	1.4203	123.6	43.2	1.78	64	21	1.22
450	0.95	0.0414	1.4203	122.3	43.0	1.78	64	21	1.22
450	0.95	0.0416	0.7170	131.1	26.4	1.10	64	21	1.22
450	0.95	0.0416	0.7446	132.6	26.4	1.10	64	21	1.22
450	0.95	0.0416	1.4203	119.3	42.8	1.78	64	21	1.22
450	0.95	0.0417	1.4203	121.7	42.7	1.78	64	21	1.22
450	0.95	0.0418	0.7170	141.6	26.3	1.10	64	21	1.22
450	0.95	0.0418	0.7997	136.0	26.3	1.10	64	21	1.22
450	0.95	0.0418	1.4203	114.4	42.6	1.78	64	21	1.22
450	0.95	0.0420	1.4203	115.2	42.4	1.78	64	21	1.22
450	0.95	0.0420	1.4203	119.2	42.4	1.78	64	21	1.22
450	0.95	0.0422	1.4203	114.7	42.2	1.78	64	21	1.22
450	0.95	0.0422	0.7170	135.2	26.0	1.10	64	21	1.22
450	0.95	0.0825	0.8549	104.6	21.6	1.78	64	21	1.22
450	0.95	0.0825	0.8549	98.1	21.6	1.78	64	21	1.22
450	0.95	0.0825	1.5720	82.5	35.5	2.93	64	21	1.22
450	0.95	0.0828	0.8549	98.0	21.5	1.78	64	21	1.22
450	0.95	0.0829	1.2134	87.0	28.4	2.36	64	21	1.22
450	0.95	0.0829	1.2134	87.5	28.4	2.36	64	21	1.22
450	0.95	0.0829	1.2134	89.5	28.4	2.36	64	21	1.22
450	0.95	0.0835	1.2134	86.9	28.2	2.36	64	21	1.22
450	0.95	0.0835	1.2272	90.1	28.2	2.36	64	21	1.22
450	0.95	0.0838	1.2134	88.3	28.1	2.36	64	21	1.22
450	0.95	0.0838	1.2272	91.3	28.1	2.36	64	21	1.22
450	0.95	0.0841	1.2134	87.5	28.0	2.36	64	21	1.22
450	0.95	0.0841	1.2272	92.1	28.0	2.36	64	21	1.22
450	0.95	0.0842	1.5720	85.0	34.8	2.93	64	21	1.22
450	0.95	0.0842	1.5857	83.4	34.8	2.93	64	21	1.22
450	0.95	0.0844	1.5857	81.2	34.7	2.93	64	21	1.22
450	0.95	0.0847	1.5857	82.5	34.6	2.93	64	21	1.22
450	0.95	0.0848	0.8549	102.1	21.0	1.78	64	21	1.22
450	0.95	0.0848	0.8549	98.1	21.0	1.78	64	21	1.22
450	0.95	0.0852	0.8549	95.2	20.9	1.78	64	21	1.22

Glycerine-Water-Polymer Mixture Data (continued)

450	0.95	0.0856	0.8411	93.4	20.8	1.78	64	21	1.22
450	0.95	0.0856	0.8411	92.7	20.8	1.78	64	21	1.22
450	0.95	0.0856	0.8411	91.3	20.8	1.78	64	21	1.22
450	0.95	0.0990	1.7926	71.1	35.4	3.50	64	21	1.22
450	0.95	0.0992	1.7926	73.7	35.3	3.50	64	21	1.22
450	0.95	0.0995	1.7926	70.3	35.2	3.50	64	21	1.22
450	0.95	0.1004	1.7236	72.3	34.9	3.50	64	21	1.22
450	0.95	0.1021	1.7236	74.7	34.3	3.50	64	21	1.22
450	0.95	0.1024	1.7236	71.2	34.2	3.50	64	21	1.22
450	0.95	0.1618	1.1307	63.4	18.1	2.93	64	21	1.22
450	0.95	0.1635	0.8549	70.6	14.4	2.36	64	21	1.22
450	0.95	0.1646	1.1307	64.8	17.8	2.93	64	21	1.22
450	0.95	0.1655	1.1307	64.1	17.7	2.93	64	21	1.22
450	0.95	0.1659	0.8411	67.7	14.2	2.36	64	21	1.22
450	0.95	0.1659	0.8411	69.0	14.2	2.36	64	21	1.22
450	0.95	0.1659	0.8411	67.7	14.2	2.36	64	21	1.22
450	0.95	0.1659	0.8549	67.6	14.2	2.36	64	21	1.22
450	0.95	0.1659	0.8549	66.6	14.2	2.36	64	21	1.22
450	0.95	0.1668	1.3927	60.4	21.0	3.50	64	21	1.22
450	0.95	0.1676	1.3513	61.6	20.9	3.50	64	21	1.22
450	0.95	0.1676	1.3927	60.9	20.9	3.50	64	21	1.22
450	0.95	0.1676	1.3927	59.1	20.9	3.50	64	21	1.22
450	0.95	0.1684	1.3513	61.6	20.8	3.50	64	21	1.22
450	0.95	0.1684	1.3513	60.3	20.8	3.50	64	21	1.22
450	0.95	0.1685	1.6547	56.4	24.2	4.08	64	21	1.22
450	0.95	0.1692	1.6547	55.0	24.1	4.08	64	21	1.22
450	0.95	0.1692	1.6547	57.4	24.1	4.08	64	21	1.22
450	0.95	0.1692	1.6547	55.3	24.1	4.08	64	21	1.22
450	0.95	0.1699	1.6547	55.2	24.0	4.08	64	21	1.22
450	0.95	0.1699	1.6547	57.4	24.0	4.08	64	21	1.22
450	0.95	0.1703	1.0893	68.6	17.2	2.93	64	21	1.22
450	0.95	0.1703	1.0893	66.3	17.2	2.93	64	21	1.22
450	0.95	0.1713	1.0893	64.2	17.1	2.93	64	21	1.22
450	0.95	0.1713	1.0893	66.0	17.1	2.93	64	21	1.22
450	0.95	0.1732	0.8549	69.5	13.6	2.36	64	21	1.22
450	0.95	0.1754	1.0893	61.4	16.7	2.93	64	21	1.22
450	0.95	0.1758	0.8549	69.3	13.4	2.36	64	21	1.22
450	0.95	0.1758	0.8549	67.4	13.4	2.36	64	21	1.22
450	0.95	0.1786	1.0893	61.7	16.4	2.93	64	21	1.22
450	0.95	0.2450	1.1858	51.5	14.3	3.50	64	21	1.22
450	0.95	0.2474	1.6271	49.5	18.8	4.65	64	21	1.22
450	0.95	0.2482	0.9652	55.0	11.8	2.93	64	21	1.22
450	0.95	0.2484	1.1858	51.2	14.1	3.50	64	21	1.22
450	0.95	0.2484	1.1858	51.8	14.1	3.50	64	21	1.22
450	0.95	0.2486	1.4065	51.1	16.4	4.08	64	21	1.22
450	0.95	0.2487	1.6271	49.7	18.7	4.65	64	21	1.22
450	0.95	0.2487	1.6271	50.1	18.7	4.65	64	21	1.22
450	0.95	0.2501	1.4065	51.5	16.3	4.08	64	21	1.22

Glycerine-Water-Polymer Mixture Data (continued)

450	0.95	0.2501	1.4065	52.1	16.3	4.08	64	21	1.22
450	0.95	0.2501	1.4065	50.3	16.3	4.08	64	21	1.22
450	0.95	0.2501	1.4065	49.9	16.3	4.08	64	21	1.22
450	0.95	0.2503	0.9652	55.3	11.7	2.93	64	21	1.22
450	0.95	0.2503	0.9652	55.4	11.7	2.93	64	21	1.22
450	0.95	0.2517	1.4065	50.2	16.2	4.08	64	21	1.22
450	0.95	0.2547	0.9514	55.3	11.5	2.93	64	21	1.22
450	0.95	0.2547	0.9514	55.7	11.5	2.93	64	21	1.22
450	0.95	0.2547	0.9514	56.4	11.5	2.93	64	21	1.22
450	0.95	0.2547	0.9514	54.6	11.5	2.93	64	21	1.22
450	0.95	0.2557	1.1583	52.9	13.7	3.50	64	21	1.22
450	0.95	0.2569	0.9514	56.7	11.4	2.93	64	21	1.22
450	0.95	0.2569	0.9514	56.8	11.4	2.93	64	21	1.22
450	0.95	0.2569	1.6547	47.1	18.1	4.65	64	21	1.22
450	0.95	0.2569	1.6547	48.0	18.1	4.65	64	21	1.22
450	0.95	0.2569	1.6547	47.0	18.1	4.65	64	21	1.22
450	0.95	0.2576	1.1583	53.7	13.6	3.50	64	21	1.22
450	0.95	0.2576	1.1583	51.1	13.6	3.50	64	21	1.22
450	0.95	0.2595	1.1583	53.5	13.5	3.50	64	21	1.22
450	0.95	0.2595	1.1583	52.6	13.5	3.50	64	21	1.22
450	0.95	0.2595	1.1583	52.2	13.5	3.50	64	21	1.22
450	0.95	0.3288	1.2686	47.0	12.4	4.08	64	21	1.22
450	0.95	0.3288	1.2824	46.6	12.4	4.08	64	21	1.22
450	0.95	0.3305	1.0755	48.1	10.6	3.50	64	21	1.22
450	0.95	0.3305	1.0755	47.0	10.6	3.50	64	21	1.22
450	0.95	0.3305	1.0755	44.9	10.6	3.50	64	21	1.22
450	0.95	0.3305	1.0755	45.8	10.6	3.50	64	21	1.22
450	0.95	0.3315	1.2686	48.0	12.3	4.08	64	21	1.22
450	0.95	0.3315	1.2686	47.6	12.3	4.08	64	21	1.22
450	0.95	0.3328	1.6961	45.4	15.7	5.22	64	21	1.22
450	0.95	0.3328	1.6961	45.6	15.7	5.22	64	21	1.22
450	0.95	0.3328	1.6961	44.7	15.7	5.22	64	21	1.22
450	0.95	0.3336	1.0755	47.0	10.5	3.50	64	21	1.22
450	0.95	0.3336	1.0755	46.4	10.5	3.50	64	21	1.22
450	0.95	0.3342	1.2824	48.2	12.2	4.08	64	21	1.22
450	0.95	0.3369	1.2824	44.0	12.1	4.08	64	21	1.22
450	0.95	0.3369	1.2824	45.5	12.1	4.08	64	21	1.22
450	0.95	0.3369	1.2824	44.8	12.1	4.08	64	21	1.22
450	0.95	0.3395	1.4754	45.4	13.7	4.65	64	21	1.22
450	0.95	0.3397	1.2824	44.7	12.0	4.08	64	21	1.22
450	0.95	0.3401	1.0480	49.7	10.3	3.50	64	21	1.22
450	0.95	0.3420	1.4616	44.4	13.6	4.65	64	21	1.22
450	0.95	0.3420	1.4616	44.4	13.6	4.65	64	21	1.22
450	0.95	0.3420	1.4616	44.1	13.6	4.65	64	21	1.22
450	0.95	0.3420	1.4754	44.9	13.6	4.65	64	21	1.22
450	0.95	0.3420	1.4754	44.6	13.6	4.65	64	21	1.22
450	0.95	0.3434	1.0480	49.8	10.2	3.50	64	21	1.22
450	0.95	0.3434	1.0480	49.3	10.2	3.50	64	21	1.22
510	0.85	0.0396	1.3789	107.1	45.0	1.78	64	22	1.13

Glycerine-Water-Polymer Mixture Data (continued)

510	0.85	0.0401	1.3789	107.8	44.4	1.78	64	22	1.13
510	0.85	0.0404	1.3789	103.9	44.1	1.78	64	22	1.13
510	0.85	0.0408	0.3998	149.9	18.4	0.75	64	22	1.13
510	0.85	0.0419	1.0342	103.3	35.7	1.49	64	22	1.13
510	0.85	0.0422	1.0342	100.2	35.4	1.49	64	22	1.13
510	0.85	0.0432	1.5857	104.1	47.9	2.07	64	22	1.13
510	0.85	0.0433	1.5857	103.7	47.8	2.07	64	22	1.13
510	0.85	0.0434	1.5857	106.4	47.7	2.07	64	22	1.13
510	0.85	0.0829	0.7722	91.3	21.6	1.79	64	22	1.13
510	0.85	0.0833	1.2824	84.2	31.7	2.64	64	22	1.13
510	0.85	0.0836	1.2824	86.4	31.6	2.64	64	22	1.13
510	0.85	0.0841	1.2824	86.2	31.4	2.64	64	22	1.13
510	0.85	0.0842	1.6409	82.6	38.2	3.22	64	22	1.13
510	0.85	0.0844	1.4203	82.9	34.7	2.93	64	22	1.13
510	0.85	0.0846	1.6409	83.1	38.0	3.22	64	22	1.13
510	0.85	0.0847	1.0617	87.4	27.8	2.36	64	22	1.13
510	0.85	0.0849	1.6409	82.0	37.9	3.22	64	22	1.13
510	0.85	0.0849	1.4203	81.4	34.5	2.93	64	22	1.13
510	0.85	0.0878	0.7722	96.9	20.4	1.79	64	22	1.13
510	0.85	0.0882	0.7722	94.9	20.3	1.79	64	22	1.13
510	0.85	0.0899	0.5929	99.7	16.8	1.51	64	22	1.13
510	0.85	0.0900	1.8340	82.0	38.7	3.48	64	22	1.13
510	0.85	0.0902	1.0617	84.4	26.1	2.36	64	22	1.13
510	0.85	0.0905	1.8340	79.2	38.5	3.48	64	22	1.13
510	0.85	0.0909	1.0617	81.3	25.9	2.36	64	22	1.13
510	0.85	0.0926	0.5929	103.5	16.3	1.51	64	22	1.13
510	0.85	0.0957	0.8687	86.3	21.6	2.07	64	22	1.13
510	0.85	0.0994	0.8687	78.5	20.8	2.07	64	22	1.13
510	0.85	0.1034	0.8687	84.8	20.0	2.07	64	22	1.13
510	0.85	0.1358	1.4892	66.5	27.9	3.79	64	22	1.13
510	0.85	0.1398	1.4892	66.2	27.1	3.79	64	22	1.13
510	0.85	0.1409	1.4892	68.7	26.9	3.79	64	22	1.13
510	0.85	0.1600	0.7860	77.8	14.8	2.37	64	22	1.13
510	0.85	0.1616	1.5168	60.5	25.1	4.06	64	22	1.13
510	0.85	0.1631	0.8825	68.0	16.2	2.64	64	22	1.13
510	0.85	0.1632	1.1169	65.0	19.7	3.22	64	22	1.13
510	0.85	0.1646	0.9928	71.4	17.8	2.93	64	22	1.13
510	0.85	0.1672	0.6481	79.2	12.5	2.09	64	22	1.13
510	0.85	0.1672	0.6481	75.2	12.5	2.09	64	22	1.13
510	0.85	0.1699	0.6481	75.4	12.3	2.09	64	22	1.13
510	0.85	0.1705	0.8825	71.7	15.5	2.64	64	22	1.13
510	0.85	0.1711	1.1169	70.5	18.8	3.22	64	22	1.13
510	0.85	0.1716	0.7860	72.8	13.8	2.37	64	22	1.13
510	0.85	0.1726	1.5168	63.0	23.5	4.06	64	22	1.13
510	0.85	0.1734	1.1858	63.9	20.2	3.50	64	22	1.13
510	0.85	0.1740	1.5168	64.7	23.3	4.06	64	22	1.13
510	0.85	0.1750	0.8825	71.5	15.1	2.64	64	22	1.13
510	0.85	0.1754	0.7860	73.4	13.5	2.37	64	22	1.13

Glycerine-Water-Polymer Mixture Data (continued)

510	0.85	0.1757	1.1169	66.6	18.3	3.22	64	22	1.13
510	0.85	0.1764	0.9928	67.0	16.6	2.93	64	22	1.13
510	0.85	0.1808	0.9928	67.2	16.2	2.93	64	22	1.13
510	0.85	0.1914	1.1858	61.3	18.3	3.50	64	22	1.13
510	0.85	0.1990	1.1858	63.7	17.6	3.50	64	22	1.13
510	0.85	0.2383	1.0755	60.2	14.7	3.50	64	22	1.13
510	0.85	0.2411	1.4065	54.0	18.1	4.36	64	22	1.13
510	0.85	0.2429	1.1721	56.9	15.6	3.79	64	22	1.13
510	0.85	0.2445	1.1721	56.5	15.5	3.79	64	22	1.13
510	0.85	0.2484	1.0755	59.6	14.1	3.50	64	22	1.13
510	0.85	0.2508	1.4065	55.6	17.4	4.36	64	22	1.13
510	0.85	0.2510	1.1721	57.0	15.1	3.79	64	22	1.13
510	0.85	0.2514	1.4892	52.4	18.4	4.63	64	22	1.13
510	0.85	0.2514	1.4892	56.1	18.4	4.63	64	22	1.13
510	0.85	0.2517	0.8687	55.7	11.7	2.94	64	22	1.13
510	0.85	0.2528	1.4892	51.1	18.3	4.63	64	22	1.13
510	0.85	0.2532	1.2686	57.3	16.1	4.08	64	22	1.13
510	0.85	0.2532	0.9376	58.3	12.7	3.22	64	22	1.13
510	0.85	0.2557	1.0755	57.8	13.7	3.50	64	22	1.13
510	0.85	0.2592	0.7584	66.7	10.3	2.67	64	22	1.13
510	0.85	0.2592	0.7584	61.9	10.3	2.67	64	22	1.13
510	0.85	0.2670	0.7584	59.6	10.0	2.67	64	22	1.13
510	0.85	0.2702	0.9376	57.3	11.9	3.22	64	22	1.13
510	0.85	0.2749	0.9376	59.0	11.7	3.22	64	22	1.13
510	0.85	0.2752	0.8687	60.0	10.7	2.94	64	22	1.13
510	0.85	0.2755	1.2686	52.0	14.8	4.08	64	22	1.13
510	0.85	0.2804	0.8687	60.5	10.5	2.94	64	22	1.13
510	0.85	0.2851	1.2686	54.0	14.3	4.08	64	22	1.13
510	0.85	0.2981	1.4203	49.8	15.6	4.65	64	22	1.13
510	0.85	0.3060	1.4203	49.5	15.2	4.65	64	22	1.13
510	0.85	0.3164	1.4203	49.1	14.7	4.65	64	22	1.13
510	0.85	0.3212	1.0893	52.1	11.8	3.79	64	22	1.13
510	0.85	0.3231	0.9790	52.4	10.9	3.52	64	22	1.13
510	0.85	0.3268	1.5995	47.4	15.9	5.20	64	22	1.13
510	0.85	0.3270	1.4892	47.3	15.1	4.94	64	22	1.13
510	0.85	0.3292	1.4892	46.5	15.0	4.94	64	22	1.13
510	0.85	0.3296	1.0893	50.1	11.5	3.79	64	22	1.13
510	0.85	0.3296	1.0893	52.2	11.5	3.79	64	22	1.13
510	0.85	0.3310	1.5995	48.8	15.7	5.20	64	22	1.13
510	0.85	0.3351	0.8963	52.66	9.7	3.25	64	22	1.13
510	0.85	0.3351	0.8963	55.47	9.7	3.25	64	22	1.13
510	0.85	0.3351	0.8963	52.54	9.7	3.25	64	22	1.13
510	0.85	0.3353	1.5995	44.7	15.5	5.20	64	22	1.13
510	0.85	0.3354	0.9790	53.5	10.5	3.52	64	22	1.13
510	0.85	0.3357	1.2686	47.7	13.0	4.36	64	22	1.13
510	0.85	0.3359	1.4892	50.4	14.7	4.94	64	22	1.13
510	0.85	0.3397	1.1721	50.7	12.0	4.08	64	22	1.13
510	0.85	0.3397	1.1721	49.1	12.0	4.08	64	22	1.13
510	0.85	0.3419	0.9790	52.4	10.3	3.52	64	22	1.13

Glycerine-Water-Polymer Mixture Data (continued)

510	0.85	0.3426	1.1721	47.4	11.9	4.08	64	22	1.13
510	0.85	0.3491	1.2686	46.1	12.5	4.36	64	22	1.13
510	0.85	0.3667	1.2686	45.8	11.9	4.36	64	22	1.13
520	0.94	0.0391	0.7997	156.3	28.1	1.10	64	22	1.22
520	0.94	0.0395	0.7997	154.1	27.8	1.10	64	22	1.22
520	0.94	0.0404	0.7997	158.0	27.2	1.10	64	22	1.22
520	0.94	0.0406	0.8411	146.8	27.2	1.10	64	22	1.22
520	0.94	0.0407	0.8411	144.6	27.1	1.10	64	22	1.22
520	0.94	0.0407	0.8411	147.5	27.1	1.10	64	22	1.22
520	0.94	0.0429	1.4065	116.7	41.5	1.78	64	22	1.22
520	0.94	0.0431	1.4065	118.8	41.3	1.78	64	22	1.22
520	0.94	0.0433	1.4065	125.7	41.1	1.78	64	22	1.22
520	0.94	0.0437	1.4203	127.9	41.0	1.79	64	22	1.22
520	0.94	0.0445	1.4203	126.3	40.2	1.79	64	22	1.22
520	0.94	0.0821	1.2824	91.0	28.7	2.36	64	22	1.22
520	0.94	0.0826	1.2824	88.3	28.5	2.36	64	22	1.22
520	0.94	0.0828	0.8549	96.2	21.5	1.78	64	22	1.22
520	0.94	0.0832	0.8549	96.8	21.4	1.78	64	22	1.22
520	0.94	0.0833	0.8687	101.3	21.5	1.79	64	22	1.22
520	0.94	0.0839	1.5995	87.7	34.9	2.93	64	22	1.22
520	0.94	0.0840	1.2686	96.2	28.2	2.37	64	22	1.22
520	0.94	0.0843	1.2686	93.2	28.1	2.37	64	22	1.22
520	0.94	0.0843	1.2686	94.8	28.1	2.37	64	22	1.22
520	0.94	0.0844	1.5995	88.4	34.7	2.93	64	22	1.22
520	0.94	0.0853	0.8687	111.0	21.0	1.79	64	22	1.22
520	0.94	0.0854	1.5995	87.7	34.3	2.93	64	22	1.22
520	0.94	0.0857	0.8687	104.8	20.9	1.79	64	22	1.22
520	0.94	0.0864	1.6133	93.2	34.1	2.94	64	22	1.22
520	0.94	0.0874	1.6133	91.5	33.7	2.94	64	22	1.22
520	0.94	0.1061	1.7236	73.9	33.0	3.50	64	22	1.22
520	0.94	0.1081	1.7236	73.8	32.4	3.50	64	22	1.22
520	0.94	0.1081	1.7236	77.9	32.4	3.50	64	22	1.22
520	0.94	0.1116	1.6961	79.7	31.4	3.50	64	22	1.22
520	0.94	0.1123	1.6961	77.6	31.2	3.50	64	22	1.22
520	0.94	0.1123	1.6961	80.5	31.2	3.50	64	22	1.22
520	0.94	0.1624	0.8549	73.8	14.5	2.36	64	22	1.22
520	0.94	0.1635	0.8549	70.3	14.4	2.36	64	22	1.22
520	0.94	0.1644	1.6823	59.4	24.8	4.08	64	22	1.22
520	0.94	0.1651	1.6823	60.3	24.7	4.08	64	22	1.22
520	0.94	0.1651	1.6823	60.8	24.7	4.08	64	22	1.22
520	0.94	0.1659	0.8549	72.7	14.2	2.36	64	22	1.22
520	0.94	0.1684	1.4065	62.9	20.8	3.50	64	22	1.22
520	0.94	0.1684	1.4065	59.9	20.8	3.50	64	22	1.22
520	0.94	0.1685	1.6961	61.1	24.2	4.08	64	22	1.22
520	0.94	0.1685	1.6961	63.5	24.2	4.08	64	22	1.22
520	0.94	0.1692	1.6961	61.6	24.1	4.08	64	22	1.22
520	0.94	0.1692	1.4065	61.8	20.7	3.50	64	22	1.22
520	0.94	0.1693	1.4065	65.0	20.8	3.52	64	22	1.22

Glycerine-Water-Polymer Mixture Data (continued)

520	0.94	0.1693	1.1307	63.8	17.3	2.93	64	22	1.22
520	0.94	0.1701	1.4065	65.8	20.7	3.52	64	22	1.22
520	0.94	0.1709	1.4065	66.4	20.6	3.52	64	22	1.22
520	0.94	0.1712	1.1307	67.1	17.2	2.94	64	22	1.22
520	0.94	0.1713	1.1307	64.7	17.1	2.93	64	22	1.22
520	0.94	0.1713	1.1307	64.1	17.1	2.93	64	22	1.22
520	0.94	0.1716	0.8687	76.4	13.8	2.37	64	22	1.22
520	0.94	0.1722	1.1307	73.2	17.1	2.94	64	22	1.22
520	0.94	0.1722	1.1307	69.7	17.1	2.94	64	22	1.22
520	0.94	0.1741	0.8687	73.0	13.6	2.37	64	22	1.22
520	0.94	0.1754	0.8687	74.9	13.5	2.37	64	22	1.22
520	0.94	0.2482	0.9652	58.5	11.8	2.93	64	22	1.22
520	0.94	0.2486	1.4341	51.4	16.4	4.08	64	22	1.22
520	0.94	0.2498	1.1996	57.0	14.1	3.52	64	22	1.22
520	0.94	0.2500	1.6823	49.1	18.6	4.65	64	22	1.22
520	0.94	0.2501	1.4341	52.1	16.3	4.08	64	22	1.22
520	0.94	0.2502	1.1858	53.9	14.0	3.50	64	22	1.22
520	0.94	0.2502	1.1858	57.4	14.0	3.50	64	22	1.22
520	0.94	0.2503	0.9652	59.1	11.7	2.93	64	22	1.22
520	0.94	0.2503	0.9652	58.2	11.7	2.93	64	22	1.22
520	0.94	0.2514	1.6823	49.1	18.5	4.65	64	22	1.22
520	0.94	0.2514	1.6823	49.7	18.5	4.65	64	22	1.22
520	0.94	0.2515	1.1996	59.8	14.0	3.52	64	22	1.22
520	0.94	0.2515	1.1996	55.3	14.0	3.52	64	22	1.22
520	0.94	0.2517	1.4341	51.7	16.2	4.08	64	22	1.22
520	0.94	0.2520	1.1858	53.8	13.9	3.50	64	22	1.22
520	0.94	0.2530	1.4203	53.3	16.2	4.10	64	22	1.22
520	0.94	0.2538	0.9514	61.1	11.6	2.94	64	22	1.22
520	0.94	0.2541	1.6823	49.2	18.3	4.65	64	22	1.22
520	0.94	0.2546	1.4203	51.6	16.1	4.10	64	22	1.22
520	0.94	0.2555	1.6823	50.1	18.2	4.65	64	22	1.22
520	0.94	0.2555	1.6823	50.0	18.2	4.65	64	22	1.22
520	0.94	0.2562	1.4203	53.3	16.0	4.10	64	22	1.22
520	0.94	0.2583	0.9514	61.8	11.4	2.94	64	22	1.22
520	0.94	0.2583	0.9514	60.6	11.4	2.94	64	22	1.22
520	0.94	0.3274	1.1031	50.1	10.7	3.50	64	22	1.22
520	0.94	0.3288	1.3100	47.5	12.4	4.08	64	22	1.22
520	0.94	0.3315	1.3100	46.0	12.3	4.08	64	22	1.22
520	0.94	0.3315	1.3100	49.5	12.3	4.08	64	22	1.22
520	0.94	0.3322	1.0893	51.0	10.6	3.52	64	22	1.22
520	0.94	0.3336	1.1031	50.6	10.5	3.50	64	22	1.22
520	0.94	0.3336	1.1031	48.2	10.5	3.50	64	22	1.22
520	0.94	0.3370	1.5168	44.9	13.8	4.65	64	22	1.22
520	0.94	0.3370	1.5168	45.8	13.8	4.65	64	22	1.22
520	0.94	0.3386	1.0893	51.7	10.4	3.52	64	22	1.22
520	0.94	0.3388	1.5168	46.6	13.8	4.68	64	22	1.22
520	0.94	0.3393	1.7374	43.5	15.4	5.22	64	22	1.22
520	0.94	0.3393	1.7512	44.8	15.4	5.22	64	22	1.22

Glycerine-Water-Polymer Mixture Data (continued)

520	0.94	0.3393	1.7512	43.8	15.4	5.22	64	22	1.22
520	0.94	0.3393	1.7512	44.3	15.4	5.22	64	22	1.22
520	0.94	0.3395	1.5168	44.7	13.7	4.65	64	22	1.22
520	0.94	0.3415	1.7374	45.8	15.3	5.22	64	22	1.22
520	0.94	0.3415	1.3100	49.0	12.0	4.10	64	22	1.22
520	0.94	0.3415	1.3100	49.0	12.0	4.10	64	22	1.22
520	0.94	0.3419	1.0893	51.0	10.3	3.52	64	22	1.22
520	0.94	0.3437	1.7374	44.7	15.2	5.22	64	22	1.22
520	0.94	0.3438	1.5168	47.6	13.6	4.68	64	22	1.22
520	0.94	0.3438	1.5168	47.9	13.6	4.68	64	22	1.22
520	0.94	0.3444	1.3100	49.4	11.9	4.10	64	22	1.22
570	0.90	0.0415	0.7170	133.9	26.6	1.10	64	21	1.20
570	0.90	0.0416	1.1031	113.4	35.9	1.49	64	21	1.20
570	0.90	0.0417	0.7170	129.7	26.5	1.10	64	21	1.20
570	0.90	0.0417	1.3789	107.3	42.7	1.78	64	21	1.20
570	0.90	0.0417	1.1031	113.3	35.8	1.49	64	21	1.20
570	0.90	0.0417	1.1031	116.9	35.8	1.49	64	21	1.20
570	0.90	0.0419	0.4136	146.8	17.7	0.74	64	21	1.20
570	0.90	0.0419	0.4136	144.0	17.7	0.74	64	21	1.20
570	0.90	0.0421	1.3789	100.8	42.3	1.78	64	21	1.20
570	0.90	0.0422	0.4136	148.8	17.6	0.74	64	21	1.20
570	0.90	0.0423	1.3789	104.0	42.1	1.78	64	21	1.20
570	0.90	0.0428	1.6547	96.2	48.3	2.07	64	21	1.20
570	0.90	0.0434	1.6547	98.7	47.7	2.07	64	21	1.20
570	0.90	0.0437	1.6547	102.5	47.3	2.07	64	21	1.20
570	0.90	0.0837	1.5857	76.2	35.0	2.93	64	21	1.20
570	0.90	0.0837	1.7650	72.7	38.4	3.22	64	21	1.20
570	0.90	0.0839	1.5857	75.2	34.9	2.93	64	21	1.20
570	0.90	0.0841	1.4065	71.6	31.4	2.64	64	21	1.20
570	0.90	0.0841	1.4065	68.5	31.4	2.64	64	21	1.20
570	0.90	0.0842	1.7650	75.5	38.2	3.22	64	21	1.20
570	0.90	0.0844	1.7650	75.7	38.1	3.22	64	21	1.20
570	0.90	0.0844	1.4065	69.9	31.3	2.64	64	21	1.20
570	0.90	0.0847	1.5857	72.5	34.6	2.93	64	21	1.20
570	0.90	0.0850	1.1858	69.5	27.7	2.36	64	21	1.20
570	0.90	0.0853	0.8273	90.7	21.0	1.79	64	21	1.20
570	0.90	0.0857	0.8273	83.3	20.9	1.79	64	21	1.20
570	0.90	0.0863	1.1858	71.8	27.3	2.36	64	21	1.20
570	0.90	0.0866	1.1858	73.0	27.2	2.36	64	21	1.20
570	0.90	0.0869	0.6756	85.5	17.2	1.49	64	21	1.20
570	0.90	0.0869	0.6756	84.1	17.2	1.49	64	21	1.20
570	0.90	0.0879	0.6756	82.8	17.0	1.49	64	21	1.20
570	0.90	0.0905	1.8477	72.2	38.7	3.50	64	21	1.20
570	0.90	0.0910	1.8477	72.8	38.5	3.50	64	21	1.20
570	0.90	0.0915	1.8477	71.3	38.3	3.50	64	21	1.20
570	0.90	0.1009	0.9101	72.8	20.5	2.07	64	21	1.20
570	0.90	0.1029	0.9101	69.1	20.1	2.07	64	21	1.20

Glycerine-Water-Polymer Mixture Data (continued)

570	0.90	0.1624	1.2548	52.3	19.8	3.22	64	21	1.20
570	0.90	0.1633	0.8549	60.4	14.5	2.37	64	21	1.20
570	0.90	0.1658	1.2548	50.8	19.4	3.22	64	21	1.20
570	0.90	0.1658	1.2548	51.7	19.4	3.22	64	21	1.20
570	0.90	0.1664	1.6409	53.7	24.5	4.08	64	21	1.20
570	0.90	0.1671	1.6409	51.2	24.4	4.08	64	21	1.20
570	0.90	0.1674	1.0893	54.3	17.5	2.93	64	21	1.20
570	0.90	0.1676	1.3513	53.0	20.9	3.50	64	21	1.20
570	0.90	0.1676	1.3513	50.8	20.9	3.50	64	21	1.20
570	0.90	0.1678	1.6409	53.7	24.3	4.08	64	21	1.20
570	0.90	0.1683	0.9652	52.3	15.7	2.64	64	21	1.20
570	0.90	0.1684	1.3513	50.8	20.8	3.50	64	21	1.20
570	0.90	0.1684	1.4892	50.2	22.5	3.79	64	21	1.20
570	0.90	0.1692	1.4892	49.6	22.4	3.79	64	21	1.20
570	0.90	0.1694	0.9652	53.8	15.6	2.64	64	21	1.20
570	0.90	0.1700	1.4892	53.4	22.3	3.79	64	21	1.20
570	0.90	0.1703	1.0893	53.0	17.2	2.93	64	21	1.20
570	0.90	0.1713	1.0893	51.2	17.1	2.93	64	21	1.20
570	0.90	0.1716	0.8549	56.5	13.8	2.37	64	21	1.20
570	0.90	0.1716	0.8549	58.9	13.8	2.37	64	21	1.20
570	0.90	0.1723	0.7032	55.3	12.0	2.07	64	21	1.20
570	0.90	0.1738	0.7032	56.2	11.9	2.07	64	21	1.20
570	0.90	0.1797	0.9652	52.3	14.7	2.64	64	21	1.20
570	0.90	0.2173	1.0342	45.2	14.8	3.22	64	21	1.20
570	0.90	0.2467	1.0893	44.6	14.2	3.50	64	21	1.20
570	0.90	0.2477	1.2962	42.7	15.3	3.79	64	21	1.20
570	0.90	0.2484	1.0893	45.5	14.1	3.50	64	21	1.20
570	0.90	0.2484	1.0893	44.6	14.1	3.50	64	21	1.20
570	0.90	0.2493	1.2962	43.7	15.2	3.79	64	21	1.20
570	0.90	0.2508	1.5030	42.4	17.4	4.36	64	21	1.20
570	0.90	0.2516	0.8273	49.8	10.5	2.64	64	21	1.20
570	0.90	0.2517	1.3927	43.4	16.2	4.08	64	21	1.20
570	0.90	0.2527	1.2962	43.5	15.0	3.79	64	21	1.20
570	0.90	0.2528	1.6271	42.5	18.4	4.65	64	21	1.20
570	0.90	0.2532	1.0342	46.0	12.7	3.22	64	21	1.20
570	0.90	0.2537	1.5030	42.1	17.2	4.36	64	21	1.20
570	0.90	0.2555	1.6271	42.5	18.2	4.65	64	21	1.20
570	0.90	0.2567	1.5030	42.3	17.0	4.36	64	21	1.20
570	0.90	0.2569	1.6271	41.7	18.1	4.65	64	21	1.20
570	0.90	0.2573	1.0342	44.9	12.5	3.22	64	21	1.20
570	0.90	0.2583	0.9238	48.2	11.4	2.94	64	21	1.20
570	0.90	0.2590	0.8273	48.7	10.2	2.64	64	21	1.20
570	0.90	0.2613	1.3927	40.9	15.6	4.08	64	21	1.20
570	0.90	0.2613	1.3927	41.2	15.6	4.08	64	21	1.20
570	0.90	0.2629	0.9238	47.5	11.2	2.94	64	21	1.20
570	0.90	0.2642	0.8273	47.3	10.0	2.64	64	21	1.20
570	0.90	0.2677	0.9238	45.8	11.0	2.94	64	21	1.20
570	0.90	0.3239	1.1721	39.1	11.7	3.79	64	21	1.20
570	0.90	0.3296	1.1721	39.0	11.5	3.79	64	21	1.20
570	0.90	0.3296	1.1721	39.7	11.5	3.79	64	21	1.20

Glycerine-Water-Polymer Mixture Data (continued)

570	0.90	0.3322	1.4754	37.8	14.0	4.65	64	21	1.20
570	0.90	0.3359	1.5995	37.7	14.7	4.94	64	21	1.20
570	0.90	0.3371	1.7098	37.6	15.5	5.22	64	21	1.20
570	0.90	0.3382	1.5995	38.2	14.6	4.94	64	21	1.20
570	0.90	0.3383	1.3927	38.3	12.9	4.36	64	21	1.20
570	0.90	0.3393	1.7098	38.8	15.4	5.22	64	21	1.20
570	0.90	0.3395	1.4754	37.6	13.7	4.65	64	21	1.20
570	0.90	0.3397	1.2548	38.5	12.0	4.08	64	21	1.20
570	0.90	0.3405	1.5995	37.2	14.5	4.94	64	21	1.20
570	0.90	0.3415	1.7098	37.8	15.3	5.22	64	21	1.20
570	0.90	0.3419	1.0342	39.5	10.3	3.52	64	21	1.20
570	0.90	0.3420	1.4754	37.0	13.6	4.65	64	21	1.20
570	0.90	0.3421	0.9652	41.2	9.4	3.22	64	21	1.20
570	0.90	0.3436	1.3927	37.4	12.7	4.36	64	21	1.20
570	0.90	0.3455	1.2548	36.9	11.8	4.08	64	21	1.20
570	0.90	0.3463	1.3927	37.7	12.6	4.36	64	21	1.20
570	0.90	0.3484	1.2548	36.2	11.7	4.08	64	21	1.20
570	0.90	0.3557	1.0342	39.8	9.9	3.52	64	21	1.20
570	0.90	0.3573	0.9652	41.0	9.0	3.22	64	21	1.20
570	0.90	0.3613	0.9652	40.9	8.9	3.22	64	21	1.20
570	0.90	0.3707	1.0342	40.3	9.5	3.52	64	21	1.20
780	0.90	0.0381	0.9238	105.3	29.0	1.10	64	22	1.20
780	0.90	0.0385	0.9238	109.7	28.7	1.10	64	22	1.20
780	0.90	0.0386	0.9238	96.9	28.6	1.10	64	22	1.20
780	0.90	0.0458	1.1721	92.7	32.8	1.50	64	22	1.20
780	0.90	0.0461	1.1721	86.2	32.6	1.50	64	22	1.20
780	0.90	0.0465	1.1721	83.6	32.3	1.50	64	22	1.20
780	0.90	0.0842	1.1307	69.4	24.7	2.08	64	22	1.20
780	0.90	0.0842	1.1307	78.1	24.7	2.08	64	22	1.20
780	0.90	0.0845	1.1307	69.3	24.6	2.08	64	22	1.20
780	0.90	0.0849	0.9376	70.8	21.1	1.79	64	22	1.20
780	0.90	0.0852	1.2824	72.5	27.8	2.37	64	22	1.20
780	0.90	0.0853	0.9376	71.4	21.0	1.79	64	22	1.20
780	0.90	0.0855	1.2824	66.6	27.7	2.37	64	22	1.20
780	0.90	0.0857	0.9376	67.4	20.9	1.79	64	22	1.20
780	0.90	0.0861	1.2824	72.2	27.5	2.37	64	22	1.20
780	0.90	0.0896	1.4754	72.9	32.7	2.93	64	22	1.20
780	0.90	0.0896	1.4754	68.8	32.7	2.93	64	22	1.20
780	0.90	0.0901	1.4754	72.3	32.5	2.93	64	22	1.20
780	0.90	0.0913	1.4065	67.3	29.1	2.66	64	22	1.20
780	0.90	0.0922	1.4065	65.9	28.8	2.66	64	22	1.20
780	0.90	0.0925	1.4065	65.1	28.7	2.66	64	22	1.20
780	0.90	0.1027	1.6547	64.0	31.3	3.22	64	22	1.20
780	0.90	0.1034	1.6547	67.3	31.1	3.22	64	22	1.20
780	0.90	0.1037	1.6547	67.3	31.0	3.22	64	22	1.20
780	0.90	0.1168	1.6961	62.3	30.0	3.50	64	22	1.20
780	0.90	0.1172	1.6961	63.3	29.9	3.50	64	22	1.20
780	0.90	0.1175	1.6961	65.5	29.8	3.50	64	22	1.20

Glycerine-Water-Polymer Mixture Data (continued)

780	0.90	0.1617	1.3375	50.9	20.0	3.23	64	22	1.20
780	0.90	0.1618	1.1996	49.4	18.2	2.94	64	22	1.20
780	0.90	0.1625	1.3375	51.7	19.9	3.23	64	22	1.20
780	0.90	0.1625	1.3375	54.1	19.9	3.23	64	22	1.20
780	0.90	0.1627	1.1996	54.0	18.1	2.94	64	22	1.20
780	0.90	0.1627	1.1996	51.9	18.1	2.94	64	22	1.20
780	0.90	0.1660	1.0204	53.3	16.0	2.66	64	22	1.20
780	0.90	0.1660	1.4203	51.7	21.1	3.50	64	22	1.20
780	0.90	0.1660	1.4203	49.9	21.1	3.50	64	22	1.20
780	0.90	0.1664	1.7098	55.1	24.5	4.08	64	22	1.20
780	0.90	0.1668	1.4203	52.0	21.0	3.50	64	22	1.20
780	0.90	0.1670	1.5857	52.0	22.7	3.79	64	22	1.20
780	0.90	0.1671	1.7098	55.8	24.4	4.08	64	22	1.20
780	0.90	0.1677	1.5857	51.6	22.6	3.79	64	22	1.20
780	0.90	0.1677	1.5857	53.4	22.6	3.79	64	22	1.20
780	0.90	0.1678	1.7098	57.2	24.3	4.08	64	22	1.20
780	0.90	0.1691	0.8963	52.7	14.0	2.37	64	22	1.20
780	0.90	0.1703	0.8963	50.5	13.9	2.37	64	22	1.20
780	0.90	0.1714	1.0204	49.5	15.5	2.66	64	22	1.20
780	0.90	0.1728	0.8963	51.2	13.7	2.37	64	22	1.20
780	0.90	0.1736	1.0204	51.5	15.3	2.66	64	22	1.20

780	0.90	0.2454	0.9928	46.5	12.0	2.94	64	22	1.20
780	0.90	0.2474	0.9928	44.5	11.9	2.94	64	22	1.20
780	0.90	0.2494	1.5720	44.1	17.5	4.36	64	22	1.20
780	0.90	0.2495	0.9928	45.1	11.8	2.94	64	22	1.20
780	0.90	0.2508	1.5720	45.4	17.4	4.36	64	22	1.20
780	0.90	0.2515	1.1858	42.6	14.0	3.52	64	22	1.20
780	0.90	0.2522	1.5720	44.2	17.3	4.36	64	22	1.20
780	0.90	0.2523	1.3375	43.0	15.1	3.81	64	22	1.20
780	0.90	0.2532	1.4341	43.3	16.1	4.08	64	22	1.20
780	0.90	0.2533	1.1858	46.4	13.9	3.52	64	22	1.20
780	0.90	0.2540	1.3375	42.1	15.0	3.81	64	22	1.20
780	0.90	0.2540	1.3375	44.2	15.0	3.81	64	22	1.20
780	0.90	0.2548	1.4341	45.9	16.0	4.08	64	22	1.20
780	0.90	0.2548	1.4341	43.1	16.0	4.08	64	22	1.20
780	0.90	0.2566	1.0066	45.4	12.6	3.23	64	22	1.20
780	0.90	0.2570	1.1858	43.9	13.7	3.52	64	22	1.20
780	0.90	0.2607	1.0066	41.8	12.4	3.23	64	22	1.20
780	0.90	0.2628	1.0066	43.8	12.3	3.23	64	22	1.20

780	0.90	0.3253	1.3100	39.5	12.6	4.10	64	22	1.20
780	0.90	0.3313	1.0617	41.3	11.5	3.81	64	22	1.20
780	0.90	0.3322	1.1031	40.3	10.6	3.52	64	22	1.20
780	0.90	0.3322	1.1031	38.4	10.6	3.52	64	22	1.20
780	0.90	0.3332	1.3100	39.4	12.3	4.10	64	22	1.20
780	0.90	0.3346	1.5168	37.6	13.9	4.65	64	22	1.20
780	0.90	0.3354	1.1031	39.0	10.5	3.52	64	22	1.20

Glycerine-Water-Polymer Mixture Data (continued)

780	0.90	0.3359	1.3100	39.2	12.2	4.10	64	22	1.20
780	0.90	0.3370	1.5168	41.0	13.8	4.65	64	22	1.20
780	0.90	0.3370	1.5168	38.4	13.8	4.65	64	22	1.20
780	0.90	0.3372	1.0617	38.1	11.3	3.81	64	22	1.20
780	0.90	0.3372	1.0617	38.9	11.3	3.81	64	22	1.20
780	0.90	0.3405	1.6133	40.6	14.5	4.94	64	22	1.20
780	0.90	0.3453	1.6133	41.2	14.3	4.94	64	22	1.20
780	0.90	0.3477	1.6133	40.1	14.2	4.94	64	22	1.20
780	0.90	0.3482	1.4065	37.6	12.6	4.39	64	22	1.20
780	0.90	0.3510	1.4065	38.3	12.5	4.39	64	22	1.20
780	0.90	0.3567	1.4065	39.6	12.3	4.39	64	22	1.20
840	0.94	0.0427	0.8963	87.0	25.7	1.10	64	22	1.22
840	0.94	0.0840	0.9928	68.4	21.2	1.78	64	22	1.22
840	0.94	0.0840	0.9928	68.3	21.2	1.78	64	22	1.22
840	0.94	0.0844	0.9928	66.9	21.1	1.78	64	22	1.22
840	0.94	0.0869	1.3513	84.8	27.1	2.36	64	22	1.22
840	0.94	0.0872	1.3513	82.4	27.0	2.36	64	22	1.22
840	0.94	0.0879	1.3513	82.1	26.8	2.36	64	22	1.22
840	0.94	0.0892	1.2686	70.5	26.4	2.36	64	22	1.22
840	0.94	0.1191	1.4341	77.9	24.6	2.93	64	22	1.22
840	0.94	0.1231	1.4341	64.5	23.8	2.93	64	22	1.22
840	0.94	0.1629	1.5306	69.5	21.5	3.50	64	22	1.22
840	0.94	0.1660	1.5306	68.6	21.1	3.50	64	22	1.22
840	0.94	0.1664	1.1996	59.1	17.6	2.93	64	22	1.22
840	0.94	0.1668	1.5306	69.3	21.0	3.50	64	22	1.22
840	0.94	0.1670	0.9652	54.1	14.1	2.36	64	22	1.22
840	0.94	0.1674	1.1996	62.7	17.5	2.93	64	22	1.22
840	0.94	0.1682	0.9376	55.9	14.0	2.36	64	22	1.22
840	0.94	0.1682	0.9652	50.9	14.0	2.36	64	22	1.22
840	0.94	0.1694	0.9652	49.7	13.9	2.36	64	22	1.22
840	0.94	0.1703	1.2272	54.0	17.2	2.93	64	22	1.22
840	0.94	0.1723	1.2272	53.7	17.0	2.93	64	22	1.22
840	0.94	0.1969	1.6133	54.6	20.7	4.08	64	22	1.22
840	0.94	0.1979	1.6133	56.0	20.6	4.08	64	22	1.22
840	0.94	0.1989	1.6133	63.0	20.5	4.08	64	22	1.22
840	0.94	0.1998	1.6133	61.6	20.4	4.08	64	22	1.22
840	0.94	0.2008	1.6133	54.8	20.3	4.08	64	22	1.22
840	0.94	0.2018	1.6133	62.6	20.2	4.08	64	22	1.22
840	0.94	0.2487	1.7374	54.5	18.7	4.65	64	22	1.22
840	0.94	0.2487	1.7374	54.4	18.7	4.65	64	22	1.22
840	0.94	0.2500	1.7374	52.9	18.6	4.65	64	22	1.22
840	0.94	0.2502	1.2686	49.4	14.0	3.50	64	22	1.22
840	0.94	0.2502	1.2686	49.6	14.0	3.50	64	22	1.22
840	0.94	0.2503	1.0480	45.0	11.7	2.93	64	22	1.22
840	0.94	0.2503	1.0480	42.5	11.7	2.93	64	22	1.22
840	0.94	0.2514	1.7236	53.1	18.5	4.65	64	22	1.22

Glycerine-Water-Polymer Mixture Data (continued)

840	0.94	0.2520	1.2686	52.7	13.9	3.50	64	22	1.22
840	0.94	0.2525	1.0204	47.9	11.6	2.93	64	22	1.22
840	0.94	0.2525	1.0480	46.3	11.6	2.93	64	22	1.22
840	0.94	0.2532	1.4892	55.7	16.1	4.08	64	22	1.22
840	0.94	0.2541	1.7236	55.2	18.3	4.65	64	22	1.22
840	0.94	0.2548	1.4892	56.4	16.0	4.08	64	22	1.22
840	0.94	0.2548	1.4892	46.7	16.0	4.08	64	22	1.22
840	0.94	0.2548	1.4892	53.9	16.0	4.08	64	22	1.22
840	0.94	0.2557	1.2548	46.0	13.7	3.50	64	22	1.22
840	0.94	0.2557	1.2548	45.6	13.7	3.50	64	22	1.22
840	0.94	0.2569	1.0204	48.3	11.4	2.93	64	22	1.22
840	0.94	0.2576	1.2548	45.2	13.6	3.50	64	22	1.22
840	0.94	0.2584	1.7236	54.9	18.0	4.65	64	22	1.22
840	0.94	0.2597	1.4892	46.7	15.7	4.08	64	22	1.22
840	0.94	0.3245	1.8064	49.8	16.1	5.22	64	22	1.22
840	0.94	0.3286	1.8064	47.8	15.9	5.22	64	22	1.22
840	0.94	0.3307	1.8064	49.6	15.8	5.22	64	22	1.22
840	0.94	0.3328	1.7926	49.1	15.7	5.22	64	22	1.22
840	0.94	0.3328	1.7926	50.3	15.7	5.22	64	22	1.22
840	0.94	0.3349	1.7926	47.0	15.6	5.22	64	22	1.22
840	0.94	0.3368	1.1307	40.4	10.4	3.50	64	22	1.22
840	0.94	0.3368	1.1307	40.1	10.4	3.50	64	22	1.22
840	0.94	0.3369	1.3375	42.9	12.1	4.08	64	22	1.22
840	0.94	0.3395	1.5582	49.3	13.7	4.65	64	22	1.22
840	0.94	0.3397	1.2962	40.7	12.0	4.08	64	22	1.22
840	0.94	0.3397	1.2962	40.8	12.0	4.08	64	22	1.22
840	0.94	0.3397	1.2962	40.3	12.0	4.08	64	22	1.22
840	0.94	0.3397	1.3375	43.8	12.0	4.08	64	22	1.22
840	0.94	0.3397	1.3375	42.6	12.0	4.08	64	22	1.22
840	0.94	0.3401	1.1307	41.4	10.3	3.50	64	22	1.22
840	0.94	0.3420	1.5582	49.3	13.6	4.65	64	22	1.22
840	0.94	0.3445	1.5582	48.3	13.5	4.65	64	22	1.22
840	0.94	0.3503	1.1307	44.8	10.0	3.50	64	22	1.22
840	0.94	0.3503	1.1307	42.8	10.0	3.50	64	22	1.22
930	0.86	0.0365	0.9101	137.4	30.1	1.10	64	25	1.13
930	0.86	0.0383	0.9101	136.1	28.7	1.10	64	25	1.13
930	0.86	0.0388	0.9101	140.1	28.3	1.10	64	25	1.13
930	0.86	0.0440	1.4616	107.1	40.5	1.78	64	25	1.13
930	0.86	0.0445	1.4616	109.5	40.0	1.78	64	25	1.13
930	0.86	0.0449	1.4616	109.7	39.7	1.78	64	25	1.13
930	0.86	0.0788	1.2824	87.6	29.9	2.36	64	25	1.13
930	0.86	0.0793	1.2824	90.3	29.7	2.36	64	25	1.13
930	0.86	0.0821	1.2824	92.0	28.7	2.36	64	25	1.13
930	0.86	0.0823	1.5995	77.7	35.6	2.93	64	25	1.13
930	0.86	0.0837	1.5995	74.7	35.0	2.93	64	25	1.13
930	0.86	0.0849	1.6133	82.7	34.5	2.93	64	25	1.13
930	0.86	0.0854	1.5995	75.5	34.3	2.93	64	25	1.13

Glycerine-Water-Polymer Mixture Data (continued)

930	0.86	0.0854	1.6133	82.9	34.3	2.93	64	25	1.13
930	0.86	0.0856	0.8549	96.4	20.8	1.78	64	25	1.13
930	0.86	0.0864	1.6133	80.2	33.9	2.93	64	25	1.13
930	0.86	0.0877	0.8549	100.8	20.3	1.78	64	25	1.13
930	0.86	0.0882	0.8549	93.4	20.2	1.78	64	25	1.13
930	0.86	0.1001	1.7788	76.2	35.0	3.50	64	25	1.13
930	0.86	0.1036	1.7512	67.9	33.8	3.50	64	25	1.13
930	0.86	0.1043	1.7512	72.7	33.6	3.50	64	25	1.13
930	0.86	0.1043	1.7512	70.6	33.6	3.50	64	25	1.13
930	0.86	0.1624	0.8273	77.9	14.5	2.36	64	25	1.13
930	0.86	0.1637	1.3789	67.3	21.4	3.50	64	25	1.13
930	0.86	0.1644	1.6547	54.8	24.8	4.08	64	25	1.13
930	0.86	0.1664	1.6547	64.7	24.5	4.08	64	25	1.13
930	0.86	0.1664	1.1169	69.3	17.6	2.93	64	25	1.13
930	0.86	0.1668	1.3789	58.1	21.0	3.50	64	25	1.13
930	0.86	0.1668	1.3789	63.2	21.0	3.50	64	25	1.13
930	0.86	0.1670	0.8273	75.1	14.1	2.36	64	25	1.13
930	0.86	0.1670	0.8273	80.0	14.1	2.36	64	25	1.13
930	0.86	0.1671	1.6547	59.1	24.4	4.08	64	25	1.13
930	0.86	0.1676	1.3789	67.1	20.9	3.50	64	25	1.13
930	0.86	0.1678	1.6547	59.5	24.3	4.08	64	25	1.13
930	0.86	0.1678	1.6547	55.0	24.3	4.08	64	25	1.13
930	0.86	0.1693	1.1169	67.2	17.3	2.93	64	25	1.13
930	0.86	0.1703	1.1169	71.6	17.2	2.93	64	25	1.13
930	0.86	0.1709	1.3789	58.8	20.5	3.50	64	25	1.13
930	0.86	0.1719	0.8549	84.3	13.7	2.36	64	25	1.13
930	0.86	0.1758	0.8549	78.8	13.4	2.36	64	25	1.13
930	0.86	0.1798	0.8549	81.2	13.1	2.36	64	25	1.13
930	0.86	0.2471	1.2824	52.1	16.5	4.08	64	25	1.13
930	0.86	0.2474	1.6271	54.5	18.8	4.65	64	25	1.13
930	0.86	0.2487	1.6271	54.1	18.7	4.65	64	25	1.13
930	0.86	0.2525	0.9238	66.4	11.6	2.93	64	25	1.13
930	0.86	0.2528	1.6271	55.4	18.4	4.65	64	25	1.13
930	0.86	0.2541	1.5857	46.7	18.3	4.65	64	25	1.13
930	0.86	0.2569	0.9238	64.5	11.4	2.93	64	25	1.13
930	0.86	0.2569	0.9238	68.4	11.4	2.93	64	25	1.13
930	0.86	0.2576	1.1445	53.5	13.6	3.50	64	25	1.13
930	0.86	0.2580	1.2824	53.2	15.8	4.08	64	25	1.13
930	0.86	0.2584	1.5857	46.5	18.0	4.65	64	25	1.13
930	0.86	0.2597	1.2824	55.6	15.7	4.08	64	25	1.13
930	0.86	0.2598	1.5857	46.7	17.9	4.65	64	25	1.13
930	0.86	0.2614	1.1445	58.9	13.4	3.50	64	25	1.13
930	0.86	0.2614	1.1445	58.0	13.4	3.50	64	25	1.13
930	0.86	0.2663	0.9101	58.4	11.0	2.93	64	25	1.13
930	0.86	0.3286	1.6685	41.2	15.9	5.22	64	25	1.13
930	0.86	0.3286	1.6685	42.5	15.9	5.22	64	25	1.13
930	0.86	0.3322	1.4341	48.1	14.0	4.65	64	25	1.13

Glycerine-Water-Polymer Mixture Data (continued)

930	0.86	0.3336	1.0204	53.7	10.5	3.50	64	25	1.13
930	0.86	0.3368	1.0204	55.2	10.4	3.50	64	25	1.13
930	0.86	0.3401	1.0480	57.3	10.3	3.50	64	25	1.13
930	0.86	0.3426	1.2272	50.4	11.9	4.08	64	25	1.13
930	0.86	0.3434	1.0204	54.8	10.2	3.50	64	25	1.13
930	0.86	0.3460	1.6547	47.9	15.1	5.22	64	25	1.13
930	0.86	0.3460	1.6547	47.1	15.1	5.22	64	25	1.13
930	0.86	0.3460	1.6547	44.0	15.1	5.22	64	25	1.13
930	0.86	0.3471	1.4341	49.4	13.4	4.65	64	25	1.13
930	0.86	0.3484	1.2272	51.6	11.7	4.08	64	25	1.13
930	0.86	0.3497	1.4341	49.7	13.3	4.65	64	25	1.13
930	0.86	0.3515	1.2272	53.0	11.6	4.08	64	25	1.13
930	0.86	0.3633	1.4065	42.0	12.8	4.65	64	25	1.13

Coal-Water Slurry Mixture Data

K $cp - s^{(n-1)}$	n	ALR	Pd *MPa*	SMD μm	Liq. Mass *g/s*	Air Mass *g/s*	Surface Tens. *dyn/cm*	Ta *C*	Top Size μm	Loading *wt-%*	Density *g/cm³*
133	0.961	0.0210	0.2748	112.90	72.0	1.51	70	23	15	49	1.2
133	0.961	0.0210	0.2748	106.70	71.9	1.51	70	23	15	49	1.2
133	0.961	0.0211	0.2748	110.60	71.7	1.51	70	23	15	49	1.2
133	0.961	0.0424	0.2336	80.70	42.5	1.80	70	23	15	49	1.2
133	0.961	0.0424	0.2748	70.20	49.3	2.09	70	23	15	49	1.2
133	0.961	0.0424	0.2748	68.60	49.3	2.09	70	23	15	49	1.2
133	0.961	0.0424	0.2748	70.20	49.3	2.09	70	23	15	49	1.2
133	0.961	0.0426	0.2336	84.90	42.3	1.80	70	23	15	49	1.2
133	0.961	0.0426	0.2336	83.60	42.3	1.80	70	23	15	49	1.2
133	0.961	0.0426	0.3779	64.30	62.7	2.67	70	23	15	49	1.2
133	0.961	0.0426	0.3779	63.60	62.7	2.67	70	23	15	49	1.2
133	0.961	0.0426	0.3779	64.20	62.7	2.67	70	23	15	49	1.2
133	0.961	0.0433	0.2199	87.60	41.6	1.80	70	23	15	49	1.2
133	0.961	0.0433	0.2199	84.00	41.6	1.80	70	23	15	49	1.2
133	0.961	0.0433	0.2199	82.70	41.6	1.80	70	23	15	49	1.2
133	0.961	0.0845	0.4122	44.60	45.3	3.83	70	23	15	49	1.2
133	0.961	0.0845	0.4122	44.60	45.3	3.83	70	23	15	49	1.2
133	0.961	0.0847	0.4122	45.00	45.2	3.83	70	23	15	49	1.2
133	0.961	0.0849	0.3779	47.10	41.7	3.54	70	23	15	49	1.2
133	0.961	0.0849	0.3779	47.20	41.7	3.54	70	23	15	49	1.2
133	0.961	0.0849	0.3779	46.40	41.7	3.54	70	23	15	49	1.2
133	0.961	0.0850	0.5497	42.30	55.3	4.70	70	23	15	49	1.2
133	0.961	0.0850	0.5497	40.80	55.3	4.70	70	23	15	49	1.2
133	0.961	0.0850	0.5497	43.00	55.3	4.70	70	23	15	49	1.2
133	0.961	0.0851	0.4466	43.60	48.4	4.12	70	23	15	49	1.2
133	0.961	0.0851	0.4466	43.60	48.4	4.12	70	23	15	49	1.2
133	0.961	0.0853	0.4466	43.80	48.3	4.12	70	23	15	49	1.2
133	0.961	0.1679	0.5290	30.30	41.8	7.02	70	23	15	49	1.2
133	0.961	0.1683	0.5290	31.50	41.7	7.02	70	23	15	49	1.2
133	0.961	0.1683	0.5290	30.60	41.7	7.02	70	23	15	49	1.2
133	0.961	0.1700	0.7214	31.10	43.0	7.31	70	23	15	49	1.2
133	0.961	0.1700	0.7214	30.40	43.0	7.31	70	23	15	49	1.2
133	0.961	0.1700	0.7214	30.30	43.0	7.31	70	23	15	49	1.2
133	0.961	0.1700	0.7558	31.10	44.7	7.60	70	23	15	49	1.2
133	0.961	0.1700	0.7558	30.40	44.7	7.60	70	23	15	49	1.2
133	0.961	0.1700	0.7558	31.10	44.7	7.60	70	23	15	49	1.2
133	0.961	0.1827	0.7352	30.10	41.6	7.60	70	23	15	49	1.2
133	0.961	0.1836	0.7352	29.50	41.4	7.60	70	23	15	49	1.2
133	0.961	0.1836	0.7352	28.90	41.4	7.60	70	23	15	49	1.2

Coal-Water Slurry Mixture Data (continued)

180.9	1.033	0.0187	0.2061	133.00	40.2	0.75	54	24	45	65	1.2
180.9	1.033	0.0187	0.2061	127.70	40.2	0.75	54	24	45	65	1.2
180.9	1.033	0.0187	0.2061	132.50	40.2	0.75	54	24	45	65	1.2
180.9	1.033	0.0205	0.1924	106.80	40.9	0.84	54	24	45	65	1.2
180.9	1.033	0.0206	0.1924	114.70	40.7	0.84	54	24	45	65	1.2
180.9	1.033	0.0207	0.1924	113.00	40.6	0.84	54	24	45	65	1.2

180.9	1.033	0.0374	0.2817	68.30	40.4	1.51	54	24	45	65	1.2
180.9	1.033	0.0374	0.2817	67.10	40.4	1.51	54	24	45	65	1.2
180.9	1.033	0.0374	0.2817	68.40	40.4	1.51	54	24	45	65	1.2
180.9	1.033	0.0422	0.3435	66.50	42.7	1.80	54	24	45	65	1.2
180.9	1.033	0.0424	0.4260	62.20	49.3	2.09	54	24	45	65	1.2
180.9	1.033	0.0424	0.4260	60.80	49.3	2.09	54	24	45	65	1.2
180.9	1.033	0.0424	0.4260	62.30	49.3	2.09	54	24	45	65	1.2
180.9	1.033	0.0425	0.3435	64.90	42.4	1.80	54	24	45	65	1.2
180.9	1.033	0.0426	0.3435	64.60	42.3	1.80	54	24	45	65	1.2
180.9	1.033	0.0426	0.6184	63.00	62.7	2.67	54	24	45	65	1.2
180.9	1.033	0.0426	0.6184	62.80	62.7	2.67	54	24	45	65	1.2
180.9	1.033	0.0426	0.6184	62.60	62.7	2.67	54	24	45	65	1.2

180.9	1.033	0.0844	0.6871	45.80	48.8	4.12	54	24	45	65	1.2
180.9	1.033	0.0846	0.6871	45.40	48.7	4.12	54	24	45	65	1.2
180.9	1.033	0.0846	0.6871	46.20	48.7	4.12	54	24	45	65	1.2
180.9	1.033	0.0848	0.8039	44.70	55.4	4.70	54	24	45	65	1.2
180.9	1.033	0.0848	0.8039	44.20	55.4	4.70	54	24	45	65	1.2
180.9	1.033	0.0849	0.6321	46.90	45.1	3.83	54	24	45	65	1.2
180.9	1.033	0.0849	0.6321	46.10	45.1	3.83	54	24	45	65	1.2
180.9	1.033	0.0849	0.6321	47.00	45.1	3.83	54	24	45	65	1.2
180.9	1.033	0.0850	0.8039	44.00	55.3	4.70	54	24	45	65	1.2
180.9	1.033	0.0861	0.5497	46.90	41.1	3.54	54	24	45	65	1.2
180.9	1.033	0.0866	0.5497	47.10	40.9	3.54	54	24	45	65	1.2
180.9	1.033	0.0868	0.5497	47.10	40.8	3.54	54	24	45	65	1.2

180.9	1.033	0.1693	0.9963	31.90	44.9	7.60	54	24	45	65	1.2
180.9	1.033	0.1696	0.9619	32.00	43.1	7.31	54	24	45	65	1.2
180.9	1.033	0.1696	0.9963	31.90	44.8	7.60	54	24	45	65	1.2
180.9	1.033	0.1696	0.9963	31.70	44.8	7.60	54	24	45	65	1.2
180.9	1.033	0.1700	0.9619	32.00	43.0	7.31	54	24	45	65	1.2
180.9	1.033	0.1700	0.9619	31.90	43.0	7.31	54	24	45	65	1.2
180.9	1.033	0.1721	0.9276	32.00	40.8	7.02	54	24	45	65	1.2
180.9	1.033	0.1725	0.9276	32.10	40.7	7.02	54	24	45	65	1.2
180.9	1.033	0.1733	0.9276	32.20	40.5	7.02	54	24	45	65	1.2

Coal-Water Slurry Mixture Data (continued)

639	0.878	0.0423	0.3092	135.20	49.4	2.09	71	23	15	49	1.2
639	0.878	0.0423	0.3092	136.60	49.4	2.09	71	23	15	49	1.2
639	0.878	0.0424	0.3092	130.40	49.3	2.09	71	23	15	49	1.2
639	0.878	0.0425	0.2405	142.60	42.4	1.80	71	23	15	49	1.2
639	0.878	0.0426	0.2405	141.40	42.3	1.80	71	23	15	49	1.2
639	0.878	0.0427	0.2405	147.20	42.2	1.80	71	23	15	49	1.2
639	0.878	0.0845	0.4466	79.70	45.3	3.83	71	23	15	49	1.2
639	0.878	0.0847	0.5840	65.90	55.5	4.70	71	23	15	49	1.2
639	0.878	0.0847	0.5840	66.70	55.5	4.70	71	23	15	49	1.2
639	0.878	0.0847	0.5840	64.40	55.5	4.70	71	23	15	49	1.2
639	0.878	0.0847	0.4466	79.10	45.2	3.83	71	23	15	49	1.2
639	0.878	0.0848	0.4810	71.90	48.6	4.12	71	23	15	49	1.2
639	0.878	0.0849	0.3916	83.00	41.7	3.54	71	23	15	49	1.2
639	0.878	0.0849	0.3916	85.00	41.7	3.54	71	23	15	49	1.2
639	0.878	0.0849	0.3916	85.80	41.7	3.54	71	23	15	49	1.2
639	0.878	0.0849	0.4466	77.90	45.1	3.83	71	23	15	49	1.2
639	0.878	0.0849	0.4810	73.20	48.5	4.12	71	23	15	49	1.2
639	0.878	0.0849	0.4810	73.70	48.5	4.12	71	23	15	49	1.2
639	0.878	0.1683	0.7214	41.50	41.7	7.02	71	23	15	49	1.2
639	0.878	0.1683	0.7214	41.10	41.7	7.02	71	23	15	49	1.2
639	0.878	0.1683	0.7214	41.30	41.7	7.02	71	23	15	49	1.2
639	0.878	0.1700	0.7901	39.80	44.7	7.60	71	23	15	49	1.2
639	0.878	0.1700	0.7901	39.60	44.7	7.60	71	23	15	49	1.2
639	0.878	0.1704	0.7558	41.10	42.9	7.31	71	23	15	49	1.2
639	0.878	0.1704	0.7558	40.90	42.9	7.31	71	23	15	49	1.2
639	0.878	0.1704	0.7558	41.30	42.9	7.31	71	23	15	49	1.2
639	0.878	0.1704	0.7901	39.70	44.6	7.60	71	23	15	49	1.2
639	0.878	0.1827	0.7764	37.90	41.6	7.60	71	23	15	49	1.2
639	0.878	0.1831	0.7764	37.80	41.5	7.60	71	23	15	49	1.2
639	0.878	0.1854	0.7764	37.10	41.0	7.60	71	23	15	49	1.2
1777	0.617	0.0366	0.3435	69.50	41.3	1.51	78	23	100	57	1.2
1777	0.617	0.0369	0.3435	72.70	40.9	1.51	78	23	100	57	1.2
1777	0.617	0.0369	0.3435	72.10	40.9	1.51	78	23	100	57	1.2
1777	0.617	0.0424	0.3435	64.90	42.5	1.80	78	23	100	57	1.2
1777	0.617	0.0424	0.5703	58.40	62.9	2.67	78	23	100	57	1.2
1777	0.617	0.0424	0.5703	61.00	62.9	2.67	78	23	100	57	1.2
1777	0.617	0.0425	0.3435	67.70	42.4	1.80	78	23	100	57	1.2
1777	0.617	0.0425	0.3435	64.30	42.4	1.80	78	23	100	57	1.2
1777	0.617	0.0425	0.4191	60.90	49.2	2.09	78	23	100	57	1.2
1777	0.617	0.0425	0.4191	61.90	49.2	2.09	78	23	100	57	1.2
1777	0.617	0.0425	0.5703	59.60	62.8	2.67	78	23	100	57	1.2
1777	0.617	0.0426	0.4191	60.80	49.1	2.09	78	23	100	57	1.2

Coal-Water Slurry Mixture Data (continued)

1777	0.617	0.0708	0.5840	46.30	54.1	3.83	78	23	100	57	1.2
1777	0.617	0.0844	0.6527	43.10	55.7	4.70	78	23	100	57	1.2
1777	0.617	0.0845	0.6527	41.20	55.6	4.70	78	23	100	57	1.2
1777	0.617	0.0848	0.6527	42.50	55.4	4.70	78	23	100	57	1.2
1777	0.617	0.0848	0.7214	46.50	55.4	4.70	78	23	100	57	1.2
1777	0.617	0.0848	0.7214	46.00	55.4	4.70	78	23	100	57	1.2
1777	0.617	0.0849	0.5016	46.90	41.7	3.54	78	23	100	57	1.2
1777	0.617	0.0849	0.6321	46.40	48.5	4.12	78	23	100	57	1.2
1777	0.617	0.0849	0.6321	45.50	48.5	4.12	78	23	100	57	1.2
1777	0.617	0.0849	0.6321	44.80	48.5	4.12	78	23	100	57	1.2
1777	0.617	0.0851	0.5016	46.60	41.6	3.54	78	23	100	57	1.2
1777	0.617	0.0851	0.5497	46.40	45.0	3.83	78	23	100	57	1.2
1777	0.617	0.0851	0.5840	46.70	45.0	3.83	78	23	100	57	1.2
1777	0.617	0.0851	0.5840	45.90	45.0	3.83	78	23	100	57	1.2
1777	0.617	0.0851	0.5840	44.80	48.4	4.12	78	23	100	57	1.2
1777	0.617	0.0853	0.5840	47.00	48.3	4.12	78	23	100	57	1.2
1777	0.617	0.0853	0.5497	45.90	44.9	3.83	78	23	100	57	1.2
1777	0.617	0.0853	0.5497	45.80	44.9	3.83	78	23	100	57	1.2
1777	0.617	0.0853	0.5016	46.80	41.5	3.54	78	23	100	57	1.2
1777	0.617	0.0853	0.5290	46.30	41.5	3.54	78	23	100	57	1.2
1777	0.617	0.0853	0.5290	48.20	41.5	3.54	78	23	100	57	1.2
1777	0.617	0.0855	0.7214	45.20	55.0	4.70	78	23	100	57	1.2
1777	0.617	0.0855	0.5840	44.70	48.2	4.12	78	23	100	57	1.2
1777	0.617	0.0859	0.5290	47.20	41.2	3.54	78	23	100	57	1.2

1777	0.617	0.1687	0.8382	33.60	41.6	7.02	78	23	100	57	1.2
1777	0.617	0.1689	0.8932	33.50	45.0	7.60	78	23	100	57	1.2
1777	0.617	0.1692	0.7901	34.80	41.5	7.02	78	23	100	57	1.2
1777	0.617	0.1692	0.7901	34.70	41.5	7.02	78	23	100	57	1.2
1777	0.617	0.1692	0.8382	33.40	41.5	7.02	78	23	100	57	1.2
1777	0.617	0.1692	0.8382	33.20	41.5	7.02	78	23	100	57	1.2
1777	0.617	0.1693	0.8932	33.10	44.9	7.60	78	23	100	57	1.2
1777	0.617	0.1696	0.7901	34.80	41.4	7.02	78	23	100	57	1.2
1777	0.617	0.1696	0.8588	33.70	43.1	7.31	78	23	100	57	1.2
1777	0.617	0.1696	0.8588	34.40	43.1	7.31	78	23	100	57	1.2
1777	0.617	0.1696	0.8588	34.10	43.1	7.31	78	23	100	57	1.2
1777	0.617	0.1700	0.8245	33.70	43.0	7.31	78	23	100	57	1.2
1777	0.617	0.1700	0.8932	34.20	44.7	7.60	78	23	100	57	1.2
1777	0.617	0.1704	0.8245	34.50	42.9	7.31	78	23	100	57	1.2
1777	0.617	0.1704	0.8588	34.00	44.6	7.60	78	23	100	57	1.2
1777	0.617	0.1708	0.8588	34.10	44.5	7.60	78	23	100	57	1.2
1777	0.617	0.1712	0.8245	34.20	42.7	7.31	78	23	100	57	1.2
1777	0.617	0.1719	0.8588	38.40	44.2	7.60	78	23	100	57	1.2
1777	0.617	0.1858	0.8932	31.80	40.9	7.60	78	23	100	57	1.2
1777	0.617	0.1863	0.8932	31.80	40.8	7.60	78	23	100	57	1.2
1777	0.617	0.1867	0.8932	31.60	40.7	7.60	78	23	100	57	1.2
1777	0.617	0.1872	0.8245	34.00	40.6	7.60	78	23	100	57	1.2
1777	0.617	0.1872	0.8245	33.20	40.6	7.60	78	23	100	57	1.2
1777	0.617	0.1881	0.8245	33.90	40.4	7.60	78	23	100	57	1.2

Coal-Water Slurry Mixture Data (continued)

1964	0.763	0.0368	0.2473	58.30	41.0	1.51	72	25	15	58	1.2
1964	0.763	0.0370	0.2473	56.30	40.8	1.51	72	25	15	58	1.2
1964	0.763	0.0372	0.2473	57.70	40.6	1.51	72	25	15	58	1.2
1964	0.763	0.0420	0.4122	51.60	42.9	1.80	72	25	15	58	1.2
1964	0.763	0.0422	0.4122	53.20	42.7	1.80	72	25	15	58	1.2
1964	0.763	0.0422	0.5153	50.70	63.2	2.67	72	25	15	58	1.2
1964	0.763	0.0422	0.5153	51.20	63.2	2.67	72	25	15	58	1.2
1964	0.763	0.0423	0.5153	49.10	63.1	2.67	72	25	15	58	1.2
1964	0.763	0.0424	0.4122	53.40	42.5	1.80	72	25	15	58	1.2
1964	0.763	0.0424	0.4466	51.30	49.3	2.09	72	25	15	58	1.2
1964	0.763	0.0425	0.4466	51.20	49.2	2.09	72	25	15	58	1.2
1964	0.763	0.0426	0.4466	51.60	49.1	2.09	72	25	15	58	1.2
1964	0.763	0.0841	0.5153	39.70	42.1	3.54	72	25	15	58	1.2
1964	0.763	0.0843	0.5153	39.50	42.0	3.54	72	25	15	58	1.2
1964	0.763	0.0845	0.5290	39.50	45.3	3.83	72	25	15	58	1.2
1964	0.763	0.0845	0.5290	40.20	45.3	3.83	72	25	15	58	1.2
1964	0.763	0.0847	0.5290	39.60	45.2	3.83	72	25	15	58	1.2
1964	0.763	0.0849	0.5153	39.50	41.7	3.54	72	25	15	58	1.2
1964	0.763	0.0849	0.5703	39.20	48.5	4.12	72	25	15	58	1.2
1964	0.763	0.0849	0.5703	38.80	48.5	4.12	72	25	15	58	1.2
1964	0.763	0.0849	0.5703	38.50	48.5	4.12	72	25	15	58	1.2
1964	0.763	0.0850	0.6596	38.20	55.3	4.70	72	25	15	58	1.2
1964	0.763	0.0850	0.6596	38.60	55.3	4.70	72	25	15	58	1.2
1964	0.763	0.0851	0.6596	38.70	55.2	4.70	72	25	15	58	1.2
1964	0.763	0.1704	0.8795	28.30	42.9	7.31	72	25	15	58	1.2
1964	0.763	0.1704	0.8795	28.20	42.9	7.31	72	25	15	58	1.2
1964	0.763	0.1708	0.9138	28.00	44.5	7.60	72	25	15	58	1.2
1964	0.763	0.1708	0.9138	28.30	44.5	7.60	72	25	15	58	1.2
1964	0.763	0.1708	0.9138	28.50	44.5	7.60	72	25	15	58	1.2
1964	0.763	0.1708	0.8795	28.40	42.8	7.31	72	25	15	58	1.2
1964	0.763	0.1716	0.8245	28.80	40.9	7.02	72	25	15	58	1.2
1964	0.763	0.1721	0.8245	28.70	40.8	7.02	72	25	15	58	1.2
1964	0.763	0.1725	0.8245	28.70	40.7	7.02	72	25	15	58	1.2
1964	0.763	0.1872	0.9069	27.20	40.6	7.60	72	25	15	58	1.2
1964	0.763	0.1872	0.9069	27.40	40.6	7.60	72	25	15	58	1.2
1964	0.763	0.1895	0.9069	26.80	40.1	7.60	72	25	15	58	1.2

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