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The Coagulation of Cellulose Pulp Fibers and
Fines as a Mechanism of Retention

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THE COAGULATION OF CELLULOSE PULP FIBERS AND FINES
AS A MECHANISM OF RETENTION

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SUMMARY

The retention of cellulose pulp fines was investigated in an agitated suspension of wood pulp fibers. It was concluded that fines retention in this system could be explained by the classic coagulation mechanism usually associated with hydrophobic colloids. The amount retained was dependent upon the electrolyte environment and the relative shear conditions. Under optimum electrolyte conditions, the retained fines could be removed easily by increasing the relative shear conditions which indicated that the fines were bound loosely to the fibers. This weak attractive force was attributed to the shallow secondary energy minimum predicted by the Verwey and Overbeek theory for coarse particles which can coagulate at large separation distances.

Retention was calculated from fines concentration measurements made with a liquid scintillation counter on fiber-free samples removed continuously from the agitated suspension through a screened sampling port. The fines were prepared from a kraft pulp made from radioactive aspenwood. Three-year-old seedlings were labeled with C-14 by periodically exposing them to a confined atmosphere containing carbon-14 dioxide. The cellulose fibers used in the experiments were from a typical papermaking softwood kraft pulp.

Retention was dependent on the cation concentration up to a critical coagulation value (CV). The CV decreased with increasing cation valence in qualitative agreement with the Schulze-Hardy coagulation rule. The CV determined with sodium, calcium, and lanthanum chloride were 4.50, 0.33, and 0.023 mM/l., respectively. The CV's determined with other sodium salts were similar to the sodium chloride value which indicated that the anion had no apparent effect on the coagulation potential of the cation.

Retention increased with increasing hydrogen ion concentration up to a pH of 3.54. The hydrogen ion behaved like the divalent cation which possibly was

due to a direct reduction of the surface potential of the fines rather than to the collapse of the double layer associated with the other cations.

The electrophoretic mobility of the fines was measured with a Numinco mass transport analyzer in the chloride salt environments and found to approach zero near the CV.

Stability factors, which have been used as a quantitative measure of the degree of coagulation for hydrophobic sols, were calculated from the retention results at various electrolyte concentrations. A linear relationship was obtained between the logs of the stability factors and the logs of the cation concentrations. This indicated that the rate of attachment was controlling the final retention level.

The final retention level could be characterized in terms of a "dynamic" equilibrium which resembled a first-order reversible chemical reaction. The final retention depended on a balance of the attachment rate and of the removal rate. Maximum retention increased with increasing pulp consistency and with decreasing agitation rate which indicated that the removal process was an important controlling factor. The weight average equivalent spherical diameter of the unretained fines, 2.12 μm , was determined with a Coulter Counter and found to be significantly greater than the average obtained for the control fines, 1.11 μm . These results indicated that the smaller fines were retained preferentially probably because the larger ones are subjected to more severe viscous drag forces. Also, maximum retention was found to increase with an increase in temperature which was attributed to a reduction in the removal rate because of the decrease in the viscous drag forces.

INTRODUCTION

One of the most complex physiochemical problems associated with papermaking is the retention of colloidal-sized particles such as rosin size, dye, fillers, and fines. In order to improve the overall process, it is important to understand the individual mechanisms concerned with the retention of these important paper constituents. In recent years, the mechanisms of surface sizing, dyeing, and filler retention have been investigated extensively (1-9). However, the retention of cellulose fines has been neglected because of experimental difficulties in measuring fines content in a fibrous media.

An analysis of this problem is made in this dissertation, and experimental data were gathered to determine if fines can be retained by a mechanism similar to hydrophobic colloidal coagulation*. Fines were prepared by grinding a high consistency radioactive wood pulp in a high-speed homogenizer for extended periods of time. The fines, classified by sedimentation, were fibril shaped and appeared to be similar to those obtained from a Valley beaten pulp.

Fines which are found in all wood pulp systems are produced primarily by mechanical and hydrodynamic shearing of cellulosic material from the fiber surface. Small fiber fragments, vessels, and ray cells, also have been considered as fines. Steenberg, et al. found the fibril-like material to be most common (10). They present light micrographs of this material which resembles the fibrils found on a beaten pulp.

*In this dissertation, flocculation refers to the general process of particle aggregation regardless of the attraction mechanism while coagulation refers to a particular form of aggregation caused by simple electrolytes. Retention is used in the general papermaking sense to describe the amount of material attached or bound to the cellulose pulp fibers.

The presence of fines in the paper furnish is reflected in their influence on many different properties including drainage, strength, and opacity (11, 12). The large surface area per unit mass (13) allows them to adsorb large quantities of other additives. They are also one of the major organic pollutants contained in paper mill effluents. It is quite evident that an improvement in fines retention through an understanding of the retention mechanism could be beneficial to the paper industry.

Haslam and Steele suggested three different mechanisms of filler retention which could as well describe the retention of most colloidal-sized particles in the papermaking system (14). The mechanisms they define are: filtration, entrapment, and coflocculation. Filtration and entrapment are both physical processes while coflocculation is physiochemical in nature.

Filtration is due to the separation of particles from the suspension during pad formation because the particles are larger than the pore openings in the paper web. This mechanism can be important if the particles are large ($> 30 \mu\text{m.}$) and if the pad is not too porous. Abrams and also Estridge studied this process on a larger scale with fibers and wire grids (15, 16).

Entrapment is due to mechanical attachment of small particles either by being caught within the lumens or by being wedged into the fiber wall structure. This mechanism has not been investigated thoroughly, but it is thought to be controlled primarily by the amount of mechanical work done on the system prior to pad formation.

Coflocculation is due to the interaction of interfacial forces which control ordinary colloidal flocculation. This mechanism, considered to be the most important (14), is controlled by the collision frequency of the particle and the

fiber and the effectiveness of the collision. The collision process depends primarily on the relative shear conditions because the diffusion coefficient of the large particles is negligible. The effectiveness of the collision is thought to be dependent primarily on flocculation parameters and subsequently on the relative shear conditions as they relate to the removal of the retained particles.

The hydrodynamic aspects of retention during pad formation were first investigated by Johnson who studied the retention of titanium dioxide by nylon mats using a permeation technique (6). He concluded that diffusion was the controlling collision mechanism in that system. Han analyzed Johnson's results by considering aerosol filtration theory from which he derived an equation for a diffusion controlled collection mechanism in a fiber mat (7). More recent investigations of titanium dioxide retention during pulp pad formation indicated that diffusion probably was not a controlling collision mechanism (16a). Han also presented a macroscopic description of the retention process which described the distribution of retained particles in a noncompressible mat formed at a low constant filtration rate. He used a dacron fiber and titanium dioxide system to test the distribution equation. Nelson has given a more general solution of retention during pad filtration (8). Han and Chang studied retention in a compressible pad using radioactive silver tagged fines and sulfite wood pulp (17). They found that retained fines could be removed by subsequent permeation of the fiber pad. It was found that electrolytes were required to control the system at "good coagulating conditions" in order to obtain measurable retention levels.

Williams and Swanson further explored the retention process by investigating the effect of electrolyte environment on the collection mechanism of titanium dioxide pigment by bleached kraft pulp (9). They concluded that particle retention was enhanced by colloidal conditions which caused a net attractive force

between particle and fiber. Ivanov and Lyadova studied the retention of mineral fillers in paper and concluded retention was dependent on particle size and the electrokinetic properties of the material (18). Wagner showed that titanium dioxide pigment was more extensively adsorbed to cotton in an aqueous electrolyte media which reduced the surface potential of the materials and less so when a dispersing agent was present (19). Lafaye and Jacquelin also agree that the surface potential of the filler must be reduced to near zero before retention is improved markedly (20). Other investigators have concluded that filler retention is a coagulation process (21, 22).

There is no question that filler materials such as titanium dioxide and kaolin clay are hydrophobic colloids and should coagulate by the classic process of reducing the repulsive potential between particles. However, coflocculation of these materials with cellulose fibers which are hydrated is difficult to prove conclusively. There is an extensive amount of information in the literature describing the technology and empirical aspects of filler retention. Casey (23) has reviewed the earlier work, and Roth, et al. and Weiner and Byrne have listed the more recent publications in two excellent bibliographies on the retention of papermaking fillers (24, 25).

In summary, it has been shown that the majority of the retention studies have dealt with filler materials while fines retention has been neglected because of experimental difficulties. Since cellulose fines are so small, one would expect that the same mechanism of filler retention should apply to fines retention. The filler retention literature indicated that the coflocculation mechanism was the primary mode of retention.

PRESENTATION OF PROBLEM

Since the filler retention literature does support a coflocculation mechanism, it could be argued that cellulose fibers must be acting like a hydrophobic colloidal material. There is extensive evidence in the literature which shows that cellulose materials do develop a surface potential like hydrophobic colloids. In view of this information, it is hypothesized in this dissertation that cellulose fines could be retained by pulp fibers by a coagulation mechanism.

SUPPORTING EVIDENCE

Solids which are dispersed in a liquid can acquire an electrical charge at the liquid-solid interface either by direct ionization of constituent groups or by preferential adsorption of ionic species. Generally, the surface potential has a predominant influence in a system if the particles have a large surface area per unit mass ratio. These particles which are considered colloidal particles usually vary in size from a minimum of ca. 1 nm. to an upper limit of microscopic size, 1-10 μ m. For hydrophobic colloidal systems, the electrical surface charge is one of the primary factors which influence the suspension's stability.

Quantitative measurement of the colloidal surface charge can be accomplished by two methods: (1) investigation of electrokinetic phenomena, and (2) accurate measurement of the charge density by chemical analysis of the suspension phase in equilibrium with the solid. Kruyt lists three electrokinetic phenomena useful for studying colloidal chemistry: electroosmosis streaming current or potential, and electrophoresis (26). Holtzman successfully used chemical analysis in his stability study of kaolin clay suspensions (27).

The existence and effect of the surface potential of cellulose fibers on papermaking processes is quite evident in the numerous references to its measurement.

However, the exact mechanism of charge development is quite obscure at this time (28).

Over the years, the electrokinetic potential of cellulose has been measured with various degrees of success by utilizing each of the three phenomena listed by Kruyt. Briggs has reviewed the early history of cellulose electrokinetic phenomena (29). He indicates that Perrin, using an electroosmosis technique, was the first to show that cellulose acquired a negative potential in water and dilute salt solutions. Briggs was the first to utilize the streaming current phenomena to measure the surface potential of cotton and wood fibers.

Balodis reviewed recently the electrokinetic phenomena as related to the streaming current measurements in fiber pads (30). Some of the more important contributions to a better understanding of this complex subject have been made by Neale and Peters (31), Goring and Mason (32), and Biefer and Mason (33). Most recently, Ciriacks introduced a new method of analyzing streaming current data based on the Happel model of flow through porous media (34). Streaming current measurements have been used to correlate surface electric charge with sizing (3), floc strength (35), and drainage (36).

The method most often used to study the electrokinetic properties of cellulosic material has been the measurement of its electrophoretic mobility. This method is based on the principle of an electrically charged particle moving in an electric field. This is a convenient method to determine qualitatively the charge on a colloid. In order to obtain quantitative results, the size and shape of the particle is required. These data are often difficult to obtain.

Lottermoser measured the electrophoretic mobility of groundwood fines and ball-milled cellulose and found that the surface charge could be reduced by

monovalent cations and reversed by multivalent cations (37). Many others since have used this method to study other properties which are affected by the surface potential of cellulose fines. Ranby studied the effect of cation valence on the sedimentation volume of hydrolyzed cellulose and concluded that it behaved in the classic manner of hydrophobic colloids (38). Hukki and Rinne investigated the Sveen-Pedersen saveall operation with this method (39). Strazdins (2) and Vandenberg and Spurlin (1) studied the mechanism of surface sizing. Carolane studied the effect of additives, chrome glue and alum, on the mobility of pulp fines (40). More recently, McKenzie applied mobility measurements to pulping and bleaching investigations (41). Kratochvil, et al. used it to investigate the coagulation properties of Avicel, a microcrystalline form of cellulose (42). Hinton and Quinn studied the direct dyeing of wood pulp with this method (4).

The electroosmosis method has not been used extensively for cellulose systems although Goring and Mason and Ninck Blok were able to measure the surface potential of cellulose pulp fibers by this means (32, 43). The latter used it in elucidating the mechanism of surface sizing.

Lottermoser attempted to measure chemically the surface charge of groundwood fines by analyzing the salt concentration in the solvent phase (37). He was not successful because the cation adsorption was too small for his analytical technique.

It is quite apparent from the above discussion that cellulose in water does acquire a surface potential. All of the investigations indicated that the potential was negative in the absence of electrolytes. It is impossible to compare surface potentials cited in the literature because of the major differences in experimental method. Useful information and correlations can be obtained in a given study if care is taken in obtaining the measurements.

Neale and Peters hypothesized that the negative charge on cellulose may be due to dissociation of a proton during the ionization of an acidic group or to adsorption of suitable anions by close range forces, such as hydroxyl groups (31). They believed that the first mechanism of an acidic group ionization was not important since they found that the measured surface potential of cotton decreases with increasing carboxyl content introduced by alkaline hypobromite oxidation. Ninck Blok confirmed Neale and Peters' conclusions using an electro-osmosis method with wood pulp (43).

Jacquelin and Bourlas using the streaming current method found an increase in the surface potential with heat treatment (44). They use this evidence, however, to support the ionization mechanism of charge development because they reasoned that additional carboxyl groups were being introduced by the treatment. They also found that demineralization (acid washing), which increases the free acid form of carboxylic acid groups, increased the negative charge.

The recent work by Vandenberg and Spurlin, studying the mechanism of surface sizing, suggests that other acids, such as glucuronic and galacturonic acids, significantly affected the electrophoretic mobility of milled pulp (1). Since the pK_a of these uronic acids is approximately 3, they would be ionized at a pH 5 which indicates ionization may contribute to the surface potential of cellulose. This additional evidence indicates that there probably is not a simple correlation of surface potential with carboxyl content as has been suggested by earlier workers.

A number of other investigators have hypothesized that preferential adsorption of certain ionic species contributes to the surface charge of cellulose. Stamm hypothesized that when wood flour is dispersed in water, it acquires a negative potential through selective adsorption of hydroxyl groups from water (45). Vandenberg and Spurlin also hypothesized that hydroxyl and sulfate ions, when

in the presence of alum, contributed to the surface charge of cellulose (1). They support this claim by showing that the electrophoretic mobility of cellulose pulp was significantly less in an aluminum chloride-sodium chloride system than in an alum-sodium sulfate system at similar ionic strengths.

Balodis presents surface potential measurements on acetylated and propionylated bleached kraft pulps as evidence for the ion adsorption mechanism (30). He found that for each of the esterified pulps, the surface potential decreases up to a given degree of substitution and then increases to a negative potential greater than the starting cellulose. It was argued that if the first groups to be esterified are those which contribute the most as adsorption sites, the potential should decrease as they are esterified, but as the secondary hydroxyls are esterified, the potential increases due to the more electronegative nature of the additional ester groups. They also argued that at low degrees of substitution the accessible hydroxyls which would contribute most to the ionic adsorption are esterified, but as esterification continues within the fiber, a greater number of initially inaccessible hydroxyls are able to contribute to the surface potential due to internal swelling of the fibers.

Carolahe, studying the effect of chrome glue on the zeta potential of pulp fines, hypothesized that the negative potential of cellulose was due to hydroxyl ion adsorption (40).

There are numerous references in the literature which indicate that pH has an appreciable effect on the surface potential of cellulose. Hukki and Rinne found an increase in surface potential from -10 mv. at pH 3 to -30 mv. at pH 9 indicating a direct interaction of hydroxyl content and potential (39). More recently, Hastbacka and Nordman also found that pH had a significant influence on the surface potential of pulp (36). Jacquelin and Bourlas studying the retention of fillers

found the surface properties of fibers could be changed by varying the pH (44). Neale and Peters found that the surface potential of cotton decreases rapidly in solutions of pH 4 or less (31). Duhem related the fixation of direct dyes to the isoelectric point of cellulose fibers, pH 3.25, which she found by titration with acid (5).

In summary, it has been shown that cellulose does acquire a negative potential in water. The literature indicates that both mechanisms, ionization and preferential ion adsorption, possibly can contribute to the surface potential of cellulose surfaces. While it is recognized that the determination of the nature of the charge development mechanisms is important, it is beyond the scope of this investigation which deals mainly with the overall effect of surface charge on retention of fines.

ELECTRIC DOUBLE LAYER

When a particle possessing a surface potential is suspended in a dilute electrolyte suspension, an electric double layer is formed around the particle. There are available many excellent discussions of electric double layer theory in the literature, and it would be impossible in this dissertation to include all of the details of the structure (26, 46, 47). A brief description of the colloidal double layer and how it relates to coagulation theory is discussed below.

As the name implies, the electric double layer surrounding a colloidal particle consists of two layers, a layer of potential determining ions and a diffuse layer of counterions, which because of their opposite charge, neutralize the surface potential of the colloid.

According to Kruyt, Gouy and Chapman, independently, first described theoretically the double layer at a planar interface (26). Their theory predicted

that the surface potential should decay exponentially to zero with respect to distance from the interface. Stern in 1924 introduced the concept of a layer of strongly adsorbed, immobile, counterions to explain the discrepancy between the measured double layer capacitances and those calculated by the Gouy-Chapman theory. It also qualitatively explained the reversal of charge observed with some colloids and multivalent cations. He used the Langmuir adsorption isotherm to describe the ion distribution in this layer which generally is called the Stern layer. It has a thickness on the order of a few ionic diameters. The Gouy-Chapman theory was used to describe the exponential potential distribution in the diffuse layer. Graham attempted to further improve the double layer theory by introduction of the inner Helmholtz plane, the locus of centers of chemisorbed anions, and the outer Helmholtz plane, the locus of the centers of cations electrostatically held to the chemisorbed anions. The Gouy-Chapman theory still described the potential decrease from the outer Helmholtz plane into the bulk solution. This theory could then account for the surface charge development by specific ion adsorption.

The physical picture of the electric double layer and its response to increased electrolyte concentrations that can be drawn from this discussion is shown in Fig. 1 for a negatively charged colloidal particle.

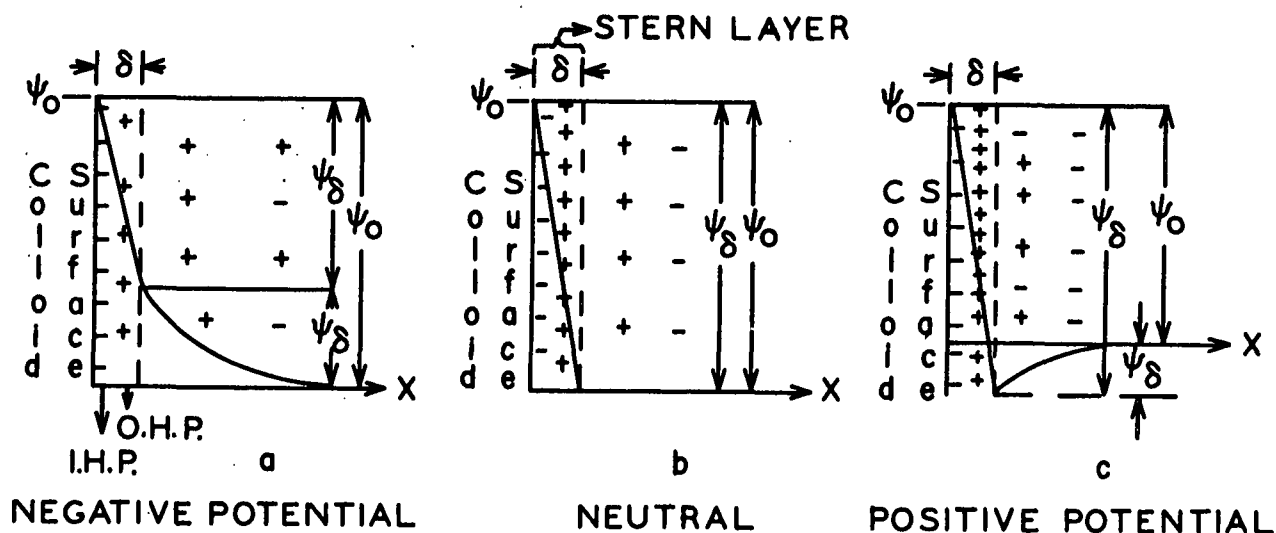


Figure 1. Electric Double Layers

When the colloidal surface is negatively charged through preferential adsorption of anions, the locus of these ion centers defines the inner Helmholtz plane, I.H.P., as shown in Fig. 1a. In the case where ionization of the solid may be important, this definition would not be applicable. The locus of the centers of the electrostatically bound, immobile counterions is defined as the outer-Helmholtz plane, O.H.P. The Stern layer which is a distance, δ , from the colloid surface includes both Helmholtz planes and is shown in Fig. 1b. The distance from the colloid surface is given by X .

The surface potential at the hydrodynamic slipping plane is defined as the zeta potential, ψ_{ζ} . It is the potential measured by the abovementioned electrokinetic methods, and it can equal the Stern potential, ψ_{δ} , if the slipping plane is at the Stern layer. The potential drop across the Stern layer is approximately zero for weakly charged colloids in very dilute electrolyte solutions which means the ψ_{δ} is equivalent to the surface potential, ψ_0 . This is important for theoretical calculations since ψ_0 cannot be determined experimentally from electrokinetic data.

The effect of additional electrolyte readily can be seen in Fig. 1b. As the electrolyte concentration is increased, a greater proportion of the surface charge is balanced in the Stern layer, and the zeta potential approaches zero because there is essentially no net charge in the Gouy layer. As the valence of the electrolyte counterion is increased, the concentration required to satisfy the surface charge decreases simply because the charge per mole of counterion increases. The fact that the surface charge of colloids can be satisfied at lower concentrations if the electrolytes contain multivalent cations is the basis for the well-known Schulze-Hardy rule which predicts that the concentration approximately decreases as the inverse sixth power of the valence. In effect, the addition

of electrolyte collapses the double layer by complete charge satisfaction within the immobile or Stern layer with essentially none occurring in the Gouy layer.

In those cases where multivalent cations reverse the sign of the zeta potential, Fig. 1c depicts an excessive charge in the Stern layer which is neutralized in the diffuse layer by the anions. The zeta potential would be positive in this particular case.

The ability of counterions to satisfy the surface potential is a basic principle underlying the hydrophobic coagulation theory of colloids.

STABILITY THEORY

The stability of a colloidal dispersion depends on the interaction of the double layers surrounding the particles. Stability in the colloidal sense generally refers to the ability of the suspension to resist changes of state with respect to time. In most instances, it refers to the state of dispersion of the system. In a stable sol, the particles are dispersed thoroughly and remain so with most particles acting independently of each other as individual entities. This system is characterized by a net repulsive interaction of the particles' double layers. In a coagulated sol, the particles initially may be dispersed thoroughly, but upon collision, they can form aggregates or flocs. This system would be characterized by a net attractive interaction of the double layers. The state of dispersion depends on the net result of two competing forces: repulsion which arises from electrical interaction of the double layers and attraction which arises from the London-Van der Waals forces.

The theory of colloidal stability was described by Verwey and Overbeek and Derjaguin on this basis (48, 49). A general description of their theories which

are in essence the same should be helpful in understanding the objectives of this dissertation.

Since each particle is surrounded by a double layer of the same electric charge, there is a resultant repulsion between the particles when they enter into mutual spheres of influence. It should be pointed out, however, that the interaction is not a simple coulombic electrostatic repulsion because in essence the particles and their surrounding diffuse layers are electrically neutral. The repulsion arises from the ionic redistribution of the electric double layers which occurs when they interpenetrate each other. The net result of the interaction depends on the thickness of the diffuse layer.

The analysis of the repulsion interaction has been approached from total energy calculations as well as from force considerations. The repulsive energy of interaction between two particles has been derived for various geometric shapes including flat parallel plates, spheres, and parallel as well as crossed cylinders (48, 50). Sparnaay found crossed cylinder interaction was similar to sphere interaction while parallel cylinders behave midway between the spherical and parallel plate form (50). Generally, it is found that counterion concentration and valence influence the repulsion interaction through collapse of the double layer as described above in the Schulze-Hardy rule.

Once the repulsive interaction has been removed by double layer collapse, an attractive force is required to hold the agglomerate together. An attractive force which can operate over relatively long distances compared to atomic dimensions is found in the London-Van der Waals forces. These forces which result from the interaction of molecular dipole moments as well as induced dipole moments operate between all atoms. The attractive energy between two atoms decays approximately as the inverse sixth power of the distance, but since the forces are essentially

additive, the decay is much less for condensed systems. In fact, for the case of large parallel plates, the attractive energy only decays as the inverse square of the distance between the particles. This attractive energy is large enough to overcome the kinetic energy of the colliding particles allowing the particles to coagulate and form flocs.

The attractive energy of colloidal particles is essentially independent of the suspension medium since it depends only on the atomic or molecular structure of the material.

The resultant of these two energies determines the stability of the colloidal system which is a function of the rate of coagulation. The rate at which a dispersed sol coagulates is increased significantly as the net energy is reduced. A stable sol is characterized generally by a maximum net energy of several time kT . The primary influence of the electrolyte is to reduce the repulsive energy by collapsing the double layer to allow the particles to approach each other close enough to allow the attractive energy to become predominant.

When the attractive energy is predominant, each collision results in permanent contact. This case, which is defined as rapid coagulation, was analyzed theoretically by von Smoluchowski (26). He described rapid coagulation in terms of the usual diffusion equations for Brownian motion of the particles.

When the repulsive energy is predominant, each collision may not result in permanent contact. This case, which is defined as slow coagulation, was analyzed theoretically by Fuchs who substituted an expression for diffusion in a force field for the diffusion equation used by von Smoluchowski (26). Fuchs's theory bridged the gap between the complete repulsion of a stable sol and the opposite situation of complete attraction which causes rapid coagulation.

The change from slow to rapid coagulation can be described by a stability ratio introduced by Fuchs. The stability ratio is defined as the ratio of the rate of the rapid coagulation to the rate of slow coagulation. It is a function of the net energy of interaction of the colliding particles and can vary between one (rapid coagulation) and infinity (slow coagulation). The log of the stability ratio should be a linear function of the log of the counterion concentration up to the concentration at which rapid coagulation begins. Then the stability ratio becomes independent of concentration because the double layer has been collapsed completely which removes the repulsive energy barrier between the particles.

Reerink and Overbeek measured the rate of coagulation of several silver iodide sols and showed that the stability ratio was a linear function of the counterion concentration and that it was dependent primarily on the maximum energy of interaction (51). Kruyt graphically summarizes other experimental data which support Fuchs's theory for a number of hydrophobic sols (26). Daluja and Srivastara more recently tested this theory using an arsenic trisulfide sol with fairly good results (52).

Although the above discussion has been brief, it can be seen from the theory of Verwey and Overbeek that coagulation depends on the total interaction of the repulsive and attractive energy of two approaching particles. If the net result is one of attraction, every collision results in coagulation. A large repulsion energy causes the sol to remain stable and unflocculated. Addition of electrolytes can reduce the interaction by collapsing the double layer around the colloid. The effect of electrolytes on colloidal stability (rate of coagulation) is explained in terms of a stability factor introduced by Fuchs. Other factors such as surface potential, Van der Waals constant, and the type of electrolyte also influence the stability of sols. A rigorous test and confirmation of the stability theory of

Verwey and Overbeek has not been possible because the surface potential and the Van der Waals constant have to be approximated, but this has not prevented the theory from being used to explain successfully the coagulation process (53).

ANALYSIS OF THE PROBLEM

According to McKenzie, there are three factors which control the retention of papermaking wet-end additives: the collision process, aggregate formation, and the overall strength of the aggregate (54). Fines could be considered an in situ "wet-end additive" since they are not present in the system initially but are created during the stock preparation.

The first factor controlling the retention of particulate matter is the collision of the particle and the fiber. For particles smaller than 1 $\mu\text{m.}$, the collision frequency due to Brownian motion is sufficiently high to cause a reasonable number of collisions while particles larger than 10 $\mu\text{m.}$ require additional energy in the form of mechanical agitation. The collision frequency also depends on the concentration of the two components. Mason has investigated the collision process of equal-sized particles of different shapes in a laminar shear field (55). The collision between a fiber and fine could be compared to the coagulation process of polydispersed systems treated by Muller (56). Generally, it was predicted that as the concentration of the larger particle increased and the difference in relative sizes increased, the rate of flocculation increased substantially. Heller and co-workers working with unequal-sized polystyrene latices did observe an increase in the average particle size of unflocculated particles indicating the collision rate between unequal-sized particles was more rapid than that between those of equal size (57). According to the latter workers who also reviewed this concept, others have observed this phenomenon of more rapid flocculation in polydispersed systems.

Once the two components collide, the next factor controlling retention is the formation of an aggregate or floc. Many different mechanisms could be postulated as possible sources for the flocculation force. These could include the polymeric flocculation of Lamer and Healy (58), hydrophobic colloid coagulation of Verwey and Overbeek (48), salt bridging as suggested by Lamer and Smellie for the flocculation of phosphate slimes by starch (59), or hydrophilic colloid flocculation by solvent layer denaturation. The colloidal coagulation process is considered by many to be the most important (14, 18, 20, 21, 54).

The final factor which McKenzie indicates is important to wet-end retention is the overall strength of the floc once it forms. Generally speaking, the Brownian motion of the retained fines probably would not be sufficient to disrupt the aggregate because of their large size. However, the floc usually is subjected to very severe hydrodynamic shear forces which could disrupt the structure easily. Mason observed that at a given shear rate, an equilibrium was approached between the rate of floc destruction and formation with various equal-sized particles (55). Reich and Vold studying the flocculation of carbon and ferric oxide sols in agitated suspension concluded that the equilibrium resembled a reversible chemical reaction (60). The average floc size depended on the degree of agitation, increasing with decreasing agitation rate.

The physical properties of the system such as particle size, concentration, and agitation rate control the first and last factor to a large extent. The physical processes involved are understood fairly well even though experimentally they may not be measured accurately. However, the second factor, the nature of the attractive flocculation forces for a fiber-fines system, has not been identified conclusively. A number of the different mechanisms suggested above may operate on the system at a given time, and it becomes necessary to determine which are most important. The

significance of the coagulation theory of Verwey and Overbeek as it relates to fines retention will be determined in this dissertation.

A rigorous test of their theory is not possible even for an ideal system let alone a fiber-fines system. Kruyt lists a number of pertinent reasons which include a lack of knowledge of the Van der Waals constant, which affects the attractive potential between particles, and the colloidal surface potential, which is related to the collapse of the repulsion potential. Furthermore, the cation concentration in the double layer at the onset of rapid flocculation may be different than the bulk concentration. The sols usually used are heterodispersed, and the average size must be known which is not amenable to accurate measurement. He concludes, "The best thing to do is to see whether the experiments are grossly at variance with the theory" (26).

A study of coagulation behavior in a system requires some knowledge, whether direct or indirect, of the particle concentration in the suspension. Direct techniques used include light scattering with small particles and direct microscopic observation for the larger particles. The easiest, most often utilized, is the indirect technique of measuring the settling rate or final settled volume of a series of coagulated sols. In the study of filler retention, the concentration of particles retained by the fibers has been determined by ash weight and also by chemical analysis since it is a two-component system.

In this system of fiber-fines, the primary difference between components is particle size; therefore, another property is required to distinguish between the particles. Fines have been identified with colored dyes and radioactive isotopes (61, 17). With both of these techniques, there is a problem with desorption of the tagging material which would confound analytical techniques. Another objection

especially in the case of adsorbed radioactive silver is the unknown effect it could have on the surface properties of the fines.

The surest method of alleviating these objectional problems would be to include a radioactive isotope within the chemical structure of the fines. Selders and co-workers labeled wood cellulose in live trees by injecting aqueous sodium carbonate containing C-14 and by exposing the trees to an atmosphere of carbon-14 dioxide. More recently, Larson used the latter technique to study the growth of reaction wood in pine (63). This technique which has the primary advantage of yielding large quantities of radioactive wood was used in growing radioactive poplar for this investigation. The wood was pulped and converted into radioactive tagged fines.

The first requirement of this study, knowing the concentration of unretained (free) particles, could then be met by radioactivity analysis of the free fines remaining in suspension. Since the fibers and fines have such a large difference in size, the unretained fines could be removed easily by a simple screening operation.

Since a rigorous test of colloidal coagulation theory is in itself not possible, a satisfactory agreement with observed coagulation behavior of known hydrophobic systems is essential to test the theory for fines retention. If the dominant mechanism of fines retention investigated in this system is analogous to hydrophobic colloid coagulation, the following observations should be confirmed by experiment:

- a. Retention should be dependent on electrolyte concentration only up to a critical concentration, the coagulation value, which reduces the surface potential to near zero,
- b. the Schulze-Hardy rule should apply which states that the coagulation values would be approximately inversely proportional to the sixth power of the counterion valence,
- c. an empirical linear relationship between coagulation values and the log of the valence should exist,

- d. the electrolyte anion should have little or no effect on the coagulation value,
- e. the zeta potential of the fines should decrease with increasing counterion concentration up to the coagulation value at which point it should be approximately equal to zero,
- f. The retention process should behave as a bimolecular reaction with the rate being first order with respect to fines concentration,
- g. in a heterodispersed system, the smallest particles should be retained most rapidly, and
- h. the log of the stability factor, which is the ratio of the rates of coagulation, should be a linear function of the log of counterion concentration up to the coagulation value at which point it should approximate unity.

An experimental program was completed which compares the fines retention process to these observations to test the feasibility of explaining the coflocculation mechanism of fines retention as a coagulation process.

EXPERIMENTAL

The development of a sound analytical tool for investigating fines retention was most important to the overall success of the experimental program. As was discussed previously, the most promising technique appeared to be the preparation of a radioactive wood supply that could be converted into tagged fines. A radiochemical technique was particularly advantageous because it yielded an accurate measurement proportional to a very small mass of fines. In addition, an automatic liquid scintillation counter was available which could be used for quick, accurate radioactivity measurements.

Three-year-old seedlings of trembling aspen, Populus tremuloides, were tagged successfully with C-14 in the summer of 1967 by intermittent growth in an atmosphere of carbon-14 dioxide. Fifteen aspen and, in addition, fifteen red pine, Pinus resinosa, seedlings were treated in a small, plastic enclosure with 125 mCi of carbon-14 dioxide throughout the summer. A detailed description of the treatment procedures and results is found in Appendix I. Nine of the aspen seedlings were harvested for this work. It should be noted that all of the wood components (leaves, bark, stem, branches, etc.) were tagged with C-14. After harvesting, the branch stems were barked and cut into 3/4-in. lengths. The primary stem or bole was not included because of the resultant radioactivity dilution from the untagged wood. The wood was prepared for pulping by extraction with alcohol:benzene, alcohol, and water according to TAPPI Standard T 12 m-59. A total of 84.3 g. of extracted wood was readied for pulping.

RADIOACTIVE PULP PREPARATION

The radioactive aspenwood was pulped by the kraft process at typical pulping conditions in small 500-ml. bomb digesters. A kraft pulp was used for fines

preparation because it is representative of the papermaking system. A detailed description of the pulping conditions is found in Appendix II. After pulping, the cooking liquor was removed by filtration and the pulp washed with deionized water. The pulp was defibered in a Waring Blendor and thoroughly washed with 6 l. of deionized water. There were no shives or uncooked chips found in the pulp after the treatment. The pulping yield was 48.8%.

The pulp was bleached with 10% acidified sodium chlorite at 1% consistency for 14 days at room temperature. The pulp was washed with distilled water, thickened, and redispersed in 0.1N sodium hydroxide to remove the chlorinated lignin residue. After the alkali wash, the pulp was treated overnight in dilute acetic acid to neutralize any remaining alkali. The bleached pulp was washed thoroughly with distilled water, thickened, and air dried. The final yield of bleached pulp was 42.8% or approximately 36 g.

The radioactivity of the primary bleached pulp monosaccharides was measured to determine the randomness of the tagging process. Selders and coworkers determined the radioactivity of the carbohydrate fractions from a hydrolyzed sodium chlorite holocellulose prepared from red pine that was exposed previously to carbon-14 dioxide. They found the hemicellulose or beta fraction was slightly more radioactive than the cellulose or alpha fraction (62). They also found that xylose was slightly more radioactive than glucose in a holocellulose prepared from red pine injected with aqueous sodium carbonate containing carbon-14. The differences were minor in both instances indicating the tagging process was random. A radioactive bleached pulp sample prepared above was hydrolyzed for quantitative analysis and separation by anion-exchange chromatography to determine if the monosaccharides were tagged randomly.

The sample was hydrolyzed by the same procedure Saeman and coworkers used for preparing paper chromatography hydrolyzates (64). An aliquot of the hydrolyzate was analyzed quantitatively by the anion-exchange chromatography technique of Kesler (65). In this procedure, the sugar content of the hydrolyzate is determined after separation on an anion-exchange column by a Technicon AutoAnalyzer using the orcinol colorimetric technique.

A larger volume of the hydrolyzate was fractionated for subsequent radioactivity measurements on a prep anion-exchange column filled with Bio-Rad Ag1-x8 resin. The effluent fractions of each of the constituent sugars found - mannose, xylose, and glucose - were combined and counted with a Beckman model LS-100 liquid scintillation counter (66). It was necessary to first treat the solution fractions with a cation exchange resin, Amberlite IR-120, before they were miscible with Beckman's scintillation Cocktail D (66).

Approximately 91.5% of the hydrolyzate spotted was recovered in the glucose and xylose fractions which is considered a satisfactory yield for this technique. The mannose fraction which was too small for radioactivity analysis would account for part of the lost material. Other losses may have occurred with trace amounts of other monosaccharides, unhydrolyzed oligosaccharides and/or furfural, and hydroxymethyl furfural formed in the color reaction but not accounted for in the radioactivity analysis.

The average radioactivity of the glucose and xylose was 32.0 and 34.5 c.p.m./ μ g., respectively, which indicates the tagging process was random. Since a direct comparison was adequate, the counting efficiency was not determined for these solutions.

RADIOACTIVE FINES PREPARATION AND CHARACTERIZATION

It was necessary to develop an efficient technique for reducing the pulp to usable fines because there was only a small quantity of radioactive pulp available. An attempt was made to use a ball mill to grind milled pulp into fines, but there was a serious problem with contamination from the equipment. Other equipment such as a Waring Blendor or TAPPI disintegrator could possibly have been used, but problems are encountered with heat dissipation and extensive grinding time.

Preliminary investigative work indicated a Virtis "45" homogenizer could be used to reduce milled pulp into fibril-like fines very efficiently. Particle size reduction is realized through the shearing action of a razor sharp, 1-in. blade rotating at 45,000 r.p.m. in a 125-ml. convoluted sample container. It was designed for rupturing concentrated suspensions of microorganisms (67). Efficient particle size reduction was obtained in a reasonable length of time if the pulp consistency was maintained at approximately 10%.

The radioactive pulp was first ground dry in a Wiley mill to pass an 80-mesh screen. After milling, approximately 10.0 g. of pulp was dispersed in 100 ml. of distilled water having a specific conductance of 0.9×10^{-6} mhos./cm. or less. The pulp was ground for 4.0 hr. while in an ice bath which maintained the temperature below 50°C.

An International centrifuge, model V, was used to fractionate the homogenized pulp. Holtzman used a similar technique to fractionate kaolin clay (27). Like Holtzman, an equation based on Stokes's equation which described spherical particles settling in a gravitational field, was used to calculate the centrifugal speed and time required to sediment a given equivalent size sphere through a known distance. A siphon was then used to draw off the suspension of unsedimented particles which

were theoretically smaller than the calculated size. The maximum theoretical size selected for the fines was 1.5 μm . which required a 5.0-min. centrifuging time at 1500 r.p.m. It was assumed the density of cellulose was 1.5 g./cc., and the settling distance was from 9.4 to 16.7 cm. measured from the center of rotation. It should be noted that the theoretical size is an equivalent spherical diameter, E.S.D.

Before centrifugation, the homogenized pulp was divided into four equal aliquots and transferred to 250-ml. glass centrifuge bottles, diluted with distilled water to a depth which places the surface of the suspension 9.4 cm. from the center of rotation, and thoroughly dispersed with a lighting mixer. Then the suspensions were centrifuged at the above conditions. The centrifugate was siphoned off into a large carboy to a depth equivalent to 16.7 cm. from the center of rotation, the sediment was redispersed in distilled water, and the fractionation process repeated 6-8 times on the same grinding sediment until the centrifugate was clear indicating complete removal of all particles less than 1.5 μm . E.S.D. The sediment from the final fractionation was combined and an approximate yield measurement made to determine the quantity of additional pulp required to maintain the grinding consistency. The equivalent weight of fines produced was made up with milled pulp and the process repeated starting with the 4.0-hr. homogenization.

When the grinding was completed, the combined centrifugate suspension of fines was concentrated by another centrifugation in a Beta-fuge centrifuge. The conditions were set at 5500 r.p.m. for 20 min. which essentially sedimented all the fines.

The concentrated fines were refractionated with the International centrifuge to further narrow the particle size distribution. The maximum diameter was reduced to 0.75 μm . E.S.D. which required a 20.0-min. centrifuging time at 1500 r.p.m. The same routine process of centrifuging and redispersing the sediment described above

was followed with the concentrated fines. The refractionated fines were concentrated with the Beta-fuge.

It was found that the fines could be preserved by freezing without having to add formaldehyde or another biostatic agent which might have interfered with colloidal properties. Preliminary work with untagged fines indicated freezing and subsequent thawing, and redispersion did not change the particle size distribution. Therefore, the fines were frozen in polyethylene bottles in convenient 200-ml. volumes. A bottle of fines could then be thawed and redispersed to the original particle size distribution by 1.0 hr. of additional homogenization with the Virtis. Approximately 14.4 g. of fines at 0.0024 g./ml. were prepared and frozen.

Examples of the fines prepared by the above procedure are shown in the micrographs in Fig. 2. The photomicrograph of the radioactive fines in Fig. 2a shows that they appear to have the same fibril-like structure of those found in a Valley beaten sulfite pulp, Fig. 2b. The electron micrograph of the radioactive fines in Fig. 2c clearly shows the wide distribution of particle sizes present. A crude average fines length was determined by a technique similar to TAPPI Standard 232 54-68 which normally is used for fiber length measurements, and the average width was measured with a microcomparator. These measurements were taken from electron micrographs. The approximate weighted average length and width were 19.2 $\mu\text{m}.$ and 0.18 $\mu\text{m}.$, respectively. The approximate arithmetic average length and widths were 12.8 $\mu\text{m}.$ and 0.09 $\mu\text{m}.$, respectively, which indicates both distributions were quite wide.

Since size measurements by this technique were too time consuming for routine particle size analyses, an alternate method using a Coulter Counter, model B, was evaluated and used successfully with the fines (68). This instrument electronically scales the particle sizes as the electrically conducting suspension is pumped



Figure 2a. Photomicrograph of Radioactive Aspen Pulp Fines Obtained with Virtis Homogenizer



Figure 2b. Photomicrograph of Sulfite Pulp Fines Obtained with Valley Beater

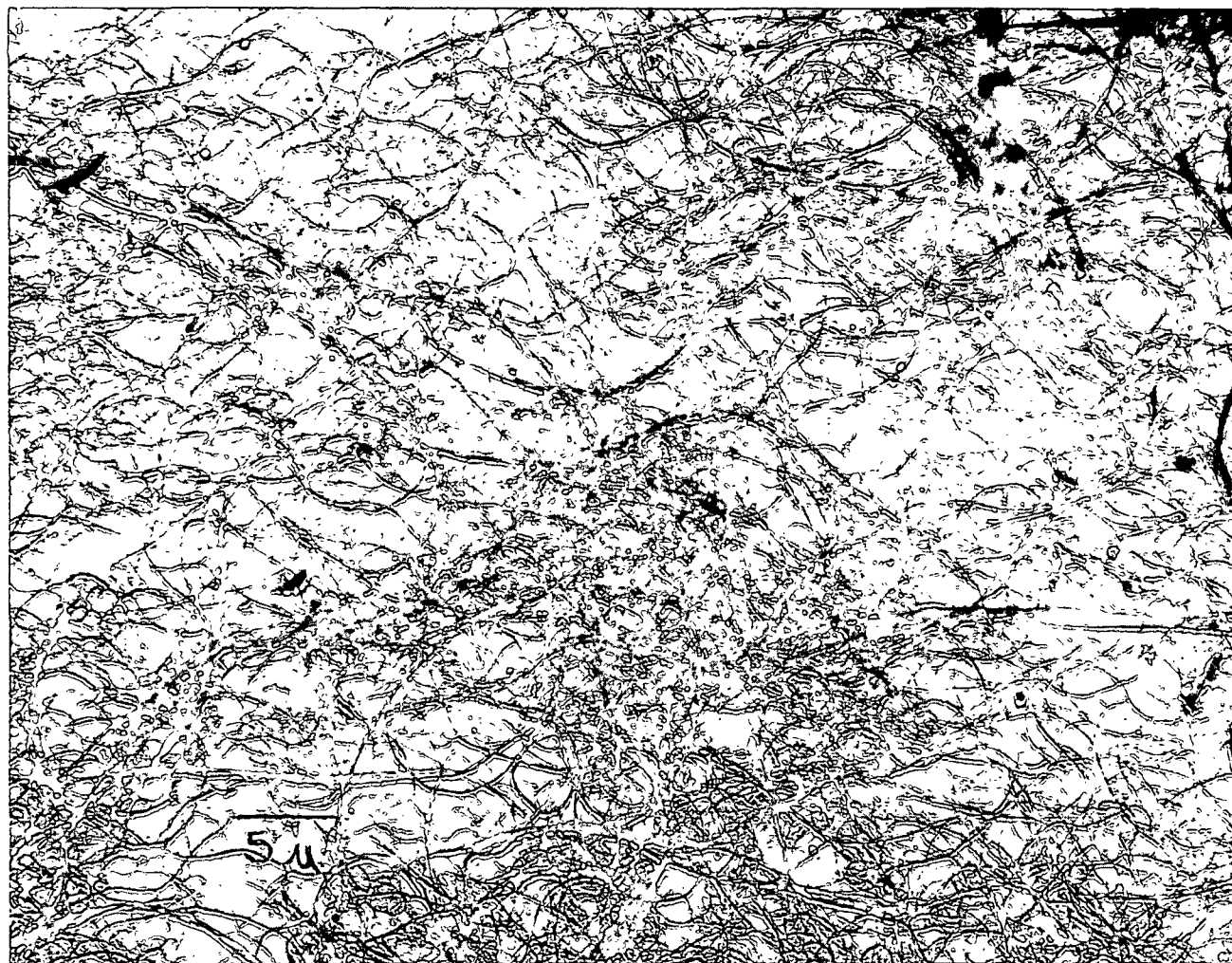


Figure 2c. Electron Micrograph of Radioactive Aspen Fines

Figure 2. Cellulose Wood Pulp Fines

through a precision bored orifice. A voltage pulse proportional to particle volume is measured across a pair of immersion electrodes placed on either side of the orifice. The voltage pulse is caused by a change in resistance between the electrodes. The instrument is calibrated to yield an equivalent spherical diameter.

A Coulter Counter was used by O'Connell and Martsch to measure the fiber diameter distribution in wool (69). Knowing the average length of microtomed wool samples, they were able to calculate the average fiber diameter from Coulter Counter E.S.D. data which agreed within 3% of microscopic measurements. Block and Gusack confirmed their work by measuring the denier distribution of synthetic textile fibers in the same manner assuming cylindrical particles (70). They concluded that cross-sectional shape did not appreciably affect the denier distribution. The instrument precision was ca. $\pm 3\%$ on a given sample.

The Coulter Counter was used successfully to characterize the E.S.D. distribution of the radioactive fines. The fines suspensions were counted in a 4% NaCl solution using the recommended procedures (68). It should be pointed out that the fines normally are flocced at this electrolyte concentration, but it is felt that the flocs are subjected to sufficient shear in the apparatus to disrupt them so that individual particles are being measured. A preliminary comparison of distributions obtained with the Coulter Counter and a centrifugal sedimentation technique were very good. A computer program which was written to analyze the frequency data is found in Appendix III along with the data obtained for the above fines. The average results of four distribution measurements on the same sample of fines are shown in Table I and Fig. 3. The weight average and number average E.S.D.'s were 1.11 and 1.07 $\mu\text{m.}$, respectively. The E.S.D. calculated from the weighted average length and width is 0.97 $\mu\text{m.}$ which is in fairly good agreement with the Coulter Counter E.S.D. This would indicate that the Coulter Counter is probably measuring one particle at a time as was suggested above.

TABLE I
RADIOACTIVE FINES PARTICLE SIZE DISTRIBUTION
COULTER COUNTER ANALYSIS OF E.S.D., μm .

Size Range	Average Weight, %
1.0	18.0
1.0-2.0	41.0
2.0-3.0	11.0
3.0-4.0	2.0
4.0-5.0	7.0
5.0-6.0	5.0
6.0-7.0	3.0
7.0-8.0	3.0
8.0-9.0	4.0
9.0	7.0

The radioactive fines were chemically characterized by specific activity measurements, monosaccharide content, and total carboxyl content. The results of these analyses are shown in Table II.

TABLE II
CHEMICAL CHARACTERIZATION OF RADIOACTIVE FINES

Fines Constituent	Concentration, %
Specific activity, c.p.m./g.	4.17×10^7
Monosaccharides ^a , %	
Glucose	79.6
Xylose	16.5
Mannose	0.4
Arabinose	0.3
Galactose	0.5
Total carboxyl content ^a , mM/100 g.	5.9

^aDetermined by Analytical Chemistry Group of The Institute of Paper Chemistry.

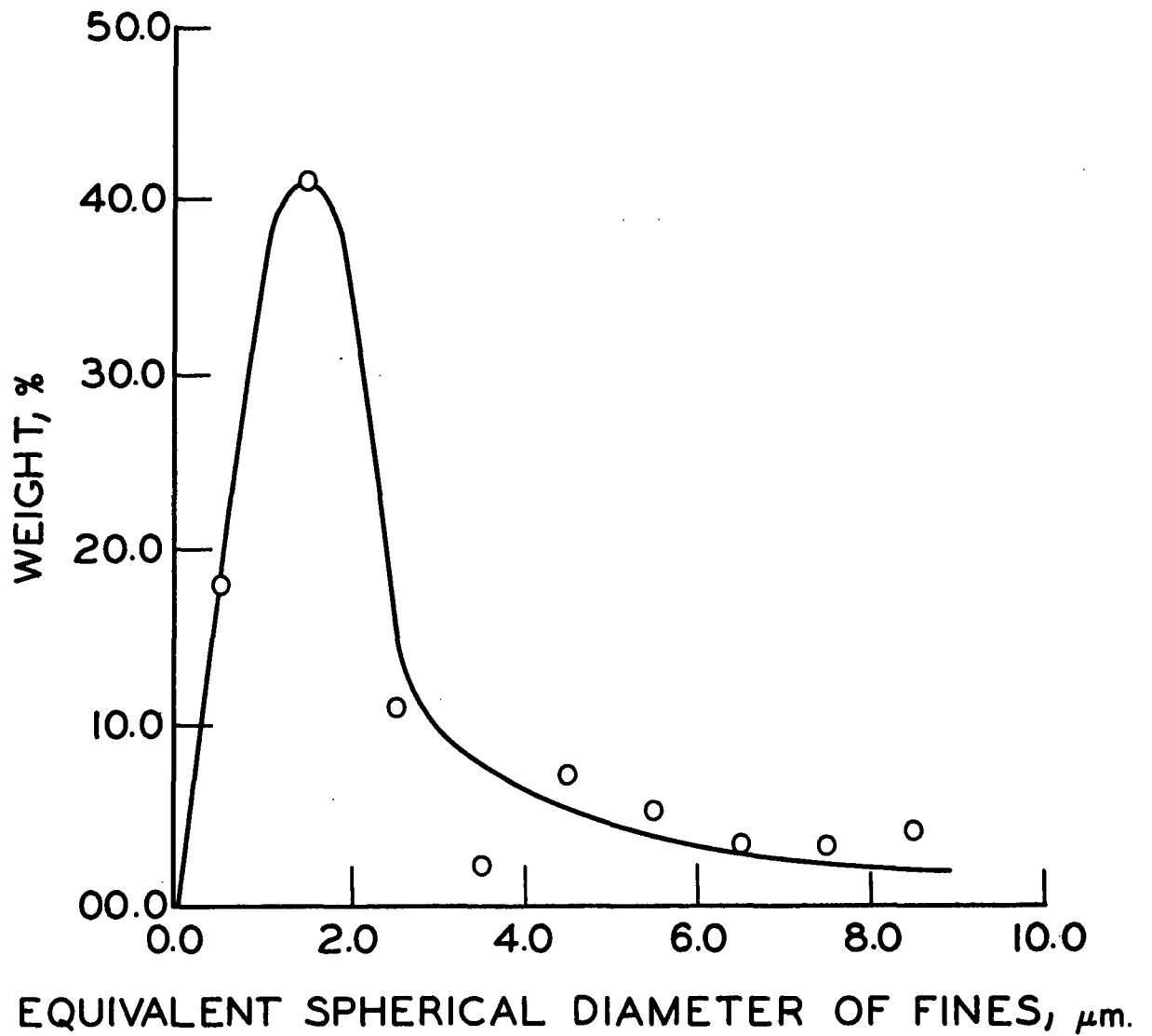


Figure 3. Radioactive Fines Particle Size Distribution

The specific activity, defined as the number of radioactive disintegrations per unit mass of fines was determined by scintillation counting with the Beckman model LS-100 scintillation counter (66). The instrument indirectly measures radioactivity by measuring the ultraviolet light emitted by a phosphor, 2,5-diphenyloxazole, when it is bombarded by the radioactive emission particle. Quenching agents, i.e., materials which adsorb ultraviolet light, can reduce the counting efficiency significantly. The counting efficiency defined as the ratio of measured disintegrations to the actual disintegrations occurring was determined in the counting cocktail by adding an internal standard of known radioactivity, C-14 toluene. The counting efficiency for a 0.50-ml. water sample in 5.0 ml. of the counting cocktail was 96.9%.

The counting cocktail used for all radioactivity analyses included: 5.0 g. 2,5-diphenyloxazole phosphor (PPO), 100.0 g. reagent-grade naphthalene, 1000 ml. 1,4-dioxane, and 125 ml. ethyleneglycolmonomethyl ether emulsifier.

The specific activity of the fines was determined by counting a number of 0.50-ml. fines samples of known mass concentration in 5.0 ml. of the cocktail. The mass concentration of the stock suspension used for counting was determined by drying and weighing aliquots of the suspensions. Preliminary work with fines radioactivity analysis showed that fines concentration did not affect counting efficiency so the efficiency determined with the C-14 toluene was applied directly to these suspensions to calculate the specific activity.

PULP PREPARATION

The pulp used for the retention investigation was a typical bleached kraft softwood papermaking pulp, Weyerhaeuser S.G. It was made from mixed western softwoods including hemlock, cedar, Douglas-fir, and true fir.

The pulp was first extracted with ether and ethyl alcohol according to TAPPI Standard T 204 m-54 to remove pitch and other extractives. It was dispersed in a Valley beater with distilled water by a 10-min. beating with no bedplate load followed by 5 min. at a bedplate load of 5500 g. The pulp had a corrected Canadian standard freeness of 680 ml. which indicated there was very little fibrillation.

The pulp was first classified on a Bauer-McNett classifier using stainless steel screens of 20, 35, and 60 mesh to remove all of the fines. A 20-g. charge was classified for 1 hr. using filtered distilled water. It was reclassified with 14 and 20-mesh screens and distilled water to increase the average fiber length of the pulp.

After classification, the thickened pulp was washed three times with distilled water and dewatered. It was stored in a refrigerator without a preservative.

The pulp was characterized physically by fiber length and width measurements, and specific area and volume determinations by The Institute of Paper Chemistry staff. These results are summarized in Table III.

TABLE III

PHYSICAL CHARACTERIZATION OF KRAFT PULP

Property	Value
Fiber length, mm.	
Arithmetic average	2.70
Weighted average	3.00
Arithmetic average fiber width, μm .	47.10
Specific surface area, m^2/g .	0.74
Specific volume, cc./g .	2.61

The pulp was characterized chemically by monosaccharide and total carboxyl content analyses. The results of these determinations are summarized in Table IV.

TABLE IV

CHEMICAL CHARACTERIZATION OF KRAFT PULP^a

Pulp Constituent	Concentration, %
Monosaccharides	
Glucose	88.3
Mannose	5.9
Xylose	5.8
Arabinose	0.2
Galactose	2.2
Total carboxyl content, mM/100 g.	4.22

^aDetermined by Analytical Chemistry Group of The Institute of Paper Chemistry.

EXPERIMENTAL APPARATUS

The primary function of the experimental apparatus was to separate the unre-
tained fines from the pulp fibers so that retention could be calculated by a mass
balance. This was accomplished with a continuous filtering system in which the
free fines suspension was pumped through a screened sampling port positioned at
the periphery of a small agitated vessel. The actual equipment is shown in Fig. 4
and described below.

The retention apparatus was made from an 8.0-in. section of 5.0-in. inside
diameter Lucite pipe which had been fitted with an end plate of Lucite sheeting.
A sampling port was positioned 1.5 in. from the bottom and covered with a 35-mesh
S.S. wire screen having a pore size of 420 μ m. and an open area of 33.8%. The
classified pulp was excluded by the screen while the free fines suspension was
being recirculated continuously.

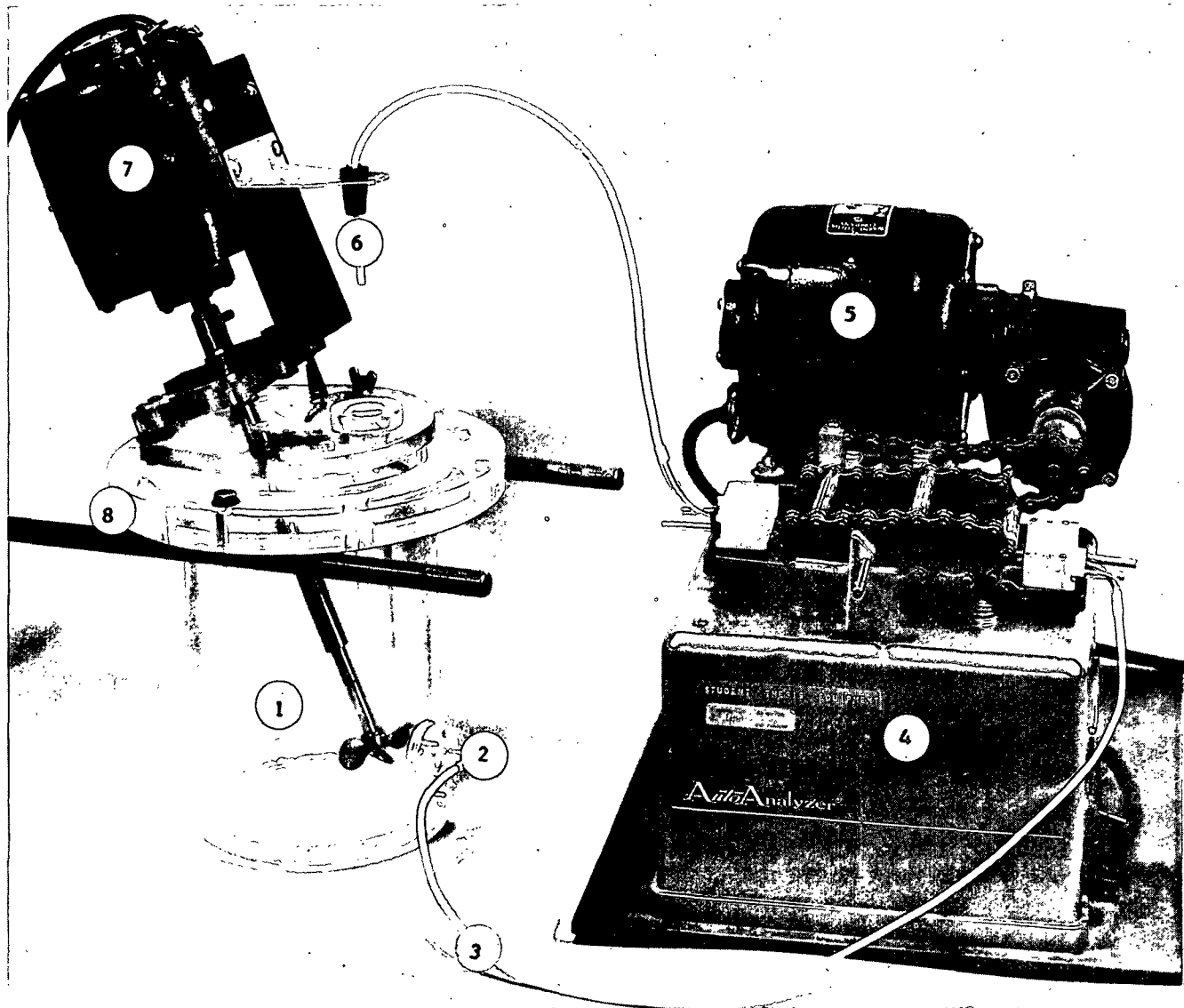


Figure 4. Experimental Retention Apparatus

1. Basic Retention Apparatus - 5.0 in. Diam. Lucite Pipe Section 8.0 in. Long
2. One Inch Diam. Sampling Port Covered with 35-Mesh Screen
3. Transmission Tubing of 0.125-in. I.D. Teflon Tubing
4. Basic AutoAnalyzer Pump Fitted with 0.110-in. I.D. Pumping Tube
5. Auxillary AutoAnalyzer Motor, Bodine Motor Model NSH-54RL
6. Return Transmission Tubing as Above
7. Agitator Motor, Bodine Motor Model NSH-34
8. Retention Apparatus Hangar Assembly

The free fines suspension was sampled from the recirculation line running from the sampling port through an AutoAnalyzer pump back into the pulp suspension. The AutoAnalyzer pump was fitted with an 1/8-horsepower variable speed d.c. Bodine motor, model NSH-54RL, controlled by a solid state Minarik speed controller, model SH-53, to increase the pumping capacity for a single pumping tube geometry. When a multiple pumping tube geometry and manifold was used, fines became trapped in the system which resulted in false concentration measurements. A standard AutoAnalyzer pumping tube of 3.4 ml./min. was used, but with the increased motor speed, a rate of 12.5 ml./min. was realized. The standard deviation of flow rate was ca. 1.3%.

Agitation was supplied by a 3-blade impeller mounted to a 1/15-horsepower d.c. Bodine motor, model NSH-34, controlled by a Minarik variable speed controller, model SH-33. The agitation speed could be varied from 90-700 r.p.m. without cavitation in 1.0 l. of water at a standard deviation of ca. 1.5%.

It was found in preliminary work with the apparatus that the impeller had to be placed as near the sampling screen as possible to obtain a representative sample of the suspension. Sampling accuracy in distilled water was confirmed by comparing fines concentration from the recirculation line and pipetted samples from the suspension.

Retention could be calculated by a mass balance knowing the amount of fines added initially, the total suspension volume, and the concentration of free fines.

MATERIALS AND ANALYSES

The experimental program outlined above required a number of electrolyte solutions, all of analytical reagent grade, and high quality water. The preparation of these materials is discussed briefly.

DISTILLED WATER

In all of the retention experiments, distilled water was used having a conductivity of less than 1.0×10^{-6} mhos./cm. Appleton city water was first treated in a filter press, deionized, and then distilled in a 10-gph. Barnstead still. The distilled water was filtered through a 1.0 μ m.-millipore filter. Before being used, it was refiltered on a 0.45- μ m. millipore filter to remove any colloidal materials that might have interfered with the retention experiments.

ELECTROLYTE SOLUTIONS

Sodium Chloride

Most of the experimental work was done with sodium chloride as the electrolyte. A 5.0M-stock solution was prepared and used throughout the investigation. Sodium analysis of all solutions was performed by flame photometry using the Beckman DU spectrophotometer equipped with a flame analyzer. A hydrogen-oxygen flame was used in these analyses.

A sodium calibration curve was prepared using eight solutions varying in concentration from 0.0-20.0 mM/l., a slit width of 0.07 mm. and a wavelength of 587 nm. Minimum detection limits reported by Beckman for these conditions are 3.5×10^{-5} mM/l. (71).

Calcium Chloride

A stock 0.50M calcium chloride solution was prepared from dried analytical reagent-grade chemical and analyzed by flame photometry.

A calcium calibration curve, 0.0-2.0 mM/l., was prepared as above by flame photometry analysis at a wavelength of 422 nm. and a slit width of 0.28 mm. Minimum detection limits reported are 2.7×10^{-5} mM/l. (71).

Lanthanum Chloride

A stock lanthanum chloride solution at 0.05M was prepared from the chemically pure heptahydrate salt supplied by Sargent. Since the water of hydration cannot be driven off quantitatively by drying, it was necessary to check the stock solution concentration by chemical analysis. It was determined by the traditional rare earth analysis technique of titrating the oxalate salt with a standard permanganate solution (72).

A standard calibration curve for flame photometry was then prepared with the stock solution since its concentration was known. The concentration range covered was from 0.0-0.5 mM/l. The calibration wavelength was 442 nm. and slit width 0.05 mm. Maximum sensitivity reported in a water solution was 0.003 mM/l. (73).

Other Electrolytes

The effect of anion species on retention was investigated using sodium sulfate and sodium iodide. Stock solutions of each were prepared, and concentrations were checked by sodium flame analysis as above.

The effect of pH on retention was determined using 0.10N standard HCl. All pH measurements were made with a standardized Heath recording pH meter, model EUA-20-11.

RADIOACTIVITY ANALYSES

The counting efficiency of a scintillation counter is dependent on the quenching agents in the counting cocktail and must be determined if the concentrations of these agents is different in each sample. The degree of quench in a given sample can be determined with the Beckman counter by means of an external standard counting technique. The instrument automatically positions an external standard, Cesium-137, near the sample bottle generating a constant counting spectrum for a given type of sample. When a quenching agent is present, the spectrum changes in proportion to

the quench degree. The change in the spectrum is proportional to an external standard ratio which can be correlated with counting efficiency to obtain a continuous quench curve.

The primary quenching agents encountered in measuring fines concentration during the retention experiments were sample volume and sodium chloride concentration. All of the samples counted were essentially the same volume, 1.5 ml., so no quench corrections were required for this. However, the wide range of sodium chloride concentrations encountered in some of the samples required small corrections for counting efficiency.

A quench curve was prepared with sodium chloride by determining the counting efficiency and external standard ratio at several degrees of quench. The quench curve was based on a counting efficiency of 100.0% in a 0.50-ml. water sample. This is a legitimate basis for comparative analysis of radioactivity, but if an absolute fines mass were required, the count would also have to be corrected for the actual counting efficiency, 96.9%, in a 0.5-ml. sample reported above. A 0.5-ml. water sample was chosen as a convenient basis for preparing the quench curve since varying concentrations of salt solution could be added to the sample and a recount performed to determine the relative efficiency.

Twenty 0.50-ml. samples of fines were counted, an additional 1.00 ml. of salt solution varying in concentration from 0.0-1.0M added to each and the samples counted again. The counting efficiency was then calculated as the ratio of the second count to the first. The external standard ratio was correlated with the counting efficiency by a least squares analysis to determine the efficiency curve.

The correction in distilled water at an external standard ratio of 5.6 was 89.8% while in 0.7M NaCl, the ratio was 4.5 and the efficiency 83.5%. As can be

seen, the correction is small but was applied in all of the calculations. None of the other electrolytes had an external standard ratio much different than that of distilled water so the same correlation was used for these samples. Beckman reports the external standard ratio variation is at best approximately 5% (66).

PROCEDURES

COAGULATION ISOTHERM

A coagulation isotherm experiment basically determined the equilibrium concentration of the fines retained by the pulp fibers as a function of the total amount of fines added to the suspension at a constant electrolyte concentration. The isotherm is determined by adding fines in small increments to an agitated pulp suspension in a controlled electrolyte environment. Equilibrium generally was realized within a few seconds as shown in Appendix IV which describes a number of experiments performed attempting to measure the rate of retention. The general procedure followed to obtain a coagulation isotherm is described below.

Preliminary preparations to an experiment included dispersion of 1.0 g. classified pulp in 1.0 l. of electrolyte solution with a magnetic stirrer while under vacuum. The pulp was then conditioned at 20.0°C. overnight. The radioactive fines were deaerated in distilled water by evacuation and conditioned for 1 hr. at 20.0°C.

When these preparations were completed, the pulp suspension was placed in the retention apparatus described above, the agitator speed set, and the recirculation pump started. A routine fines addition and sampling sequence was then followed which yielded a total of 10 equilibrium retention measurements. Ten selected volumes of the fines suspension were added from a buret with the retention being based on the total amount added to that time. A total of approximately 0.10 g. fines were added in each experiment. Five minutes after a fines sample was added,

three samples of 1.3-1.5 ml. were taken from the recirculation line at 1.0-min. intervals. It was necessary to add various amounts of electrolyte after each fines addition to maintain the desired concentration and total volume. After the 10 additions were made, 300-400 ml. of fines were siphoned from the pulp suspension via the transmission line for other analyses. The cation concentration and pH of this suspension was checked to confirm the experimental conditions. The pulp weight was determined by filtration and drying to complete the experiment.

The raw data obtained from a coagulation isotherm determination included three radiation background counts, the radioactivity and weight of the fines samples from each loading, the external standard ratios of these samples, and the concentration of the fines suspension added to the pulp.

A computer program written to treat the raw data is given in Appendix V. Essentially, the program computes the concentration of fines and corrects it for background count and counting efficiency. The total radioactivity of fines and suspension volume at each loading is calculated and corrected for the samples removed during the sampling. These results are used to compute the percent retention of each sample for an error analysis of a single factor experiment (74). The computed results included the average percentage retention and fines added at each loading and the standard deviation of the retention. Other computations are performed with these results, but they will be discussed later.

A summary of the coagulation isotherm experiments, results, and raw data are given in Appendix V. Generally, this procedure was used to investigate the effect of electrolyte environment on retention at constant consistency, 0.10%; temperature, 20.0°C.; and agitation rate, 150 r.p.m.

RETENTION ISOTHERM

A retention isotherm experiment basically determined the equilibrium concentration of the fines retained by the pulp fibers as a function of the electrolyte concentration at a constant amount of fines. The isotherm is similar to a coagulation isotherm except the electrolyte is added in small increments instead of the fines.

Procedurally, the preliminary preparations were the same as above except the pulp was dispersed in 950 ml. distilled water. Fifty milliliters of fines, approximately 0.10 g., were added at the start of the experiment, and then the same addition and sampling routine described above was followed with the electrolyte solution. After sampling, 4.0 ml. of salt solution were added which maintained the pulp suspension volume at ca. 1.0 l. A total of 13 different electrolyte concentrations were used to obtain the isotherm.

The raw data and treatment of them was the same as described above for the retention isotherm. The data and results of these experiments are summarized in Appendix VI. The various parameters tested with this technique include cation and anion species at constant experimental conditions, temperature with a single electrolyte, and consistency and agitation rate.

ELECTROPHORETIC MOBILITY

The electrophoretic mobility of the radioactive fines was measured in various electrolyte environments using the Numinco Mass Transport Unit (75). This instrument utilizes the Hittorf principle of measuring electrophoresis (26). This principle states the mass of colloidal material transported to the cathode or anode in a known electric field is proportional to the mobility of the particles.

The mobility calculation requires the specific conductivity and concentration of the suspension, time, amperage, and the mass change at the electrode.

The instrument was recently developed by Sennett and coworkers for measuring the mobility of fairly dense colloids such as clay or titanium dioxide filler (76). The instrument is not directly applicable to low density materials because the mass changes are too small to determine accurately. However, the mobility of the fines was measured successfully by taking advantage of the fairly large differences in radioactivity which are proportional to the small mass transports of this material.

The instrument and procedures have been described elsewhere in detail (75, 76). In a particular fines mobility determination, the conductivity and the initial concentration of the suspension was measured, and the collection and sample containers filled with the fines suspension. The time was usually set at 10.0 min., and the amperage varied from 0.4-5.0 ma. depending on the specific conductivity of the sample. It should be noted that at high salt concentrations, problems were encountered with electrolysis of the electrolyte. After the experiment was completed, the collection chamber, a 5.67-ml. Lucite reservoir, was removed and the fines transferred quantitatively to a 25-ml. volumetric flask with a syringe and distilled water. The final fines concentration was measured with the scintillation counter and used to calculate by difference the total mass transport. These data were then used to calculate the electrophoretic mobility of the samples.

Mobility determinations were made in three different electrolyte environments - sodium, calcium, and lanthanum chloride. The basic calculations of mobility and the data and results are summarized in Appendix VII.

PARTICLE SIZE

The particle size distributions of a number of samples of unretained fines from various experiments were determined with the Coulter Counter to determine if a given size fraction was retained preferentially by the pulp. The samples analyzed included the unretained fines from a number of coagulation isotherm experiments and from experiments investigating the effect of agitation rate.

The procedures used in the analyses were discussed above as was the computer program for data reduction. The data and results of these determinations are found in Appendix III.

RESULTS AND DISCUSSION

RETENTION ISOTHERMS

One of the most important parameters affecting colloidal coagulation is the electrolyte environment surrounding the particle. Its affect on fines retention was investigated thoroughly in a series of retention isotherm determinations with various electrolytes.

The effect of sodium chloride concentration on fines retention is shown in the retention isotherm presented in Fig. 5 as percentage retention versus log cation concentration. The data and numerical results are summarized in Appendix V. Generally, it can be seen that fines retention is dependent on the salt concentration up to approximately 0.01M. This observation will be discussed more extensively later with the results of the other electrolytes, but of immediate concern is the blank retention obtained in the absence of pulp.

It can be seen in Table V that for a number of experiments the sample obtained from the recirculation line was representative of the suspension concentration in distilled water. The percentage difference between the pump sample and the pipetted sample appears to be randomly scattered around the average difference of 0.05%. In experiments Blank 5-10, the combined standard deviation of the pump samples was 1.34%. The sampling accuracy is acceptable because the average percentage difference is less than the pumping standard deviation. Since a small difference between large numbers is being used to calculate retention, a small error in either the initial or equilibrium radioactivity concentration can be very significant. The radioactivity measurements were obtained at a counting error of 0.7-1.0% which contributes to the sampling error, also.

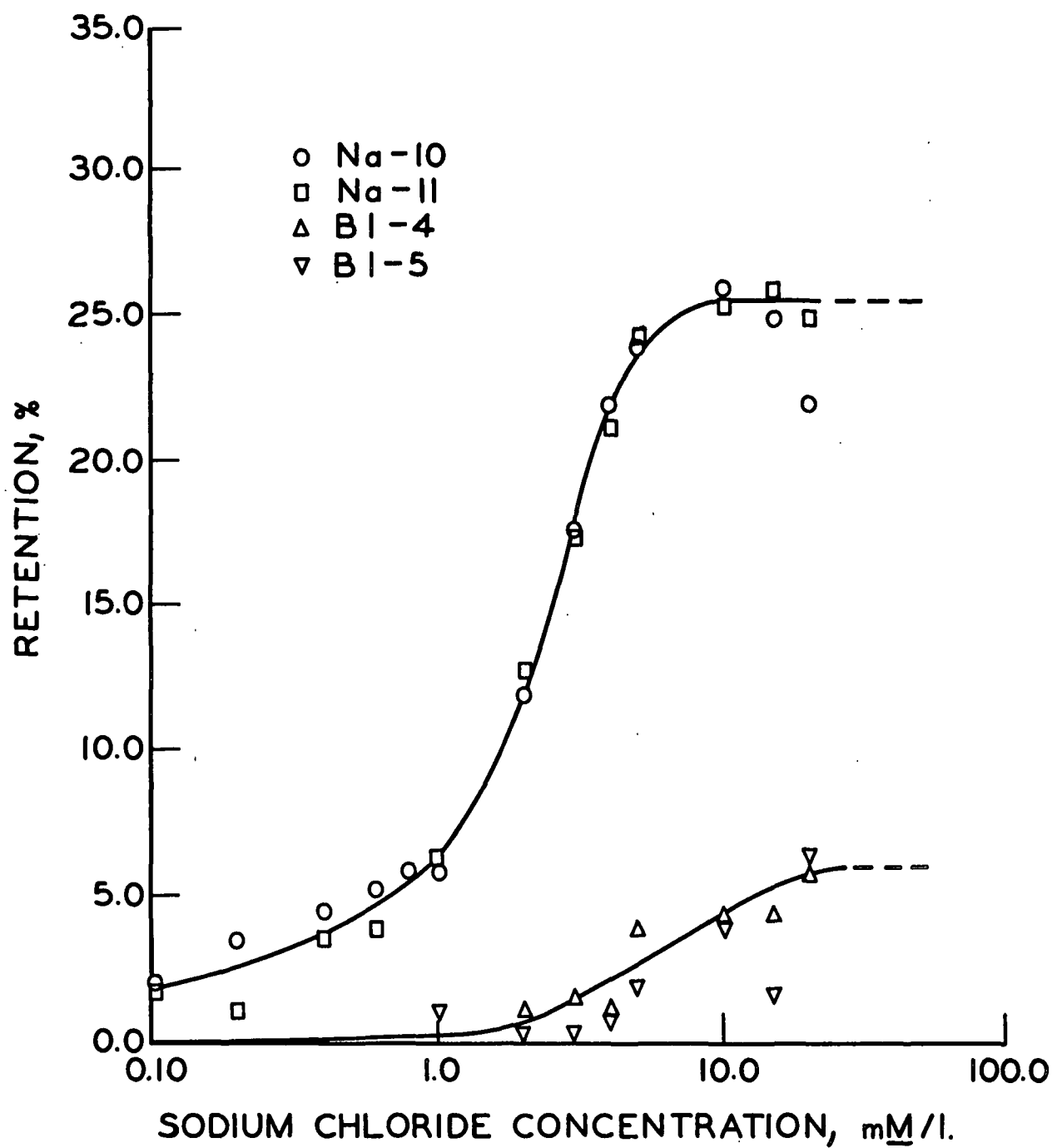


Figure 5. Sodium Chloride Retention Isotherms

TABLE V

SAMPLING ACCURACY IN DISTILLED WATER

Experiment	Agitation, r.p.m.	Concentration, c.p.m./ml.		Difference, %
		Pipet	Pump	
Blank 5	150	5101	5067	-0.67
Blank 6	150	5068	5050	-0.36
Blank 7	150	5076	5163	+1.68
Blank 9	150	4221	4303	+1.88
Blank 10	150	4310	4258	-1.24
	300	1724	1734	+0.61
	500	1724	1719	-0.27
	700	1724	1704	<u>-1.23</u>
Average				+0.05

When an electrolyte is added to the fines suspension, an appreciable sampling error is obtained as indicated by the blank retention isotherm from experiments Blank 5 and 6 shown in Fig. 5. The probable cause for the blank is the formation of large agglomerates which cannot pass through the sampling screen. In fact, when a smaller mesh screen was used, the deviation was even more apparent. Since the blank isotherm is the same shape as the retention isotherm in sodium chloride, the same phenomenon is probably causing both the sampling error and the retention.

In order to obtain the true retention isotherms for each of the electrolytes, it was necessary to correct the original results for the blank isotherms. This was accomplished by adding the blank percentage of unretained fines to the raw data count and recalculating the retention, i.e., the raw sample count was low by this amount. The blank corrections for each electrolyte were taken from the average blank retention isotherm at the same cation concentrations investigated in the

retention isotherm. The correction was included in the computer program found in Appendix V.

The corrected retention isotherm results for sodium, calcium, and lanthanum chloride were combined under similar experimental conditions and are summarized in Fig. 6. It is readily apparent from these results that the valence of the cation significantly affects fines retention, i.e., the higher the valence the lower the concentration required to obtain the same retention level. Retention is also dependent on the individual cation concentration up to a critical concentration called the coagulation value, CV. The CV was taken as the electrolyte concentration at which the linearly extrapolated portions of the retention isotherms intersected as seen in Fig. 6. Above the CV, retention levels off and becomes independent of cation concentration. This can be seen easily in the calcium and lanthanum isotherms which were extended beyond the CV a full concentration decade. The CV's obtained from Fig. 6 for sodium, calcium, and lanthanum are 4.50, 0.33, and 0.023 mM/l., respectively.

Normally, the CV's for hydrophobic colloids range between 25-150, 0.5-2, and 0.01-0.1 mM/l. for mono-, di-, and trivalent cations, respectively (26). The CV's for sodium and calcium obtained for fines retention are somewhat less than the minimum values usually found while the lanthanum CV is well within the range. There are two possible explanations for these discrepancies. First, Sparnaay pointed out in his theoretical analysis of the coagulation of small cylinders that the CV's for this system should be less than for flat plates depending on orientation of the colliding particles (50). This would indicate that elongated particles such as fines possibly could have lower CV's. The second possible explanation which will be discussed more extensively later is that the coagulation is due to a relatively deep secondary energy well that can exert its influence at low counterion concentrations if the particles are large or of irregular shape.

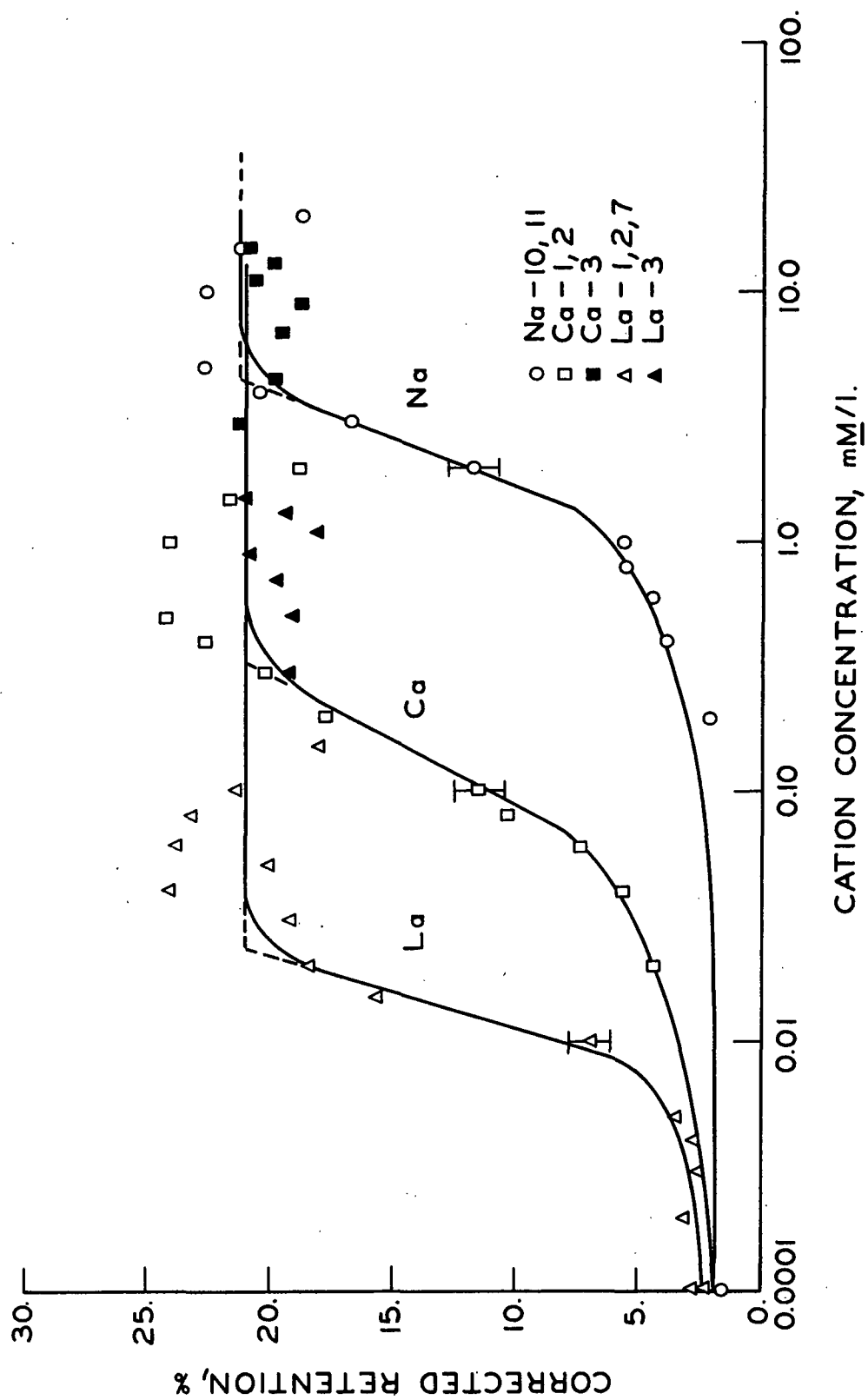


Figure 6. Combined Retention Isotherms

An attempt was made to obtain visual evidence of fines retention on the fibers to determine if there was a preferential retention site or a preferential orientation. Scanning electron micrographs were taken of the fibers in lanthanum experiment seven at various electrolyte concentrations. The micrographs are shown in Fig. 7.*

As can be seen in Fig. 7A, the control pulp fibers are very clean with little apparent fibrillation on the surface. It should be pointed out that these samples were all dried from water which would cause some fibril collapse on the surface.

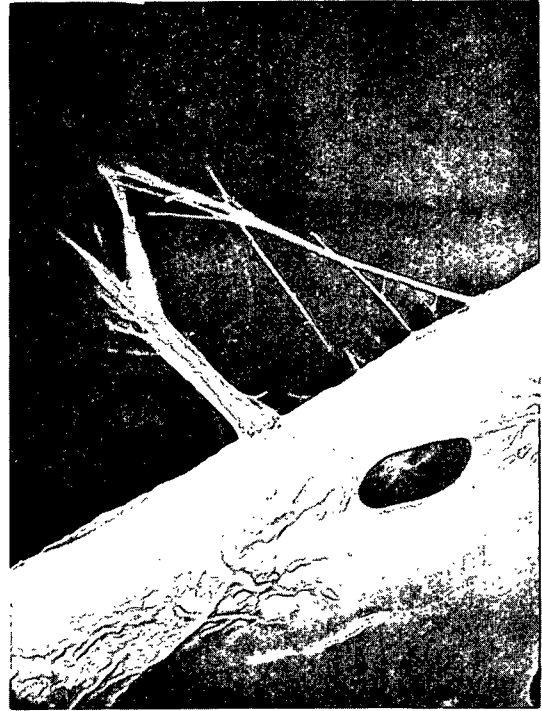
In Fig. 7B, a fiber is shown that was removed by dipping a curved wire into the suspension in distilled water. There was 3.0% retention in this medium. The sample was washed free of unretained fines by transferring the fibers into a small volume of distilled water, gently shaking them, and then dipping them out with the wire into another volume of distilled water. This was repeated a total of three times before the fibers were dried on the slide. The fines shown on the fiber edge were the only ones that could be found on the fiber. The fines perhaps did not collapse to the fiber because they bonded to the glass slide surface. The resolution was not good enough to see any fines on the surface.

In Fig. 7C, a fiber is shown that was taken at a lanthanum chloride concentration of 0.01 mM/l. which yielded 7.23% retention. The fibers were washed as above but in the same electrolyte environment of 0.01 mM/l. lanthanum chloride that they were removed from. It can be seen that there are significantly more fines retained than in Fig. 7B. The fines were present periodically along the fiber. It should be pointed out that since the shear conditions during the first wash were less severe than in the original suspension, the exact retention may be different than that quoted above.

*These micrographs were taken at the Research Center of Consolidated Papers, Inc. in Biron, Wisconsin, on a Jeolco scanning electron microscope.



A
Control Fiber



B
Washed 3.0% Retention



C
Washed 7.2% Retention



D
Unwashed 20.5% Retention

Figure 7. Scanning Electron Micrographs of Pulp Fibers Taken from Experiment Lanthanum - 7, 3000X Magnification

In Fig. 7D, a fiber is shown that was removed from the suspension at 0.10 mM/l. lanthanum chloride and placed on the slide without washing. The retention measured at this concentration was 20.5%. As can be seen, the background contains a substantial amount of unretained fines. It is apparent that the washing procedure was fairly efficient if the backgrounds are compared in these micrographs. The concentration of fines appears to be greater along the fiber edge in Fig. 7D than in Fig. 7C, but the presence of the unretained fines in Fig. 7D could cause this.

Since the resolution of the scanning electron microscope was not adequate to show any detail on the fiber surface, a surface replica was prepared with washed fibers prepared from the sample used in Fig. 7D for the transmission electron microscope. This electron micrograph is shown in Fig. 8.

This micrograph shows two crossed fibers with a concentration of fines located at the intersection point. There are also a number of fines visible around the pit openings and on the fiber surface. The fines are most apparent in the pit region of the fiber because of the contrast with the circular fibril orientation of the pits proper. However, this should not be taken to mean that the fines preferentially are retained in these regions. Also, it should be kept in mind that some of these fines could have been deposited during the drying process if the washing was not complete. The fines appear to be randomly scattered over the surface with no particular orientation.

Generally, the micrographs show that the fines are being retained on the fibers, but it would be difficult to say if there was a preferential retention site or a particular orientation. Also, because of the difference in agitation during the washing procedure and the experiment, it would be impossible to correlate the number of retained fines and the retention obtained in the retention isotherms.

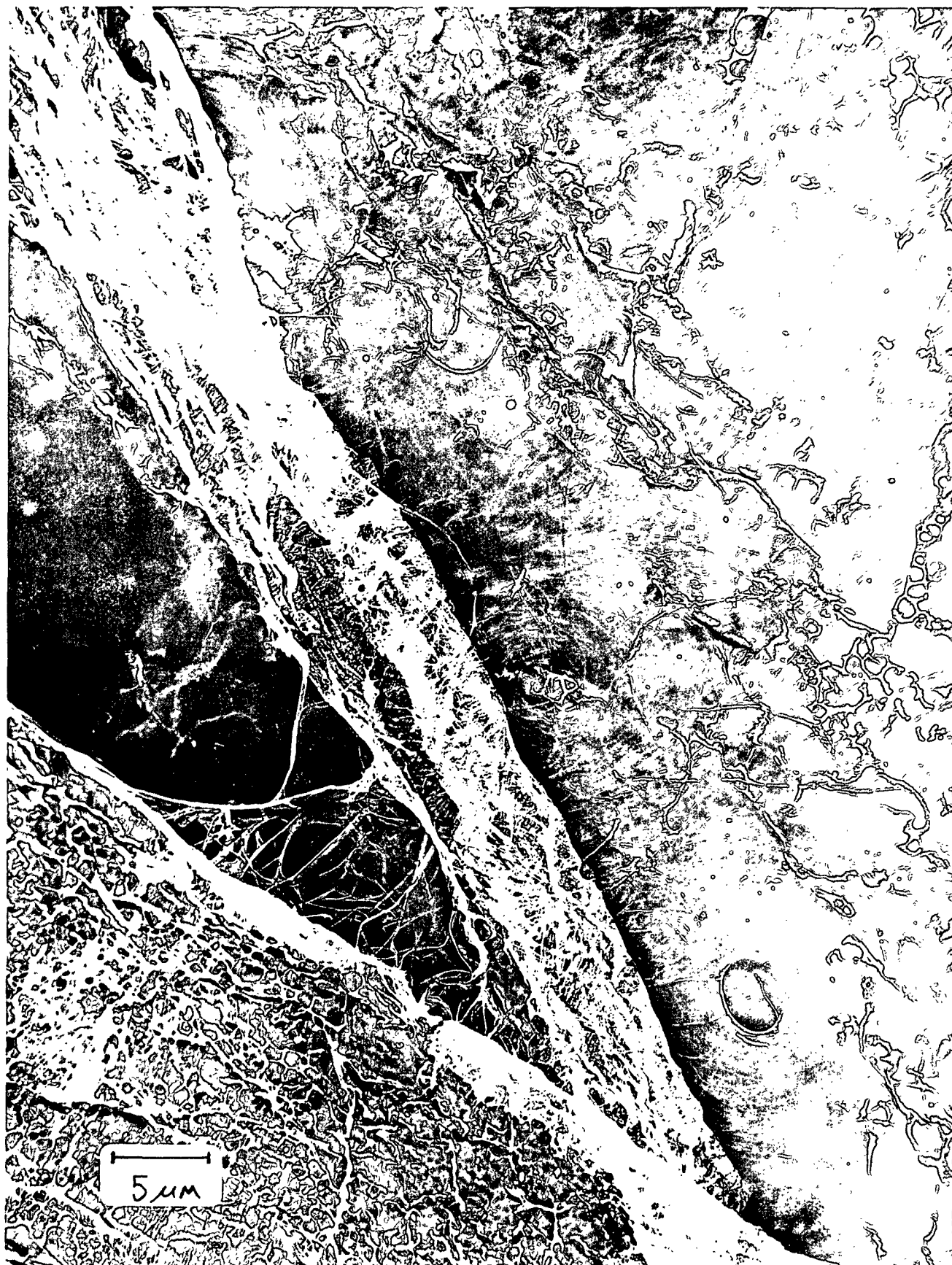


Figure 8. Transmission Electron Micrograph of Pulp Fibers and Fines Taken from a Washed Sample at 20.5% Retention from Experiment Lanthanum - 7

The general shape of the retention isotherms is very typical of those obtained with other hydrophobic colloidal particles, i.e., arsenic trisulfide (52), polystyrene (53), and silver halides (77). The concentration dependent region of the curve generally is associated with an increasing rate of coagulation as the repulsive potential is reduced partially by collapsing the double layer. The independent region where coagulation is unaffected by cation concentration is associated with a rapid rate of coagulation. This occurs when the net potential barrier is negligible at all separation distances which means the repulsive potential is reduced to less than the attractive potential by collapsing the double layer. Once the repulsive potential has been removed and there is no specific ion adsorption, additional cation has no effect on the collision efficiency and each collision results in coagulation. In those cases where there is specific ion adsorption, the colloid can go through a second stable region due to the reversal of the sign of the surface potential.

There are two possible explanations for the small percentage of retention observed in distilled water. One possibility is that the fines are being retained by the entrapment mechanism proposed by Haslam and Steele (14). Since this is a physical process, one would expect the retention to be dependent on the pulp consistency which will be shown to be the case later. The other possibility is that this percentage of fines possesses sufficient kinetic energy on collision to overcome the potential energy barrier and cause coagulation. This would be the case probably only for the smallest fines. However, it would be difficult to prove either of these explanations.

The Schulze-Hardy rule predicts that the CV for mono-, di-, and trivalent cations should be proportional to the inverse sixth power of the valence if the surface potential is high. Theoretically, the CV's should be in the ratios of

1.00, 0.016, and 0.0013. For relatively low surface potentials, the above proportionality constant is reduced to the inverse square of the valence. The proportionality constant is derived by calculating the cation concentration at which there is no net potential energy of interaction. The CV primarily depends on the Van der Waals forces of attraction, the surface potential of the particles, and the cation valence. The CV ratios obtained by comparing the CV at each valence for fines retention are summarized in Table VI along with values obtained for other sols. As can be seen in Table VI, fines retention is in better agreement with the theoretically predicted values than are the other cellulosic materials although they are all higher than the theoretical ratios. The microcrystalline cellulose used by Kratochvil and coworkers was Avicel which is a highly crystalline cellulose obtained from pure alpha wood pulp (42). Ranby's cellulose was an acid-hydrolyzed acetylation-grade sulfite wood pulp (38). In both of these investigations, the CV was defined as the lowest concentration of electrolyte required to cause complete settling of the sol. Ranby concluded from his data that cellulose coagulation was qualitatively in agreement with classic coagulation theory.

TABLE VI
COAGULATION CONCENTRATION RATIOS

Valence	Theoretical Ratio	Fines Retention ^a	Micro-crystalline Cellulose (<u>37</u>)	Ranby's Cellulose (<u>38</u>)	Silver Iodide (<u>26</u>)
1	1.00	1.00	1.00	1.00	1.00
2	0.016	0.073	0.38	0.22	0.017
3	0.0013	0.005	0.062	0.091	0.0005

^aThe CV's for the mono-, di-, and trivalent cations were 4.5, 0.33, and 0.023 mM/l., respectively.

Another reflection of the Schulze-Hardy rule is found in the empirical linear correlation of the log CV and the valence of the cation (42). The CV's used to calculate the ratios in Table VI were plotted in this manner in Fig. 9. It is readily apparent that the CV's obtained from the retention isotherms fit this correlation very well. Fines retention more nearly agrees with the hydrophobic colloid, silver iodide, than do the other cellulose particles. It should be noted that the cellulosic materials generally have lower CV's than do the hydrophobic particle. The Avicel and Ranby's cellulose could be lower because of the insensitivity of the flocculation measuring techniques to all but gross differences in the degree of coagulation. In other words, these CV's could easily be less than the concentration at which true rapid flocculation occurs.

Kratohvil, et al. pointed out that if the Avicel was highly hydrated, CV's greater than usually observed with hydrophobic sols would be required to dehydrate the surface first before electrical interaction could cause coagulation, i.e., hydrophilic-type coagulation (42). It was argued that the Avicel coagulation was probably due to a deep secondary minimum in the net potential energy curve because the sol could easily be redispersed by gentle mixing.

Generally, the potential energy curves for coarse particles possess a comparatively deep energy well at large separation distances because of the gradual decay of the attractive potential. At low cation concentrations, the minimum can be deep enough to cause coagulation. It is a highly reversible form of coagulation because there is no potential barrier to overcome as in the case of true coagulation. This type of coagulation has not been investigated extensively because it is only observed with large or unusual shaped particles. Schenkel and Kitchener showed that this type of coagulation was predictable with 10 μ m. polystyrene spheres (53).

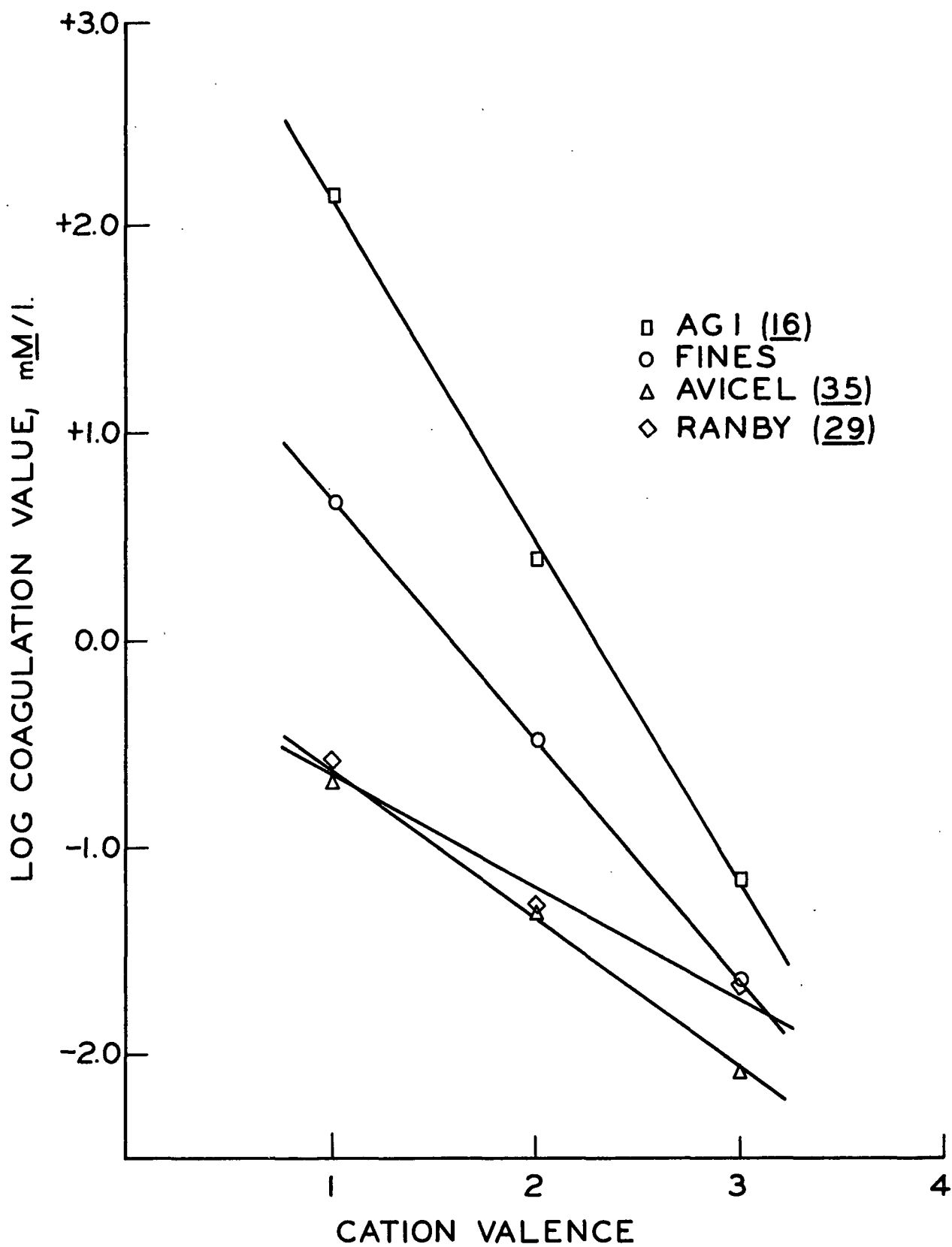


Figure 9. Coagulation Value Correlation

The average maximum retention for each cation was essentially the same (21%) which indicates that the electrolytes must be affecting a common property of the fines. The factors affecting the maximum retention will be discussed in detail later.

The effect of cation concentration and valence on fines retention is in excellent agreement with similar observations made with hydrophobic colloidal coagulation.

ELECTROPHORETIC MOBILITY

The degree of coagulation of a hydrophobic sol is primarily dependent on the extent the double layer has been collapsed around the particles. Generally speaking, the double layer collapse usually is associated with the particle's zeta potential because the latter is indicative of the double layer constitution, and it can be determined approximately by electrophoresis.

Electrophoretic mobility is proportional to the zeta potential with the constant of proportionality being dependent on the radius of the particle and the reciprocal thickness of the double layer (78). In the case of cylinders, the proportionality also depends on the position of the particle relative to the electric field. Because the fines have a large length-to-diameter ratio, the exact proportionality constant required is not known. With this in mind though, for a given system such as fines, the electrophoretic mobility measurements can be compared without having to calculate the exact zeta potentials.

The electrophoretic mobility of the fines was measured in various electrolyte environments for comparison with the retention results. The results are summarized in Fig. 10 and can be found in Appendix VII along with the experimental data. As can be seen, the electrophoretic mobility of the fines is dependent on the electrolyte valence and concentration as it is for hydrophobic sols (26). Generally,

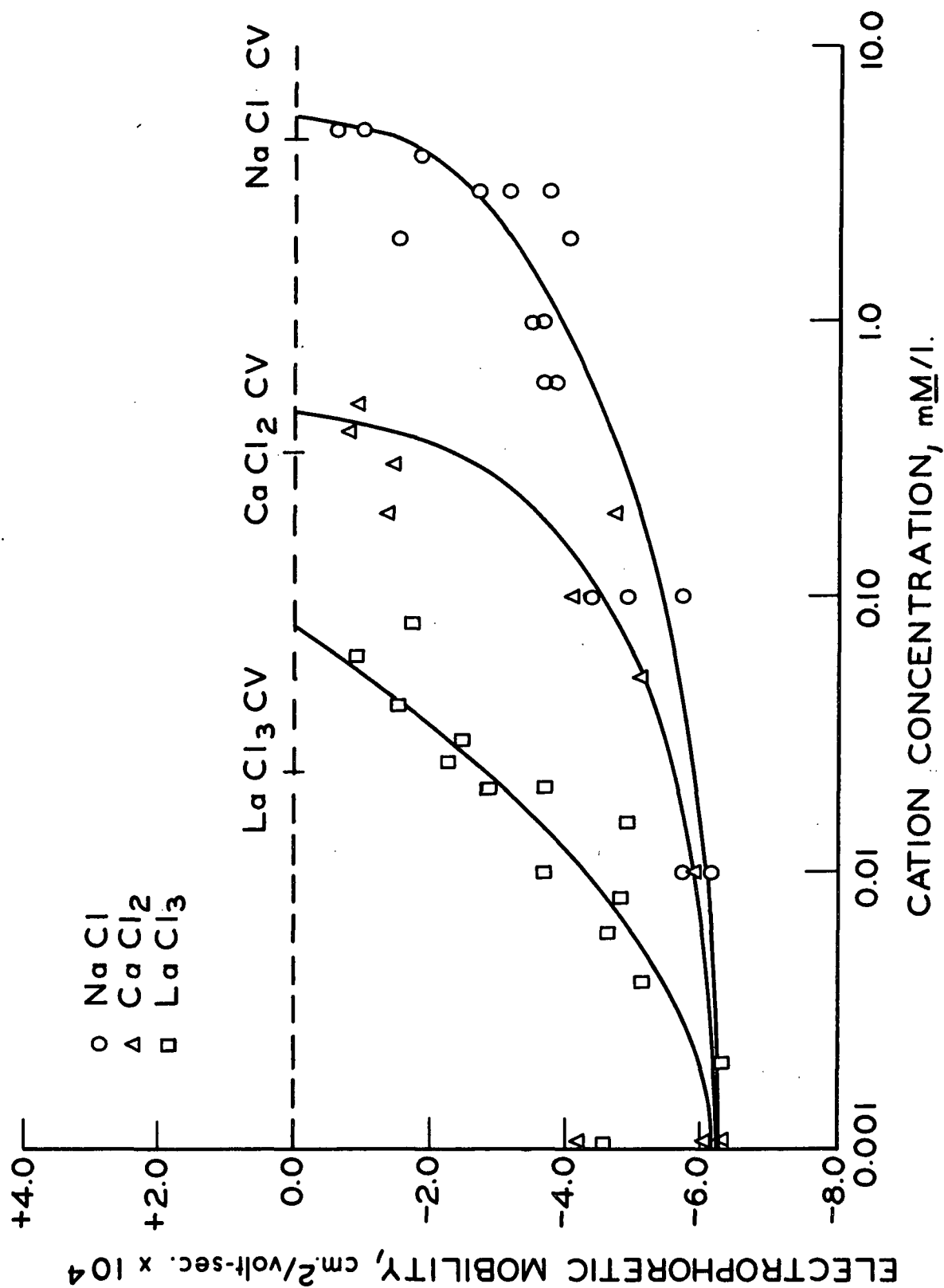


Figure 10. Electrophoretic Mobility of Fines

as the concentration is increased, the mobility decreases until it approaches zero. As the valence increases, the concentration required to reduce the mobility to zero decreases. The zero mobility concentrations for sodium, calcium, and lanthanum chloride were 5.5, 0.47, and 0.078 mM/l. , respectively.

In Fig. 6, retention was seen to increase up to the CV and then level off at increased electrolyte concentrations. In Fig. 10, the mobilities for each electrolyte begin to decrease at approximately the same electrolyte concentrations at which retention begins to increase. The sodium chloride CV of 4.5 mM/l. compares favorably with the zero mobility concentration of 5.5 mM/l. which indicates that retention is dependent on the electrokinetic properties of the fines. The CV's for calcium and lanthanum chloride were both less than the concentrations at which the mobility was zero. In fact, the difference is more significant as the counterion valence increases. It should be remembered that the CV is determined at the electrolyte concentration where there is no net potential barrier. This implies that the mobility does not have to be zero to reduce the net energy to zero which evidently is happening here.

Above the CV, retention was seen to be independent of electrolyte concentration. For each of the electrolytes, the electrophoretic mobility approached zero in this region of the retention isotherms. Generally, when the mobility does equal zero, there is no longer sufficient repulsive energy to prevent coagulation because the double layer is collapsed completely. The addition of more electrolyte, therefore, has no effect on coagulation as was observed in the fines retention isotherm above the CV.

The similarity of the shapes of the mobility curves and the retention isotherms suggests a direct correlation between the two. However, samples for mobility measurements could not be removed during a retention isotherm determination, so a

direct comparison was not possible. However, the qualitative comparison made above does indicate that retention increases with decreasing electrophoretic mobility and approaches a maximum as the mobility approaches zero, which is what would be expected from hydrophobic coagulation theory.

The Numinco mass transport apparatus proved to be a convenient tool for measuring the electrophoretic mobility of the fines. The utilization of radioactivity analysis made it possible to measure easily the small mass transports. However, near the concentrations of zero mobility, mass transport was so small that small errors in radioactivity measurements caused significant scatter in the results. This could probably be improved by longer transport times which would increase the mass transport significantly. Some problems were encountered with gassing from hydrolysis at high electrolyte concentrations and high amperages.

EFFECT OF OTHER ELECTROLYTES

In all of the retention isotherms discussed thus far, the electrolyte anion was the same, and the cation was shown to be primarily responsible for retention. In order to determine if retention was affected by only the cation, two retention isotherms were determined with two other sodium salts, sulfate and iodide. The results are summarized in Fig. 11 and can be found in Appendix V. Also shown as a dashed curve is the retention isotherm for sodium chloride taken from Fig. 6.

It can be seen in Fig. 11 that the retention isotherms all have the same general shape. The maximum retention for the sodium iodide isotherm is significantly higher than either of the other two which are approximately the same at 21%. The sodium iodide isotherm maximum is thought to be due to an error in the counting efficiency used to correct the data. The same counting efficiency curve obtained with sodium chloride was used, but at the higher sodium iodide concentrations, the samples were colored slightly. This additional quench factor would

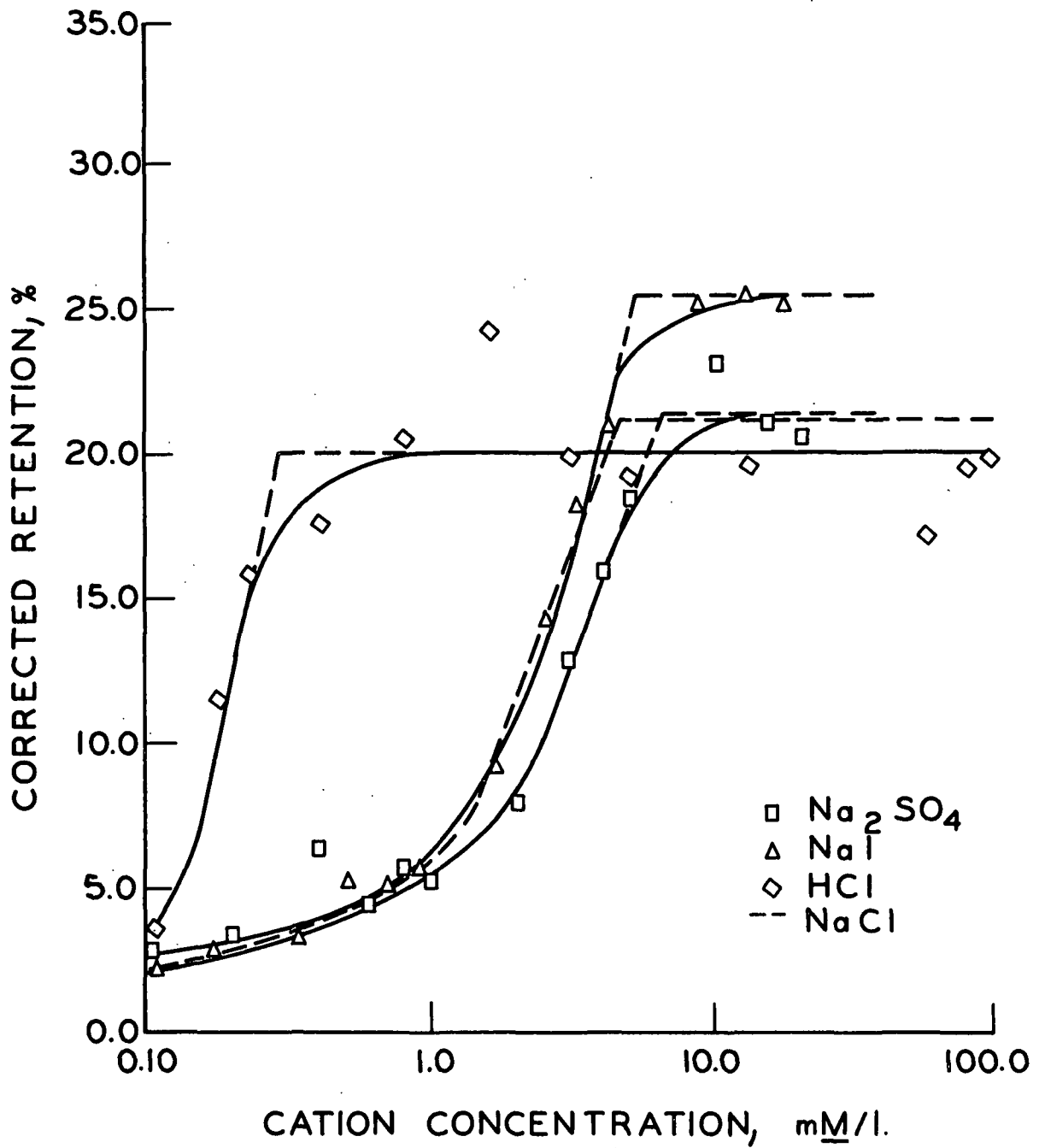


Figure 11. Retention Isotherms with Other Electrolytes

have reduced the counting efficiency more than was accounted for by the sodium chloride quench curve. The equilibrium concentration would then be low which would cause an apparently higher retention level.

The difference between the CV for sodium chloride, -iodide, and -sulfate, 4.5, 5.3, and 6.3 mM/l., respectively, are so small that it would be difficult to say with any certainty that they are real. These results indicate that retention is primarily influenced by the cation while the anion may be responsible for a small difference in the flocculation value.

The sodium sulfate CV which deviates most from the sodium chloride value has been observed before for highly charged anions and negative sols (26). Kruyt has described this phenomenon as the "relieving effect" which is thought to be due to the polyvalent ions possessing an activity coefficient less than unity in the bulk solution as per the Debye-Huckel theory. More cation would then be required to neutralize the anions in the bulk solution thus increasing the CV.

Also shown in Fig. 11 is a retention isotherm determined with hydrochloric acid as the electrolyte. As can be seen, the CV is significantly less than that obtained for the sodium salt retention isotherms. The CV is 0.29 mM/l. which is equivalent to pH 3.5⁴ according to the operational definition of pH. Hukki and Rinne obtained a zero zeta potential from electrophoretic mobility measurements at approximately pH 3 for wood pulp fines (39). Duhem found the isoelectric point of softwood pulp was at pH 3.25 by direct titration (5).

The maximum retention level is 20.2% which is approximately the same as obtained for the other electrolytes which indicates that the hydrogen ions are affecting the electrokinetic properties of the fines. However, if the hydrogen ion was acting as a counterion in neutralizing the surface potential in the double

layer, from theory one would expect the CV to increase as the ionic size decreases. Since the CV is significantly lower than the other cations, the hydrogen ion must be acting in some other manner to reduce the repulsive potential. The most obvious explanation is that the hydrogen ion must be reducing the fines surface potential directly. It has been shown that acids or other counterions which can react with the double layer ions can cause significant differences in the CV's (26). This would be possible for the fines if the surface potential was due to either preferential adsorption of hydroxyl groups or ionization of constituent groups as has been proposed frequently (1, 30, 31, 44). If the surface potential was due to hydroxyl ion adsorption, the potential would decrease as the pH decreased because the hydroxyl content would be negligible in the acid medium. And, if surface potential was due to ionization of constituent groups, the degree of ionization would decrease as the pH increased which would also reduce the potential. These results lend support to both mechanisms, but it would be impossible to say which is predominant.

EFFECT OF PULP CONSISTENCY AND AGITATION RATE

The effect of consistency on fines retention was investigated by determining retention isotherms at 0.05, 0.20, and 0.38% consistency for comparison with those available at 0.10% consistency. The effect of agitation rate was investigated after these retention isotherm experiments were completed by increasing the agitation rate in 150-r.p.m. increments to 600 r.p.m. The agitation rate was then reduced in the same increments back to the starting rate of 150 r.p.m. to determine if the retention level was similar at equivalent rates of agitation.

The retention isotherms which were determined in sodium chloride are summarized in Fig. 12 and the data can be found in Appendix V. It is readily seen from these results that at a constant amount of fines, maximum retention increases with the

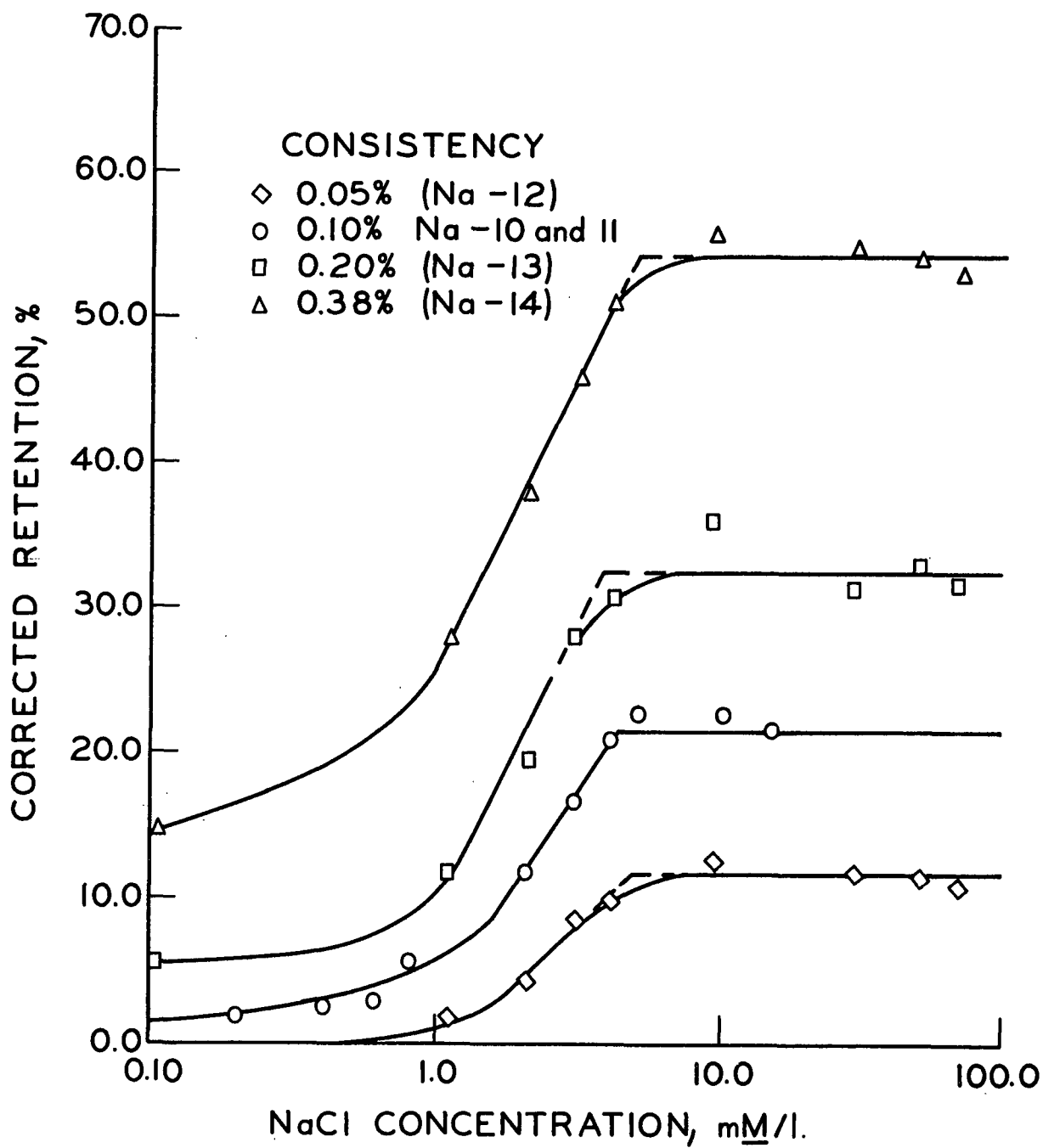


Figure 12. Sodium Chloride Retention Isotherms at Various Pulp Consistencies

amount of pulp added to the system. However, doubling the amount of pulp does not necessarily increase the retention by a factor of two as would be expected if pulp surface area was the only factor affecting the maximum retention level. In fact, in Fig. 13b, where the maximum retention level is plotted against consistency at 150-r.p.m. agitation rate, the average retention is only increased by a factor of 1.37 per unit mass of pulp. This marked deviation from the direct proportionality is probably caused by a nonlinear increase of shear force resulting from the higher pulp suspension viscosity. Even though there is more surface area available for retention, the retained fines are subjected to greater shear forces which remove a larger proportion of particles. At increased agitation rates up to 600 r.p.m., the deviation becomes even more significant as the factor, which is calculated from the slope, is decreased to approximately 1.05. The pulp fibers are probably subjected to more efficient mixing at the higher agitation rate which would subject more retained fines to increased shear.

The CV's do not appear to be significantly affected by the pulp consistency as they all fall within a narrow range of 3.8-5.0 mM/l. of sodium chloride. There is no apparent trend in the change in CV's with sol concentration for other colloidal materials since both increases and decreases have been observed (26).

As can also be seen in Fig. 12, the initial retention in distilled water which could be retained by an entrapment mechanism increases with pulp consistency. If the amount of pulp is increased, additional locations would be available for entrapping the fines so the retention should increase.

The results of the agitation rate experiments, performed at a sodium chloride concentration of 69.0 mM/l. which is at the maximum retention level, are summarized in Fig. 13a. At each of the consistencies, the maximum retention decreases with increasing agitation rate. The effect is most pronounced at the higher consistency

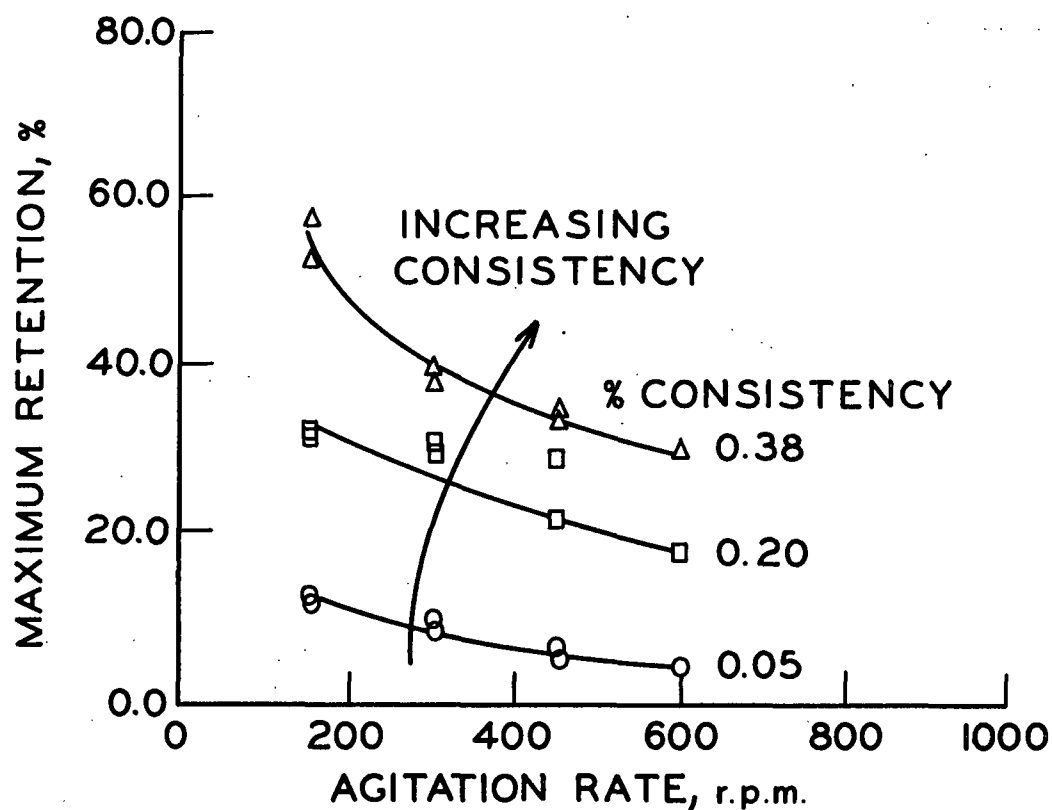


Figure 13a. Effect of Agitation on Retention

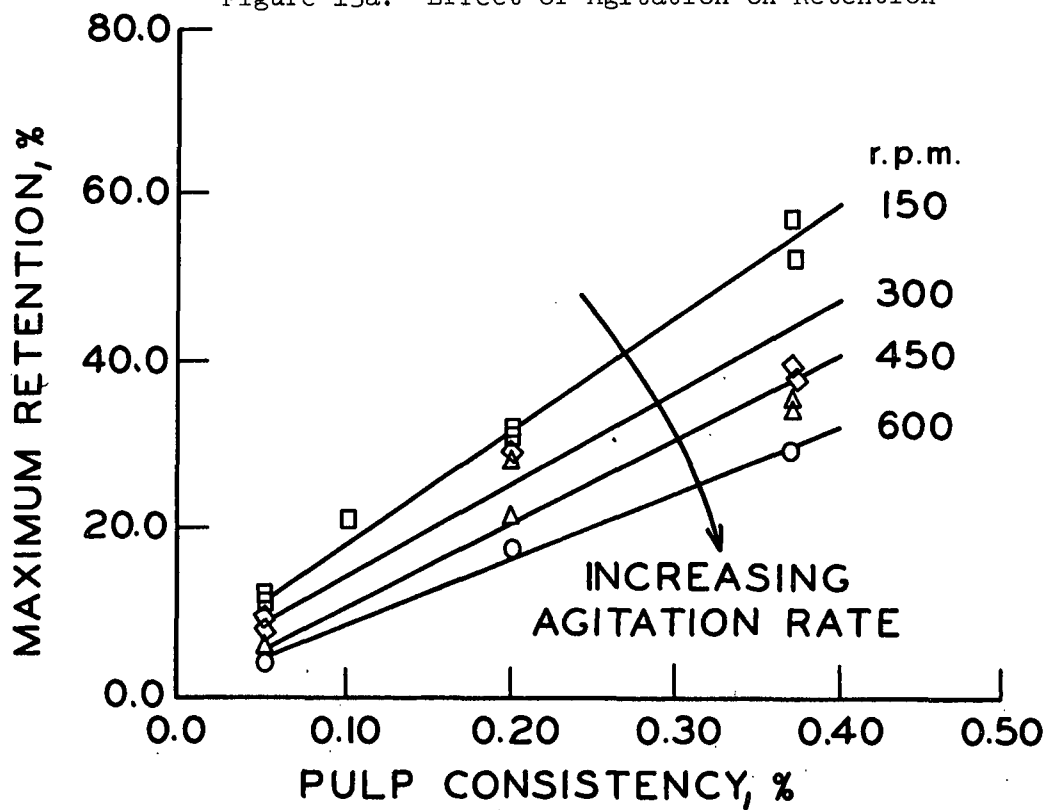


Figure 13b. Effect of Consistency on Retention

as was discussed above. A more interesting observation is the good agreement of the maximum retentions obtained when the agitation rate was reduced in the same rate increments to the starting rate of 150 r.p.m. Apparently, even after the fines are removed by increased shear, they are retained in the same proportion at similar agitation rates. This indicates that maximum retention is determined in part by a dynamic equilibrium dependent on shear rate and that the retention process is reversible. Reich and Vold observed the same phenomenon of reversibility when they studied the coagulation of ferric oxide and carbon in agitated suspensions (60). They determined average equilibrium floc size at various agitation rates by turbidity measurements and generally found the same floc size when the agitation was altered and brought back to the original value. Generally, the average floc size decreased with increasing agitation rate which is analogous to the decreased retention observed at higher agitation rates.

Fines retention might then be visualized as a dynamic equilibrium balance between retention and removal of the fines from the fibers with shear rate being the important controlling factor for removal. The rate of retention would depend on the concentration of particles, the agitation rate, and the electrolyte environment. As agitation is increased, the equilibrium shifts to a higher state of dispersion, thus reducing the maximum retention. Mason postulated the same dynamic equilibrium concept of coagulation from studies of cellulose pulp fibers flocculating in a laminar shear field (79).

Kruyt qualitatively explained why suspensions could easily be redispersed by increased agitation (26). He reasoned that the disruptive force was proportional to the radius of the particle (i.e., Stokes law) and the distance between the particle centers. This results in a total disruptive force proportional to the square of the particle radius. Since the attractive force is approximately

proportional to the radius, there would exist a critical floc size in which the disruptive hydrodynamic force would be greater than the attractive force. It would be impossible to prove this hypothesis since, in reality, the shear force on unusual shaped particles, such as fines, could not be calculated easily. As the agitation rate and shear increases, the average size of the particles retained should decrease.

The particle size distributions of a number of samples of unretained fines were measured with the Coulter Counter to determine if a distribution change could be observed because of preferential retention of a given particle size. The results are summarized in Table VII and in Appendix III. It can be seen that the weight average size of the unretained fines, 2.12 μm ., increases considerably over the control average, 1.11 μm ., at 0.10% consistency and 150 r.p.m. agitation rate. This indicates that the smaller fines are retained preferentially, as is expected, since there is less shear on these retained particles than on the larger ones. As agitation rate is increased, the average size decreases and more nearly equals the control average as can be seen in experiments Na-12-14 at 600 r.p.m.

These deviations are more apparent in Fig. 14 where some of the distributions are presented graphically. As can be seen, the distribution of unretained particles at 150 r.p.m. has a minimum at ca. 1.5 μm . which indicates this size was preferentially retained. The removal of this size fraction causes the maximum in the curve at 3.0 μm . since this size is more dominant. As the consistency is increased, this maximum is decreased which also indicates that a smaller size fraction is retained as the shear increases. In this case, the shear at the same agitation rate is increased because the suspension viscosity is greater.

As the shear is increased by higher agitation rates, the distribution approaches the control as at 600 r.p.m. The smaller particles are still preferentially retained as evident in the small deviation in the curve at 1.5 μm .

TABLE VII
DIFFERENTIAL PARTICLE SIZE DISTRIBUTIONS

Particle Size, μm .	Weight, %							
	Fines Control	Na-Av. ^a	Na-12		Na-13		Na-14	
0.97	22.8	11.3	14.4	21.7	15.1	23.1	15.8	19.1
1.23	16.9	7.5	13.8	17.2	10.2	17.5	10.4	14.9
1.55	12.7	5.6	12.0	16.1	8.0	15.9	7.9	14.1
1.95	10.1	6.6	12.0	15.3	7.5	12.8	9.3	14.6
2.46	6.1	10.3	14.5	8.8	12.1	7.2	11.3	9.8
3.10	5.3	18.5	11.9	5.4	12.5	4.2	12.2	5.3
3.91	2.8	14.9	6.2	3.1	12.4	4.3	12.1	5.2
4.93	3.7	6.1	3.5	3.8	3.8	3.9	5.5	2.3
6.22	6.1	5.1	3.9	4.8	6.2	6.0	5.4	7.6
7.84	5.2	9.5	2.6	2.2	1.3	0.0	6.6	0.0
Weight av. size, μm .	1.11	2.12	1.50	1.10	1.59	1.05	1.55	1.21
Consistency, %		0.10	0.05	0.05	0.20	0.20	0.38	0.38
Agitation rate, r.p.m.		150	150	600	150	600	150	600

^aAverage results of Experiments Na-24 and Na-25.

An increase in shear, either through increased agitation or viscosity, forces the maximum in the distribution of unretained fines at ca. 3 μm . down toward the control curve which means that smaller particles are being retained by the pulp. Heller and coworkers observed a similar shift in the particle size distribution of unaggregated polystyrene latex obtained from a suspension that was slowly shaken in a coagulating environment (57). The latex varied in size from 0.6-0.8 μm .

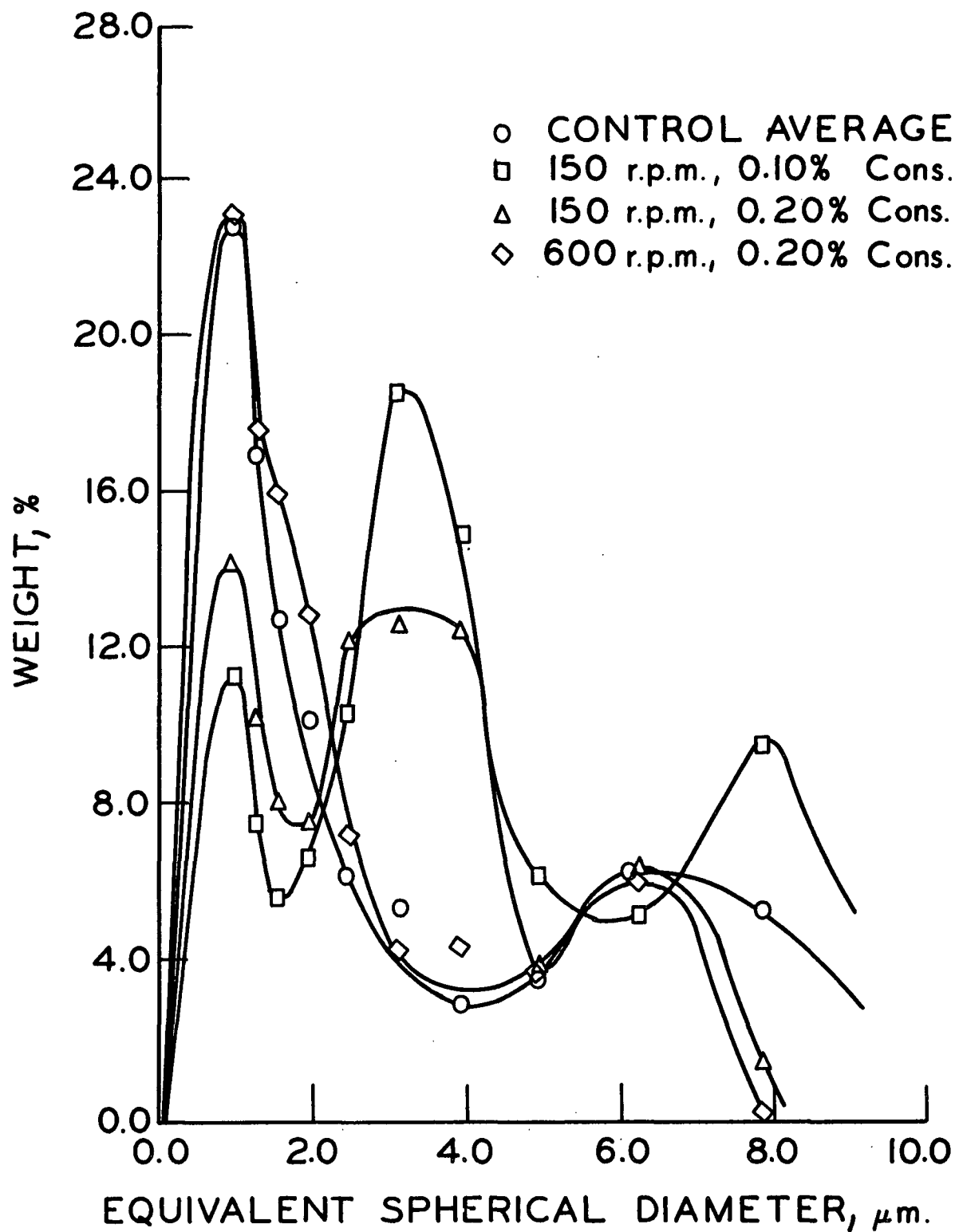


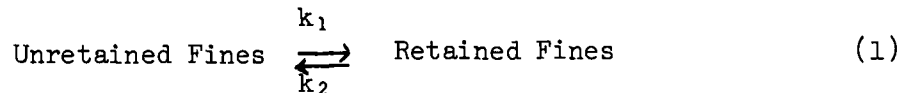
Figure 14. Particle Size Distribution of Unretained Fines

They explained that the shift in distribution was due to an increased coagulation rate of the smaller particles as predicted by the Muller theory which is based on diffusion rates (56). This explanation would probably not be applicable to fines retention because the diffusion rate of the fines is so small. The results are more in agreement with the above explanation which indicates that the shear rate primarily controls the maximum retention level.

COAGULATION ISOTHERMS

The reversible nature of the retention process was investigated further by determining the number of coagulation isotherms in various electrolyte environments at constant consistency and agitation rate. The coagulation isotherm basically shows the equilibrium retention at various concentrations of fines. The following analysis was used to treat the coagulation data.

The reversible nature of the retention process could generally be described by



with the final retention level being proportional to the ratio of $k_1:k_2$, the equilibrium constant. The rate of attachment could then be given as

$$dC/dt = -k_1 C^a \quad (2)$$

where C = concentration of free fines, c.p.m./ml.,

k_1 = attachment rate constant, and

a = attachment order,

and the rate of removal as

$$dC/dt = k_2 M^b \quad (3)$$

where \underline{M} = concentration of bound particles, c.p.m./ml.,

$$= (\underline{C}_0 - \underline{C}),$$

\underline{C}_0 = initial concentration of free fines, c.p.m./ml.,

\underline{k}_2 = removal rate constant, and

\underline{b} = removal order.

At equilibrium, then

$$dC/dt = 0 = k_2 M^b - k_1 C^a \quad (4)$$

which upon rearranging and taking the log of both sides becomes

$$\log C = b/a \log (\underline{C}_0 - C) - 1/a \log k_1/k_2 \quad (5).$$

The raw coagulation data which include the fines concentrations, \underline{C} and \underline{C}_0 , can be analyzed by this equation to determine the ratio of the retention and removal orders. Von Smoluchowski's theory of rapid flocculation predicts the flocculation rate is proportional to the second power of the sol concentration. In this instance, the rate would be proportional to first power of each of the reactants, the fines concentration, and the fiber concentration. Since the pulp concentration was kept constant in this treatment, its effect was not considered but would be implicitly included in the rate constant.

The results of a number of coagulation isotherm determinations can be found in Appendix VI. The results are summarized in Table VIII. The crude isotherm data were treated by a least square analysis according to Equation (5) to determine the ratio of $\underline{b}/\underline{a}$. As can be seen in Table VIII, the ratio varies between 0.79 and 1.36 and averages 1.14 with a standard deviation of 0.15. If one assumes that the attachment order is unity as suggested by von Smoluchowski's theory, then the removal process would also be approximately first order with respect to the

TABLE VIII
SUMMARY OF COAGULATION ISOTHERM RESULTS

Cation-Experiment	Concentration, mM/l.	Pulp Weight, g.	Slope, b/a	First-Order Reversible		Correlation	Retention, %
				Slope, K_{-Eq}	Intercept, c.p.m./ml.		
Na-30	0.0	1.002	$0.95 \pm .16$	$0.034 \pm .005$	14 ± 39	0.9428	3.29
Na-28	0.10	1.003	$1.38 \pm .24$	$0.051 \pm .005$	7 ± 41	0.9639	4.85
Na-29	0.30	0.999	$1.19 \pm .17$	$0.056 \pm .009$	4 ± 69	0.9177	5.30
Na-8	1.15	1.015	$1.12 \pm .24$	$0.034 \pm .009$	10 ± 45	0.8223	3.29
Na-21	1.15	0.987	$0.79 \pm .08$	$0.050 \pm .004$	-2 ± 31	0.9750	4.76
Na-27	1.05	1.018	$1.29 \pm .11$	$0.072 \pm .006$	21 ± 47	0.9740	6.72
Na-22	3.20	0.968	$1.03 \pm .07^a$	$0.202 \pm .013$	-21 ± 85	0.9860	16.80
Na-26	9.90	1.170	$1.15 \pm .04$	$0.319 \pm .018$	59 ± 104	0.9894	24.82
Na-32	8.80	1.042	$1.36 \pm .04$	$0.257 \pm .017$	93 ± 114	0.9865	20.44
Na-25	20.40	1.150	$1.12 \pm .05^a$	$0.297 \pm .020$	67 ± 117	0.9847	22.90
Na-4	51.00	1.054	$1.15 \pm .04$	$0.320 \pm .015$	39 ± 85	0.9931	24.24
Na-5	105.00	1.042	$1.17 \pm .05$	$0.301 \pm .024$	76 ± 142	0.9794	23.19
Na-24	196.00	1.156	$1.26 \pm .06^a$	$0.326 \pm .019$	70 ± 108	0.9889	24.50
Na-31	188.00	1.044	$1.29 \pm .05$	$0.306 \pm .012$	68 ± 77	0.9953	23.43
Na-6	500.00	1.037	$1.21 \pm .03$	$0.336 \pm .022$	71 ± 125	0.9866	25.15
Na-23	475.00	1.197	$1.30 \pm .05^a$	$0.363 \pm .013$	68 ± 72	0.9959	26.63
Ca-4	0.001	0.973	$1.22 \pm .12$	$0.065 \pm .008$	8 ± 61	0.9494	6.10
Ca-5	0.000	1.016	$1.06 \pm .09$	$0.045 \pm .005$	3 ± 45	0.9557	4.31
Ca-6	0.000	1.038	$1.14 \pm .23$	$0.039 \pm .006$	3 ± 48	0.9345	3.75
Ca-7	0.080	1.031	$0.92 \pm .06$	$0.151 \pm .012$	-25 ± 86	0.9806	13.12
Ca-8	1.000	0.969	$1.03 \pm .08$	$0.180 \pm .020$	49 ± 151	0.9598	15.25
La-6	0.005	1.035	$1.13 \pm .15$	$0.065 \pm .009$	-3 ± 72	0.9363	6.10
La-4	0.010	1.018	$1.25 \pm .11$	$0.050 \pm .007$	29 ± 54	0.9398	4.76
La-5	0.100	1.062	$0.97 \pm .05$	$0.283 \pm .017$	34 ± 110	0.9878	22.06
Average			$1.14 \pm .15$				

^aNot included in average because pulp weight is significantly greater than 1.0 g.

concentration of retained fines. Then Equation (5) simply reduces to a form analogous to a simple first-order reversible chemical reaction,

$$K_{EQ} = k_1/k_2 = (C_o - C)/C = C_o/C - 1 \quad (6).$$

Similarly, retention is calculated by a simple mass balance

$$\text{Retention} = (C_o - C)/C_o = 1 - C/C_o \quad (7).$$

Therefore,

$$\text{Retention} = K_{EQ}/(1 + K_{EQ}) \quad (8).$$

It is, therefore, possible to calculate the equilibrium constant from retention and vice versa.

In Fig. 15, four sets of coagulation isotherm data obtained at various sodium chloride concentrations are shown as a first-order reversible process. As can be seen, the data fit this process relationship quite well. This would indicate that up to the maximum loading used in these experiments an equal percentage of the fines is retained at similar electrolyte and agitation conditions. The shift in particle size distributions discussed above suggested that a given size fraction was being retained preferentially. Therefore, as more fines are added from the same distribution, the percentage of the particles of the same size remains the same as does the proportion retained. It would seem then that if the fines distribution could be reduced to a "critical" size, the maximum retention should increase at similar electrolyte conditions. However, this would have to be confirmed by further experiments.

As the concentration of sodium chloride increases, the equilibrium constant increases. Generally, there is good agreement between the retention average

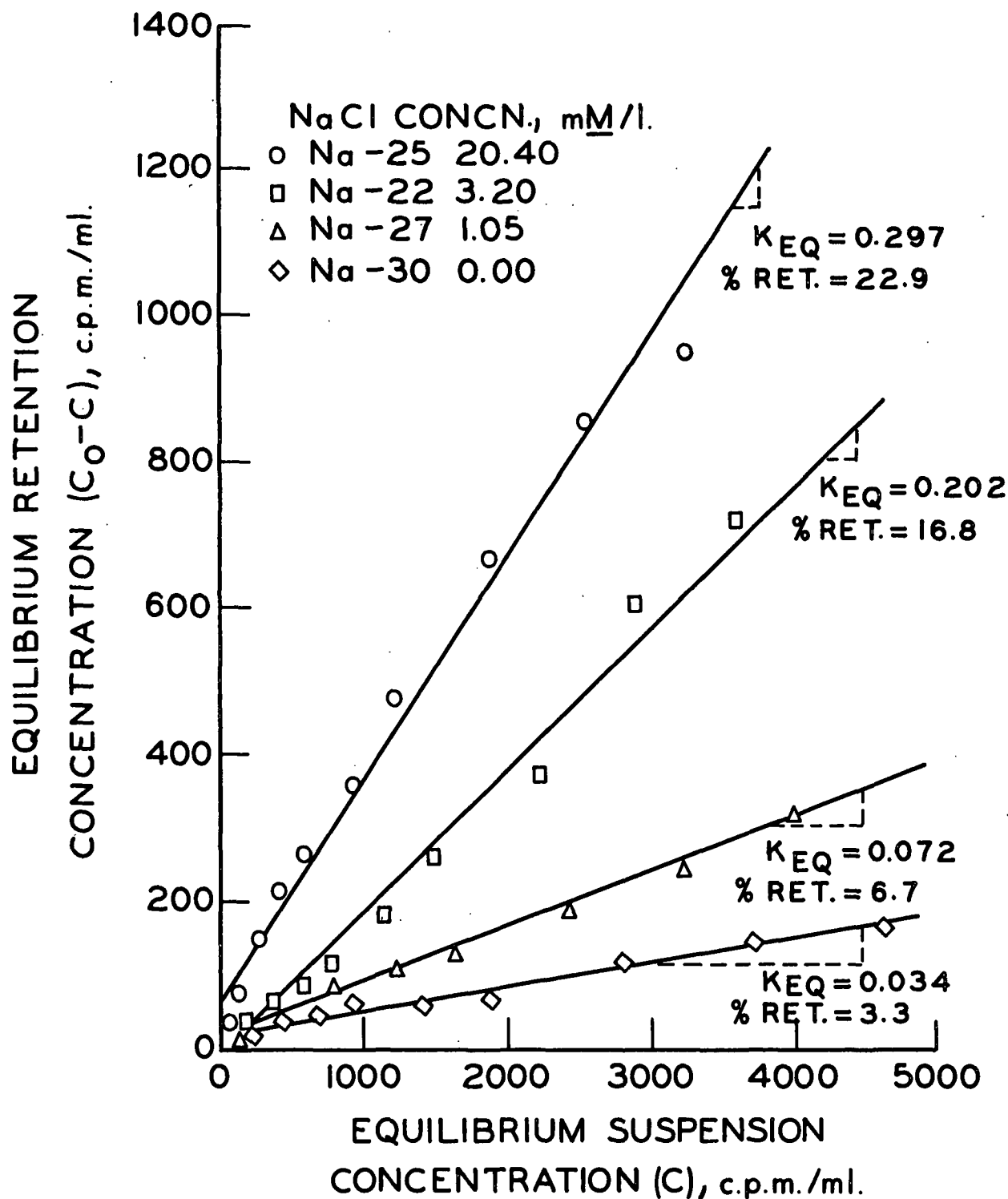


Figure 15. First-Order Reversible Coagulation Isotherms in Sodium Chloride

calculated from the equilibrium constant according to Equation (8) shown in Table VIII and the retention at the same salt concentration determined in the retention isotherms in Fig. 6. As the electrolyte concentration increases, the double layer collapses, and the repulsive potential is reduced which increases retention because more collisions are effective.

In Fig. 16, additional coagulation isotherm results are shown as a first-order reversible process in calcium and lanthanum chloride environments. As seen, the fits are also very good which indicates the same mechanism is operating in these different environments.

STABILITY FACTOR

The effect of electrolyte concentration on retention can be explained in terms of the rate of coagulation by using the concept of a stability factor. Reerink and Overbeek derived an approximate relationship between the stability factor, W , and the interaction energy of two colliding particles (51). The ratio of the rates of rapid coagulation in which the repulsive energy barrier is zero and slow coagulation in which a significant barrier still remains is equal to W . The ratio depends on the same parameters which are included in the potential energy functions for repulsion and attraction. Using the maximum energy of interaction between two spherical particles as an approximation of the total energy, they were able to show that the $\log W$ was a linear function of the \log electrolyte concentration.

Since the rate of retention could not be determined in the present system, a direct test of this functional relationship between the stability factor and the cation concentration was not possible. However, by making two reasonable assumptions from the coagulation isotherm results, the relationship can be evaluated indirectly. The first assumption required is that the removal order is unity, which is reasonable

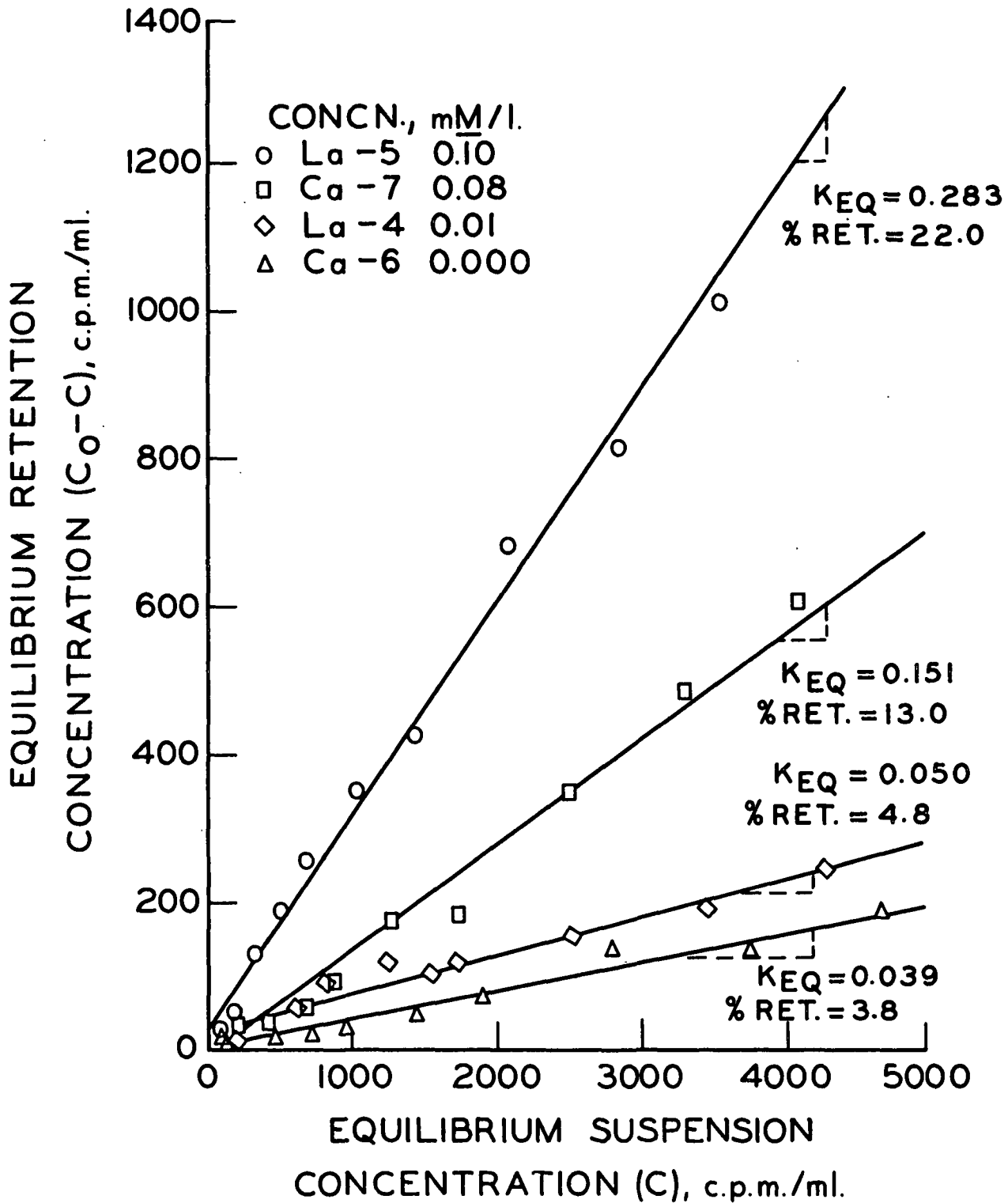


Figure 16. First-Order Reversible Coagulation Isotherms in Calcium and Lanthanum Chloride

considering that the ratio of the retention and removal order is unity as discussed, and that the retention agrees well with a first-order reversible retention process. The second assumption required is that the rate of removal is independent of cation concentration. Since the viscosity of the salt solution does not change appreciably within the salt concentrations investigated, the removal rate, which is thought to be dependent primarily on shear conditions, would not be expected to change. Also, since the attractive potential is independent of electrolyte concentration, once a fine is retained, it should be bound with the same force whether it is in a dilute electrolyte solution or in a coagulating environment.

With these assumptions, \underline{W} , can be calculated from the equilibrium constant as follows: By definition of the stability factor

$$W = k_r/k_s \quad (9)$$

where $\underline{k_r}$ = rapid coagulation rate constant and

$\underline{k_s}$ = slow coagulation rate constant.

Also,

$$K_r = k_r/k_{rr} \quad (10)$$

$$K_s = k_s/k_{sr} \quad (11)$$

where $\underline{K_r}$ = rapid coagulation equilibrium constant,

$\underline{k_{rr}}$ = rapid coagulation removal rate constant,

$\underline{K_s}$ = slow coagulation equilibrium constant, and

$\underline{k_{sr}}$ = slow coagulation removal rate constant,

so that

$$W = K_r k_{rr} / K_s k_{sr} \quad (12),$$

but as was assumed,

$$k_{rr} = k_{sr} \quad (13)$$

which leads to

$$W = K_r/K_s \quad (14).$$

Therefore, the stability factor can be calculated from the ratio of the equilibrium constants according to Equation (14). The equilibrium constant for rapid coagulation would be that obtained from the average maximum retention.

In all of the retention isotherms, there was always a small amount of retention in distilled water which is thought to be due to either physical entrapment or to particles which possess sufficient kinetic energy to overcome the potential barrier in distilled water. Since the stability ratio only describes a coagulation process, the total retention would have to be corrected for this retention if it was due to physical entrapment in order to calculate \underline{W} . This was accomplished by taking the difference between the total retention and the retention in distilled water. The differences were used to calculate the equilibrium constants for coagulation retention by Equation (8). These data were used then to calculate \underline{W} according to Equation (14). This was done for retention isotherms in which retention was determined at various electrolyte concentrations throughout the entire isotherm, i.e., Experiments Na-10 and 11, Ca-1 and 2, and La-7. The equilibrium constant used for rapid coagulation was the average obtained from the electrolyte independent retention measurements. It should be pointed out that when \underline{W} was calculated without subtracting the initial retention, the log stability curves leveled off at a value of ca. 1.0. If the initial retention was due to an energy factor, the curve should continue to infinity at low salt concentrations. Since it does reach a maximum, the initial retention must be controlled by another factor such as physical entrapment.

The corrected stability factors are shown in Fig. 17 as a function of electrolyte concentration for the above experiments. As can be seen, the log of the stability factor as calculated above is a linear function of the log of the cation concentration as predicted by coagulation theory. The fits are especially good for sodium and calcium. Only one lanthanum experiment was available to test this relationship, but it appears to fit it, also.

This functional relationship indicates that retention increases with electrolyte concentration because the rate of coagulation increases. The increase being due to a reduction in repulsive potential which essentially increases the number of effective collisions. Once the repulsive potential has been removed, the stability factor becomes independent of electrolyte concentration ($\underline{W} = 1$). This would be in the region of rapid coagulation in which each collision leads to coagulation.

The slope of the log \underline{W} -log concentration relationship was found to vary between -2 and -14 for a number of hydrophobic colloids (51). The slope calculated for sodium in Fig. 17 is approximately unity which is significantly less than other observed values. This discrepancy could be due to two factors. The first factor is that the rate constants used are in essence pseudo-rates because they include the concentration of one of the reactants, the pulp fibers. At higher pulp consistencies, the equilibrium constants would be much larger which would increase \underline{W} . The other factor which could possibly affect the slope is the shape of the particles. Reerink and Overbeek derived the following equation for the slope of the stability curve for two colliding spheres which can be used to calculate the

$$d \log W / d \log C_e = - 2.15 \times 10^7 a \gamma^2 / v^2 \quad (15)$$

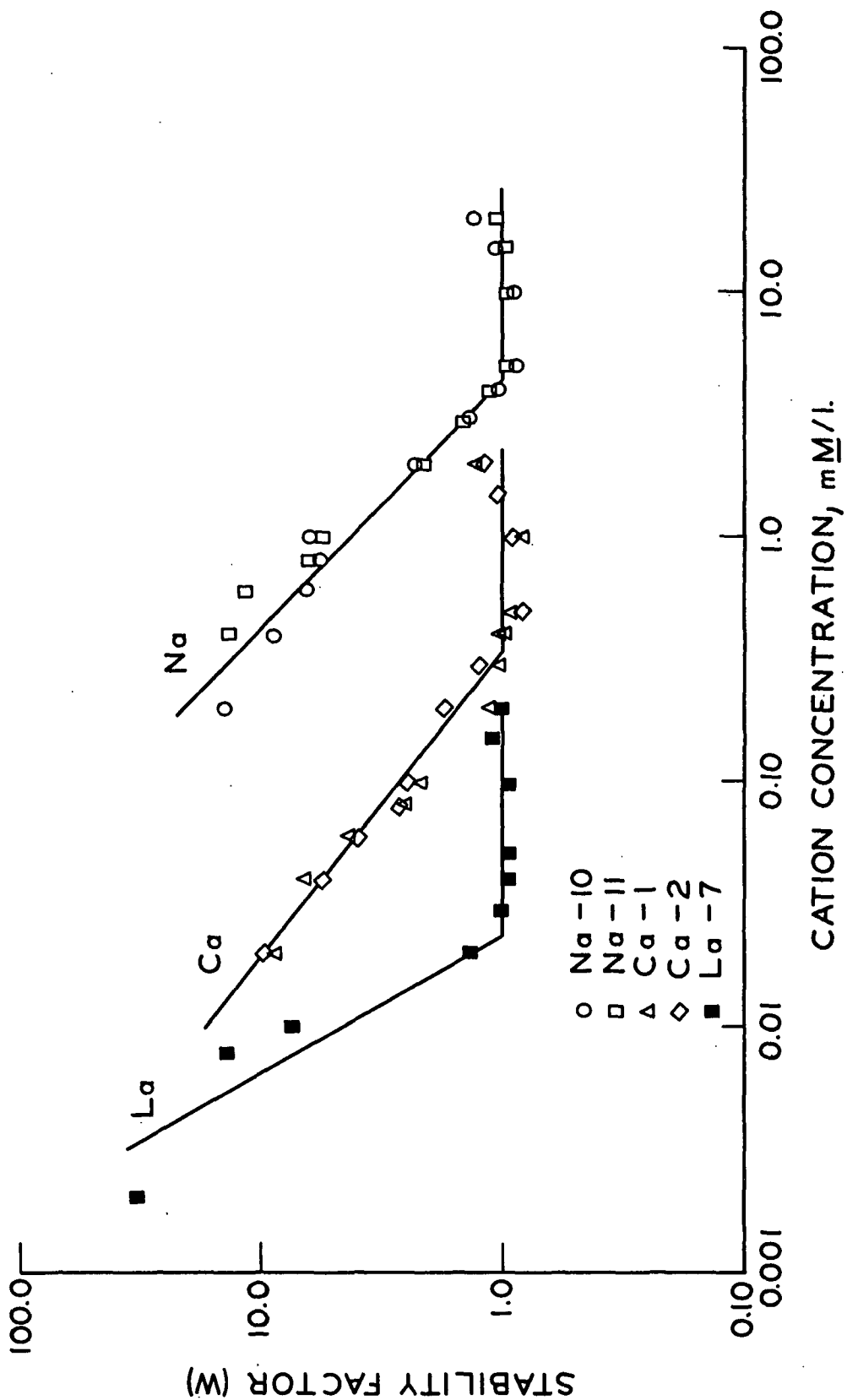


Figure 17. Log Stability Factor Versus Log Cation Concentration

where \underline{C}_e = concentration of electrolyte, mM/l.,

\underline{a} = radius of particle, cm.,

\underline{v} = valence of cation,

$\gamma = ((\exp \underline{z}/2) - 1) / ((\exp \underline{z}/2) + 1)$,

$\underline{z} = \underline{v}e \psi_\delta / kT$,

e = electronic charge, esu,

ψ_δ = Stern layer potential, statvolts,

k = Boltzman's constant, and

T = absolute temperature, °K.

Stern potential should be approximately the same as the zeta potential in distilled water (51). Using the average radius of the fines, 0.09 μm ., the calculated Stern potential equals -7.1 mv. Assuming a spherical shape, the zeta potential of the fines calculated using the measured electrophoretic mobility in distilled water is approximately -82 mv. which is better than an order of magnitude larger. (See Appendix VIII for calculation of zeta potential.) This large difference indicates that the fines cannot be treated as a sphere which would make Equation (15) invalid for this system.

Ottewill and Shaw determined the stability factor/cation concentration slope for various polystyrene latices and generally found a lower slope than those obtained for inorganic hydrophobic colloids (80).

It should be noted that Equation (15) predicts the slope of the stability curve is inversely proportional to the square of the cation valence. It can be seen in Fig. 17 that the calcium stability slope is less than that of sodium which is qualitatively in agreement with theory. However, the lanthanum stability slope is greater than the sodium stability slope. The differences in slope cannot be explained at this time.

EFFECT OF TEMPERATURE

The effect of temperature on fines retention was investigated by determining retention isotherms with sodium chloride at various temperatures. A constant amount of fines was used in each determination at a pulp consistency of 0.10%. The average results obtained from the isotherms are summarized in Table IX.

TABLE IX
EFFECT OF TEMPERATURE ON RETENTION

Experiment No.	Temperature, °C.	Average % Retention		Coagulation Value, mM/l. Na ⁺
		Initial	Maximum	
Na- 9	20.0	1.96	21.22	4.5
Na-10	20.0			
Na-20	30.0	2.89	20.93	3.2
Na-19	30.0			
Na-18	40.0	3.547	23.97	2.7
Na-17	40.0			
Na-16	50.0	3.05	26.08	2.7
Na-15	50.0			

The average maximum retention increases, and the CV decreases slightly with increasing temperature. It should also be noted that there appears to be a small increase in the initial retention in distilled water at the higher temperature.

The increase in maximum retention with temperature is thought to be due to a decrease in viscosity which would reduce the removal rate because the shear has been reduced. Since the fines are so large, the effect of temperature on the diffusion rate would probably be so small that it wouldn't have a significant effect on the retention rate. Others have observed an increase in the flocculating tendency of wood pulp fibers with an increase in the suspension temperature (81-83). In each investigation, the change was thought to be due to a decrease in viscosity and shear. The effect of temperature on hydrophobic colloid coagulation has not

been investigated very extensively. Kharin and Chaikovskaya observed an increase in the rate of rapid coagulation of a colloidal sulfur sol under mild agitation with an increase in temperature (84).

The theoretical expression of the Schulze-Hardy rule predicts that the coagulation value should increase with an increase in temperature. As can be seen in Table IX, the coagulation value for fines retention actually decreases slightly with increases in temperature. This difference may be due to less swelling or hydration of the fibers which could improve the effectiveness of the counterions.

APPLICATION OF COAGULATION THEORY

If this system is scrutinized very carefully, it becomes readily apparent that a quantitative application of coagulation theory to fines retention would be very difficult and probably fruitless. The first major problem encountered is the selection of a model to describe the interaction of two cylinderlike particles of vastly different sizes. Some of the geometries investigated include infinite flat plates, spheres, and uniform size cylinders. If one of these geometries was selected assuming all of the variables were known, it would probably be fortuitous that good agreement with theory was obtained. More than likely, the agreement would not be good, and then there would be no way of determining whether the variable quantities were in error, or the model was in error.

If the fiber and fine interaction was treated as two cylinders of different sizes as Sparnaay's analysis of two equal-sized cylinders (50), additional parameters such as fines flexibility or shape and orientation of the colliding particles would also have to be considered to make the analysis rigorous. The effect of shear would also have to be introduced to account for its effect on attachment and removal. Assuming a satisfactory theoretical analysis of this geometry could be

completed, the two most important variables would have to be approximated since absolute determinations are not possible. The surface potential would have to be obtained from electrophoretic mobility data which can be in appreciable error itself, and the Van der Waals constant for a fiber fines interaction would have to be approximated. The other variables which could be determined accurately include temperature, valence, ionic concentration, and dielectric constant. The particle sizes would also have to be known which at best would be an average since the particles are heterodispersed. Ideally, a monodispersed suspension of fines and fibers would be required. Obviously, the fiber-fines system would be one of the poorest selections one could make to test a theoretical analysis of colloidal coagulation of cylindrical particles.

It has been suggested by Kruyt that in a situation like this, one can only compare experimental results to the general theory and determine if they are grossly different (26). In general, it has been shown that fines can be retained by a colloidal coagulation process similar in nature to hydrophobic colloidal theory.

SUMMARY AND CONCLUSIONS

The coflocculation mechanism of cellulose fines retention in a pulp suspension was investigated and compared to the classic coagulation theory of hydrophobic colloids. The results are in excellent agreement with theory and show that coagulation of the fiber and fines is an important mechanism of retention.

Fines retention reacts to the electrolyte environment in the same manner as hydrophobic colloids. As per the Schulze-Hardy rule of colloid coagulation, the coagulation value for mono-, di-, and trivalent cations decreases with increasing counterion valence. Also, the log coagulation value was shown to be a linear function of counterion valence as is the case for hydrophobic colloids. The anion species had no apparent effect on the coagulation value of different sodium salts which is in agreement with coagulation theory.

The effect of electrolyte environment on retention was related to the electrokinetic properties of the fines. Retention was shown to increase with a decrease in the electrophoretic mobility of the fines as the electrolyte concentration increases. When hydrophobic colloids coagulate, the double-layer repulsive potential energy is reduced by increasing concentrations of counterions which reduces the surface potential of the particles. Maximum retention was obtained near the same electrolyte concentration which reduced the mobility to zero.

The retention isotherms could be described by a linear correlation of the log stability factor as calculated from the equilibrium retention and the log cation concentration. This indicated that retention was being controlled by the remaining repulsive potential which determines the rate of coagulation. As the repulsive potential is reduced at higher electrolyte concentrations, the rate of coagulation increases which increases the equilibrium constant and total retention. Once the

repulsive potential is eliminated, the rate is constant, and the retention levels off at some maximum.

Retention was shown to be dependent on a dynamic equilibrium that could be characterized in terms of a first-order reversible process. The maximum retention in this case was dependent on the concentration of pulp and the agitation rate. As pulp concentration increased and agitation rate decreased, the maximum retention was determined by a balance of the attachment and removal rates. The rate of attachment was controlled primarily by the colloidal parameters while the removal rate was controlled by physical parameters affecting shear.

It can be concluded that fines retention is controlled by a dynamic equilibrium process. The system has to be in a favorable coagulating environment which can be described by hydrophobic coagulation theory before any appreciable attachment can occur. Once the fines are retained, the extent to which they remain attached to the pulp fiber depends on the physical parameters which affect the shear exerted on them in the suspension. The fines retention process can be compared to the coagulation of a coarse suspension which is described by hydrophobic colloidal coagulation theory.

FUTURE WORK

The results of this investigation have shown that fines can be retained by a coagulation process, but it should be recognized that further investigations are required before the retention process is understood completely. With respect to the coagulation mechanism, future work should be focussed on investigations dealing with other factors associated with the papermaking system.

One of the most important factors that should be investigated is the effect of alum on retention since it is the primary electrolyte used in papermaking. It probably would not have as simple an effect on retention as the trivalent cation used in this thesis investigation because of its complex chemical equilibria. The presence of other colloidal materials such as filler and sizing would probably affect fines retention also since they are thought to be retained by a similar mechanism.

Since fines retention was shown to be dependent on surface potential, it would be necessary to further our understanding of how cellulose develops its surface charge. If the source of the charge or the factors which affect its magnitude could be determined, they could possibly be manipulated in such a way that retention could be improved significantly. In this respect, the Numinco electrophoretic mass transport analyzer could hold the key to surface electric studies on cellulose materials as it has been shown to work quite well with fines. A combination of this tool and the potential of the analytical techniques available with the radioactive pulp could lead to some very interesting and worthwhile studies on the electrokinetic properties of cellulose. It should be noted that not all of the trees tagged with C-14 were harvested for this thesis investigation. As of this writing, no further work was done with the remaining tagged aspen or

red pine seedlings. Additional seedlings which were treated in the summer of 1968 by Mr. A. J. Morak of The Institute of Paper Chemistry staff would probably also be available for future work in this or any other area.

Since fines retention due to coagulation was shown to be dependent on a dynamic equilibrium controlled in part by shear conditions, it would be necessary to look more closely at the removal process. Of interest here would be the strength of the fiber-fine attractive force and the shear forces required to disrupt this "bond." In addition, the mechanism by which polymeric retention aids enhance retention should also be investigated since the effect of surface potential alone has been shown. It might be possible to determine the effect of polymer bridging on fines retention by comparing the results of this thesis to those obtained with various polymers using the same experimental techniques.

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APPENDIX I

GROWTH OF RADIOACTIVE ASPEN SEEDLINGS

The preparation of radioactive fines was shown to be most important for the successful completion of the thesis experimental program. In the summer of 1966, before the thesis proposal was made, twenty triploid aspen seedlings were intermittently exposed to a total of 8.0 mCi of carbon-14 dioxide to determine if this technique was feasible. The growing results were encouraging, and preliminary investigations on the effect of electrolyte environment on fines retention were satisfactory enough to continue the effort in this thesis. However, there was a definite need for a starting material, with higher specific activity, so in the summer of 1967, the growing process was repeated with 125 mCi of carbon-14 dioxide. The details of this second growing cycle which are essentially the same as the first are discussed below.

A growing chamber was constructed to contain the radioactive atmosphere by covering a large wooden frame with 10 ml. polyvinyl chloride construction plastic. It should be noted that this plastic had the lowest carbon dioxide diffusion coefficient of any available. It would be better to use glass if the added expense could be justified. The outside dimensions of the chamber included a 60 by 70-in. base, 60-in. sides, and a 72-in. center height. One side of the chamber was removable for easy access to the trees. The door frame and all other joints were carefully sealed to prevent excessive leakage of the radioactive atmosphere.

A total of 30 seedlings were individually potted and placed in a shallow trough in the bottom of the chamber for easy watering. Fifteen, two-year-old Pinus resinosa; ten, three-year-old Populus tremuloides treated the previous summer but not harvested; and five of the poplar seedlings treated and harvested the previous summer were treated in the cycle.

The treatment procedure was essentially the same for both growing cycles. At the beginning of each week throughout the summer, the chamber was first closed and sealed tightly and then purged with carbon dioxide free air for ca. 4 hr. to reduce photosynthesis. Compressed air was scrubbed in a dilute alkali solution and fed through a stopcock placed in the wooden frame. The chamber was vented through another stopcock. The effectiveness of this purging process in displacing the carbon dioxide in the chamber was not determined, however.

After the purge was completed, a carbon-14 dioxide generator was attached to the inlet stopcock. The carbon-14 dioxide was generated in a round-bottom flask by addition of dilute acid to aqueous barium carbonate containing C-14. The amount of carbon-14 dioxide generated varied from 10-20 mCi as seen in the treatment schedule shown in Table X. Additional carbon dioxide was generated, also at this time, to maintain the overall concentration at 0.03% which is the normal atmospheric concentration.

TABLE X
TREATMENT SCHEDULE

Treatment Number	Date Started	Purge Time, hr.	Carbon-14 Dioxide Added, mCi	Treatment Period, hr.
1	6/26/67	4	10.0	78
2	7/ 6/67	10	10.0	134
3	7/17/67	9	10.0	58
4	7/24/67	3	10.0	58
5	7/31/67	5	20.0	58
6	8/ 7/67	4	10.0	58
7	8/14/67	4	20.0	58
8	8/21/67	4	20.0	58
9	8/28/67	4	15.0	58

The background radiation level in the chamber was monitored during the first five treatments of 1967 with a Geiger-Mueller tube positioned in the wooden frame. The results presented in Fig. 18 generally show the rapid build-up of background radiation during the first hour after the carbon-14 dioxide was generated, the gradual decay due to photosynthesis during the daylight hours, and a small increase during the second day. There are two possible explanations for the second peak: either the trees respired some of the carbon-14 dioxide assimilated the first day, and/or the increasing temperature inside the chamber released carbon-14 dioxide adsorbed in the water. It can also be seen that at the end of the usual growing period of 2.5 days, the radiation level was almost reduced to the background level. It should also be noted the initial radiation level increased with each treatment monitored which indicated the trees were assimilating and retaining C-14.

The first treatment curve is different than the next three curves because the Geiger-Mueller tube counting voltage was erroneously set too high which causes an excessive amount of ionization of the counting tube gas.

In the first growing cycle during 1966, a second generation of carbon dioxide was performed 7-8 hr. after the carbon-14 dioxide was generated to increase the atmospheric carbon dioxide concentration to 0.5% to sustain photosynthesis. This was also done in the first three feedings of 1967, but there was some question as to the value of this process because it was thought there could be sufficient diffusion and leakage of carbon dioxide into the chamber to maintain tree growth. Since the second maximum in the radiation curves also indicated there was carbon-14 dioxide in the system, it was decided to eliminate this step in the fourth treatment. As can be seen in Fig. 18, the only effect of the elimination was a slight shift in the second minimum to a shorter time. This meant the carbon-14 dioxide was assimilated sooner which was advantageous because there was less chance of loss

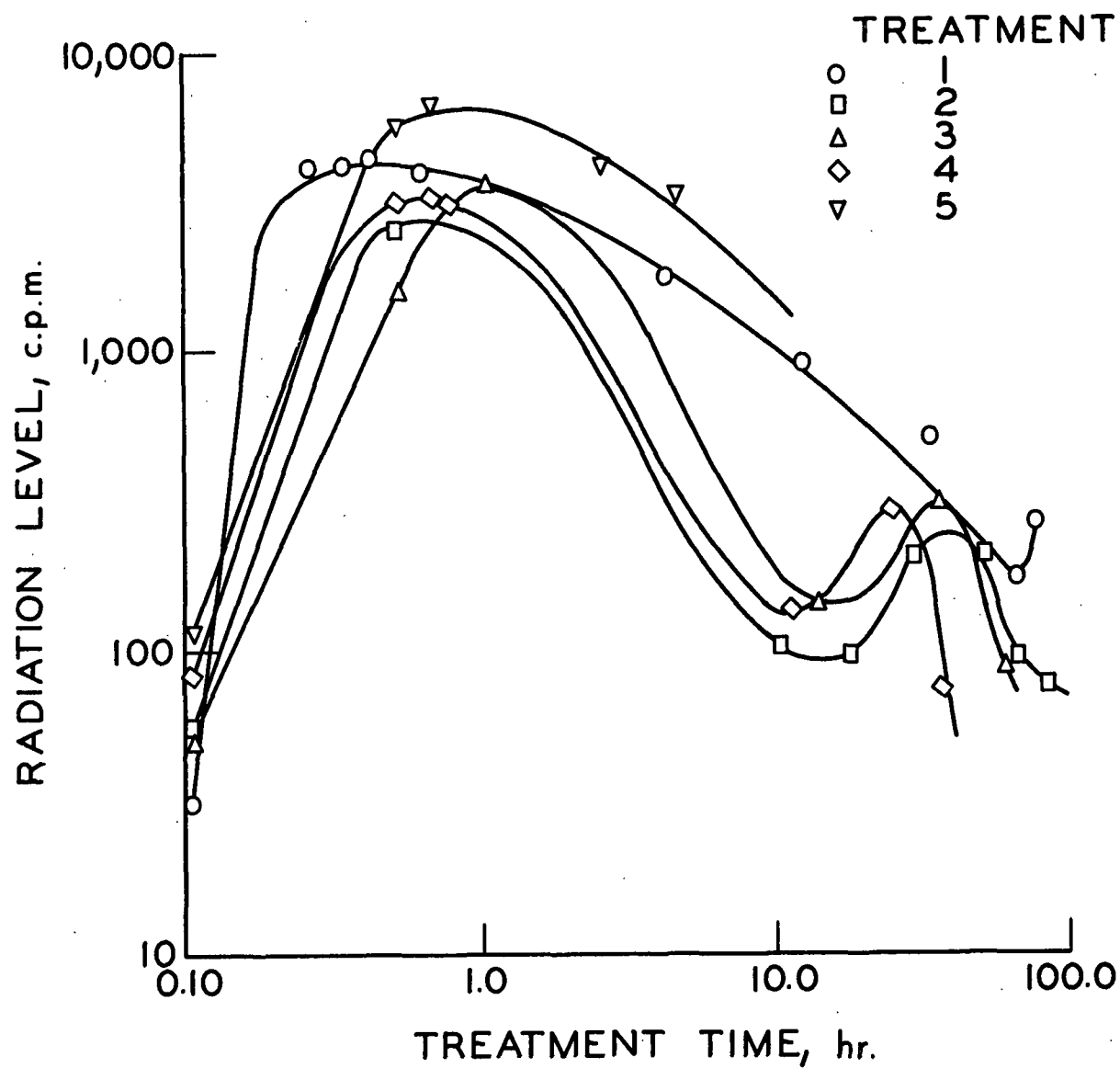


Figure 18. Growing Chamber Radiation Level

from the chamber. Therefore, it was decided to eliminate this step in the remaining treatments.

In the fifth treatment, the initial dosage was doubled because the 10.0 mCi carbon-14 dioxide was readily assimilated in the first day. A few radiation counts were made during the first day, but failure of the Geiger-Mueller tube prevented any further measurements. Since a replacement was not readily available, the same treatment procedure used in the fourth addition was used in the remaining feedings.

Since the growing season was rapidly closing during the last treatment, it was decided to increase the dosages as listed in Table X. It would have been better to have had the higher dosages during the peak growing time earlier in the season rather than as was done when the cell reproduction rate was beginning to slow down.

An estimate of the amount of C-14 assimilated by the trees during each treatment was obtained by scrubbing the chamber air in a concentrated barium hydroxide solution. This was essentially the same procedure described above for the initial purge but in the reverse direction. It was started some two and one half days after the carbon-14 dioxide was generated prior to opening the chamber to the atmosphere. Total purge time was at least 4.0 hr.

After the growing chamber was purged, the side door was removed, and the trees were allowed to grow in the open atmosphere for the remainder of the week. The procedure was then repeated each week throughout the summer.

The estimate of the assimilation rate was obtained by filtering, drying, weighing, and measuring the specific activity of the radioactive barium carbonate formed in the latter purge. The specific activity was determined by the same procedure used by Cluley (85). The results for each of the treatments are summarized in Table XI.

TABLE XI
CARBON-14 DIOXIDE RECOVERY

Treatment Number	Carbon-14 Dioxide Added, mCi	Radioactive Barium Carbonate Recovered, g.	Specific Activity, ^a $\mu\text{Ci/g.}$	Total C-14 Recovered, μCi	Recovery, %
1	10.0	3.26	6.89	22.45	0.22
2	10.0	5.01	1.00	5.01	0.05
3	10.0	6.65	1.76	11.70	0.12
4	10.0	7.40	2.20	16.25	0.16
5	20.0	9.59	4.12	19.28	0.09
6	10.0	9.09	2.65	24.10	0.24
7	20.0	10.54	4.47	47.20	0.24
8	20.0	3.03	3.84	11.62	0.06
9	15.0	20.19	6.61	133.50	0.90

^aBased on a counting efficiency of 90.0%.

It can be noted that of the total 125 mCi carbon-14 dioxide only 291 μCi were recovered which would indicate a total assimilation rate of 99.8%. However, this does not mean all of the C-14 was consumed by the trees since there was some unaccountable loss by diffusion and water adsorption. Also, the actual recovery efficiency of the purge was not known. Therefore, no specific conclusions can be drawn from these results.

Nine of the aspen seedlings treated in both cycles were harvested by cutting the primary branch off near the main stem. The trees would then sprout a new branch the following summer and continue growing. The other trees were kept in the pots, stored over the winter, and retreated again by other workers the next summer to build up an inventory of radioactive wood.

The specific activity of the different tree components was determined with the scintillation counter described previously. The solid samples were suspended in a counting cocktail made with colloidal silica, toluene, and PPO phosphor. The procedure was the same that Cluley used for analyzing solid barium carbonate samples (85). The counting efficiency in this cocktail was determined by addition of standard C-14-toluene to two samples having a fairly large difference in external standard ratios. A linear relationship was assumed in calculating the efficiency curve. Counting efficiency varied from 70-80% depending on the external standard ratio. The average specific activity determinations for the various tree components are summarized in Table XII.

TABLE XII
SPECIFIC ACTIVITY OF RADIOACTIVE ASPEN

Component	Quantity, g.	Specific Activity, μCi/g.
Wood total	84.3	13.88
Branch base	--	6.07
Branch middle	--	14.21
Branch tip	--	21.17
Leaves	--	9.71
Bark	71.0	16.81
Extractives		
Alcohol:benzene	5.08	38.2
Alcohol	3.67	32.9
Hot water	3.48	27.9

As can be seen, all of the tree components were tagged with C-14. It should be noted the branch tips had consistently higher specific activities than the other positions because they were not diluted by the old untagged wood. The high specific activity of the extractives is probably due to the immature nature of the wood which usually has a very high extractive content compared to normal pulpwood. Young trees abound in pectin materials which are removed as extractives.

This technique was shown to be a rather simple method for radioactively tagging large quantities of wood. The method can be summarized as three easy steps: purging the system of carbon dioxide, addition of radioactive carbon dioxide, and removal of unassimilated C-14 after a 2-3 day growing period. However, it could be improved by building an air-tight chamber that contained only the leaves and branches because this would reduce C-14 loss to the atmosphere and eliminate adsorption in the water that was used to maintain the soil moisture content. This later problem is thought to be the most serious and should be eliminated in future growing cycles.

APPENDIX II

RADIOACTIVE ASPEN KRAFT PULPING CONDITIONS

A summary of the pulping conditions used to prepare the radioactive pulp is in Table XIII.

TABLE XIII

RADIOACTIVE ASPEN PULPING CONDITIONS

Wood:	
Airdry weight, g.	88.5
Moisture content, %	5.8
Ovendry weight, g.	83.4
Liquor:	
Liquor-to-wood ratio	6:1
Active alkali, g./l. as NaOH	40.2
Sulfidity, %	20.0
Cook:	
Maximum temperature, °C.	170
Time to temperature, min.	120
Time at temperature, min.	75
Yield:	
Pulping, %	48.8
Bleaching, %	88.0
Total, %	42.8

APPENDIX III

COULTER COUNTER SIZE ANALYSIS OF RADIOACTIVE FINES

The particle size distributions of a number of samples of unretained radioactive fines were determined using a Coulter Counter, Model B. The frequency data were gathered by Mr. H. Grady of The Institute of Paper Chemistry staff following the recommended procedures (68). The samples that were analyzed are summarized in Table XIV. The average frequency data and computed results can be found in the subsequent pages, 108-119. The computer program used to analyze the data is at the end of the appendix.

TABLE XIV

FINES PARTICLE SIZE DISTRIBUTION SUMMARY

Sample Number	Experiment Number	Consistency, %	Agitation Rate, r.p.m.	Electrolyte Conc., mM/l.	Wt. Av. Size, μ m.	Retention, %
3	Na 12	0.05	150	74.0	1.50	11.40
6	Na 12	0.05	600	74.0	1.10	3.84
7	Na 13	0.20	150	72.0	1.59	31.15
8	Na 13	0.20	600	72.0	1.05	17.25
9	Na 14	0.38	150	72.5	1.55	54.95
10	Na 14	0.38	600	72.5	1.21	29.67
11	Control A	--	--	0.0	1.12	0.00
12	Repeat 11	--	--	0.0	1.12	0.00
13	Control B	--	--	0.0	1.08	0.00
14	Repeat 13	--	--	0.0	1.12	0.00
15	Na 24	0.10	150	198.0	2.33	24.50
16	Na 25	0.10	150	20.4	1.91	22.90

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 3 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	3.00	499.80	0.736
8.74	4.00	3504.29	5.160
7.79	12.50	3754.27	5.528
6.93	13.50	5256.99	7.741
6.17	22.00	6819.88	10.043
5.50	34.50	7880.98	11.605
4.90	46.50	9632.03	14.184
4.36	74.50	10251.23	15.096
3.88	88.51	12706.82	18.712
3.46	167.02	14476.84	21.318
3.08	247.05	18694.93	27.530
2.74	516.71	22598.62	33.278
2.44	869.58	27626.63	40.682
2.17	1512.26	32468.57	47.813
1.94	2387.37	36918.15	54.365
1.72	3524.51	40650.23	59.861
1.53	4873.15	45116.94	66.438
1.37	7155.50	48811.32	71.879
1.22	9824.72	53034.94	78.098
1.08	14139.68	58151.23	85.633
0.96	21530.58	63392.59	93.351
0.86	32236.77	67907.88	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	14.367
1.225	13.754
1.545	12.018
1.949	12.048
2.457	14.534
3.099	11.960
3.908	6.223
4.929	3.490
6.216	3.864
7.839	2.581

WEIGHT AVERAGE ESD = 1.500 MICROMETERS
WEIGHT AVERAGE SIGMA = 2.391 MICROMETERS
NUMBER AVERAGE ESD = 1.166 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 6 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	2.00	-249.90	-1.490
8.74	1.50	280.30	1.671
7.79	3.00	30.32	0.181
6.93	2.00	649.08	3.869
6.17	5.50	836.62	4.987
5.50	7.00	1455.56	8.676
4.90	14.00	1955.83	11.658
4.36	22.00	2088.51	12.449
3.88	25.00	2338.72	13.941
3.46	33.00	2604.16	15.523
3.08	45.00	3003.07	17.901
2.74	70.50	3512.02	20.934
2.44	116.51	4243.70	25.296
2.17	210.03	4982.66	29.700
1.94	343.59	6367.00	37.952
1.72	697.37	7553.06	45.022
1.53	1125.97	9119.45	54.359
1.37	1926.35	10249.42	61.094
1.22	2742.77	11792.55	70.293
1.08	4319.27	13140.46	78.327
0.96	6266.45	14943.34	89.074
0.86	9949.07	16776.36	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	21.673
1.225	17.233
1.545	16.072
1.949	15.322
2.457	8.766
3.099	5.412
3.908	3.074
4.929	3.773
6.216	4.807
7.839	2.198

WEIGHT AVERAGE ESD = 1.101 MICROMETERS
WEIGHT AVERAGE SIGMA = 1.991 MICROMETERS
NUMBER AVERAGE ESD = 1.103 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 7 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.0	249.90	1.632
8.74	0.50	1663.77	10.866
7.79	4.50	1413.79	9.234
6.93	3.50	1855.76	12.120
6.17	6.00	2230.84	14.570
5.50	9.00	2805.58	18.323
4.90	15.50	2836.84	18.528
4.36	16.00	3389.65	22.138
3.88	28.50	3937.00	25.713
3.46	46.00	5286.38	34.526
3.08	107.01	5959.13	38.919
2.74	150.02	7192.98	46.978
2.44	261.55	8042.25	52.524
2.17	370.11	9049.96	59.106
1.94	552.23	9543.45	62.329
1.72	678.35	10198.72	66.608
1.53	915.14	10757.39	70.257
1.37	1200.61	11425.30	74.619
1.22	1683.18	12045.82	78.672
1.08	2317.12	12993.00	84.858
0.96	3685.40	13855.74	90.493
0.86	5447.66	15311.45	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	15.142
1.225	10.239
1.545	8.011
1.949	7.503
2.457	12.128
3.099	12.452
3.908	12.388
4.929	3.815
6.216	6.203
7.839	1.254

WEIGHT AVERAGE ESD = 1.586 MICROMETERS.
WEIGHT AVERAGE SIGMA = 2.609 MICROMETERS.
NUMBER AVERAGE ESD = 1.125 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 8 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	1.50	249.90	1.611
8.74	2.00	780.10	5.028
7.79	3.50	780.10	5.028
6.93	3.50	780.10	5.028
6.17	3.50	1717.80	11.073
5.50	11.00	1717.80	11.073
4.90	11.00	2061.73	13.290
4.36	16.50	2327.08	15.000
3.88	22.50	2624.21	16.916
3.46	32.00	2989.18	19.268
3.08	48.50	3302.06	21.285
2.74	68.50	3633.97	23.424
2.44	98.51	4060.44	26.173
2.17	153.02	4749.52	30.615
1.94	277.56	5630.46	36.294
1.72	502.69	6749.66	43.508
1.53	907.13	8075.17	52.052
1.37	1584.43	9216.36	59.408
1.22	2408.95	10450.04	67.361
1.08	3669.31	11931.05	76.907
0.96	5808.75	13488.91	86.949
0.86	8990.89	15513.60	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	23.093
1.225	17.499
1.545	15.900
1.949	12.893
2.457	7.191
3.099	4.156
3.908	4.268
4.929	3.927
6.216	6.044
7.839	0.0

WEIGHT AVERAGE ESD = 1.045 MICROMETERS
 WEIGHT AVERAGE SIGMA = 2.227 MICROMETERS
 NUMBER AVERAGE ESD = 1.079 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 9 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.0	749.70	3.350
8.74	1.50	749.70	3.350
7.79	1.50	2499.54	11.168
6.93	8.50	2234.36	9.983
6.17	7.00	2734.47	12.217
5.50	11.00	3441.84	15.378
4.90	19.00	3629.44	16.216
4.36	22.00	4668.74	20.860
3.88	45.50	6013.71	26.869
3.46	88.51	7385.30	32.997
3.08	150.52	8386.69	37.471
2.74	214.54	10124.29	45.235
2.44	371.61	11584.42	51.758
2.17	558.24	12653.35	56.534
1.94	751.43	13850.42	61.883
1.72	1057.36	14743.16	65.871
1.53	1379.96	15438.60	68.978
1.37	1735.31	16507.80	73.756
1.22	2507.82	17490.67	78.147
1.08	3511.95	18844.61	84.196
0.96	5467.83	20352.57	90.934
0.86	8548.03	22381.75	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	15.804
1.225	10.441
1.545	7.884
1.949	9.337
2.457	11.300
3.099	12.238
3.908	12.137
4.929	5.482
6.216	5.395
7.839	6.633

WEIGHT AVERAGE ESD = 1.553 MICROMETERS
WEIGHT AVERAGE SIGMA = 2.538 MICROMETERS
NUMBER AVERAGE ESD = 1.126 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 10 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	1.00	249.90	1.482
8.74	1.50	1663.77	9.868
7.79	5.50	1913.75	11.350
6.93	6.50	1560.17	9.253
6.17	4.50	2435.36	14.444
5.50	11.50	2833.26	16.804
4.90	16.00	2864.52	16.989
4.36	16.50	3218.32	19.088
3.88	24.50	3578.00	21.221
3.46	36.00	3754.96	22.271
3.08	44.00	3473.38	20.601
2.74	26.00	4651.68	27.589
2.44	132.51	5387.29	31.952
2.17	226.54	6300.66	37.369
1.94	391.62	7653.76	45.394
1.72	737.42	8758.11	51.944
1.53	1136.49	10080.17	59.785
1.37	1812.02	11129.35	66.008
1.22	2570.07	12309.67	73.009
1.08	3775.91	13635.53	80.872
0.96	5691.22	14899.24	88.367
0.86	8272.53	16860.58	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	19.128
1.225	14.864
1.545	14.064
1.949	14.575
2.457	9.780
3.099	5.318
3.908	3.183
4.929	2.284
6.216	7.551
7.839	-0.614

WEIGHT AVERAGE ESD = 1.210 MICROMETERS
WEIGHT AVERAGE SIGMA = 2.447 MICROMETERS
NUMBER AVERAGE ESD = 1.103 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 11 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.50	249.90	3.510
8.74	1.00	780.10	10.958
7.79	2.50	905.09	12.714
6.93	3.00	1258.66	17.681
6.17	5.00	1258.66	17.681
5.50	5.00	1435.50	20.165
4.90	7.00	1529.30	21.483
4.36	8.50	1728.31	24.278
3.88	13.00	1743.95	24.498
3.46	13.50	1766.07	24.809
3.08	14.50	2211.89	31.072
2.74	43.00	2294.87	32.237
2.44	50.50	2427.88	34.106
2.17	67.50	2701.80	37.953
1.94	117.01	3118.64	43.809
1.72	223.54	3380.25	47.484
1.53	318.08	3918.83	55.050
1.37	593.27	4322.05	60.714
1.22	884.60	4898.15	68.807
1.08	1473.17	5570.26	78.248
0.96	2444.08	6205.78	87.176
0.86	3742.22	7118.71	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	21.752
1.225	17.534
1.545	13.230
1.949	9.531
2.457	5.716
3.099	7.428
3.908	0.530
4.929	4.113
6.216	2.484
7.839	6.723

WEIGHT AVERAGE ESD = 1.116 MICROMETERS
 WEIGHT AVERAGE SIGMA = 2.520 MICROMETERS
 NUMBER AVERAGE ESD = 1.068 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 12 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.50	249.90	2.726
8.74	1.00	1133.57	12.368
7.79	3.50	1508.53	16.459
6.93	5.00	1685.32	18.387
6.17	6.00	2060.40	22.480
5.50	9.00	2369.87	25.856
4.90	12.50	2307.34	25.174
4.36	11.50	2528.46	27.586
3.88	16.50	2700.48	29.463
3.46	22.00	2722.60	29.704
3.08	23.00	2902.49	31.667
2.74	34.50	3112.70	33.961
2.44	53.50	3316.13	36.180
2.17	79.50	3659.23	39.923
1.94	141.52	3876.45	42.293
1.72	197.03	4437.09	48.410
1.53	399.62	4934.58	53.838
1.37	653.83	5530.52	60.340
1.22	1084.40	6283.96	68.560
1.08	1854.14	7112.92	77.604
0.96	3051.64	8008.11	87.371
0.86	4880.20	9165.62	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	22.396
1.225	17.264
1.545	11.930
1.949	8.487
2.457	5.963
3.099	4.256
3.908	2.118
4.929	1.730
6.216	7.469
7.839	6.020

WEIGHT AVERAGE ESD = 1.115 MICROMETERS
 WEIGHT AVERAGE SIGMA = 2.574 MICROMETERS
 NUMBER AVERAGE ESD = 1.060 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 13 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	1.00	-249.90	-2.878
8.74	0.50	280.30	3.228
7.79	2.00	530.27	6.107
6.93	3.00	441.88	5.089
6.17	2.50	816.96	9.408
5.50	5.50	1214.85	13.990
4.90	10.00	1214.85	13.990
4.36	10.00	1590.76	18.319
3.88	18.50	1731.50	19.940
3.46	23.00	2030.11	23.379
3.08	36.50	2405.56	27.703
2.74	60.50	2471.94	28.467
2.44	66.50	2788.83	32.116
2.17	107.01	3032.33	34.921
1.94	151.02	3590.12	41.344
1.72	293.57	4040.06	46.526
1.53	456.16	4631.65	53.338
1.37	758.44	5182.63	59.683
1.22	1156.53	5894.43	67.881
1.08	1883.72	6637.53	76.438
0.96	2957.20	7593.26	87.445
0.86	4909.42	8683.52	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	23.562
1.225	16.755
1.545	13.158
1.949	11.605
2.457	6.454
3.099	5.088
3.908	5.060
4.929	4.329
6.216	8.902
7.839	1.861

WEIGHT AVERAGE ESD = 1.078 MICROMETERS
WEIGHT AVERAGE SIGMA = 2.167 MICROMETERS
NUMBER AVERAGE ESD = 1.073 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 14 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.0	249.90	3.279
8.74	0.50	603.36	7.916
7.79	1.50	978.33	12.836
6.93	3.00	1066.72	13.996
6.17	3.50	1254.26	16.456
5.50	5.00	1475.31	19.356
4.90	7.50	1850.51	24.279
4.36	13.50	1850.51	24.279
3.88	13.50	2038.17	26.741
3.46	19.50	2104.52	27.612
3.08	22.50	2315.70	30.383
2.74	36.00	2453.99	32.197
2.44	48.50	2774.79	36.406
2.17	89.51	2943.57	38.620
1.94	120.01	3305.62	43.370
1.72	212.53	3770.73	49.473
1.53	380.61	4194.76	55.036
1.37	597.27	4707.48	61.763
1.22	967.72	5224.79	68.550
1.08	1496.22	5916.72	77.629
0.96	2495.78	6662.86	87.418
0.86	4019.87	7621.82	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	22.371
1.225	15.866
1.545	12.290
1.949	10.853
2.457	6.423
3.099	4.585
3.908	3.333
4.929	4.923
6.216	5.361
7.839	6.079

WEIGHT AVERAGE ESD = 1.123 MICROMETERS
 WEIGHT AVERAGE SIGMA = 2.487 MICROMETERS
 NUMBER AVERAGE ESD = 1.067 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 15 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.0	0.0	0.0
8.74	0.0	0.0	0.0
7.79	0.0	874.92	8.109
6.93	3.50	1405.28	13.024
6.17	6.50	1530.30	14.183
5.50	7.50	1883.99	17.461
4.90	11.50	2196.65	20.359
4.36	16.50	2904.25	26.917
3.88	32.50	3654.91	33.874
3.46	56.50	4772.02	44.227
3.08	107.01	5788.99	53.652
2.74	172.02	6895.62	63.909
2.44	272.06	7271.32	67.391
2.17	320.08	7761.25	71.931
1.94	408.63	8060.80	74.707
1.72	485.18	8387.61	77.736
1.53	603.28	8654.04	80.206
1.37	739.42	8999.82	83.410
1.22	989.25	9297.42	86.168
1.08	1293.29	9717.60	90.063
0.96	1900.27	10159.06	94.154
0.86	2802.02	10789.82	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	9.937
1.225	6.652
1.545	5.674
1.949	5.805
2.457	8.023
3.099	19.681
3.908	17.311
4.929	9.456
6.216	4.437
7.839	13.024

WEIGHT AVERAGE ESD = 2.334 MICROMETERS
WEIGHT AVERAGE SIGMA = 2.683 MICROMETERS
NUMBER AVERAGE ESD = 1.208 MICROMETERS

COULTER COUNTER
SPHERICAL PARTICLE SIZE ANALYSIS

SAMPLE NUMBER 16 FRACTIONS 22

ACCUMULATIVE SIZE DISTRIBUTION, MICROMETERS			
SIZE	AVERAGE COUNT	SUMMATION	WEIGHT PERCENT
9.82	0.0	0.0	0.0
8.74	0.0	1060.40	9.287
7.79	3.00	1560.35	13.665
6.93	5.00	1737.14	15.213
6.17	6.00	1737.14	15.213
5.50	6.00	2400.30	21.021
4.90	13.50	2369.03	20.747
4.36	13.00	2722.83	23.845
3.88	21.00	3285.81	28.776
3.46	39.00	4159.55	36.428
3.08	78.50	5184.30	45.402
2.74	144.02	6130.42	53.688
2.44	229.54	6948.33	60.851
2.17	334.09	7562.85	66.232
1.94	445.15	7987.73	69.953
1.72	553.74	8407.38	73.628
1.53	705.38	8676.79	75.988
1.37	843.05	9026.79	79.053
1.22	1095.92	9413.70	82.441
1.08	1491.21	9978.48	87.387
0.96	2307.08	10559.73	92.478
0.86	3494.35	11418.67	100.000

DIFFERENTIAL RESULTS	
AVERAGE DIAMETER	WEIGHT PERCENT
0.971	12.613
1.225	8.335
1.545	5.425
1.949	7.396
2.457	12.545
3.099	17.260
3.908	12.582
4.929	2.825
6.216	5.808
7.839	5.927

WEIGHT AVERAGE ESD = 1.911 MICROMETERS
WEIGHT AVERAGE SIGMA = 2.720 MICROMETERS
NUMBER AVERAGE ESD = 1.160 MICROMETERS

```

C      COULTER COUNTER SIZE ANALYSIS  PROGRAM NAME IS PSIZE
      DIMENSION AN(25,2),BKG(25,2),AVGCT(25),AVGBK(25),DELTA(25)
      DIMENSION DELSQ(25)
      DIMENSION DELNV(25),SUM(25),WTPER(25),DIA(25),WTDEL(10),AVGD(10)
1      READ(5,99)ITOT,NEXP
      READ(5,100)((AN(I,J),J=1,2),I=1,ITOT)
      READ(5,100)((BKG(I,J),J=1,2),I=1,ITOT)
      DO 4 I=1,ITOT
      AVGCT(I)=(AN(I,1)+AN(I,2))/2.0
4      AVGBK(I)=(BKG(I,1)+BKG(I,2))/2.0
      DO 5 K=1,ITOT
      AVGCT(K)=AVGCT(K)-AVGBK(K)
      COINC=((AVGCT(K)/1000.)*(AVGCT(K)/1000.))*0.77
5      AVGCT(K)=AVGCT(K)+COINC
      B=AVGCT(ITOT)
      K=2
      ITOT=ITOT-1
      DO 6 L=1,ITOT
      DELTA(L)=AVGCT(K)-AVGCT(K-1)
6      K=K+1
      V=499.8
      DELNV(1)=V*DELTA(1)
      DELSQ(1)=DELN(1)*V
      DO 7 K=2,ITOT
      V=V/1.414
      DELNV(K)=V*DELTA(K)
7      DELSQ(K)=DELN(K)*V
      SS=0.0
      C=0.0
      DO 8 K=1,ITOT
      SS=DELSQ(K)+SS
      SUM(K)=DELN(K)+C
8      C=SUM(K)
      CFM=(C*C)/B
      TSS=(SS-CFM)/B
      SIGMA=SQRT(TSS)
      SIGMA=((0.2395*SIGMA)**0.333)*2
      WTAvg=C/B
      DO 9 K=1,ITOT
9      WTPER(K)=(SUM(K)/C)*100.
      D=9.820
      DIA(1)=D
      DO 10 K=2,ITOT
      DIA(K)=D/1.123
10     D=DIA(K)
      ACON=0.0
      DO 11 K=1,ITOT
      A=(DIA(K)*DELTA(K))+ACON
11     ACON=A
      AVGN0=A/B
      MDEL=ITOT
      DO 109 M=1,10
      WTDEL(M)=WTPER(MDEL)-WTPER(MDEL-2)
      AVGD(M)=(DIA(MDEL)+DIA(MDEL-2))/2.0
109    MDEL=MDEL-2
      WRITE(6,196)
      WRITE(6,197)
      WRITE(6,198)NEXP,ITOT
      WRITE(6,199)

```

```
WRITE(6,200)
WRITE(6,201)(DIA(K),AVGCT(K),SUM(K),WTPER(K),K=1,ITOT)
WRITE(6,298)
WRITE(6,299)
WRITE(6,300)(AVGD(M),WTDEL(M),M=1,10)
WRITE(6,301)WTAVG
WRITE(6,303)SIGMA
WRITE(6,302)AVGNO
99  FORMAT(12,1X12)
100 FORMAT(F5.0,F5.0)
196 FORMAT('0', '          COULTER COUNTER ')
197 FORMAT('          SPHERICAL PARTICLE SIZE ANALYSIS')
198 FORMAT('0','SAMPLE NUMBER',1X12,3X,'FRACTIONS',1X12)
199 FORMAT('0',5X, 'ACUMMULATIVE SIZE DISTRIBUTION,MICRONS')
200 FORMAT(' SIZE      AVERAGE COUNT      SUMMATION      WEIGHT PERCENT')
201 FORMAT(F6.2,5XF9.2,6XF9.2,7XF7.3)
298 FORMAT('0','          DIFFERENTIAL RESULTS')
299 FORMAT('AVERAGE DIAMETER      WEIGHT PERCENT ')
300 FORMAT(5XF6.3,15XF6.3)
301 FORMAT('0','WEIGHT AVERAGE ESD =',1XF6.3,1X,'MICRONS')
303 FORMAT('WEIGHT AVERAGE SIGMA =',1XF6.3,1X,'MICRONS')
302 FORMAT('NUMBER AVERAGE ESD =',1XF6.3,1X,'MICRONS')
GO TO 1
END
```

APPENDIX IV

DETERMINATION OF RETENTION RATE

An extensive amount of preliminary work on fines retention was devoted to the determination of the rate of retention. Initially, rate measurements were tried at 500-700 r.p.m. agitation rates, but at these conditions, equilibrium was reached in less time than it took to take the first samples. Later, after it was found that representative fines samples could be obtained at a 150 r.p.m. agitation rate another attempt was made to measure the rate of retention. The basic technique that was used to determine the rate of retention was to add the fines rapidly to an agitated pulp suspension, i.e., a step function addition and then follow the approach to equilibrium.

In these experiments, 15.0 ml. of fines equivalent to a final fines concentration of ca. 1500 c.p.m./ml. were added to the pulp suspension at 0.10% consistency in about 2-3 sec. Samples of the fines suspension were taken every 2 sec. and analyzed in the scintillation counter. The data were plotted as concentration versus time and compared to blank curves obtained by adding fines at the same rate to a pulp free solution. Four experiments are summarized in Fig. 19. They are two blank determinations, one in distilled water and one in 0.25M sodium chloride solution, and two retention rate determinations, one in distilled water and the other in 0.25M sodium chloride.

As can be seen in Fig. 19, the blank step function in distilled water is a very good, smooth function. This is similar to the response expected for a well-mixed tank model. The curve obtained for the retention rate in distilled water indicates there may be a measurable approach to equilibrium. However, it would have been necessary to run a number of these experiments in order to have any

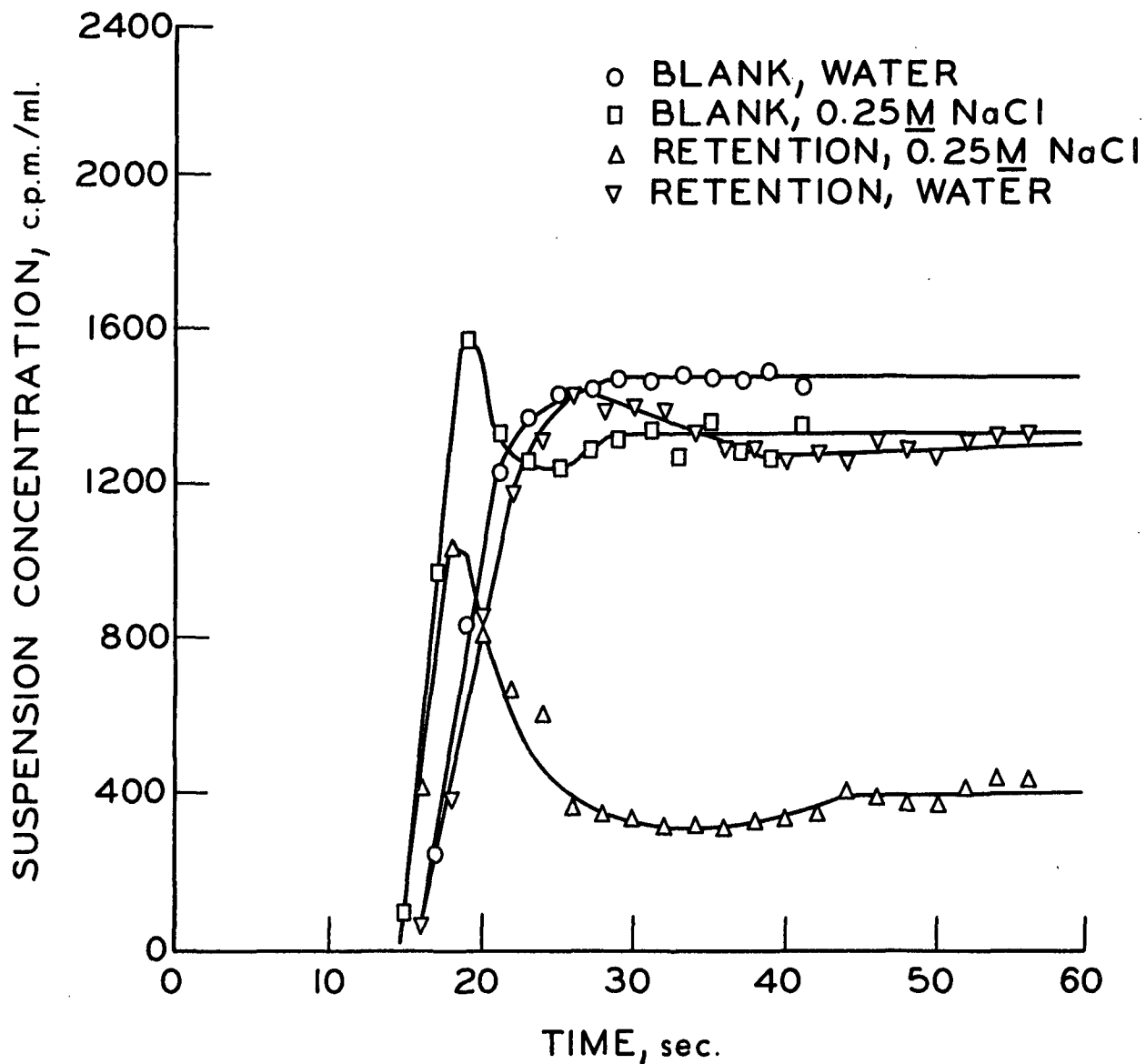


Figure 19. Rate of Retention Experimental Results

confidence in the data because of the extensive scatter. No attempt was made to analyze the data because of its inherent scatter at these low retention levels.

The blank step function for the addition of fines to 0.25M sodium chloride is more steep than that obtained in distilled water, and there is an apparent maximum concentration at ca. 19 sec. This indicates that the fines are not being dispersed efficiently in this electrolyte environment. Evidently, coagulation is occurring during the addition of the fines followed by a time dependent dispersion of the aggregates. This would make it impossible to measure the rate of retention since the blank depends on the rate of dispersion. However, the retention rate curve in 0.25M sodium chloride is also shown, but as was suggested, it would be very difficult to separate the blank curve from the rate curve with any degree of confidence. It can also be seen in this retention rate curve that another odd characteristic of it is the apparent gradual increase in concentration of fines which corresponds to decreasing retention. It should be pointed out that all the data from the coagulation and retention isotherms which were taken at 1.0-min. intervals 5.0 min. after the fines were added indicate the system was always at equilibrium since they do not vary significantly.

It was concluded from these data that the rate of retention could not be measured in this system with this technique. It was thought that the problem with fines coagulation during the step function addition could have been alleviated by a ramp function addition. A few experiments were performed with this technique, and the results were analyzed as a first-order reversible process, but again, the rates could not be determined successfully.

APPENDIX V

RETENTION ISOTHERM DATA AND RESULTS

The results of the retention isotherm experiments listed in Table XV can be found in subsequent pages, 126-153. The computer program used to treat the raw data is found at the end of this appendix.

TABLE XV

RETENTION ISOTHERM EXPERIMENTS

Experiment Number	Electrolyte		Final pH	Pulp Weight, g.	Temp., °C.
	Species	Concn., mM/l.			
Blank 4	NaCl	20.0	--	0.0	20.0
Blank 5	NaCl	20.0	--	0.0	20.0
Blank 6	CaCl ₂	2.0	--	0.0	20.0
Blank 7	LaCl ₃	0.2	--	0.0	20.0
Blank 9	CaCl ₂	2.0	--	0.0	20.0
Blank 10	LaCl ₃	0.2	--	0.0	20.0
Blank 11	HCl	--	1.18	0.0	20.0
Na-10	NaCl	20.1	5.60	0.999	20.0
Na-11	NaCl	20.0	5.55	0.974	20.0
Na-12	NaCl	74.0	5.70	0.508	20.0
Na-13	NaCl	72.0	5.56	1.948	20.0
Na-14	NaCl	72.5	5.55	3.780	20.0
Na-15	NaCl	73.0	5.69	1.017	50.0
Na-16	NaCl	74.0	5.73	1.006	50.0
Na-17	NaCl	71.0	5.64	1.006	40.0
Na-18	NaCl	74.0	5.62	0.981	40.0
Na-19	NaCl	70.5	5.62	0.999	30.0
Na-20	NaCl	71.5	5.62	1.005	30.0
Na-33	NaI	16.8	5.61	1.003	20.0
Na-34	Na ₂ SO ₄	16.8	5.52	1.052	20.0
Na-35	HCl	--	0.98	0.965	20.0
Ca-1	CaCl ₂	2.00	5.10	0.969	20.0
Ca-2	CaCl ₂	2.30	5.47	1.024	20.0
Ca-3	CaCl ₂	1.50	5.34	1.025	20.0
La-1	LaCl ₃	0.02	5.28	1.026	20.0
La-2	LaCl ₃	0.02	5.26	0.999	20.0
La-3	LaCl ₃	1.50	5.15	1.015	20.0
La-7	LaCl ₃	0.02	4.97	1.017	20.0

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 4
50.00 ML. OF FINES ADDED AT 93827.19 CPM/ML
BACKGROUND COUNT = 45.00 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.498	5.61	6380.	0.0	5.72	6374.	0.0	5.75	6329.
0.200	1.490	5.63	6338.	0.0	5.65	6264.	0.0	5.64	6316.
0.400	1.491	5.67	6271.	0.0	5.66	6276.	0.0	5.61	6292.
0.600	1.488	5.67	6195.	0.0	5.69	6218.	0.0	5.71	6311.
0.800	1.499	5.65	6163.	0.0	5.68	6226.	0.0	5.68	6232.
1.000	1.491	5.70	6139.	0.0	5.55	6194.	0.0	5.58	6290.
2.000	1.489	5.69	6071.	0.0	5.48	6227.	0.0	5.67	6052.
3.000	1.490	5.67	6052.	0.0	5.62	6179.	0.0	5.61	5979.
4.000	1.487	5.51	5931.	0.0	5.50	6058.	0.0	5.66	6133.
5.000	1.487	5.51	6073.	0.0	5.50	5731.	0.0	5.57	5745.
10.000	1.490	5.33	5847.	0.0	5.55	5719.	0.0	5.50	5734.
15.000	1.482	5.27	5658.	0.0	5.20	5677.	0.0	5.33	5684.
20.000	1.491	5.23	5566.	0.0	5.31	5606.	0.0	5.28	5546.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION		TOTAL VOLUME	PERCENT RETENTION
	INITIAL	FINAL		
0.0	4691.36	4691.36	1000.00	-0.000
0.200	4672.58	4665.60	999.53	0.149
0.400	4653.91	4644.06	999.06	0.211
0.600	4635.31	4603.06	998.59	0.696
0.800	4616.88	4583.29	998.12	0.728
1.000	4598.52	4601.29	997.65	-0.060
2.000	4580.06	4532.69	997.17	1.034
3.000	4561.89	4491.86	996.70	1.535
4.000	4543.89	4491.51	996.23	1.153
5.000	4525.87	4356.72	995.76	3.737
10.000	4508.44	4313.16	995.29	4.331
15.000	4491.19	4294.83	994.82	4.372
20.000	4474.01	4216.31	994.35	5.760
RETENTION STANDARD DEVIATION =			1.50	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM CONSTANT
AVERAGE	BLANK	CORRECTED	
-0.000	0.0	-0.000	-0.0000
0.149	0.0	0.149	0.0015
0.211	0.0	0.211	0.0021
0.696	0.0	0.696	0.0070
0.728	0.0	0.728	0.0073
-0.060	0.0	-0.060	-0.0006
1.034	0.0	1.034	0.0105
1.535	0.0	1.535	0.0156
1.153	0.0	1.153	0.0117
3.737	0.0	3.737	0.0388
4.331	0.0	4.331	0.0453
4.372	0.0	4.372	0.0457
5.760	0.0	5.760	0.0611

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 5
50.00 ML. OF FINES ADDED AT 101350.19 CPM/ML
BACKGROUND COUNT = 39.00 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.507	5.68	6942.	0.0	5.63	6962.	0.0	5.68	6884.
0.200	1.492	5.69	6930.	0.0	5.62	6876.	0.0	5.73	6796.
0.400	1.513	5.60	6904.	0.0	5.68	6795.	0.0	5.71	6862.
0.600	1.502	5.64	6851.	0.0	5.71	6844.	0.0	5.58	6827.
0.800	1.509	5.53	6777.	0.0	5.63	6863.	0.0	5.65	6816.
1.000	1.507	5.70	6737.	0.0	5.69	6673.	0.0	5.65	6776.
2.000	1.512	5.55	6654.	0.0	5.59	6735.	0.0	5.54	6752.
3.000	1.505	5.45	6612.	0.0	5.53	6706.	0.0	5.55	6670.
4.000	1.505	5.50	6548.	0.0	5.54	6696.	0.0	5.47	6536.
5.000	1.510	5.37	6462.	0.0	5.47	6521.	0.0	5.47	6417.
10.000	1.512	5.46	6308.	0.0	5.40	6319.	0.0	5.38	6286.
15.000	1.515	5.26	6106.	0.0	5.30	6143.	0.0	5.31	6871.
20.000	1.513	5.21	6042.	0.0	5.35	5975.	0.0	5.28	6098.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION		TOTAL VOLUME	PERCENT RETENTION
	INITIAL	FINAL		
0.0	5067.51	5067.52	1000.00	-0.000
0.200	5047.23	5016.50	999.48	0.609
0.400	5027.16	5011.79	998.95	0.306
0.600	5007.09	5008.31	998.43	-0.024
0.800	4987.01	5004.90	997.90	-0.359
1.000	4966.93	4914.74	997.38	1.051
2.000	4947.24	4940.76	996.86	0.131
3.000	4927.41	4918.50	996.33	0.181
4.000	4907.66	4869.05	995.81	0.787
5.000	4888.11	4795.38	995.28	1.897
10.000	4868.88	4681.04	994.76	3.858
15.000	4850.14	4769.91	994.24	1.654
20.000	4830.99	4521.16	993.71	6.413
RETENTION STANDARD DEVIATION =			2.00	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM CONSTANT
AVERAGE	BLANK	CORRECTED	
-0.000	0.0	-0.000	-0.0000
0.609	0.0	0.609	0.0061
0.306	0.0	0.306	0.0031
-0.024	0.0	-0.024	-0.0002
-0.359	0.0	-0.359	-0.0036
1.051	0.0	1.051	0.0106
0.131	0.0	0.131	0.0013
0.181	0.0	0.181	0.0018
0.787	0.0	0.787	0.0079
1.897	0.0	1.897	0.0193
3.858	0.0	3.858	0.0401
1.654	0.0	1.654	0.0168
6.413	0.0	6.413	0.0685

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 6
50.00 ML. OF FINES ADDED AT 101012.00 CPM/ML
BACKGROUND COUNT = 39.00 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.499	5.54	6850.	0.0	5.57	6820.	0.0	5.67	6898.
0.020	1.497	5.69	6818.	0.0	5.62	6781.	0.0	5.61	6760.
0.040	1.500	5.64	6778.	0.0	5.63	6810.	0.0	5.62	6773.
0.060	1.508	5.58	6839.	0.0	5.54	6720.	0.0	5.71	6735.
0.080	1.508	5.61	6745.	0.0	5.67	6719.	0.0	5.76	6734.
0.100	1.500	5.64	6609.	0.0	5.60	6680.	0.0	5.82	6627.
0.200	1.506	5.74	6486.	0.0	5.73	6538.	0.0	5.60	6607.
0.300	1.509	5.61	6632.	0.0	5.56	6626.	0.0	5.56	6560.
0.400	1.501	5.55	6544.	0.0	5.56	6512.	0.0	5.56	6485.
0.500	1.503	5.66	6557.	0.0	5.50	6510.	0.0	5.61	6400.
1.000	1.512	5.53	6193.	0.0	5.62	6257.	0.0	5.64	6187.
1.500	1.504	5.56	6087.	0.0	5.61	6067.	0.0	5.53	6062.
2.000	1.498	5.50	5911.	0.0	5.61	5970.	0.0	5.56	5913.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	5050.60	5050.88	1000.00	-0.006
0.020	5030.39	4984.72	999.49	0.908
0.040	5010.45	4988.05	998.98	0.447
0.060	4990.48	4977.97	998.47	0.250
0.080	4970.53	4932.69	997.96	0.761
0.100	4950.77	4861.45	997.45	1.804
0.200	4931.31	4790.50	996.94	2.855
0.300	4912.16	4870.63	996.43	0.845
0.400	4892.61	4808.05	995.92	1.728
0.500	4873.34	4779.96	995.41	1.916
1.000	4854.17	4572.97	994.90	5.793
1.500	4835.92	4477.47	994.39	7.412
2.000	4818.08	4375.96	993.88	9.176

RETENTION STANDARD DEVIATION = 0.77

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
-0.006	0.0	-0.006	-0.0001
0.908	0.0	0.908	0.0092
0.447	0.0	0.447	0.0045
0.250	0.0	0.250	0.0025
0.761	0.0	0.761	0.0077
1.804	0.0	1.804	0.0184
2.855	0.0	2.855	0.0294
0.845	0.0	0.845	0.0085
1.728	0.0	1.728	0.0176
1.916	0.0	1.916	0.0195
5.793	0.0	5.793	0.0615
7.412	0.0	7.412	0.0801
9.176	0.0	9.176	0.1010

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 7
50.00 ML. OF FINES ADDED AT 103266.19 CPM/ML
BACKGROUND COUNT = 40.00 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.486	5.69	6961.	0.0	5.74	6895.	0.0	5.58	6927.
0.002	1.487	5.74	6844.	0.0	5.69	6757.	0.0	5.76	6857.
0.004	1.486	5.66	6765.	0.0	5.67	6633.	0.0	5.73	6701.
0.006	1.469	5.78	6690.	0.0	5.74	6527.	0.0	5.68	6620.
0.008	1.474	5.66	6584.	0.0	5.86	6557.	0.0	5.80	6588.
0.010	1.477	5.67	6495.	0.0	5.66	6594.	0.0	5.73	6521.
0.020	1.472	5.67	6471.	0.0	5.72	6464.	0.0	5.81	6442.
0.030	1.473	5.83	6351.	0.0	5.68	6315.	0.0	5.70	6479.
0.040	1.471	5.63	6350.	0.0	5.76	6432.	0.0	5.72	6407.
0.050	1.476	5.58	6324.	0.0	5.63	6251.	0.0	5.76	6285.
0.100	1.480	5.68	6222.	0.0	5.69	6240.	0.0	5.69	6277.
0.150	1.485	5.70	6084.	0.0	5.63	6082.	0.0	5.67	5947.
0.200	1.488	5.71	6219.	0.0	5.70	6132.	0.0	5.79	6168.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	5163.31	5163.31	1000.00	-0.000
0.002	5142.64	5062.76	999.56	1.553
0.004	5122.41	4987.15	999.13	2.640
0.006	5102.50	4907.25	998.69	3.826
0.008	5082.92	4868.37	998.25	4.221
0.010	5063.50	4865.08	997.82	3.919
0.020	5044.07	4792.60	997.38	4.985
0.030	5024.95	4734.29	996.95	5.784
0.040	5006.08	4754.83	996.51	5.019
0.050	4987.09	4686.70	996.07	6.023
0.100	4968.39	4647.56	995.64	6.457
0.150	4949.86	4496.87	995.20	9.151
0.200	4931.97	4579.15	994.76	7.154

RETENTION STANDARD DEVIATION = 0.89

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
-0.000	0.0	-0.000	-0.0000
1.553	0.0	1.553	0.0158
2.640	0.0	2.640	0.0271
3.826	0.0	3.826	0.0398
4.221	0.0	4.221	0.0441
3.919	0.0	3.919	0.0408
4.985	0.0	4.985	0.0525
5.784	0.0	5.784	0.0614
5.019	0.0	5.019	0.0528
6.023	0.0	6.023	0.0641
6.457	0.0	6.457	0.0690
9.151	0.0	9.151	0.1007
7.154	0.0	7.154	0.0770

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 9
 50.00 ML. OF FINES ADDED AT 86065.00 CPM/ML
 BACKGROUND COUNT = 49.18 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.467	5.50	5727.	0.0	5.56	5696.	0.0	5.54	5662.
0.020	1.473	5.55	5632.	0.0	5.61	5717.	0.0	5.55	5615.
0.040	1.469	5.60	5629.	0.0	5.58	5722.	0.0	5.60	5665.
0.060	1.463	5.58	5615.	0.0	5.47	5514.	0.0	5.53	5624.
0.080	1.466	5.49	5559.	0.0	5.52	5496.	0.0	5.51	5608.
0.100	1.466	5.69	5579.	0.0	5.51	5582.	0.0	5.53	5615.
0.200	1.467	5.55	5532.	0.0	5.54	5579.	0.0	5.56	5511.
0.300	1.469	5.49	5519.	0.0	5.64	5548.	0.0	5.55	5535.
0.400	1.461	5.55	5460.	0.0	5.57	5421.	0.0	5.60	5602.
0.500	1.463	5.43	5390.	0.0	5.62	5525.	0.0	5.60	5359.
1.000	1.467	5.57	5595.	0.0	5.53	5406.	0.0	5.50	5313.
1.500	1.466	5.48	5238.	0.0	5.42	5234.	0.0	5.52	5433.
2.000	1.472	5.49	5164.	0.0	5.51	5224.	0.0	5.41	5182.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4303.25	4303.25	1000.00	-0.000
0.020	4286.03	4262.50	999.60	0.549
0.040	4268.98	4269.50	999.20	-0.012
0.060	4251.88	4220.48	998.80	0.738
0.080	4234.98	4203.03	998.40	0.754
0.100	4218.15	4213.17	998.00	0.118
0.200	4201.26	4181.14	997.59	0.479
0.300	4184.49	4173.62	997.19	0.260
0.400	4167.75	4139.54	996.79	0.677
0.500	4151.14	4093.06	996.39	1.399
1.000	4134.73	4107.09	995.99	0.669
1.500	4118.24	4018.45	995.59	2.423
2.000	4102.13	3934.20	995.19	4.094
RETENTION STANDARD DEVIATION =			1.22	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
-0.000	0.0	-0.000	-0.0000
0.549	0.0	0.549	0.0055
-0.012	0.0	-0.012	-0.0001
0.738	0.0	0.738	0.0074
0.754	0.0	0.754	0.0076
0.118	0.0	0.118	0.0012
0.479	0.0	0.479	0.0048
0.260	0.0	0.260	0.0026
0.677	0.0	0.677	0.0068
1.399	0.0	1.399	0.0142
0.669	0.0	0.669	0.0067
2.423	0.0	2.423	0.0248
4.094	0.0	4.094	0.0427

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 10
50.00 ML. OF FINES ADDED AT 85167.56 CPM/ML
BACKGROUND COUNT = 78.05 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.478	5.57	5668.	0.0	5.50	5771.	0.0	5.57	5748.
0.002	1.483	5.61	5683.	0.0	5.60	5706.	0.0	5.59	5645.
0.004	1.482	5.65	5569.	0.0	5.44	5688.	0.0	5.59	5589.
0.006	1.475	5.62	5536.	0.0	5.57	5581.	0.0	5.51	5677.
0.008	1.483	5.50	5532.	0.0	5.72	5432.	0.0	5.52	5458.
0.010	1.482	5.68	5535.	0.0	5.60	5461.	0.0	5.43	5430.
0.020	1.481	5.49	5150.	0.0	5.51	5492.	0.0	5.54	5459.
0.030	1.482	5.55	5482.	0.0	5.55	5384.	0.0	5.50	5408.
0.040	1.483	5.52	5254.	0.0	5.51	5213.	0.0	5.43	5264.
0.050	1.485	5.60	5272.	0.0	5.54	5269.	0.0	5.67	5104.
0.100	1.490	5.52	5074.	0.0	5.53	5103.	0.0	5.64	5046.
0.150	1.483	5.54	4981.	0.0	5.86	5081.	0.0	5.62	4997.
0.200	1.483	5.60	4949.	0.0	5.46	4914.	0.0	5.48	4955.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4258.38	4258.38	1000.00	-0.000
0.002	4241.34	4205.82	999.55	0.837
0.004	4224.52	4169.79	999.10	1.295
0.006	4207.84	4154.84	998.66	1.259
0.008	4191.21	4057.89	998.21	3.181
0.010	4175.00	4061.14	997.76	2.727
0.020	4158.77	3993.76	997.31	3.968
0.030	4142.82	4032.48	996.87	2.663
0.040	4126.68	3907.57	996.42	5.310
0.050	4111.09	3857.38	995.97	6.171
0.100	4095.71	3761.18	995.52	8.168
0.150	4080.74	3694.43	995.08	9.467
0.200	4066.05	3671.13	994.63	9.713
RETENTION STANDARD DEVIATION =			1.46	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
-0.000	0.0	-0.000	-0.0000
0.837	0.0	0.837	0.0084
1.295	0.0	1.295	0.0131
1.259	0.0	1.259	0.0128
3.181	0.0	3.181	0.0329
2.727	0.0	2.727	0.0280
3.968	0.0	3.968	0.0413
2.663	0.0	2.663	0.0274
5.310	0.0	5.310	0.0561
6.171	0.0	6.171	0.0658
8.168	0.0	8.168	0.0889
9.467	0.0	9.467	0.1046
9.713	0.0	9.713	0.1076

RETENTION ISOTHERM RESULTS

CATION BL EXPERIMENT 11
50.00 ML. OF FINES ADDED AT 88618.38 CPM/ML
BACKGROUND COUNT = 40.10 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
5.380	1.427	5.75	5741.	0.0	5.56	5739.	0.0	5.61	5780.
4.050	1.437	5.50	5715.	0.0	5.58	5627.	0.0	5.49	5695.
3.780	1.429	5.57	5455.	0.0	5.57	5521.	0.0	5.63	5403.
3.600	1.419	5.56	5506.	0.0	5.45	5481.	0.0	5.59	5570.
3.420	1.426	5.58	5410.	0.0	5.52	5444.	0.0	5.53	5450.
3.010	1.438	5.44	5053.	0.0	5.34	5052.	0.0	5.33	5071.
2.700	1.424	5.14	4856.	0.0	5.04	4935.	0.0	5.14	5099.
2.530	1.443	4.85	4972.	0.0	4.89	5066.	0.0	4.92	4880.
2.300	1.595	4.67	5318.	0.0	4.78	4807.	0.0	4.83	4872.
2.150	1.429	4.33	4862.	0.0	4.43	4786.	0.0	4.31	4879.
1.710	1.446	3.57	4412.	0.0	3.58	4546.	0.0	3.64	4528.
1.370	1.433	3.21	4429.	0.0	3.14	4362.	0.0	3.14	4250.
1.180	1.268	3.12	3928.	0.0	2.96	4173.	0.0	2.93	4219.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
5.380	4430.92	4430.92	1000.00	-0.000
4.050	4413.19	4405.76	999.70	0.168
3.780	4395.55	4216.49	999.41	4.074
3.600	4378.73	4277.86	999.11	2.303
3.420	4361.63	4209.20	998.82	3.495
3.010	4344.81	3959.27	998.52	8.874
2.700	4329.06	3950.62	998.22	8.742
2.530	4313.34	4015.50	997.93	6.905
2.300	4297.32	4072.01	997.63	5.243
2.150	4281.06	4051.28	997.33	5.367
1.710	4264.88	3964.48	997.04	7.043
1.370	4249.06	3955.77	996.74	6.902
1.180	4233.27	3781.26	996.45	10.678
RETENTION STANDARD DEVIATION =			2.33	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
-0.000	0.0	-0.000	-0.0000
0.168	0.0	0.168	0.0017
4.074	0.0	4.074	0.0425
2.303	0.0	2.303	0.0236
3.495	0.0	3.495	0.0362
8.874	0.0	8.874	0.0974
8.742	0.0	8.742	0.0958
6.905	0.0	6.905	0.0742
5.243	0.0	5.243	0.0553
5.367	0.0	5.367	0.0567
7.043	0.0	7.043	0.0758
6.902	0.0	6.902	0.0741
10.678	0.0	10.678	0.1195

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 10
50.00 ML. OF FINES ADDED AT 92837.50 CPM/ML
BACKGROUND COUNT = 43.33 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.379	5.72	5733.	1.389	5.67	5759.	1.377	5.65	5694.
0.200	1.358	5.68	5445.	1.384	5.65	5610.	1.362	5.68	5595.
0.400	1.376	5.71	5489.	1.381	5.58	5521.	1.360	5.65	5440.
0.600	1.361	5.71	5393.	1.363	5.62	5297.	1.360	5.62	5429.
0.800	1.366	5.71	5327.	1.366	5.73	5362.	1.366	5.55	5342.
1.000	1.371	5.58	5341.	1.364	5.53	5305.	1.370	5.58	5277.
2.000	1.367	5.59	4940.	1.368	5.59	4962.	1.366	5.55	4924.
3.000	1.372	5.62	4514.	1.356	5.38	4658.	1.364	5.57	4609.
4.000	1.365	5.60	4302.	1.367	5.53	4420.	1.369	5.51	4333.
5.000	1.375	5.51	4222.	1.364	5.53	4259.	1.376	5.43	4184.
10.000	1.379	5.42	4019.	1.368	5.29	4098.	1.372	5.42	4107.
15.000	1.371	5.29	4047.	1.368	5.32	4110.	1.372	5.36	4146.
20.000	1.368	5.23	4312.	1.372	5.25	4131.	1.373	5.14	4210.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4641.88	4558.45	1000.00	1.797
0.200	4623.65	4462.40	999.89	3.487
0.400	4605.81	4401.16	999.78	4.443
0.600	4588.23	4345.47	999.67	5.291
0.800	4570.86	4301.54	999.56	5.892
1.000	4553.68	4292.89	999.45	5.727
2.000	4536.52	3995.42	999.34	11.928
3.000	4520.59	3732.69	999.23	17.429
4.000	4505.73	3520.76	999.12	21.860
5.000	4491.75	3414.57	999.01	23.981
10.000	4478.19	3316.26	998.90	25.946
15.000	4465.04	3355.01	998.79	24.860
20.000	4451.73	3476.17	998.68	21.914
RETENTION STANDARD DEVIATION =			1.18	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
1.797	0.0	1.797	0.0183
3.487	0.0	3.487	0.0361
4.443	0.0	4.443	0.0465
5.291	0.0	5.291	0.0559
5.892	0.200	5.704	0.0605
5.727	0.300	5.444	0.0576
11.928	0.600	11.399	0.1287
17.429	0.900	16.686	0.2003
21.860	1.200	20.923	0.2646
23.981	1.600	22.765	0.2947
25.946	4.000	22.984	0.2984
24.860	5.500	20.728	0.2615
21.914	6.000	17.229	0.2082

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 11
25.00 ML. OF FINES ADDED AT 91866.19 CPM/ML
BACKGROUND COUNT = 49.00 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.360	5.62	2812.	1.361	5.68	2841.	1.361	5.71	2813.
0.200	1.359	5.53	2834.	1.363	5.66	2835.	1.360	5.68	2792.
0.400	1.361	5.79	2750.	1.352	5.78	2766.	1.356	5.62	2738.
0.600	1.362	5.78	2747.	1.365	5.74	2754.	1.357	5.71	2724.
0.800	1.359	5.79	2682.	1.359	5.71	2609.	1.365	5.68	2730.
1.000	1.532	5.68	2926.	1.358	5.73	2673.	1.354	5.68	2645.
2.000	1.355	5.61	2436.	1.355	5.65	2452.	1.359	5.66	2439.
3.000	1.358	5.55	2299.	1.185	5.76	2022.	1.353	5.58	2300.
4.000	1.360	5.52	2189.	1.702	5.22	2644.	1.357	5.48	2197.
5.000	1.354	5.46	2087.	1.354	5.47	2099.	1.354	5.54	2075.
10.000	1.357	5.33	1996.	1.358	5.28	2016.	1.362	5.33	2080.
15.000	1.358	5.26	2013.	1.359	5.28	2015.	1.355	5.19	1970.
20.000	1.358	5.20	1999.	1.358	5.16	2006.	1.357	5.17	2038.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	2296.65	2258.99	1000.00	1.640
0.200	2287.62	2264.62	999.88	1.005
0.400	2278.56	2199.98	999.77	3.449
0.600	2269.77	2182.59	999.65	3.841
0.800	2261.04	2130.05	999.54	5.793
1.000	2252.54	2112.31	999.42	6.225
2.000	2244.10	1959.12	999.31	12.699
3.000	2236.29	1846.85	999.19	17.414
4.000	2228.94	1758.59	999.07	21.102
5.000	2221.95	1687.04	998.96	24.074
10.000	2215.26	1653.43	998.84	25.362
15.000	2208.70	1636.23	998.73	25.919
20.000	2202.21	1655.61	998.61	24.820
RETENTION STANDARD DEVIATION =			1.00	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
1.640	0.0	1.640	0.0167
1.005	0.0	1.005	0.0102
3.449	0.0	3.449	0.0357
3.841	0.0	3.841	0.0399
5.793	0.200	5.605	0.0594
6.225	0.300	5.944	0.0632
12.699	0.600	12.175	0.1386
17.414	0.900	16.671	0.2001
21.102	1.200	20.155	0.2524
24.074	1.600	22.859	0.2963
25.362	4.000	22.376	0.2883
25.919	5.500	21.844	0.2795
24.820	6.000	20.310	0.2549

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 12
50.00 ML. OF FINES ADDED AT 80333.88 CPM/ML
BACKGROUND COUNT = 43.49 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.463	5.83	5375.	1.443	5.75	5349.	1.454	5.60	5220.
0.005	1.445	5.71	5252.	1.465	5.74	5453.	1.460	5.71	5403.
0.010	1.468	5.78	5371.	1.460	5.74	5470.	1.450	5.80	5313.
0.050	1.471	5.79	5465.	1.451	5.77	5308.	1.452	5.76	5398.
0.100	1.475	5.71	5392.	1.474	5.71	5359.	1.455	5.67	5385.
1.100	1.485	5.65	5219.	1.451	5.66	5162.	1.465	5.60	5137.
2.100	1.453	5.64	4939.	1.464	5.64	4929.	1.478	5.57	5011.
3.100	1.459	5.61	4756.	1.457	5.64	4649.	1.480	5.63	4734.
4.100	1.454	5.58	4572.	1.464	5.58	4590.	1.453	5.59	4543.
9.100	1.471	5.41	4354.	1.469	5.48	4379.	1.466	5.42	4262.
29.100	1.452	5.15	4089.	1.481	5.18	4269.	1.483	5.24	4207.
49.100	1.454	5.05	4067.	1.476	5.08	4180.	1.456	5.05	4107.
69.100	1.461	4.91	4058.	1.468	5.00	4090.	1.456	4.97	4119.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4016.69	4006.78	1000.00	0.247
0.005	4000.66	4040.03	999.61	-0.984
0.010	3984.48	4030.43	999.23	-1.153
0.050	3968.32	4039.45	998.84	-1.793
0.100	3952.11	4022.10	998.45	-1.771
1.100	3935.96	3883.29	998.06	1.338
2.100	3920.41	3733.20	997.68	4.775
3.100	3905.51	3541.81	997.29	9.312
4.100	3891.44	3461.10	996.90	11.059
9.100	3877.72	3283.73	996.51	15.318
29.100	3864.76	3217.56	996.13	16.746
49.100	3852.09	3212.36	995.74	16.607
69.100	3839.43	3210.59	995.35	16.378

RETENTION STANDARD DEVIATION = 0.97

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
0.247	0.0	0.247	0.0025
-0.984	0.0	-0.984	-0.0097
-1.153	0.0	-1.153	-0.0114
-1.793	0.0	-1.793	-0.0176
-1.771	0.0	-1.771	-0.0174
1.338	0.0	1.338	0.0136
4.775	0.600	4.204	0.0439
9.312	0.900	8.496	0.0929
11.059	1.200	9.991	0.1110
15.318	3.600	12.269	0.1399
16.746	6.000	11.751	0.1332
16.607	6.000	11.604	0.1313
16.378	6.000	11.361	0.1282

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 13
50.00 ML. OF FINES ADDED AT 81680.13 CPM/ML
BACKGROUND COUNT = 43.49 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.335	5.77	4873.	1.342	5.73	4870.	1.340	5.86	4846.
0.005	1.340	5.90	4800.	1.342	5.71	4867.	1.343	5.72	4884.
0.010	1.350	5.81	4854.	1.347	5.92	4748.	1.347	5.92	4767.
0.050	1.351	5.80	4781.	1.346	5.66	4725.	1.348	5.72	4784.
0.100	1.347	5.72	4696.	1.350	5.80	4740.	1.351	5.75	4709.
1.100	1.359	5.65	4380.	1.357	5.65	4382.	1.355	5.63	4336.
2.100	1.356	5.63	3975.	1.356	5.78	3949.	1.352	5.63	3956.
3.100	1.354	5.58	3473.	1.357	5.64	3516.	1.355	5.67	3554.
4.100	1.361	5.54	3362.	1.356	5.61	3376.	1.362	5.57	3351.
9.100	1.368	5.52	3087.	1.368	5.51	3017.	1.369	5.58	3016.
29.100	1.370	5.34	3167.	1.356	5.28	3106.	1.368	5.35	3129.
49.100	1.372	5.07	2980.	1.370	5.05	2932.	1.374	5.04	3107.
69.100	1.372	4.97	3147.	1.376	5.02	2993.	1.374	5.04	3075.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4084.01	3960.80	1000.00	3.017
0.005	4068.17	3945.23	999.93	3.022
0.010	4052.40	3852.25	999.86	4.939
0.050	4037.00	3867.30	999.79	4.203
0.100	4021.54	3817.04	999.72	5.085
1.100	4006.28	3537.00	999.65	11.713
2.100	3992.16	3202.49	999.58	19.780
3.100	3979.40	2845.72	999.51	28.489
4.100	3968.09	2722.26	999.44	31.396
9.100	3957.28	2448.02	999.37	38.139
29.100	3947.59	2566.36	999.30	34.989
49.100	3937.41	2490.43	999.23	36.749
69.100	3927.54	2548.53	999.16	35.111
RETENTION STANDARD DEVIATION =				1.03

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
3.017	0.0	3.017	0.0311
3.022	0.0	3.022	0.0312
4.939	0.0	4.939	0.0520
4.203	0.0	4.203	0.0439
5.085	0.0	5.085	0.0536
11.713	0.0	11.713	0.1327
19.780	0.600	19.299	0.2391
28.489	0.900	27.845	0.3859
31.396	1.200	30.573	0.4404
38.139	3.600	35.912	0.5603
34.989	6.000	31.088	0.4511
36.749	6.000	32.954	0.4915
35.111	6.000	31.218	0.4539

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 14
50.00 ML. OF FINES ADDED AT 84211.75 CPM/ML
BACKGROUND COUNT = 48.50 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.399	5.81	4773.	1.401	5.79	4681.	1.393	5.68	4625.
0.005	1.402	5.68	4630.	1.409	5.77	4709.	1.393	5.80	4731.
0.010	1.389	5.70	4669.	1.402	5.60	4784.	1.386	5.71	4661.
0.050	1.404	5.74	4620.	1.394	5.74	4654.	1.395	5.78	4699.
0.100	1.396	5.73	4475.	1.387	5.67	4545.	1.379	5.76	4471.
1.100	1.395	5.63	3791.	1.395	5.67	3866.	1.407	5.68	3783.
2.100	1.406	5.66	3367.	1.588	5.45	3624.	1.401	5.65	3194.
3.100	1.410	5.65	2801.	1.410	5.58	2870.	1.403	5.56	2868.
4.100	1.412	5.57	2458.	1.417	5.58	2635.	1.412	5.59	2624.
9.100	1.414	5.43	2305.	1.419	5.50	2293.	1.427	5.49	2237.
29.100	1.421	5.29	2186.	1.424	5.27	2303.	1.425	5.22	2254.
49.100	1.425	5.09	2186.	1.422	5.04	2221.	1.418	5.08	2313.
69.100	1.422	5.02	2244.	1.424	4.95	2262.	1.426	5.02	2370.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4210.59	3663.14	1000.00	13.002
0.005	4196.05	3653.51	999.78	12.930
0.010	4181.55	3706.95	999.56	11.350
0.050	4166.82	3637.23	999.33	12.710
0.100	4152.38	3543.49	999.11	14.664
1.100	4138.32	2984.58	998.89	27.879
2.100	4126.63	2547.09	998.67	38.277
3.100	4116.77	2213.31	998.45	46.237
4.100	4108.32	1990.16	998.22	51.558
9.100	4100.82	1762.94	998.00	57.010
29.100	4094.28	1758.10	997.78	57.060
49.100	4087.75	1775.75	997.56	56.559
69.100	4081.14	1823.71	997.34	55.314
RETENTION STANDARD DEVIATION =			1.21	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
13.002	0.0	13.002	0.1494
12.930	0.0	12.930	0.1485
11.350	0.0	11.350	0.1280
12.710	0.0	12.710	0.1456
14.664	0.0	14.664	0.1718
27.879	0.0	27.879	0.3866
38.277	0.600	37.906	0.6105
46.237	0.900	45.753	0.8434
51.558	1.200	50.976	1.0398
57.010	3.600	55.463	1.2453
57.060	6.000	54.483	1.1970
56.559	6.000	53.953	1.1717
55.314	6.000	52.632	1.1111

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 15
50.00 ML. OF FINES ADDED AT 80657.38 CPM/ML
BACKGROUND COUNT = 38.60 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.390	5.79	4889.	1.383	5.77	4862.	1.372	5.85	4822.
0.005	1.380	5.69	4785.	1.388	5.78	4901.	1.381	5.84	4880.
0.010	1.381	5.82	4802.	1.390	5.77	4833.	1.394	5.78	4918.
0.050	1.395	5.68	4902.	1.398	5.84	4901.	1.416	5.73	4866.
0.100	1.419	5.71	4884.	1.403	5.78	4857.	1.403	5.79	4952.
1.100	1.413	5.67	4308.	1.393	5.69	4227.	1.404	5.67	4277.
2.100	1.400	5.66	3839.	1.384	5.68	3784.	1.386	5.63	3819.
3.100	1.403	5.57	3567.	1.396	5.60	3471.	1.412	5.69	3660.
4.100	1.402	5.71	3511.	1.432	5.67	3686.	1.406	5.53	3695.
9.100	1.401	5.38	3373.	1.404	5.51	3452.	1.386	5.36	3425.
29.100	1.411	5.30	3263.	1.423	5.29	3537.	1.411	5.21	3575.
49.100	1.403	5.11	3391.	1.415	5.11	3391.	1.408	5.11	3302.
69.100	1.406	5.01	3413.	1.415	5.02	3303.	1.413	5.02	3270.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4032.87	3833.93	1000.00	4.933
0.005	4017.57	3836.59	999.80	4.505
0.010	4002.25	3814.17	999.60	4.699
0.050	3987.03	3814.47	999.40	4.328
0.100	3971.79	3802.83	999.19	4.254
1.100	3956.60	3340.95	998.99	15.560
2.100	3943.35	3013.68	998.79	23.576
3.100	3931.46	2794.29	998.59	28.925
4.100	3920.50	2822.98	998.39	27.994
9.100	3909.41	2723.66	998.19	30.330
29.100	3898.73	2748.15	997.99	29.512
49.100	3887.95	2709.86	997.78	30.301
69.100	3877.32	2694.26	997.58	30.512
RETENTION STANDARD DEVIATION =			1.48	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
4.933	0.0	4.933	0.0519
4.505	0.0	4.505	0.0472
4.699	0.0	4.699	0.0493
4.328	0.0	4.328	0.0452
4.254	0.0	4.254	0.0444
15.560	0.0	15.560	0.1843
23.576	0.600	23.117	0.3007
28.925	0.900	28.285	0.3944
27.994	1.200	27.130	0.3723
30.330	3.600	27.822	0.3855
29.512	6.000	25.282	0.3384
30.301	6.000	26.119	0.3535
30.512	6.000	26.343	0.3576

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 16
50.00 ML. OF FINES ADDED AT 80657.38 CPM/ML
BACKGROUND COUNT = 36.50 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.327	5.97	4905.	1.370	5.83	4928.	1.349	5.97	4958.
0.005	1.354	5.73	4780.	1.352	5.84	4874.	1.354	5.80	4884.
0.010	1.350	5.73	4887.	1.352	5.85	4917.	1.354	5.92	4937.
0.050	1.349	5.91	4915.	1.356	5.70	4954.	1.357	5.95	4951.
0.100	1.362	5.83	4841.	1.363	5.85	4909.	1.364	5.87	4911.
1.100	1.361	5.80	4273.	1.361	5.72	4220.	1.364	5.67	4316.
2.100	1.362	5.84	3767.	1.364	5.68	3744.	1.364	5.89	3773.
3.100	1.362	5.67	3472.	1.362	5.64	3587.	1.366	5.66	3640.
4.100	1.361	5.64	3563.	1.372	5.68	3580.	1.374	5.62	3543.
9.100	1.363	5.48	3463.	1.368	5.58	3479.	1.371	5.54	3391.
29.100	1.377	5.18	3414.	1.379	5.36	3283.	1.374	5.30	3318.
49.100	1.378	5.17	3417.	1.379	5.10	3351.	1.372	5.19	3304.
69.100	1.381	4.95	3403.	1.383	5.03	3322.	1.384	4.97	3432.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION		TOTAL VOLUME	PERCENT RETENTION
	INITIAL	FINAL		
0.0	4032.87	3959.16	1000.00	1.828
0.005	4017.04	3909.15	999.92	2.686
0.010	4001.41	3958.27	999.84	1.078
0.050	3985.57	3969.74	999.75	0.397
0.100	3969.69	3899.75	999.67	1.762
1.100	3954.09	3433.14	999.59	13.175
2.100	3940.40	3003.40	999.51	23.779
3.100	3928.45	2871.42	999.43	26.907
4.100	3917.05	2858.86	999.35	27.015
9.100	3905.69	2787.06	999.26	28.641
29.100	3894.63	2726.23	999.18	30.000
49.100	3883.81	2763.88	999.10	28.836
69.100	3872.83	2805.96	999.02	27.548
RETENTION STANDARD DEVIATION =			1.09	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM CONSTANT
AVERAGE	BLANK	CORRECTED	
1.828	0.0	1.828	0.0186
2.686	0.0	2.686	0.0276
1.078	0.0	1.078	0.0109
0.397	0.0	0.397	0.0040
1.762	0.0	1.762	0.0179
13.175	0.0	13.175	0.1517
23.779	0.600	23.322	0.3042
26.907	0.900	26.249	0.3559
27.015	1.200	26.139	0.3539
28.641	3.600	26.072	0.3527
30.000	6.000	25.800	0.3477
28.836	6.000	24.566	0.3257
27.548	6.000	23.201	0.3021

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 17
50.00 ML. OF FINES ADDED AT 80657.38 CPM/ML
BACKGROUND COUNT = 42.85 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.297	5.82	4671.	1.283	5.79	4614.	1.285	5.89	4597.
0.005	1.270	5.86	4598.	1.278	5.81	4510.	1.229	5.89	4453.
0.010	1.292	5.85	4530.	1.284	5.81	4567.	1.301	5.92	4653.
0.050	1.304	5.84	4611.	1.312	5.87	4646.	1.313	5.81	4639.
0.100	1.313	5.76	4534.	1.310	5.86	4557.	1.314	5.79	4570.
1.100	1.313	5.78	4236.	1.321	5.80	4146.	1.318	5.74	4264.
2.100	1.320	5.84	3736.	1.324	5.73	3700.	1.319	5.74	3673.
3.100	1.316	5.73	3574.	1.321	5.66	3517.	1.324	5.73	3584.
4.100	1.312	5.63	3529.	1.315	5.68	3472.	1.314	5.63	3442.
9.100	1.309	5.65	3383.	1.313	5.69	3306.	1.315	5.57	3329.
29.100	1.317	5.36	3350.	1.323	5.31	3489.	1.324	5.26	3491.
49.100	1.322	5.20	3457.	1.323	5.11	3289.	1.326	5.22	3358.
69.100	1.323	4.94	3403.	1.332	5.09	3334.	1.329	5.09	3374.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4032.87	3904.10	1000.00	3.193
0.005	4017.24	3896.69	1000.08	3.001
0.010	4001.65	3849.13	1000.15	3.811
0.050	3986.25	3842.92	1000.23	3.595
0.100	3970.87	3778.12	1000.30	4.854
1.100	3955.75	3488.94	1000.38	11.801
2.100	3941.76	3051.98	1000.45	22.573
3.100	3929.50	2944.60	1000.53	25.064
4.100	3917.65	2905.96	1000.60	25.824
9.100	3905.96	2789.87	1000.68	28.574
29.100	3894.72	2919.16	1000.75	25.048
49.100	3882.98	2873.09	1000.83	26.008
69.100	3871.43	2892.28	1000.90	25.292
RETENTION STANDARD DEVIATION = 1.13				

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
3.193	0.0	3.193	0.0330
3.001	0.0	3.001	0.0309
3.811	0.0	3.811	0.0396
3.595	0.0	3.595	0.0373
4.854	0.0	4.854	0.0510
11.801	0.0	11.801	0.1338
22.573	0.600	22.109	0.2838
25.064	0.900	24.390	0.3226
25.824	1.200	24.934	0.3322
28.574	3.600	26.003	0.3514
25.048	6.000	20.551	0.2587
26.008	6.000	21.569	0.2750
25.292	6.000	20.809	0.2628

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 18
50.00 ML. OF FINES ADDED AT 80657.38 CPM/ML
BACKGROUND COUNT = 42.85 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.300	5.87	4728.	1.294	5.96	4681.	1.299	5.92	4738.
0.005	1.298	5.85	4728.	1.456	5.77	5200.	1.459	5.84	5170.
0.010	1.454	5.71	5095.	1.630	5.62	5717.	1.460	5.73	5135.
0.050	1.463	5.77	5108.	1.468	5.81	5087.	1.466	5.82	5130.
0.100	1.462	5.71	5101.	1.464	5.76	5158.	1.468	5.71	5140.
1.100	1.463	5.64	4676.	1.468	5.61	4654.	1.468	5.75	4674.
2.100	1.470	5.64	4171.	1.468	5.56	4208.	1.469	5.64	4269.
3.100	1.465	5.59	3938.	1.469	5.55	4019.	1.473	5.58	3996.
4.100	1.472	5.58	3984.	1.467	5.50	3858.	1.472	5.49	3912.
9.100	1.479	5.50	3800.	1.477	5.44	3765.	1.475	5.51	3900.
29.100	1.484	5.12	3827.	1.487	5.21	3781.	1.482	5.17	3925.
49.100	1.481	5.02	3866.	1.486	4.97	3798.	1.481	5.06	3871.
69.100	1.483	4.98	3762.	1.491	4.87	3714.	1.488	4.88	3662.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4032.87	3930.37	1000.00	2.541
0.005	4017.17	3904.11	999.67	2.815
0.010	4001.59	3854.78	999.33	3.669
0.050	3986.20	3800.66	999.00	4.654
0.100	3971.04	3838.26	998.67	3.344
1.100	3955.71	3497.28	998.34	11.589
2.100	3941.84	3159.89	998.00	19.837
3.100	3929.43	2992.29	997.67	23.849
4.100	3917.74	2949.26	997.34	24.720
9.100	3906.24	2869.62	997.01	26.538
29.100	3895.07	2931.06	996.67	24.749
49.100	3883.62	2964.07	996.34	23.678
69.100	3872.02	2871.71	996.01	25.834
RETENTION STANDARD DEVIATION = 0.91				

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
2.541	0.0	2.541	0.0261
2.815	0.0	2.815	0.0290
3.669	0.0	3.669	0.0381
4.654	0.0	4.654	0.0488
3.344	0.0	3.344	0.0346
11.589	0.0	11.589	0.1311
19.837	0.600	19.356	0.2400
23.849	0.900	23.164	0.3015
24.720	1.200	23.817	0.3126
26.538	3.600	23.893	0.3139
24.749	6.000	20.234	0.2537
23.678	6.000	19.098	0.2361
25.834	6.000	21.384	0.2720

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 19
50.00 ML. OF FINES ADDED AT 80806.50 CPM/ML
BACKGROUND COUNT = 40.56 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.496	5.61	5338.	1.499	5.76	5315.	1.495	5.62	5325.
0.005	1.493	5.77	5300.	1.492	5.76	5321.	1.494	5.78	5267.
0.010	1.493	5.70	5244.	1.488	5.81	5236.	1.486	5.67	5299.
0.050	1.486	5.66	5266.	1.491	5.72	5268.	1.487	5.81	5283.
0.100	1.489	5.68	5243.	1.487	5.65	5260.	1.324	5.84	4673.
1.100	1.493	5.62	4889.	1.498	5.56	4979.	1.494	5.69	4965.
2.100	1.491	5.58	4446.	1.490	5.54	4441.	1.487	5.61	4505.
3.100	1.488	5.55	4087.	1.493	5.54	4130.	1.829	5.40	4910.
4.100	1.493	5.48	3952.	1.494	5.52	4000.	1.490	5.46	4011.
9.100	1.492	5.43	3872.	1.492	5.38	3989.	1.493	5.40	3967.
29.100	1.496	5.07	3772.	1.494	5.15	3832.	1.494	5.20	3892.
49.100	1.500	5.05	3805.	1.495	5.01	3794.	1.494	5.13	3857.
69.100	1.498	4.91	3764.	1.499	4.84	3792.	1.502	4.86	3843.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4040.32	3916.72	1000.00	3.059
0.005	4024.71	3877.41	999.52	3.660
0.010	4009.26	3871.40	999.04	3.438
0.050	3993.81	3883.43	998.56	2.764
0.100	3978.30	3867.64	998.09	2.782
1.100	3962.85	3647.01	997.61	7.970
2.100	3948.37	3312.20	997.13	16.112
3.100	3935.38	3033.58	996.65	22.915
4.100	3923.64	2965.69	996.17	24.415
9.100	3912.18	2947.41	995.69	24.661
29.100	3900.80	2908.74	995.21	25.432
49.100	3889.58	2908.97	994.74	25.211
69.100	3878.35	2925.66	994.26	24.564
RETENTION STANDARD DEVIATION = 0.81				

CORRECTED RESULTS

AVERAGE	PERCENT BLANK	RETENTION CORRECTED	EQUILIBRIUM CONSTANT
3.059	0.0	3.059	0.0316
3.660	0.0	3.660	0.0380
3.438	0.0	3.438	0.0356
2.764	0.0	2.764	0.0284
2.782	0.0	2.782	0.0286
7.970	0.0	7.970	0.0866
16.112	0.600	15.609	0.1850
22.915	0.900	22.221	0.2857
24.415	1.200	23.508	0.3073
24.661	3.600	21.949	0.2812
25.432	6.000	20.958	0.2652
25.211	6.000	20.724	0.2614
24.564	6.000	20.038	0.2506

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 20
50.00 ML. OF FINES ADDED AT 80749.69 CPM/ML
BACKGROUND COUNT = 43.49 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.483	5.78	5404.	1.486	5.59	5315.	1.489	5.58	5319.
0.005	1.487	5.71	5304.	1.486	5.79	5234.	1.491	5.62	5332.
0.010	1.491	5.72	5293.	1.490	5.81	5349.	1.488	5.73	5275.
0.050	1.493	5.72	5393.	1.490	5.68	5240.	1.551	5.58	5521.
0.100	1.499	5.77	5195.	1.498	5.61	5254.	1.498	5.74	5237.
1.100	1.501	5.61	4971.	1.494	5.59	4963.	1.494	5.65	4993.
2.100	1.494	5.60	4560.	1.499	5.55	4554.	1.495	5.60	4529.
3.100	1.499	5.48	4174.	1.498	5.54	4242.	1.496	5.54	4237.
4.100	1.500	5.55	4130.	1.498	5.53	4058.	1.501	5.47	4087.
9.100	1.498	5.43	3928.	1.501	5.40	3906.	1.501	5.44	3873.
29.100	1.502	5.21	3879.	1.505	5.13	3995.	1.503	5.21	4066.
49.100	1.509	4.99	3997.	1.508	5.01	4004.	1.507	5.07	4022.
69.100	1.508	4.90	3692.	1.509	4.95	3931.	1.511	4.95	3762.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4037.48	3960.18	1000.00	1.915
0.005	4021.67	3899.15	999.51	3.046
0.010	4006.12	3895.78	999.02	2.754
0.050	3990.57	3920.13	998.52	1.765
0.100	3974.89	3827.44	998.03	3.710
1.100	3959.62	3665.37	997.54	7.431
2.100	3945.06	3355.99	997.05	14.932
3.100	3931.88	3117.92	996.56	20.701
4.100	3919.76	3021.51	996.07	22.916
9.100	3908.07	2896.49	995.57	25.884
29.100	3896.92	2993.71	995.08	23.177
49.100	3885.33	3037.16	994.59	21.830
69.100	3873.53	2888.02	994.10	25.442
RETENTION STANDARD DEVIATION = 1.07				

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
1.915	0.0	1.915	0.0195
3.046	0.0	3.046	0.0314
2.754	0.0	2.754	0.0283
1.765	0.0	1.765	0.0180
3.710	0.0	3.710	0.0385
7.431	0.0	7.431	0.0803
14.932	0.600	14.421	0.1685
20.701	0.900	19.988	0.2498
22.916	1.200	21.991	0.2819
25.884	3.600	23.216	0.3024
23.177	6.000	18.568	0.2280
21.830	6.000	17.140	0.2069
25.442	6.000	20.969	0.2653

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 33
50.00 ML. OF FINES ADDED AT 92748.00 CPM/ML
BACKGROUND COUNT = 37.68 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.485	5.52	6073.	0.0	5.39	5984.	0.0	5.51	5945.
0.200	1.486	5.52	5926.	0.0	5.54	5950.	0.0	5.43	5919.
0.400	1.485	5.54	5701.	0.0	5.55	5839.	0.0	5.51	5779.
0.600	1.486	5.40	5777.	0.0	5.49	5831.	0.0	5.30	5841.
0.800	1.487	5.12	5612.	0.0	5.14	5602.	0.0	5.41	5723.
1.000	1.493	5.38	5688.	0.0	5.32	5778.	0.0	5.19	5560.
2.000	1.485	5.35	5563.	0.0	5.17	5358.	0.0	5.21	5465.
3.000	1.487	5.32	5143.	0.0	5.18	5142.	0.0	5.23	5101.
4.000	1.485	5.18	4931.	0.0	5.05	4825.	0.0	5.11	4883.
5.000	1.494	5.17	4658.	0.0	5.02	4683.	0.0	5.11	4740.
10.000	1.498	4.80	4134.	0.0	4.71	4285.	0.0	4.75	4226.
15.000	1.482	4.56	4256.	0.0	4.53	4165.	0.0	4.60	4187.
20.000	1.484	4.36	4189.	0.0	4.26	4148.	0.0	4.42	4155.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4637.40	4499.32	1000.00	2.977
0.200	4619.46	4440.52	999.54	3.873
0.400	4601.76	4311.44	999.08	6.309
0.600	4584.63	4381.95	998.61	4.421
0.800	4567.16	4299.75	998.15	5.855
1.000	4550.04	4301.88	997.69	5.454
2.000	4532.91	4153.62	997.23	8.367
3.000	4516.41	3898.31	996.76	13.686
4.000	4501.05	3738.87	996.30	16.933
5.000	4486.39	3598.58	995.84	19.789
10.000	4472.34	3303.36	995.38	26.138
15.000	4459.60	3335.42	994.91	25.208
20.000	4446.71	3353.55	994.45	24.583
RETENTION STANDARD DEVIATION =			0.94	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
2.977	0.0	2.977	0.0307
3.873	0.0	3.873	0.0403
6.309	0.0	6.309	0.0673
4.421	0.0	4.421	0.0463
5.855	0.200	5.667	0.0601
5.454	0.300	5.170	0.0545
8.367	0.600	7.818	0.0848
13.686	0.900	12.909	0.1482
16.933	1.200	15.937	0.1896
19.789	1.600	18.506	0.2271
26.138	4.000	23.183	0.3018
25.208	5.500	21.094	0.2673
24.583	6.000	20.058	0.2509

RETENTION ISOTHERM RESULTS

CATION NA EXPERIMENT 34
50.00 ML. OF FINES ADDED AT 92748.00 CPM/ML
BACKGROUND COUNT = 35.86 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.417	5.85	5874.	0.0	5.81	5854.	0.0	5.78	5810.
0.200	1.414	5.66	5740.	0.0	5.81	5809.	0.0	5.77	5695.
0.400	1.402	5.86	5627.	0.0	5.75	5734.	0.0	5.94	5735.
0.600	1.400	5.70	5564.	0.0	5.80	5544.	0.0	5.77	5579.
0.800	1.394	5.80	5550.	0.0	5.70	5582.	0.0	5.83	5518.
1.000	1.400	5.76	5478.	0.0	5.81	5446.	0.0	5.71	5508.
2.000	1.404	5.75	5246.	0.0	5.73	5305.	0.0	5.85	5227.
3.000	1.402	5.74	4891.	0.0	5.79	4955.	0.0	5.74	4910.
4.000	1.399	5.75	4577.	0.0	5.61	4629.	0.0	5.68	4740.
5.000	1.409	5.69	4430.	0.0	5.76	4411.	0.0	5.75	4543.
10.000	1.407	5.69	4055.	0.0	5.65	4067.	0.0	5.61	4204.
15.000	1.403	5.88	4088.	0.0	5.69	4006.	0.0	5.64	4006.
20.000	1.409	5.84	4038.	0.0	5.69	4003.	0.0	5.79	4054.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4637.40	4543.98	1000.00	2.014
0.200	4619.24	4485.94	999.79	2.886
0.400	4601.32	4418.94	999.57	3.963
0.600	4583.67	4337.47	999.36	5.371
0.800	4566.36	4322.26	999.14	5.345
1.000	4549.10	4269.68	998.93	6.142
2.000	4532.06	4094.44	998.71	9.656
3.000	4515.75	3832.40	998.50	15.133
4.000	4500.55	3637.66	998.29	19.173
5.000	4486.15	3478.27	998.07	22.466
10.000	4472.43	3217.93	997.86	28.049
15.000	4459.79	3141.30	997.64	29.564
20.000	4447.48	3132.65	997.43	29.563
RETENTION STANDARD DEVIATION =			0.98	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
2.014	0.0	2.014	0.0206
2.886	0.0	2.886	0.0297
3.963	0.0	3.963	0.0413
5.371	0.0	5.371	0.0568
5.345	0.200	5.156	0.0544
6.142	0.300	5.861	0.0623
9.656	0.600	9.114	0.1003
15.133	0.900	14.369	0.1678
19.173	1.200	18.203	0.2225
22.466	1.600	21.226	0.2695
28.049	4.000	25.171	0.3364
29.564	5.500	25.690	0.3457
29.563	6.000	25.337	0.3394

RETENTION ISOTHERM RESULTS

CATION H EXPERIMENT 35
45.00 ML. OF FINES ADDED AT 98208.06 CPM/ML
BACKGROUND COUNT = 37.14 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.004	1.465	5.80	5683.	0.0	5.73	5754.	0.0	5.77	5773.
0.129	1.465	5.63	5199.	0.0	5.68	5209.	0.0	5.64	5116.
0.178	1.463	5.75	4866.	0.0	5.62	4930.	0.0	5.72	4930.
0.225	1.459	5.73	4590.	0.0	5.61	4632.	0.0	5.69	4645.
0.400	1.466	5.71	4423.	0.0	5.66	4397.	0.0	5.61	4263.
0.800	1.472	5.51	4024.	0.0	5.43	4108.	0.0	5.57	4138.
1.590	1.478	5.32	4213.	0.0	5.39	4240.	0.0	5.41	4223.
3.180	1.483	5.21	4220.	0.0	5.22	4239.	0.0	5.15	4191.
5.040	1.480	5.01	4158.	0.0	5.03	4168.	0.0	4.98	4236.
1.330	1.483	4.50	3922.	0.0	4.48	4010.	0.0	4.42	4085.
56.500	1.483	3.60	3869.	0.0	3.71	3851.	0.0	3.75	3981.
79.800	1.485	3.29	3755.	0.0	3.33	3679.	0.0	3.25	3582.
0.0	1.486	2.92	3402.	0.0	2.98	3603.	0.0	2.94	3654.

AVERAGE RESULTS

CATION	FINES CONCENTRATION	TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	RETENTION
0.004	4419.36	4259.23	1000.00
0.129	4402.38	3867.30	999.58
0.178	4387.13	3656.36	999.15
0.225	4372.80	3445.90	998.73
0.400	4359.38	3252.65	998.31
0.800	4346.82	3079.06	997.88
1.590	4335.01	3208.52	997.46
3.180	4322.61	3239.11	997.03
5.040	4310.07	3255.52	996.61
1.330	4297.45	3227.48	996.19
56.500	4284.95	3317.01	995.76
79.800	4272.02	3212.31	995.34
0.0	4259.56	3187.87	994.92
RETENTION STANDARD DEVIATION = 1.28			

CORRECTED RESULTS

PERCENT	RETENTION	EQUILIBRIUM
AVERAGE	BLANK	CORRECTED
3.623	0.0	3.623
12.154	0.800	11.452
16.657	1.600	15.324
21.197	4.600	17.572
25.387	6.400	20.612
29.165	6.900	24.277
25.986	6.900	20.879
25.066	6.900	19.895
24.467	6.900	19.255
24.898	6.900	19.716
22.589	6.900	17.248
24.806	6.900	19.617
25.160	6.900	19.996
		0.0376
		0.1293
		0.1810
		0.2132
		0.2596
		0.3206
		0.2639
		0.2484
		0.2385
		0.2456
		0.2084
		0.2441
		0.2499

RETENTION ISOTHERM RESULTS

CATION CA EXPERIMENT 1
50.00 ML. OF FINES ADDED AT 92044.75 CPM/ML
BACKGROUND COUNT = 47.82 CPM

CRUDE ISOTHERM DATA

CATION	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES	SAMPLE	EX ST	FINES
MMOL/L	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.	VOLUME	RATIO	CONC.
0.0	1.347	5.67	5580.	1.346	5.74	5503.	1.347	5.63	5554.
0.020	1.348	5.67	5404.	1.346	5.66	5401.	1.348	5.66	5312.
0.040	1.349	5.63	5378.	1.346	5.68	5293.	1.353	5.76	5303.
0.060	1.342	5.63	5127.	1.347	5.62	5140.	1.345	5.62	5152.
0.080	1.343	5.69	4985.	1.341	5.58	4878.	1.343	5.61	4974.
0.100	1.345	5.64	4857.	1.339	5.62	4809.	1.342	5.62	4886.
0.200	1.346	5.60	4510.	1.343	5.75	4331.	1.346	5.67	4333.
0.300	1.251	5.72	4026.	1.349	5.69	4442.	1.346	5.65	4309.
0.400	1.343	5.68	4235.	1.341	5.61	4184.	1.344	5.58	4317.
0.500	1.344	5.66	4120.	1.514	5.42	4658.	1.342	5.56	4231.
1.000	1.346	5.73	3999.	1.344	5.52	4017.	1.345	5.60	4026.
1.500	1.347	5.60	4007.	1.343	5.58	4170.	1.344	5.58	4095.
2.000	1.347	5.56	4153.	1.344	5.59	4093.	1.346	5.51	4225.

AVERAGE RESULTS

CATION	FINES CONCENTRATION		TOTAL	PERCENT
MMOL/L	INITIAL	FINAL	VOLUME	RETENTION
0.0	4602.23	4521.92	1000.00	1.745
0.020	4584.15	4382.81	999.98	4.392
0.040	4566.62	4329.73	999.97	5.187
0.060	4549.30	4209.75	999.95	7.464
0.080	4532.47	4055.05	999.94	10.533
0.100	4516.26	3977.80	999.92	11.923
0.200	4500.35	3579.24	999.91	20.467
0.300	4486.05	3543.94	999.89	21.001
0.400	4471.89	3475.55	999.88	22.280
0.500	4458.00	3422.47	999.86	23.229
1.000	4444.32	3278.78	999.84	26.225
1.500	4431.23	3350.06	999.83	24.399
2.000	4417.84	3410.55	999.81	22.801
RETENTION STANDARD DEVIATION =			1.22	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM
AVERAGE	BLANK	CORRECTED	CONSTANT
1.745	0.0	1.745	0.0178
4.392	0.0	4.392	0.0459
5.187	0.0	5.187	0.0547
7.464	0.400	7.094	0.0764
10.533	0.500	10.086	0.1122
11.923	0.600	11.394	0.1286
20.467	1.000	19.672	0.2449
21.001	1.200	20.053	0.2508
22.280	1.500	21.114	0.2677
23.229	1.700	21.923	0.2808
26.225	3.200	23.865	0.3134
24.399	5.000	20.619	0.2597
22.801	6.600	17.705	0.2151

RETENTION ISOTHERM RESULTS

CATION CA EXPERIMENT 2
50.00 ML. OF FINES ADDED AT 84168.63 CPM/ML
BACKGROUND COUNT = 45.28 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.364	5.73	5167.	1.366	5.79	5195.	1.340	5.69	5048.
0.020	1.348	5.79	4945.	1.337	5.76	4933.	1.337	5.73	4897.
0.040	1.339	5.74	4800.	1.335	5.83	4778.	1.335	5.78	4805.
0.060	1.335	5.78	4675.	1.336	5.78	4639.	1.338	5.72	4708.
0.080	1.339	5.77	4464.	1.339	5.70	4538.	1.339	5.82	4527.
0.100	1.344	5.71	4442.	1.346	5.80	4416.	1.341	5.72	4510.
0.200	1.341	5.77	4202.	1.344	5.65	4317.	1.342	5.72	4205.
0.300	1.344	5.62	3993.	1.341	5.71	3977.	1.347	5.80	3960.
0.400	1.345	5.74	3766.	1.341	5.74	3774.	1.347	5.78	3871.
0.500	1.348	5.73	3606.	1.351	5.71	3631.	1.345	5.71	3619.
1.000	1.343	5.64	3638.	1.348	5.85	3678.	1.347	5.71	3601.
1.500	1.342	5.63	3675.	1.341	5.69	3644.	1.340	5.70	3677.
2.000	1.343	5.58	3693.	1.341	5.60	3694.	1.347	5.59	3724.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4208.43	4141.28	1000.00	1.596
0.020	4191.86	4011.73	999.97	4.297
0.040	4175.82	3911.38	999.93	6.333
0.060	4160.18	3817.55	999.90	8.236
0.080	4144.93	3674.76	999.87	11.343
0.100	4130.24	3622.48	999.84	12.294
0.200	4115.76	3455.55	999.80	16.041
0.300	4101.96	3234.84	999.77	21.139
0.400	4089.05	3082.87	999.74	24.606
0.500	4076.75	2929.90	999.70	28.131
1.000	4065.06	2948.10	999.67	27.477
1.500	4053.30	2991.78	999.64	26.189
2.000	4041.36	3033.02	999.60	24.950
RETENTION STANDARD DEVIATION =			0.80	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
1.596	0.0	1.596	0.0162
4.297	0.0	4.297	0.0449
6.333	0.0	6.333	0.0676
8.236	0.400	7.869	0.0854
11.343	0.500	10.900	0.1223
12.294	0.600	11.767	0.1334
16.041	1.000	15.201	0.1793
21.139	1.200	20.193	0.2530
24.606	1.500	23.476	0.3068
28.131	1.700	26.909	0.3682
27.477	3.200	25.156	0.3361
26.189	5.000	22.498	0.2903
24.950	6.600	19.997	0.2500

RETENTION ISOTHERM RESULTS

CATION CA EXPERIMENT 3
50.00 ML. OF FINES ADDED AT 84939.00 CPM/ML
BACKGROUND COUNT = 42.38 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.367	5.84	5219.	1.367	5.79	5229.	1.362	5.76	5195.
0.200	1.363	5.70	4238.	1.362	5.79	4338.	1.360	5.80	4283.
0.400	1.365	5.81	4049.	1.361	5.64	3947.	1.361	5.76	3979.
0.600	1.356	5.81	3925.	1.365	5.68	3988.	1.368	5.75	3891.
0.800	1.367	5.74	3874.	1.193	5.80	3396.	1.364	5.68	3858.
1.000	1.374	5.67	3975.	1.367	5.69	3825.	1.366	5.66	3834.
3.000	1.372	5.59	3882.	1.375	5.62	3790.	1.363	5.53	3787.
5.000	1.372	5.48	3764.	1.374	5.39	3810.	1.376	5.52	4022.
7.000	1.358	5.47	3881.	1.377	5.41	3816.	1.374	5.46	3838.
9.000	1.374	5.50	3889.	1.378	5.51	3883.	1.379	5.49	3950.
11.000	1.380	5.40	3802.	1.380	5.38	3843.	1.382	5.53	3774.
13.000	1.384	5.41	3854.	1.382	5.26	3824.	1.379	5.29	3730.
15.000	1.383	5.43	3745.	1.381	5.32	3790.	1.383	5.35	3717.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION		TOTAL VOLUME	PERCENT RETENTION
	INITIAL	FINAL		
0.0	4246.95	4166.03	1000.00	1.905
0.200	4230.29	3434.63	999.89	18.809
0.400	4216.64	3199.46	999.78	24.123
0.600	4203.95	3150.38	999.66	25.062
0.800	4191.46	3094.32	999.55	26.176
1.000	4179.20	3104.42	999.44	25.717
3.000	4166.90	3072.68	999.33	26.260
5.000	4154.72	3124.68	999.22	24.792
7.000	4142.33	3120.99	999.11	24.656
9.000	4129.95	3144.63	998.99	23.858
11.000	4117.46	3067.06	998.88	25.511
13.000	4105.30	3084.39	998.77	24.868
15.000	4093.06	3031.92	998.66	25.925
RETENTION STANDARD DEVIATION =			1.11	

CORRECTED RESULTS

PERCENT RETENTION			EQUILIBRIUM CONSTANT
AVERAGE	BLANK	CORRECTED	
1.905	0.0	1.905	0.0194
18.809	1.000	17.997	0.2195
24.123	1.200	23.212	0.3023
25.062	2.000	23.563	0.3083
26.176	2.600	24.256	0.3202
25.717	3.200	23.340	0.3045
26.260	6.600	21.393	0.2721
24.792	6.600	19.828	0.2473
24.656	6.600	19.683	0.2451
23.858	6.600	18.832	0.2320
25.511	6.600	20.595	0.2594
24.868	6.600	19.909	0.2486
25.925	6.600	21.037	0.2664

RETENTION ISOTHERM RESULTS

CATION LA EXPERIMENT 1
50.00 ML. OF FINES ADDED AT 84354.56 CPM/ML
BACKGROUND COUNT = 42.85 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.365	5.66	5150.	1.372	5.72	5135.	1.367	5.79	5108.
0.0	1.367	5.71	5092.	1.363	5.71	5138.	1.371	5.67	5129.
0.0	1.366	5.74	5039.	1.366	5.77	5047.	1.361	5.75	5079.
0.0	1.346	5.81	5002.	1.338	5.76	5013.	1.342	5.77	4960.
0.0	1.347	5.72	4931.	1.352	5.76	4966.	1.349	5.66	4918.
0.001	1.347	5.72	4915.	1.352	5.72	4943.	1.345	5.79	4919.
0.002	1.350	5.66	4894.	1.347	5.77	4869.	1.353	5.74	4837.
0.003	1.358	5.71	4892.	1.366	5.76	4887.	1.354	5.67	4813.
0.004	1.361	5.71	4800.	1.363	5.75	4771.	1.365	5.76	4775.
0.005	1.360	5.68	4746.	1.361	5.76	4761.	1.367	5.70	4756.
0.010	1.364	5.75	4467.	1.370	5.81	4510.	1.364	5.65	4490.
0.015	1.366	5.77	4012.	1.366	5.83	4087.	1.364	5.69	4046.
0.020	1.366	5.77	3729.	1.364	5.71	3718.	1.368	5.64	3834.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4217.73	4108.30	1000.00	2.594
0.0	4201.30	4110.02	999.92	2.173
0.0	4184.87	4050.83	999.85	3.203
0.0	4168.67	4058.83	999.77	2.635
0.0	4152.44	4011.07	999.69	3.404
0.001	4136.40	3996.37	999.62	3.385
0.002	4120.42	3947.55	999.54	4.195
0.003	4104.63	3920.48	999.47	4.486
0.004	4088.96	3838.29	999.39	6.130
0.005	4073.61	3821.93	999.31	6.178
0.010	4058.34	3592.45	999.24	11.480
0.015	4043.99	3233.15	999.16	20.050
0.020	4031.11	3009.87	999.08	25.334
RETENTION STANDARD DEVIATION =			0.71	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
2.594	0.0	2.594	0.0266
2.173	0.0	2.173	0.0222
3.203	0.0	3.203	0.0331
2.635	0.0	2.635	0.0271
3.404	0.0	3.404	0.0352
3.385	0.0	3.385	0.0350
4.195	1.200	3.046	0.0314
4.486	1.600	2.958	0.0305
6.130	2.000	4.253	0.0444
6.178	2.400	3.927	0.0409
11.480	3.100	8.735	0.0957
20.050	3.600	17.172	0.2073
25.334	4.000	22.347	0.2878

RETENTION ISOTHERM RESULTS

CATION LA EXPERIMENT 2
50.00 ML. OF FINES ADDED AT 83452.19 CPM/ML
BACKGROUND COUNT = 41.28 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.328	5.80	4991.	1.327	5.84	4968.	1.328	5.75	4938.
0.0	1.320	5.78	4934.	1.330	5.78	4992.	1.328	5.63	4907.
0.0	1.320	5.78	4907.	1.326	5.70	4852.	1.325	5.75	4885.
0.0	1.326	5.74	4837.	1.326	5.73	4887.	1.330	5.81	4943.
0.0	1.325	5.75	4856.	1.334	5.73	4927.	1.329	5.76	4854.
0.001	1.330	5.77	4828.	1.326	5.74	4862.	1.324	5.74	4832.
0.002	1.330	5.72	4776.	1.328	5.79	4764.	1.333	5.71	4731.
0.003	1.331	5.77	4758.	1.332	5.66	4769.	1.335	5.75	4791.
0.004	1.336	5.74	4756.	1.335	5.82	4754.	1.325	5.78	4712.
0.005	1.336	5.76	4674.	1.334	5.73	4710.	1.336	5.70	4673.
0.010	1.334	5.77	4448.	1.327	5.79	4437.	1.331	5.95	4427.
0.015	1.332	5.84	4057.	1.329	5.78	4070.	1.331	5.78	4024.
0.020	1.333	5.81	3821.	1.335	5.73	3774.	1.332	5.75	3821.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4172.61	4078.31	1000.00	2.260
0.0	4156.29	4083.86	1000.01	1.743
0.0	4139.96	4034.56	1000.02	2.546
0.0	4123.82	4025.18	1000.04	2.392
0.0	4107.72	4014.85	1000.05	2.261
0.001	4091.66	3990.18	1000.06	2.480
0.002	4075.70	3912.60	1000.07	4.002
0.003	4060.05	3921.82	1000.08	3.405
0.004	4044.37	3884.40	1000.09	3.955
0.005	4028.83	3841.89	1000.11	4.640
0.010	4013.46	3624.19	1000.12	9.699
0.015	3998.96	3312.87	1000.13	17.157
0.020	3985.71	3110.55	1000.14	21.957
RETENTION STANDARD DEVIATION = 0.54				

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
2.260	0.0	2.260	0.0231
1.743	0.0	1.743	0.0177
2.546	0.0	2.546	0.0261
2.392	0.0	2.392	0.0245
2.261	0.0	2.261	0.0231
2.480	0.0	2.480	0.0254
4.002	1.200	2.850	0.0293
3.405	1.600	1.859	0.0189
3.955	2.000	2.034	0.0208
4.640	2.400	2.351	0.0241
9.699	3.100	6.900	0.0741
17.157	3.600	14.174	0.1652
21.957	4.000	18.835	0.2321

RETENTION ISOTHERM RESULTS

CATION LA EXPERIMENT 3
50.00 ML. OF FINES ADDED AT 83477.75 CPM/ML
BACKGROUND COUNT = 37.32 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.288	5.88	4861.	1.286	5.77	4811.	1.287	5.82	4768.
0.020	1.288	5.81	3920.	1.283	5.78	3883.	1.283	5.70	3866.
0.040	1.277	5.82	3507.	1.278	5.81	3578.	1.285	5.78	3478.
0.060	1.285	5.78	3405.	1.285	5.86	3543.	1.289	5.70	3543.
0.080	1.285	5.79	3526.	1.282	5.78	3502.	1.287	5.75	3474.
0.100	1.291	5.72	3574.	1.298	5.76	3467.	1.286	5.81	3468.
0.300	1.293	5.68	3560.	1.292	5.71	3622.	1.295	5.70	3608.
0.500	1.293	5.74	3544.	1.293	5.76	3601.	1.295	5.70	3672.
0.700	1.291	5.78	3569.	1.293	5.77	3533.	1.295	5.58	3574.
0.900	1.296	5.65	3518.	1.287	5.76	3543.	1.294	5.72	3434.
1.100	1.292	5.66	3610.	1.303	5.69	3578.	1.290	5.61	3624.
1.300	1.290	5.67	3548.	1.295	5.71	3512.	1.292	5.62	3531.
1.500	0.975	5.98	2707.	1.298	5.65	3548.	1.299	5.61	3317.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	4173.89	4073.46	1000.00	2.406
0.020	4157.57	3304.85	1000.20	20.510
0.040	4144.19	2991.34	1000.41	27.818
0.060	4131.99	2960.81	1000.61	28.344
0.080	4119.92	2968.42	1000.82	27.950
0.100	4107.82	2957.30	1001.02	28.008
0.300	4095.78	3045.86	1001.23	25.634
0.500	4083.40	3045.79	1001.43	25.410
0.700	4071.02	3010.68	1001.64	26.046
0.900	4058.78	2961.29	1001.84	27.040
1.100	4046.74	3056.75	1002.05	24.464
1.300	4034.34	2997.06	1002.25	25.711
1.500	4022.17	2930.24	1002.46	27.148

RETENTION STANDARD DEVIATION = 1.25

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
2.406	0.0	2.406	0.0247
20.510	4.000	17.330	0.2096
27.818	5.100	24.137	0.3182
28.344	6.300	23.830	0.3129
27.950	6.600	23.194	0.3020
28.008	7.200	22.825	0.2958
25.634	8.400	19.387	0.2405
25.410	8.400	19.145	0.2368
26.046	8.400	19.834	0.2474
27.040	8.400	20.911	0.2644
24.464	8.400	18.119	0.2213
25.711	8.400	19.471	0.2418
27.148	8.400	21.028	0.2663

RETENTION ISOTHERM RESULTS

CATION LA EXPERIMENT 7
50.00 ML. OF FINES ADDED AT 102098.00 CPM/ML
BACKGROUND COUNT = 33.80 CPM

CRUDE ISOTHERM DATA

CATION MMOL/L	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.459	5.66	6622.	0.0	5.62	6560.	0.0	5.66	6529.
0.002	1.460	5.74	6490.	0.0	5.72	6443.	0.0	5.76	6462.
0.004	1.457	5.75	6417.	0.0	5.71	6393.	0.0	5.62	6394.
0.006	1.468	5.63	6455.	0.0	5.79	6426.	0.0	5.77	6471.
0.008	1.461	5.72	6277.	0.0	5.69	6266.	0.0	5.84	6195.
0.010	1.464	5.78	6127.	0.0	5.77	6166.	0.0	5.74	6122.
0.020	1.462	5.78	5415.	0.0	5.73	5349.	0.0	5.69	5453.
0.030	1.473	5.80	5121.	0.0	5.66	5182.	0.0	5.76	5132.
0.040	1.467	5.65	5039.	0.0	5.75	5045.	0.0	5.78	5032.
0.050	1.473	5.67	4994.	0.0	5.73	4996.	0.0	5.69	5003.
0.100	1.471	5.84	4910.	0.0	5.78	4942.	0.0	5.80	4929.
0.150	1.475	5.63	4967.	0.0	5.73	4930.	0.0	5.76	5039.
0.200	1.474	5.82	5040.	0.0	5.73	4797.	0.0	5.66	4970.

AVERAGE RESULTS

CATION MMOL/L	FINES CONCENTRATION INITIAL	FINES CONCENTRATION FINAL	TOTAL VOLUME	PERCENT RETENTION
0.0	5104.90	4947.23	1000.00	3.089
0.002	5085.16	4839.55	999.60	4.830
0.004	5065.89	4805.51	999.20	5.140
0.006	5046.75	4831.98	998.80	4.255
0.008	5027.48	4671.75	998.40	7.076
0.010	5008.90	4587.00	998.00	8.423
0.020	4990.68	4044.01	997.60	18.969
0.030	4974.84	3846.22	997.20	22.686
0.040	4959.85	3769.18	996.80	24.006
0.050	4945.20	3745.46	996.40	24.261
0.100	4930.64	3666.85	996.00	25.631
0.150	4916.42	3728.64	995.60	24.159
0.200	4901.91	3689.46	995.20	24.734
RETENTION STANDARD DEVIATION =			0.80	

CORRECTED RESULTS

AVERAGE	PERCENT RETENTION BLANK	CORRECTED	EQUILIBRIUM CONSTANT
3.089	0.0	3.089	0.0319
4.830	1.200	3.688	0.0383
5.140	2.000	3.243	0.0335
4.255	2.400	1.958	0.0200
7.076	2.800	4.474	0.0468
8.423	3.000	5.676	0.0602
18.969	4.000	15.727	0.1866
22.686	4.600	19.130	0.2366
24.006	5.100	20.130	0.2520
24.261	5.600	20.019	0.2503
25.631	7.200	20.277	0.2543
24.159	8.000	18.092	0.2209
24.734	8.400	18.412	0.2257

```

C      RETENTION ISOTHERM DATA REDUCTION PROGRAM
C      PROGRAM NAME IS KUSHII
C      VARIABLE SALT CONCENTRATION AT CONSTANT FINES
      DIMENSION S(39),EXST(39),CPM(39),RETN(39),RET(13),TFINE(13)
      DIMENSION TVOL(13),DIFF(39),SCONC(13),BL(13),CRET(13),REQ(13)
      DIMENSION CONCO(13),CONC(13),DATA(13,10)
500    READ(5,100) FINEC,FINEV,BKG,EXP,SALT
      READ(5,102) (S(I),EXST(I),CPM(I),I=1,39)
      READ(5,103) (SCONC(I),BL(I),I=1,13)
103    FORMAT(F5.3,F3.2)
      WRITE(6,306)
306    FORMAT('1',10X,'RETENTION ISOTHERM RESULTS')
      WRITE(6,304)SALT,EXP
304    FORMAT('0','CATION',2X,A2,5X,'EXPERIMENT',2X,I2)
      J=1
      K=2
      I=1
29     DATA(J,K)=S(I)
      DATA(J,K+1)=EXST(I)
      DATA(J,K+2)=CPM(I)
      K=K+3
      IF(K-8)28,28,27
28     I=I+1
      GO TO 29
27     K=2
      J=J+1
      I=I+1
      IF(I-39)29,29,30
30     DO 31 I=1,13
31     DATA(I,1)=SCONC(I)
      KI=1
      IF(S(2))22,22,23
23     KI=2
      DO 24 I=1,39
      EFF=.0566*EXST(I)+.5812
24     CPM(I)=(CPM(I)-BKG)/(EFF*S(I))
22     V=0.0
      DO 21 I=1,37,3
21     V= S(I)+V
      V=V/13.
      WRITE(6,700)FINEV,FINEC
700    FORMAT(F5.2,1X,'ML. OF FINES ADDED AT', F10.2,1X,'CPM/ML')
      WRITE(6,308)BKG
308    FORMAT('BACKGROUND COUNT =',1XF5.2,1X,'CPM')
      WRITE(6,309)
      WRITE(6,310)
      WRITE(6,311)
      WRITE(6,312)((DATA(J,K),K=1,10),J=1,13)
309    FORMAT('0',10X,'CRUDE ISOTHERM DATA')
310    FORMAT('0','CATION SAMPLE EX ST FINES SAMPLE EX ST FINES SAMP,
1LE EX ST FINES')
311    FORMAT('MMOL/L VOLUME RATIO CONC. VOLUME RATIO CONC. VOLUME
2RATIO CONC. ')
312    FORMAT(F7.3,F7.3,F6.2,F8.0,F7.3,F6.2,F8.0,F7.3,F6.2,F8.0)
      IF(KI-2)26,25,25
26     DO 1 I=1,39
      EFF=.0566*EXST(I)+.5812
1     CPM(I)=(CPM(I)-BKG)/(EFF*V)
25     I=1

```

```
N=3
M=1
CPMT=0.0
FINE=FINEC*FINEV
TFINE(M)=FINE
4  M=M+1
2  CPMT=CPMT+(CPM(I)*V)
   I=I+1
   IF(I-N)2,2,3
3  TFINE(M)=FINE-CPMT
   N=N+3
   IF(M-13)4,4,5
5  M=1
   I=1
   N=3
   VOLT=1000.
   TVOL(M)=VOLT
8  VOL=0.0
   M=M+1
6  VOL=VOL+V
   I=I+1
   IF(I-N)6,6,7
7  N=N+3
   TVOL(M)=VOLT-VOL+4.0
   VOLT=TVOL(M)
   IF(M-13)8,8,9
9  M=1
   I=1
   N=3
10 RETN(I)=((TFINE(M)-TVOL(M)*CPM(I))*100.)/TFINE(M)
   DIFF(I)=(TFINE(M)/TVOL(M))-CPM(I)
   I=I+1
   IF(I-N)10,10,11
11 N=N+3
   M=M+1
   IF(M-13)10,10,12
12 CFM=0.0
   DO 13 I=1,39
13 CFM=RETN(I)+CFM
   CFMT=CFM**2 /39.
   SS=0.0
   DO 14 I=1,39
14 SS=RETN(I)**2 +SS
   SSTOT=SS-CFMT
   N=3
   I=1
   M=1
17 RETT=0.0
15 RETT=RETT+RETN(I)
   I=I+1
   IF(I-N)15,15,16
16 RET(M)=RETT/3.
   CONCO(M)=TFINE(M)/TVOL(M)
   CONC(M)=CONCO(M)*((100.000-RET(M))*0.01
   CRET(M)=RET(M)-((100.000-RET(M))*0.01*BL(M))
   REQ(M)=CRET(M)/(100.000-CRET(M))
   N=N+3
   M=M+1
   IF(M-13)17,17,18
18 SSTRT=0.0
```

```

M=1
19  SSTRT=SSTRT+((RET(M)*3.)**2 )/3.
M=M+1
IF(M-13)19,19,20
20  SSTRT=SSTRT-CFMT
SSERR=SSTOT-SSTRT
SIGMA=SQRT(SSERR/26.)
WRITE(6,197)
197  FORMAT('0',10X,'AVERAGE  RESULTS')
WRITE(6,199)
198  FORMAT('MMOL/L  INITIAL          FINAL          VOLUME          RETENTION')
WRITE(6,198)
WRITE(6,200)(DATA(M,1),CONCO(M),CONC(M),TVOL(M),RET(M),M=1,13)
WRITE(6,204)SIGMA
WRITE(6,207)
WRITE(6,205)
WRITE(6,208)
207  FORMAT('0',10X,'CORRECTED  RESULTS')
205  FORMAT('0','          PERCENT  RETENTION          EQUILIBRIUM')
208  FORMAT('  AVERAGE      BLANK      CORRECTED      CONSTANT')
WRITE(6,206)(RET(M),BL(M),CRET(M),REQ(M),M=1,13)
206  FORMAT(2XF7.3,3XF7.3,4XF7.3,6XF7.4)
100  FORMAT(F8.2,1XF3.1,1XF4.2,1XI2,A2)
102  FORMAT(F5.4,F3.2,F6.2)
199  FORMAT('0','CATION  FINES CONCENTRATION      TOTAL          PERCENT')
204  FORMAT('RETENTION STANDARD DEVIATION =' ,F6.2)
200  FORMAT(F7.3,3XF8.2,3XF8.2,1XF9.2,4XF7.3)
GO TO 500
END

```


APPENDIX VI

COAGULATION ISOTHERM DATA AND RESULTS

The experimental conditions at which the coagulation isotherms describe equilibrium fines retention are summarized in Table XVI. The raw data and computed results can be found in subsequent pages, 158-181. The computer program used to treat the raw data is found at the end of this appendix.

TABLE XVI

SUMMARY OF COAGULATION ISOTHERMS

Experiment Number	Electrolyte		Final pH	Pulp Weight, g.	Retention, %
	Species	Concn., mM/l.			
4	NaCl	51.0	5.40	1.054	24.24
5	NaCl	105.0	5.37	1.042	23.19
6	NaCl	500.0	5.54	1.037	25.15
8	NaCl	1.15	5.83	1.015	3.29
21	NaCl	1.15	5.89	0.987	4.76
22	NaCl	3.20	5.71	0.968	16.80
23	NaCl	475.0	5.43	1.197	26.63
24	NaCl	196.0	5.32	1.156	24.50
25	NaCl	20.4	5.45	1.150	22.90
26	NaCl	9.9	5.55	1.170	24.82
27	NaCl	1.05	5.69	1.018	6.72
28	NaCl	0.10	5.92	1.003	4.85
29	NaCl	0.30	5.89	0.999	5.30
30	NaCl	0.00	6.06	1.002	3.29
31	NaCl	188.00	5.54	1.044	23.43
32	NaCl	8.80	5.82	1.042	20.44
4	CaCl ₂	0.001	6.03	0.973	6.10
5	CaCl ₂	0.000	5.64	1.016	4.31
6	CaCl ₂	0.000	6.06	1.038	3.75
7	CaCl ₂	0.080	5.22	1.031	13.12
8	CaCl ₂	1.000	5.34	0.969	15.25
4	LaCl ₃	0.100	5.47	1.062	22.06
5	LaCl ₃	0.010	5.19	1.018	4.76
6	LaCl ₃	0.005	5.75	1.035	6.10

COAGULATION ISOTHERM RESULTS

CATION NA MMOL/L 50.0000 EXP 4
PULP WEIGHT = 1.054 BLANK = 6.00
STOCK FINES CONCENTRATION = 87653.13

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.041	5.23	58.1	1.041	5.25	49.0	1.039	5.44	48.3
1.25	1.385	5.04	141.0	1.387	5.10	135.1	1.390	5.22	139.6
2.50	1.383	5.10	208.6	1.385	5.12	217.4	1.387	5.17	218.0
5.00	1.387	5.12	390.8	1.389	5.18	395.6	1.387	5.15	399.0
7.50	1.377	5.10	573.1	1.383	5.20	586.5	1.383	5.17	573.4
10.00	1.382	5.04	762.3	1.381	5.06	779.0	1.382	5.07	764.9
15.00	1.380	5.11	1145.5	1.384	5.26	1171.3	1.379	5.17	1125.5
20.00	1.377	5.16	1589.3	1.382	5.08	1502.1	1.380	5.20	1544.5
30.00	1.385	5.13	2348.6	1.385	5.04	2275.4	1.384	5.10	2341.9
40.00	1.382	5.14	2926.2	1.384	5.13	3014.4	1.380	5.09	3083.2
50.00	1.401	5.12	3771.9	1.383	5.11	3726.4	1.379	5.17	3768.4

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
109.87	74.60	35.27	997.19	32.101
219.62	139.89	79.73	996.38	36.304
438.79	294.97	143.82	996.82	32.777
657.13	454.42	202.71	997.26	30.848
874.63	619.66	254.97	997.70	29.151
1307.52	948.27	359.26	1000.65	27.476
1736.56	1295.55	441.01	1003.59	25.395
2591.88	1963.44	628.44	1006.53	24.246
3433.65	2560.24	873.41	1010.41	25.437
4264.20	3193.99	1070.20	1014.29	25.097

RETENTION STANDARD DEVIATION = 1.67

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 408.88 X AVG= 1154.50
SLOPE = 0.3198 LIMITS = 0.0146
INTERCEPT = 39.73 LIMITS = 85.25
CORRELATION COEFFICIENT = 0.9931

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.82 X AVG= 2.43
SLOPE = 1.1542 LIMITS = 0.0445
INTERCEPT = 0.02 LIMITS = 0.15
CORRELATION COEFFICIENT = 0.9951

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 100.0000 EXP 5
PULP WEIGHT = 1.042 BLANK = 6.00
STOCK FINES CONCENTRATION = 87636.00

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.029	5.18	42.1	1.201	5.06	40.3	1.024	5.09	41.7
1.25	1.376	4.80	122.9	1.376	4.98	123.5	1.377	5.08	125.1
2.50	1.377	4.92	198.3	1.374	4.92	190.2	1.375	4.94	198.2
5.00	1.377	4.95	370.5	1.377	4.80	374.5	1.376	4.93	378.3
7.50	1.377	4.89	528.9	1.376	4.98	556.8	1.376	4.96	544.7
10.00	1.381	4.91	704.2	1.381	4.92	750.6	1.382	4.79	727.7
15.00	1.381	4.87	1090.4	1.382	4.83	1098.2	1.378	4.87	1063.4
20.00	1.377	4.79	1309.7	1.382	4.91	1470.7	1.383	4.92	1456.8
30.00	1.383	4.87	2248.3	1.382	4.93	2315.5	1.383	4.85	2215.9
40.00	1.380	4.79	2926.6	1.377	4.87	2987.5	1.380	4.89	2882.7
50.00	1.382	4.88	3753.5	1.381	4.83	3829.4	1.386	4.91	3670.7

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
109.85	72.50	37.36	997.21	34.006
219.58	135.27	84.31	996.42	38.397
438.71	292.79	145.92	996.87	33.261
657.00	441.53	215.47	997.33	32.796
874.49	601.66	272.82	997.79	31.198
1307.32	915.70	391.62	1000.75	29.956
1736.35	1203.25	533.09	1003.70	30.702
2592.14	1950.77	641.37	1006.66	24.743
3433.68	2547.07	886.61	1010.58	25.821
4263.97	3262.80	1001.17	1014.49	23.480

RETENTION STANDARD DEVIATION = 2.13

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 420.97 X AVG= 1142.33
SLOPE = 0.3014 LIMITS = 0.0241
INTERCEPT = 76.70 LIMITS = 142.36
CORRELATION COEFFICIENT = 0.9794

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.81 X AVG= 2.45
SLOPE = 1.1748 LIMITS = 0.0545
INTERCEPT = -0.06 LIMITS = 0.19
CORRELATION COEFFICIENT = 0.9929

COAGULATION ISOTHERM RESULTS

CATION NA MMOL/L 500.0000 EXP 6
PULP WEIGHT = 1.037 BLANK = 6.00
STOCK FINES CONCENTRATION = 88733.38

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.043	4.59	42.9	1.044	4.53	41.0	1.045	4.69	42.2
1.25	1.397	4.30	115.4	1.392	4.35	115.4	1.398	4.25	116.6
2.50	1.395	4.34	194.6	1.394	4.38	191.5	1.396	4.35	194.3
5.00	1.397	4.32	357.8	1.394	4.36	352.8	1.394	4.36	366.5
7.50	1.392	4.34	523.2	1.392	4.32	542.3	1.391	4.26	524.0
10.00	1.743	4.46	856.4	1.389	4.39	704.6	1.391	4.28	699.0
15.00	1.393	4.34	1112.8	1.394	4.33	1038.7	1.390	4.43	1068.4
20.00	1.390	4.26	1387.0	1.394	4.28	1433.3	1.392	4.33	1392.1
30.00	1.398	4.34	2141.3	1.391	4.27	2168.4	1.390	4.47	2117.5
40.00	1.568	4.19	3145.4	1.691	4.10	3319.5	1.392	4.30	2782.2
50.00	1.394	4.34	3642.5	1.393	4.25	3614.4	1.391	4.29	3659.1

CORRECTED AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
111.25	66.24	45.01	997.02	40.460
222.43	136.14	86.30	996.04	38.796
444.45	285.47	158.98	996.31	35.771
665.71	440.85	224.86	996.58	33.777
886.20	594.01	292.19	996.85	32.971
1325.07	933.55	391.51	999.62	29.547
1760.08	1232.94	527.14	1002.39	29.950
2627.63	1902.61	725.02	1005.16	27.592
3482.14	2473.39	1008.74	1008.70	28.969
4325.89	3263.10	1062.79	1012.24	24.568

RETENTION STANDARD DEVIATION = 1.28

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 452.25 X AVG= 1132.83
SLOPE = 0.3364 LIMITS = 0.0215
INTERCEPT = 71.21 LIMITS = 125.81
CORRELATION COEFFICIENT = 0.9866

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.81 X AVG= 2.48
SLOPE = 1.2118 LIMITS = 0.0313
INTERCEPT = -0.20 LIMITS = 0.11
CORRELATION COEFFICIENT = 0.9978

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 0.0010 EXP 8
PULP WEIGHT = 1.015 BLANK = 0.0
STOCK FINES CONCENTRATION = 58605.45
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.029	5.87	39.6	1.029	5.83	38.8	1.032	5.86	39.3
1.25	1.385	5.62	113.4	1.383	5.56	121.6	1.384	5.59	126.3
2.50	1.386	5.62	212.3	1.382	5.59	207.3	1.381	5.68	207.1
5.00	1.385	5.66	376.8	1.384	5.64	369.0	1.386	5.56	383.6
7.50	1.386	5.63	546.5	1.388	5.68	530.0	1.385	5.64	568.1
10.00	1.387	5.67	740.8	1.383	5.66	738.6	1.387	5.60	714.3
15.00	1.385	5.60	1086.7	1.385	5.53	1094.9	1.385	5.60	1050.9
20.00	1.385	5.72	1435.1	1.386	5.53	1403.1	1.383	5.57	1410.9
30.00	1.386	5.65	2169.1	1.388	5.72	2091.5	1.389	5.61	2100.7
40.00	1.391	5.69	2820.9	1.392	5.58	2780.3	1.391	5.61	2774.1
50.00	1.390	5.53	3392.9	1.394	5.51	3541.1	1.392	5.55	3452.7

AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML	TOTAL	PERCENT		
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
73.46	65.29	8.18	997.19	11.132
146.78	136.45	10.33	996.37	7.038
293.14	270.92	22.22	996.81	7.580
438.83	408.47	30.35	997.25	6.917
583.83	555.62	28.21	997.69	4.832
872.70	833.94	38.76	1000.62	4.441
1158.76	1106.33	52.42	1003.56	4.524
1728.72	1668.25	60.47	1006.50	3.498
2288.71	2200.56	88.15	1010.37	3.851
2840.16	2735.78	104.37	1014.25	3.675

RETENTION STANDARD DEVIATION = 2.98

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 44.35 X AVG= 998.16
SLOPE = 0.0341 LIMITS = 0.0091
INTERCEPT = 10.35 LIMITS = 45.36
CORRELATION COEFFICIENT = 0.8223

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.77 X AVG= 1.49
SLOPE = 1.1242 LIMITS = 0.2470
INTERCEPT = 1.09 LIMITS = 0.65
CORRELATION COEFFICIENT = 0.8698

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 1.0000 EXP 21
PULP WEIGHT = 0.987 BLANK = 0.0
STOCK FINES CONCENTRATION = 83397.75
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	0.995	5.86	42.8	0.992	5.88	41.6	0.990	5.93	43.8
1.25	1.488	5.51	178.3	1.491	5.50	180.8	1.489	5.60	179.3
2.50	1.488	5.48	310.3	1.501	5.38	314.5	1.492	5.51	314.9
5.00	1.483	5.53	567.8	1.499	5.56	577.1	1.491	5.43	555.3
7.50	1.496	5.53	834.3	1.493	5.58	836.6	1.497	5.57	818.8
10.00	1.495	5.53	1111.9	1.495	5.57	1089.3	1.494	5.52	1106.3
15.00	1.492	5.53	1634.5	1.494	5.44	1632.8	1.491	5.55	1639.8
20.00	1.493	5.57	2150.0	1.488	5.56	2147.2	1.492	5.47	2146.1
30.00	1.493	5.55	3197.1	1.493	5.56	3181.6	1.492	5.59	3166.0
40.00	1.495	5.54	4217.5	1.496	5.61	4258.6	1.496	5.55	4210.7
50.00	1.495	5.57	5145.4	1.496	5.64	5203.3	1.498	5.52	5192.5

AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
104.57	102.60	1.97	996.91	1.880
208.92	202.43	6.49	995.82	3.108
417.34	392.83	24.52	995.98	5.874
624.87	588.43	36.44	996.14	5.831
831.47	792.59	38.88	996.30	4.676
1243.24	1193.51	49.73	998.96	4.000
1651.08	1578.21	72.87	1001.62	4.413
2463.49	2350.79	112.70	1004.28	4.575
3262.82	3129.33	133.48	1007.60	4.091
4050.20	3838.33	211.88	1010.92	5.231

RETENTION STANDARD DEVIATION = 0.90

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 68.89 X AVG= 1416.90
SLOPE = 0.0502 LIMITS = 0.0044
INTERCEPT = -2.25 LIMITS = 30.92
CORRELATION COEFFICIENT = 0.9750

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.93 X AVG= 1.56
SLOPE = 0.7926 LIMITS = 0.0770
INTERCEPT = 1.69 LIMITS = 0.28
CORRELATION COEFFICIENT = 0.9700

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 3.0000 EXP 22
PULP WEIGHT = 0.968 BLANK = 1.20
STOCK FINES CONCENTRATION = 88649.69

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	0.943	5.88	46.3	1.446	5.51	45.6	0.451	6.22	44.4
1.25	1.446	5.56	159.3	1.447	5.46	162.1	1.450	5.53	154.0
2.50	1.446	5.54	278.3	1.445	5.45	280.4	1.451	5.39	275.9
5.00	1.448	5.51	533.9	1.441	5.51	532.6	1.446	5.49	527.3
7.50	1.448	5.51	786.8	1.454	5.54	779.4	1.452	5.56	795.5
10.00	1.460	5.53	1049.8	1.458	5.45	1008.5	1.460	5.43	1045.1
15.00	1.459	5.50	1486.3	1.463	5.56	1494.9	1.456	5.43	1526.3
20.00	1.463	5.46	1991.3	1.464	5.44	1950.5	1.465	5.49	1982.5
30.00	1.468	5.43	2958.5	1.468	5.49	2948.9	1.467	5.44	2947.8
40.00	1.474	5.60	3733.2	1.471	5.40	3849.6	1.639	5.36	4151.8
50.00	1.473	5.38	4735.0	1.471	5.51	4774.0	1.471	5.51	4624.5

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
111.14	88.41	22.73	997.02	20.455
222.13	182.15	39.98	996.03	17.997
443.75	381.06	62.68	996.30	14.126
664.40	579.23	85.16	996.56	12.818
884.09	768.21	115.88	996.83	13.107
1321.82	1131.27	190.55	999.59	14.416
1755.60	1493.18	262.42	1002.36	14.948
2620.17	2243.80	376.36	1005.12	14.364
3471.05	2867.67	603.38	1008.65	17.383
4310.77	3590.92	719.85	1012.18	16.699

RETENTION STANDARD DEVIATION = 1.51

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 247.90 X AVG= 1332.59
SLOPE = 0.2020 LIMITS = 0.0132
INTERCEPT = -21.26 LIMITS = 85.76
CORRELATION COEFFICIENT = 0.9860

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.90 X AVG= 2.17
SLOPE = 1.0270 LIMITS = 0.0665
INTERCEPT = 0.68 LIMITS = 0.23
CORRELATION COEFFICIENT = 0.9863

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 500.0000 EXP 23
PULP WEIGHT = 1.197 BLANK = 6.00
STOCK FINES CONCENTRATION = 86611.00

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.557	4.09	57.5	1.550	4.09	45.3	1.565	4.17	43.2
1.25	1.556	4.22	121.7	1.561	4.20	113.6	1.575	4.17	119.5
2.50	1.567	4.15	185.0	1.575	4.24	196.4	1.573	4.14	196.4
5.00	1.655	4.18	423.4	1.565	4.12	383.6	1.557	4.20	396.5
7.50	1.567	4.18	543.8	1.569	4.16	579.2	1.569	4.13	560.5
10.00	1.587	4.26	785.8	1.582	4.10	770.9	1.579	4.12	753.3
15.00	1.576	4.18	1109.7	1.579	4.24	1144.8	1.574	4.18	1178.6
20.00	1.573	4.20	1500.6	1.582	4.21	1571.2	1.572	4.11	1522.6
30.00	1.580	4.20	2324.0	1.578	4.17	2365.1	1.581	4.16	2279.7
40.00	1.583	4.19	3084.0	1.580	4.17	3140.4	1.581	4.19	3071.0
50.00	1.586	4.22	3832.0	1.579	4.17	3862.7	1.574	4.22	3888.0

CORRECTED AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
108.64	56.09	52.55	996.51	48.373
217.34	115.50	101.85	995.02	46.861
434.51	280.73	153.78	994.77	35.391
651.00	414.39	236.60	994.53	36.345
866.95	578.81	288.14	994.29	33.236
1296.79	883.68	413.10	996.55	31.856
1723.24	1196.59	526.65	998.80	30.562
2573.21	1832.68	740.53	1001.06	28.778
3412.46	2456.18	956.28	1003.58	28.023
4241.64	3074.66	1166.97	1006.09	27.512

RETENTION STANDARD DEVIATION = 1.95

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 463.65 X AVG= 1088.93
SLOPE = 0.3630 LIMITS = 0.0128
INTERCEPT = 68.39 LIMITS = 72.04
CORRELATION COEFFICIENT = 0.9959

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.78 X AVG= 2.50
SLOPE = 1.3010 LIMITS = 0.0489
INTERCEPT = -0.47 LIMITS = 0.17
CORRELATION COEFFICIENT = 0.9953

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 200.0000 EXP 24
PULP WEIGHT = 1.156 BLANK = 6.00
STUCK FINES CONCENTRATION = 86161.75

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.566	4.35	53.9	1.574	4.45	60.0	1.566	4.41	55.2
1.25	1.573	4.46	142.5	1.573	4.51	140.9	1.572	4.40	138.6
2.50	1.578	4.51	209.5	1.564	4.48	202.2	1.564	4.51	210.0
5.00	1.574	4.44	385.6	1.570	4.42	393.0	1.566	4.52	391.1
7.50	1.388	4.56	538.3	1.391	4.62	534.3	1.390	4.56	524.7
10.00	1.389	4.50	700.5	1.396	4.59	746.8	1.398	4.59	708.1
15.00	1.399	4.59	1071.4	1.393	4.58	1049.5	1.386	4.57	1058.5
20.00	1.399	4.42	1428.3	1.400	4.54	1384.3	1.399	4.59	1421.5
30.00	1.387	4.69	2184.6	1.387	4.57	2244.8	1.388	4.58	2167.4
40.00	1.388	4.60	2851.4	1.391	4.57	2761.4	1.386	4.43	2932.7
50.00	1.385	4.61	3559.1	1.383	4.50	3502.3	1.387	4.54	3478.9

CORRECTED AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
108.04	66.28	41.76	996.88	38.648
216.03	118.43	97.60	995.76	45.179
431.78	262.45	169.33	995.89	39.216
646.84	424.36	222.48	996.02	34.395
861.13	589.10	272.03	996.14	31.590
1287.62	894.14	393.48	998.77	30.558
1710.54	1202.65	507.90	1001.40	29.692
2553.75	1923.39	630.36	1004.03	24.684
3384.18	2502.35	881.83	1007.29	26.057
4204.25	3106.04	1098.21	1010.55	26.121

RETENTION STANDARD DEVIATION = 1.56

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 431.49 X AVG= 1108.92
SLOPE = 0.3255 LIMITS = 0.0190
INTERCEPT = 70.52 LIMITS = 108.62
CORRELATION COEFFICIENT = 0.9889

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.79 X AVG= 2.47
SLOPE = 1.2589 LIMITS = 0.0616
INTERCEPT = -0.32 LIMITS = 0.21
CORRELATION COEFFICIENT = 0.9921

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 20.0000 EXP 25
PULP WEIGHT = 1.150 BLANK = 6.00
STOCK FINES CONCENTRATION = 85622.50

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.406	4.93	39.3	1.366	5.25	35.0	1.362	5.29	35.5
1.25	1.339	5.36	124.3	1.348	5.41	118.1	1.345	5.29	125.2
2.50	1.354	5.35	205.3	1.357	5.41	198.8	1.350	5.36	202.5
5.00	1.357	5.43	366.4	1.356	5.40	350.6	1.344	5.34	360.5
7.50	1.360	5.43	539.9	1.354	5.42	517.0	1.360	5.33	550.1
10.00	1.352	5.40	691.6	1.358	5.47	722.6	1.364	5.28	747.9
15.00	1.368	5.35	1119.9	1.377	5.28	1126.8	1.361	5.30	1105.0
20.00	1.378	5.38	1493.9	1.372	5.37	1450.4	1.365	5.37	1426.8
30.00	1.370	5.38	2191.7	1.370	5.43	2197.9	1.370	5.30	2226.0
40.00	1.370	5.42	2861.6	1.367	5.37	2948.9	1.370	5.31	3030.7
50.00	1.370	5.38	3727.2	1.546	5.28	4252.2	1.376	5.31	3846.9

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
107.33	75.17	32.16	997.15	29.963
214.54	143.60	70.94	996.30	33.066
428.63	279.82	148.81	996.71	34.717
641.98	431.38	210.60	997.11	32.805
854.54	592.08	262.46	997.51	30.714
1277.57	929.38	348.20	1000.41	27.255
1696.78	1218.84	477.94	1003.31	28.167
2532.89	1864.77	668.12	1006.22	26.378
3355.95	2505.36	850.59	1010.02	25.346
4167.65	3222.69	944.96	1013.63	22.674

RETENTION STANDARD DEVIATION = 1.94

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 401.48 X AVG= 1126.31
SLOPE = 0.2967 LIMITS = 0.0203
INTERCEPT = 67.34 LIMITS = 117.96
CORRELATION COEFFICIENT = 0.9847

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.81 X AVG= 2.42
SLOPE = 1.1200 LIMITS = 0.0549
INTERCEPT = 0.10 LIMITS = 0.19
CORRELATION COEFFICIENT = 0.9921

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 10.0000 EXP 26
PULP WEIGHT = 1.170 BLANK = 6.00
STOCK FINES CONCENTRATION = 86536.25

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.378	5.47	38.1	1.382	5.45	36.1	1.378	5.48	36.3
1.25	1.375	5.43	124.4	1.365	5.54	123.0	1.371	5.48	117.8
2.50	1.364	5.46	200.5	1.366	5.38	203.0	1.370	5.53	201.5
5.00	1.370	5.53	349.4	1.366	5.45	376.1	1.360	5.45	383.8
7.50	1.371	5.56	552.1	1.376	5.45	552.0	1.377	5.42	566.8
10.00	1.371	5.49	742.6	1.375	5.41	737.9	1.381	5.49	757.3
15.00	1.372	5.51	1114.3	1.373	5.51	1086.1	1.363	5.46	1095.7
20.00	1.376	5.45	1499.3	1.369	5.48	1497.4	1.368	5.40	1526.2
30.00	1.368	5.46	2163.9	1.372	5.41	2188.9	1.367	5.38	2239.6
40.00	1.373	5.56	2957.9	1.370	5.48	3007.9	1.372	5.35	2986.4
50.00	1.371	5.54	3862.7	1.374	5.54	3701.3	1.382	5.40	3798.9

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
108.48	72.26	36.22	997.13	33.391
216.85	140.54	76.32	996.27	35.192
433.26	284.15	149.11	996.65	34.416
648.90	441.50	207.40	997.04	31.961
863.73	602.07	261.66	997.42	30.294
1291.31	905.71	385.60	1000.31	29.861
1715.18	1255.28	459.91	1003.19	26.814
2560.13	1845.91	714.23	1006.08	27.898
3392.46	2515.61	876.85	1009.85	25.847
4213.16	3194.67	1018.49	1013.61	24.174

RETENTION STANDARD DEVIATION = 1.81

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 418.58 X AVG= 1125.77
SLOPE = 0.3185 LIMITS = 0.0181
INTERCEPT = 59.98 LIMITS = 104.35
CORRELATION COEFFICIENT = 0.9894

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.81 X AVG= 2.44
SLOPE = 1.1460 LIMITS = 0.0406
INTERCEPT = 0.02 LIMITS = 0.14
CORRELATION COEFFICIENT = 0.9959

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 1.0000 EXP 27
PULP WEIGHT = 1.018 BLANK = 0.0
STOCK FINES CONCENTRATION = 88097.88
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.534	5.24	36.1	1.540	5.45	38.9	1.534	5.47	36.0
1.25	1.532	5.55	164.8	1.528	5.51	171.3	1.533	5.62	165.1
2.50	1.525	5.47	298.6	1.530	5.65	289.3	1.528	5.75	296.1
5.00	1.532	5.73	558.1	1.536	5.58	570.5	1.535	5.62	585.5
7.50	1.709	5.52	903.8	1.536	5.64	837.5	1.539	5.66	863.8
10.00	1.539	5.63	1145.0	1.537	5.58	1111.7	1.536	5.67	1160.3
15.00	1.534	5.61	1728.6	1.536	5.56	1699.6	1.537	5.67	1696.3
20.00	1.534	5.56	2237.6	1.537	5.62	2292.5	1.536	5.58	2289.7
30.00	1.536	5.54	3336.8	1.537	5.64	3467.2	1.535	5.67	3323.8
40.00	1.535	5.58	4461.5	1.538	5.51	4501.8	1.537	5.68	4459.9
50.00	1.536	5.64	5519.8	1.540	5.68	5533.7	1.539	5.64	5533.7

AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
110.50	94.50	15.99	996.60	14.474
220.87	187.66	33.21	995.20	15.035
441.36	387.43	53.93	995.05	12.219
660.99	580.62	80.37	994.90	12.159
879.78	797.42	82.37	994.75	9.362
1315.76	1210.59	105.16	997.10	7.993
1747.76	1619.88	127.88	999.45	7.317
2608.02	2418.42	189.60	1001.80	7.270
3455.65	3212.79	242.86	1004.51	7.028
4291.39	3971.60	319.79	1007.21	7.452

RETENTION STANDARD DEVIATION = 1.81

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 125.12 X AVG= 1448.09
SLOPE = 0.0720 LIMITS = 0.0065
INTERCEPT = 20.82 LIMITS = 47.00
CORRELATION COEFFICIENT = 0.9740

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.93 X AVG= 1.95
SLOPE = 1.2926 LIMITS = 0.1115
INTERCEPT = 0.40 LIMITS = 0.32
CORRELATION COEFFICIENT = 0.9761

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 0.1000 EXP 28
PULP WEIGHT = 1.003 BLANK = 0.0
STUCK FINES CONCENTRATION = 88097.88
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.537	5.74	40.8	1.523	5.79	40.0	1.355	5.70	37.4
1.25	1.530	5.70	163.5	1.530	5.56	157.4	1.529	5.73	157.5
2.50	1.531	5.71	304.5	1.527	5.60	313.0	1.529	5.52	307.0
5.00	1.534	5.67	599.6	1.535	5.73	605.8	1.535	5.68	609.5
7.50	1.535	5.58	888.8	1.534	5.69	893.3	1.536	5.52	905.3
10.00	1.537	5.65	1184.4	1.540	5.59	1222.6	1.538	5.73	1199.3
15.00	1.536	5.64	1759.3	1.534	5.68	1742.4	1.538	5.58	1797.3
20.00	1.533	5.71	2370.1	1.541	5.65	2323.2	1.534	5.80	2360.1
30.00	1.534	5.59	3480.0	1.535	5.67	3478.9	1.537	5.64	3492.1
40.00	1.531	5.65	4603.2	1.538	5.61	4531.9	1.530	5.55	4523.7
50.00	1.535	5.67	5679.9	1.535	5.77	5620.4	1.539	5.63	5675.9

AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT.
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
110.49	87.12	23.38	996.65	21.158
220.88	195.12	25.77	995.29	11.666
441.31	409.02	32.29	995.19	7.317
660.80	619.14	41.65	995.09	6.304
879.36	838.81	40.55	994.99	4.611
1315.01	1247.72	67.29	997.38	5.117
1746.70	1670.48	76.23	999.78	4.364
2606.25	2490.14	116.11	1002.18	4.455
3452.81	3267.33	185.48	1004.98	5.372
4287.57	4059.12	228.45	1007.77	5.328

RETENTION STANDARD DEVIATION = 1.27

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 83.72 X AVG= 1488.40
SLOPE = 0.0514 LIMITS = 0.0055
INTERCEPT = 7.23 LIMITS = 40.61
CORRELATION COEFFICIENT = 0.9639

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.94 X AVG= 1.79
SLOPE = 1.3807 LIMITS = 0.2403
INTERCEPT = 0.47 LIMITS = 0.62
CORRELATION COEFFICIENT = 0.9122

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 0.2500 EXP 29
PULP WEIGHT = 0.999 BLANK = 0.0
STUCK FINES CONCENTRATION = 88097.88
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.512	5.76	40.9	1.531	5.62	36.9	1.501	5.64	38.0
1.25	1.495	5.74	171.4	1.496	5.62	172.8	1.504	5.72	168.1
2.50	1.488	5.71	305.7	1.493	5.65	302.8	1.487	5.65	302.3
5.00	1.482	5.67	573.3	1.495	5.64	592.3	1.493	5.68	591.5
7.50	1.493	5.60	888.3	1.495	5.72	875.3	1.497	5.72	844.6
10.00	1.503	5.69	1157.4	1.503	5.67	1181.3	1.511	5.68	1181.6
15.00	1.505	5.65	1756.0	1.505	5.58	1764.0	1.512	5.63	1739.7
20.00	1.509	5.68	2278.2	1.504	5.78	2303.3	1.503	5.65	2325.6
30.00	1.506	5.66	3276.9	1.504	5.61	3431.6	1.512	5.66	3340.9
40.00	1.501	5.62	4424.3	1.506	5.69	4589.2	1.506	5.70	4451.1
50.00	1.510	5.56	5484.9	1.505	5.60	5521.5	1.508	5.61	5588.0

AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
110.48	97.84	12.64	996.75	11.445
220.80	197.30	23.50	995.50	10.642
441.15	407.19	33.96	995.50	7.697
660.55	616.45	44.10	995.49	6.676
879.00	835.87	43.14	995.49	4.907
1314.41	1261.43	52.98	997.99	4.031
1745.73	1668.26	77.47	1000.49	4.437
2604.76	2435.83	168.93	1002.99	6.485
3450.94	3280.59	170.35	1005.99	4.936
4284.55	4040.86	243.69	1008.98	5.688

RETENTION STANDARD DEVIATION = 1.60

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 87.07 X AVG= 1484.16
SLOPE = 0.0561 LIMITS = 0.0094
INTERCEPT = 3.83 LIMITS = 69.04
CORRELATION COEFFICIENT = 0.9177

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.94 X AVG= 1.76
SLOPE = 1.1874 LIMITS = 0.1708
INTERCEPT = 0.85 LIMITS = 0.48
CORRELATION COEFFICIENT = 0.9375

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 0.0 EXP 30
PULP WEIGHT = 1.002 BLANK = 0.0
STOCK FINES CONCENTRATION = 98764.19
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.610	5.61	42.0	1.409	5.76	39.0	1.411	5.81	37.5
1.25	1.385	5.66	193.1	1.384	5.87	188.1	1.376	5.88	177.9
2.50	1.558	5.59	367.2	1.589	5.60	365.4	1.561	5.65	369.3
5.00	1.561	5.78	684.3	1.567	5.73	680.9	1.556	5.73	690.6
7.50	1.557	5.76	1016.9	1.670	5.60	1068.4	1.559	5.69	1047.2
10.00	1.557	5.70	1329.2	1.559	5.58	1350.1	1.554	5.70	1343.4
15.00	1.561	5.65	2034.2	1.559	5.63	2036.6	1.564	5.75	2048.6
20.00	1.559	5.69	2706.2	1.558	5.78	2694.8	1.561	5.64	2719.6
30.00	1.562	5.73	4032.3	1.559	5.71	3970.2	1.559	5.69	3971.4
40.00	1.560	5.70	5227.7	1.568	5.73	5388.4	1.563	5.78	5294.7
50.00	1.553	5.62	6541.8	1.564	5.71	6595.7	1.560	5.59	6598.0

AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
123.88	117.63	6.25	996.61	5.043
247.55	231.14	16.41	995.21	6.630
494.64	457.59	37.04	995.07	7.489
740.74	697.22	43.52	994.93	5.875
985.80	925.10	60.70	994.79	6.158
1474.40	1417.80	56.60	997.14	3.839
1958.40	1892.99	65.41	999.50	3.340
2922.06	2803.17	118.89	1001.86	4.069
3871.40	3724.98	146.42	1004.57	3.782
4807.13	4641.98	165.15	1007.29	3.436

RETENTION STANDARD DEVIATION = 1.82

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 71.64 X AVG= 1690.96
SLOPE = 0.0340 LIMITS = 0.0047
INTERCEPT = 14.21 LIMITS = 39.13
CORRELATION COEFFICIENT = 0.9428

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 3.00 X AVG= 1.68
SLOPE = 0.9466 LIMITS = 0.1676
INTERCEPT = 1.41 LIMITS = 0.53
CORRELATION COEFFICIENT = 0.9095

COAGULATION ISOTHERM RESULTS

CATION NA MMOLES/L 200.0000 EXP 31
PULP WEIGHT = 1.044 BLANK = 6.00
STOCK FINES CONCENTRATION = 99618.06

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.568	4.57	41.0	1.559	4.60	43.5	1.560	4.53	37.0
1.25	1.561	4.54	137.4	1.564	4.54	135.3	1.553	4.49	128.3
2.50	1.565	4.56	232.4	1.565	4.56	223.6	1.565	4.56	225.3
5.00	1.560	4.55	449.4	1.561	4.50	429.0	1.561	4.53	442.1
7.50	1.565	4.52	668.9	1.568	4.48	669.1	1.569	4.59	653.9
10.00	1.562	4.52	920.8	1.560	4.48	951.7	1.559	4.61	922.3
15.00	1.564	4.49	1332.7	1.563	4.59	1438.3	1.562	4.56	1420.6
20.00	1.563	4.46	1848.5	1.564	4.56	1915.7	1.562	4.46	1928.2
30.00	1.564	4.55	2772.2	1.562	4.52	2807.0	1.565	4.46	2825.3
40.00	1.566	4.52	3727.0	1.565	4.56	3781.7	1.567	4.53	3817.0
50.00	1.563	4.49	4632.3	1.566	4.51	4629.3	1.565	4.55	4681.3

CORRECTED AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
124.95	73.73	51.22	996.56	40.992
249.92	147.25	102.67	995.12	41.081
499.59	316.96	182.63	994.92	36.556
748.55	493.09	255.46	994.73	34.127
996.78	709.88	286.90	994.54	28.783
1490.80	1079.89	410.91	996.85	27.563
1980.80	1479.25	501.55	999.16	25.321
2957.09	2198.67	758.43	1001.46	25.648
3920.97	2972.23	948.75	1004.08	24.197
4872.63	3667.27	1205.36	1006.70	24.737

RETENTION STANDARD DEVIATION = 1.79

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 470.39 X AVG= 1313.82
SLOPE = 0.3063 LIMITS = 0.0115
INTERCEPT = 67.95 LIMITS = 77.38
CORRELATION COEFFICIENT = 0.9953

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.87 X AVG= 2.51
SLOPE = 1.2896 LIMITS = 0.0511
INTERCEPT = -0.37 LIMITS = 0.17
CORRELATION COEFFICIENT = 0.9948

COAGULATION ISOTHERM RESULTS

CATION NA MMOL/L 10.0000 EXP 32
PULP WEIGHT = 1.042 BLANK = 6.00
STOCK FINES CONCENTRATION = 98704.81

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.544	5.29	31.5	1.541	5.53	43.0	1.548	5.28	44.5
1.25	1.539	5.35	130.9	1.544	5.47	133.1	1.545	5.40	129.1
2.50	1.546	5.49	243.1	1.543	5.47	237.7	1.548	5.39	244.8
5.00	1.546	5.38	477.5	1.546	5.50	455.7	1.550	5.30	474.5
7.50	1.548	5.40	684.5	1.376	5.50	626.1	1.547	5.38	720.3
10.00	1.544	5.38	945.3	1.547	5.39	950.3	1.543	5.46	974.2
15.00	1.549	5.43	1430.8	1.368	5.53	1297.9	1.547	5.40	1516.3
20.00	1.552	5.47	2022.2	1.553	5.41	1886.6	1.548	5.40	1957.2
30.00	1.552	5.33	2912.2	1.550	5.40	2998.9	1.549	5.34	2928.7
40.00	1.552	5.31	3960.1	1.554	5.27	4000.4	1.554	5.31	4121.2
50.00	1.551	5.32	5111.0	1.552	5.37	5018.1	1.554	5.40	5011.5

CORRECTED AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
123.80	68.98	54.82	996.61	44.284
247.63	152.80	94.83	995.21	38.296
494.93	324.96	169.97	995.07	34.342
741.51	500.98	240.53	994.93	32.438
987.33	696.55	290.78	994.78	29.451
1476.70	1086.03	390.67	997.14	26.455
1961.94	1452.42	509.52	999.50	25.970
2929.09	2206.02	723.07	1001.85	24.686
3883.35	3024.68	858.67	1004.57	22.112
4824.92	3802.14	1022.78	1007.28	21.198

RETENTION STANDARD DEVIATION = 1.74

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 435.56 X AVG= 1331.55
SLOPE = 0.2572 LIMITS =0.0165
INTERCEPT = 93.15 LIMITS =114.36
CORRELATION COEFFICIENT =0.9865

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.87 X AVG= 2.49
SLOPE = 1.3559 LIMITS =0.0411
INTERCEPT = -0.51 LIMITS = 0.14
CORRELATION COEFFICIENT =0.9969

COAGULATION ISOTHERM RESULTS

CATION CA MMOL/L 0.0010 EXP 4
PULP WEIGHT = 0.973 BLANK = 0.0
STUCK FINES CONCENTRATION = 88097.88
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.525	5.63	34.1	1.534	5.59	36.8	1.530	5.67	36.3
1.25	1.523	5.75	172.0	1.524	5.64	160.4	1.528	5.69	162.3
2.50	1.526	5.79	311.1	1.525	5.66	307.9	1.526	5.76	309.0
5.00	1.533	5.66	600.1	1.526	5.71	591.8	1.526	5.81	597.8
7.50	1.522	5.62	887.3	1.524	5.64	894.7	1.528	5.73	882.3
10.00	1.523	5.74	1180.0	1.525	5.71	1155.6	1.520	5.76	1149.0
15.00	1.525	5.69	1725.8	1.520	5.63	1722.5	1.524	5.58	1731.1
20.00	1.521	5.70	2251.1	1.520	5.70	2284.9	1.515	5.60	2284.5
30.00	1.520	5.63	3420.2	1.516	5.71	3448.6	1.523	5.69	3405.1
40.00	1.525	5.68	4465.4	1.529	5.74	4415.0	1.528	5.68	4377.0
50.00	1.473	5.76	5395.9	1.517	5.70	5620.3	1.526	5.64	5590.5

AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
110.49	93.81	16.68	996.69	15.098
220.84	198.48	22.36	995.38	10.124
441.22	406.22	35.00	995.32	7.933
660.68	618.77	41.90	995.26	6.343
879.19	818.28	60.91	995.20	6.928
1314.83	1228.72	86.11	997.64	6.549
1746.47	1630.88	115.59	1000.08	6.618
2606.14	2468.31	137.83	1002.53	5.289
3452.53	3176.97	275.56	1005.41	7.981
4287.66	4043.69	243.98	1008.29	5.690

RETENTION STANDARD DEVIATION = 1.54

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 103.59 X AVG= 1468.41
SLOPE = 0.0652 LIMITS = 0.0083
INTERCEPT = 7.91 LIMITS = 60.80
CORRELATION COEFFICIENT = 0.9494

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.94 X AVG= 1.85
SLOPE = 1.2208 LIMITS = 0.1174
INTERCEPT = 0.69 LIMITS = 0.34
CORRELATION COEFFICIENT = 0.9705

COAGULATION ISOTHERM RESULTS

CATION CA MMOLES/L 0.0030 EXP 5
PULP WEIGHT = 1.016 BLANK = 0.0
STOCK FINES CONCENTRATION = 99688.00
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.538	5.70	37.2	0.0	5.78	39.5	0.0	5.57	36.0
1.25	1.538	5.64	200.9	0.0	5.63	203.6	0.0	5.68	199.4
2.50	1.541	5.58	356.8	0.0	5.69	363.8	0.0	5.59	364.0
5.00	1.544	5.66	697.1	0.0	5.64	704.0	0.0	5.63	702.3
7.50	1.541	5.65	1025.5	0.0	5.65	1010.4	0.0	5.62	1020.4
10.00	1.541	5.67	1383.5	0.0	5.70	1336.1	0.0	5.62	1377.3
15.00	1.543	5.75	2017.6	0.0	5.65	2040.1	0.0	5.78	2036.3
20.00	1.546	5.70	2682.0	0.0	5.67	2674.5	0.0	5.52	2613.4
30.00	1.551	5.63	3892.2	0.0	5.73	3994.8	0.0	5.74	3952.3
40.00	1.548	5.71	5187.3	0.0	5.72	5223.8	0.0	5.58	5292.3
50.00	1.551	5.65	6544.8	0.0	5.47	6500.0	0.0	5.71	6448.8

AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
125.03	117.66	7.37	996.62	5.896
249.87	232.82	17.04	995.24	6.820
499.26	476.86	22.41	995.10	4.488
747.59	705.14	42.45	994.97	5.678
994.92	954.46	40.46	994.84	4.066
1487.95	1432.85	55.10	997.21	3.703
1976.44	1882.24	94.20	999.58	4.766
2949.31	2809.19	140.13	1001.95	4.751
3907.61	3734.83	172.78	1004.68	4.422
4852.20	4642.80	209.40	1007.42	4.316

RETENTION STANDARD DEVIATION = 1.11

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 80.13 X AVG= 1698.88
SLOPE = 0.0452 LIMITS = 0.0054
INTERCEPT = 3.38 LIMITS = 45.29
CORRELATION COEFFICIENT = 0.9557

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 3.01 X AVG= 1.70
SLOPE = 1.0631 LIMITS = 0.0993
INTERCEPT = 1.20 LIMITS = 0.30
CORRELATION COEFFICIENT = 0.9721

COAGULATION ISOTHERM RESULTS

CATION CA MMOL/L 0.0100 EXP 6
PULP WEIGHT = 1.038 BLANK = 0.0
STOCK FINES CONCENTRATION = 99089.00
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.501	5.72	37.0	0.0	5.57	41.5	0.0	5.84	39.3
1.25	1.508	5.84	189.1	0.0	5.89	184.6	0.0	5.69	187.1
2.50	1.515	5.70	345.3	0.0	5.80	358.6	0.0	5.70	353.8
5.00	1.510	5.76	692.8	0.0	5.81	692.8	0.0	5.67	689.7
7.50	1.518	5.80	1044.8	0.0	5.62	1025.8	0.0	5.76	1011.1
10.00	1.516	5.69	1344.4	0.0	5.76	1351.9	0.0	5.80	1364.1
15.00	1.520	5.64	2001.8	0.0	5.89	2000.0	0.0	5.76	2014.8
20.00	1.521	5.79	2619.0	0.0	5.82	2648.5	0.0	5.68	2631.9
30.00	1.514	5.86	3856.1	0.0	5.70	3851.1	0.0	5.69	3899.6
40.00	1.516	5.67	5178.0	0.0	5.67	5228.2	0.0	5.73	5136.7
50.00	1.515	5.79	6476.4	0.0	5.59	6350.0	0.0	5.74	6351.1

AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
124.27	107.59	16.68	996.71	13.423
248.37	228.31	20.07	995.42	8.079
496.22	475.50	20.71	995.37	4.175
742.95	720.02	22.93	995.33	3.086
988.59	957.79	30.80	995.29	3.116
1478.36	1432.98	45.39	997.75	3.070
1963.57	1890.39	73.18	1000.20	3.727
2929.89	2791.02	138.87	1002.66	4.740
3881.58	3747.21	134.36	1005.58	3.462
4819.14	4630.17	188.98	1008.49	3.921

RETENTION STANDARD DEVIATION = 1.09

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 69.20 X AVG= 1698.10
SLOPE = 0.0392 LIMITS = 0.0058
INTERCEPT = 2.68 LIMITS = 48.53
CORRELATION COEFFICIENT = 0.9345

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 3.00 X AVG= 1.67
SLOPE = 1.1381 LIMITS = 0.2312
INTERCEPT = 1.11 LIMITS = 0.64
CORRELATION COEFFICIENT = 0.8856

COAGULATION ISOTHERM RESULTS

CATION CA MMOL/L 0.1000 EXP 7
PULP WEIGHT = 1.031 BLANK = 0.0
STOCK FINES CONCENTRATION = 96259.00
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.524	5.55	36.3	0.0	5.69	37.2	0.0	5.71	37.1
1.25	1.532	5.71	187.1	0.0	5.76	184.5	0.0	5.60	184.8
2.50	1.526	5.76	335.7	0.0	5.74	322.3	0.0	5.60	326.6
5.00	1.519	5.80	651.7	0.0	5.66	650.5	0.0	5.71	650.3
7.50	1.531	5.76	953.7	0.0	5.78	950.0	0.0	5.68	950.8
10.00	1.530	5.72	1225.7	0.0	5.74	1244.2	0.0	5.66	1225.5
15.00	1.526	5.76	1818.8	0.0	5.67	1759.7	0.0	5.74	1771.0
20.00	1.534	5.74	2450.2	0.0	5.54	2457.5	0.0	5.69	2374.5
30.00	1.536	5.66	3436.5	0.0	5.67	3518.1	0.0	5.61	3540.0
40.00	1.538	5.59	4557.0	0.0	5.82	4671.3	0.0	5.60	4538.8
50.00	1.538	5.71	5610.6	0.0	5.62	5799.7	0.0	5.72	5632.3

AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
120.73	107.50	13.23	996.66	10.957
241.28	210.73	30.55	995.32	12.661
482.14	444.10	38.03	995.23	7.888
721.95	661.56	60.40	995.14	8.366
960.81	864.32	96.49	995.05	10.043
1437.04	1263.12	173.92	997.46	12.103
1909.14	1729.09	180.04	999.86	9.431
2849.11	2503.63	345.48	1002.27	12.126
3775.97	3292.65	483.32	1005.09	12.800
4690.45	4082.39	608.06	1007.91	12.964

RETENTION STANDARD DEVIATION = 1.33

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 202.95 X AVG= 1515.91
SLOPE = 0.1506 LIMITS = 0.0117
INTERCEPT = -25.29 LIMITS = 85.99
CORRELATION COEFFICIENT = 0.9806

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.96 X AVG= 2.04
SLOPE = 0.9216 LIMITS = 0.0636
INTERCEPT = 1.08 LIMITS = 0.23
CORRELATION COEFFICIENT = 0.9845

COAGULATION ISOTHERM RESULTS

CATION CA MMOLES/L 1.0000 EXP 8
PULP WEIGHT = 0.969 BLANK = 3.20
STUCK FINES CONCENTRATION = 99351.25

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.510	5.92	43.4	0.0	5.99	43.8	0.0	5.92	41.1
1.25	1.511	5.62	178.6	0.0	5.66	173.7	0.0	5.55	184.4
2.50	1.500	5.55	296.2	0.0	5.56	296.3	0.0	5.56	302.4
5.00	1.505	5.62	542.6	0.0	5.61	554.5	0.0	5.50	538.3
7.50	1.510	5.70	860.0	0.0	5.46	870.4	0.0	5.55	880.0
10.00	1.513	5.59	1078.9	0.0	5.47	1092.8	0.0	5.62	1052.5
15.00	1.513	5.61	1622.0	0.0	5.51	1546.5	0.0	5.64	1584.8
20.00	1.509	5.61	2133.9	0.0	5.43	2138.3	0.0	5.54	2086.6
30.00	1.518	5.52	3235.9	0.0	5.53	3178.9	0.0	5.39	3200.0
40.00	1.510	5.66	4330.9	0.0	5.42	4649.0	0.0	5.58	4320.5
50.00	1.508	5.56	5378.5	0.0	5.38	5459.9	0.0	5.55	5355.9

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
124.60	103.34	21.26	996.72	17.065
249.05	193.63	55.41	995.44	22.251
497.69	380.52	117.17	995.41	23.543
745.51	628.11	117.40	995.38	15.747
992.21	782.18	210.03	995.35	21.168
1484.04	1168.51	315.53	997.82	21.261
1971.69	1574.62	397.08	1000.29	20.139
2943.38	2398.66	544.72	1002.77	18.507
3901.05	3334.59	566.46	1005.71	14.521
4844.71	4065.17	779.55	1008.65	16.091

RETENTION STANDARD DEVIATION = 1.96

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 312.46 X AVG= 1462.93
SLOPE = 0.1797 LIMITS = 0.0204
INTERCEPT = 49.51 LIMITS = 150.95
CORRELATION COEFFICIENT = 0.9598

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.93 X AVG= 2.30
SLOPE = 1.0315 LIMITS = 0.0808
INTERCEPT = 0.56 LIMITS = 0.28
CORRELATION COEFFICIENT = 0.9802

COAGULATION ISOTHERM RESULTS

CATION LA MMOL/L 0.0100 EXP 4
PULP WEIGHT = 1.018 BLANK = 3.00
STOCK FINES CONCENTRATION = 92975.50

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.483	5.53	43.0	0.0	5.68	42.8	0.0	5.72	40.4
1.25	1.494	5.60	182.2	0.0	5.66	180.0	0.0	5.77	174.9
2.50	1.486	5.86	311.9	0.0	5.78	312.5	0.0	5.75	317.1
5.00	1.487	5.67	591.9	0.0	5.69	593.4	0.0	5.81	596.6
7.50	1.491	5.60	871.4	0.0	5.69	878.6	0.0	5.76	874.4
10.00	1.486	5.62	1150.8	0.0	5.82	1130.8	0.0	5.89	1125.9
15.00	1.485	5.67	1687.7	0.0	5.70	1717.1	0.0	5.61	1693.2
20.00	1.485	5.68	2252.4	0.0	5.67	2313.2	0.0	5.84	2335.8
30.00	1.485	5.80	3410.0	0.0	5.76	3510.5	0.0	5.78	3415.2
40.00	1.489	5.68	4537.0	0.0	5.76	4593.8	0.0	5.73	4557.8
50.00	1.489	5.64	5643.4	0.0	5.67	5694.3	0.0	5.75	5606.4

CORRECTED AVERAGE RESULTS

FINES CONCENTRATION, CPM/ML			TOTAL	PERCENT
INITIAL	FINAL	DIFFERENCE	VOLUME	RETENTION
116.59	104.38	12.21	996.79	10.474
233.00	207.12	25.89	995.58	11.109
465.53	420.83	44.70	995.61	9.602
697.08	635.05	62.03	995.65	8.898
927.65	833.84	93.81	995.69	10.112
1387.27	1263.87	123.40	998.23	8.895
1842.64	1723.48	119.16	1000.77	6.467
2749.34	2597.82	151.52	1003.30	5.511
3641.76	3451.20	190.56	1006.38	5.233
4521.20	4279.49	241.70	1009.46	5.346

RETENTION STANDARD DEVIATION = 1.29

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 106.50 X AVG= 1551.71
SLOPE = 0.0497 LIMITS = 0.0070
INTERCEPT = 29.38 LIMITS = 54.54
CORRELATION COEFFICIENT = 0.9398

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.96 X AVG= 1.89
SLOPE = 1.2475 LIMITS = 0.1155
INTERCEPT = 0.60 LIMITS = 0.33
CORRELATION COEFFICIENT = 0.9726

COAGULATION ISOTHERM RESULTS

CATION LA MMOLES/L 0.1000 EXP 5
PULP WEIGHT = 1.062 BLANK = 7.20
STOCK FINES CONCENTRATION = 92975.50

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.482	5.68	37.7	0.0	5.76	36.3	0.0	5.79	38.6
1.25	1.485	5.74	157.8	0.0	5.78	157.0	0.0	5.78	156.5
2.50	1.482	5.68	270.0	0.0	5.70	271.3	0.0	5.67	263.4
5.00	1.482	5.65	482.6	0.0	5.98	450.0	0.0	5.69	468.6
7.50	1.480	5.70	680.9	0.0	5.78	684.9	0.0	5.84	700.7
10.00	1.488	5.73	905.1	0.0	5.88	897.1	0.0	5.68	898.3
15.00	1.484	5.66	1339.6	0.0	5.71	1395.0	0.0	5.73	1365.4
20.00	1.485	5.66	1868.7	0.0	5.64	1926.0	0.0	5.65	1762.7
30.00	1.493	5.62	2588.0	0.0	5.63	2722.8	0.0	5.76	2756.3
40.00	1.491	5.71	3603.6	0.0	5.75	3676.1	0.0	5.71	3697.4
50.00	1.491	5.71	4605.0	0.0	5.70	4482.1	0.0	5.79	4531.9

CORRECTED AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
116.59	93.82	22.77	996.79	19.534
233.05	180.63	52.42	995.58	22.493
465.69	335.18	130.51	995.63	28.024
697.62	508.49	189.13	995.67	27.111
928.75	673.33	255.42	995.71	27.502
1389.07	1038.95	350.12	998.25	25.205
1845.42	1420.65	424.77	1000.80	23.018
2754.78	2073.18	681.60	1003.34	24.742
3651.79	2835.70	816.09	1006.42	22.348
4536.59	3525.34	1011.24	1009.51	22.291

RETENTION STANDARD DEVIATION = 1.95

CORRECTED FIRST ORDER REVERSIBLE

Y AVG= 393.41 X AVG= 1268.53
SLOPE = 0.2832 LIMITS = 0.0173
INTERCEPT = 34.13 LIMITS = 110.42
CORRELATION COEFFICIENT = 0.9878

CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.88 X AVG= 2.38
SLOPE = 0.9683 LIMITS = 0.0546
INTERCEPT = 0.57 LIMITS = 0.20
CORRELATION COEFFICIENT = 0.9896

COAGULATION ISOTHERM RESULTS

CATION LA MMOL/L 0.0050 EXP 6
PULP WEIGHT = 1.035 BLANK = 0.0
STOCK FINES CONCENTRATION = 92975.50
NO BLANK CORRECTION REQUIRED

CRUDE ISOTHERM DATA

FINES VOL, ML	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.	SAMPLE VOLUME	EX ST RATIO	FINES CONC.
0.0	1.470	5.65	36.1	0.0	5.73	38.3	0.0	5.77	37.0
1.25	1.474	5.69	164.4	0.0	5.63	171.9	0.0	5.68	180.5
2.50	1.471	5.74	332.2	0.0	5.80	319.5	0.0	5.85	312.2
5.00	1.472	5.66	619.6	0.0	5.73	621.8	0.0	5.76	618.6
7.50	1.474	5.75	898.9	0.0	5.72	908.8	0.0	5.82	924.1
10.00	1.479	5.76	1210.8	0.0	5.78	1197.2	0.0	5.65	1227.9
15.00	1.482	5.77	1815.6	0.0	5.73	1799.8	0.0	5.76	1791.5
20.00	1.476	5.71	2345.7	0.0	5.79	2364.2	0.0	5.70	2400.5
30.00	1.481	5.74	3578.0	0.0	5.71	3432.2	0.0	5.72	3558.9
40.00	1.479	5.66	4637.5	0.0	5.79	4471.9	0.0	5.72	4690.0
50.00	1.480	5.84	5700.0	0.0	5.72	5670.3	0.0	5.70	5716.6

AVERAGE RESULTS

INITIAL	FINES CONCENTRATION, CPM/ML FINAL	DIFFERENCE	TOTAL VOLUME	PERCENT RETENTION
116.59	101.05	15.54	996.82	13.330
233.01	212.48	20.53	995.64	8.811
465.48	435.85	29.64	995.71	6.367
696.94	653.16	43.78	995.78	6.281
927.39	878.51	48.88	995.86	5.270
1386.71	1319.94	66.77	998.43	4.815
1841.72	1744.54	97.19	1001.00	5.277
2748.06	2606.66	141.40	1003.57	5.145
3640.10	3411.81	228.29	1006.71	6.272
4519.53	4231.24	288.29	1009.85	6.379

RETENTION STANDARD DEVIATION = 2.29

FIRST ORDER REVERSIBLE ANALYSIS

Y AVG= 98.03 X AVG= 1559.52
SLOPE = 0.0646 LIMITS = 0.0094
INTERCEPT = -2.66 LIMITS = 72.08
CORRELATION COEFFICIENT = 0.9363

NTH ORDER REVERSIBLE SLOPE ANALYSIS

Y AVG= 2.97 X AVG= 1.80
SLOPE = 1.1268 LIMITS = 0.1504
INTERCEPT = 0.94 LIMITS = 0.44
CORRELATION COEFFICIENT = 0.9454

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C      KUSHI FINES RETENTION
C      TREATMENT OF RAW COAGULATION ISOTHERM DATA
      DIMENSION S(35),EXST(35),CPM(35),CONC(11),TVOL(11),TFINE(11)
      DIMENSION RET(11),CONCO(11),Y(35),GANG(11),RETN(35),XNTH(35)
      DIMENSION YNTH(35),DATA(11,10)
151    READ(5,100)FINEC,EXP,SALT,SCONC
      READ(5,102)PULP,BL
      WRITE(5,153)
153    FORMAT('1',10X,'COAGULATION ISOTHERM RESULTS')
      WRITE(6,152)SALT,SCONC,EXP
152    FORMAT('0','CATION',2X,A2,5X,'MMOLES/L',F9.4,5X,'EXP',1X12)
      WRITE(5,150)PULP,BL
150    FORMAT('PULP WEIGHT = ',F6.3,5X,'BLANK = ',F5.2)
      READ(5,101) (S(I),EXST(I),CPM(I),I=1,33)
      WRITE(5,155)FINEC
155    FORMAT('STOCK FINES CONCENTRATION = ',F10.2)
      IF(BL)70,70,71
70     INX=0
      GO TO 73
71     INX=1
73     J=1
      K=2
      I=1
170    DATA(J,K)=S(I)
      DATA(J,K+1)=EXST(I)
      DATA(J,K+2)=CPM(I)
      K=K+3
      IF(K-8)171,171,172
171    I=I+1
      GO TO 170
172    K=2
      J=J+1
      I=I+1
      IF(I-33)170,170,730
730    J=1
      N=3
      I=1
      A=0.0
1     TBKG=A+CPM(I)
      A=TBKG
      I=I+1
      IF(I-N)1,1,2
2     B=I-1
      BKG=A/B
      V=0.0
      DO 690 I=1,31,3
690    V=V+S(I)
      V=V/11.
      EXSTT=0.0
      DO 700 I=4,33
700    EXSTT=EXST(I)+EXSTT
      EXSTT=EXSTT/30.
      EFF=.0566*EXSTT+.5812
      IF(S(2))50,50,51
51     DO 52 I=4,33
52     CPM(I)=(CPM(I)-BKG)/(EFF*S(I))
      GO TO 53
50     DO 701 I=4,33
701    CPM(I)=(CPM(I)-BKG)/(EFF*V)

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53      IF(INX)215,215,214
215     WRITE(6,72)
72      FORMAT('NO BLANK CORRECTION REQUIRED')
214     I=4
        N=3
        DO 3 M=1,10
          C=0.0
          N=N+3
4         C=CPM(I)+C
          I=I+1
          IF(I-N)4,4,3
3        CONC(M)=C/B
          M=1
          N=3
          I=1
          ADD=1.25
          CON=1000.00
6         TVOL(M)=CON-V
          CON=TVOL(M)
          I=I+1
          IF(I-N)6,6,7
7         TVOL(M)=CON+ADD
          ADD=ADD+2.00
          N=N+3
          CON=TVOL(M)
          M=M+1
          IF(M-3)6,8,8
10        N=N+3
8         TVOL(M)=CON-V
          CON=TVOL(M)
          I=I+1
          IF(I-N)8,8,9
9         TVOL(M)=CON+4.50
          CON=TVOL(M)
          M=M+1
          IF(M-6)10,11,11
11        N=N+3
30       TVOL(M)=CON-V
          CON=TVOL(M)
          I=I+1
          IF(I-N)30,30,31
31       TVOL(M)=CON+7.00
          CON=TVOL(M)
          M=M+1
          IF(M-8)11,11,32
32       N=N+3
12       TVOL(M)=CON-(V*2.0)
          CON=TVOL(M)
          I=I+1
          IF(I-N)12,12,13
13       TVOL(M)=CON+12.00
          CON=TVOL(M)
          M=M+1
          IF(M-11)32,14,14
14       M=1
          TFINE(M)=FINEC*1.25
          FINEC=TFINE(M)
          M=M+1
          TFINE(M)=FINEC*2.00
          FINEC=TFINE(M)
```

```

15      M=M+1
        FACT=M-1
        TFINE(M)=FACT*FINEC
        IF(M-5)15,15,17
17      FINEC=TFINE(5)
        TFINE(M)=FINEC*1.50
18      M=M+1
        DIL=M-5
        TFINE(M)=DIL*FINEC
        IF(M-10)18,18,19
19      N=6
        FINEC=FINEC/10.
        DATA(1,1)=0.00
        DO 173 I=2,11
173     DATA(1,1)=TFINE(I-1)/FINEC
        I=4
        M=2
        CPMT=0.0
20      CPMT=CPMT+(CPM(I)*V)
        I=I+1
        IF(I-N)20,20,21
21      N=N+3
        TFINE(M)=TFINE(M)-CPMT
        M=M+1
        TOTF=TFINE(M)
        IF(M-8)20,22,22
22      CPMT=CPMT+(CPM(I)*V*2.0)
        I=I+1
        IF(I-N)22,22,23
23      TFINE(M)=TFINE(M)-CPMT
        N=N+3
        M=M+1
        IF(M-10)22,22,24
24      M=1
        I=4
        N=6
25      RETN(I)=((TFINE(M)-(TVOL(M)*CPM(I)))*100.)/TFINE(M)
        I=I+1
        IF(I-N)25,25,26
26      N=N+3
        M=M+1
        IF(M-10)25,25,27
C      ERROR ANALYSIS
27      IF(INX-1)80,81,80
81      I=4
        M=1
        N=6
83      CPM(I)=CPM(I)+((100.000-RETN(I))*0.0001*CPM(I)*8L)
        I=I+1
        IF(I-N)83,83,84
84      N=N+3
        M=M+1
        IF(M-10)83,83,85
85      INX=INX+1
        GO TO 214
80      CFM=0.0
        DO 28 I=4,33
28      CFM=RETN(I)+CFM
        CFM=(CFM**2)/30.
        SS=0.0

```

```

DO 29 I=4,33
29  SS=(RETN(I)**2)+SS
    SSTOT=SS-CFM
    N=6
    I=3
    M=1
33  RETT=0.0
34  RETT=RETT+RETN(I)
    I=I+1
    IF(I-N)34,34,35
35  RET(M)=RETT/3.
    N=N+3
    M=M+1
    IF(M-10)33,33,36
36  SSTRT=0.0
    M=1
37  SSTRT=SSTRT+((RET(M)*3.)**2)/3.
    M=M+1
    IF(M-10)37,37,38
38  SSTRT=SSTRT-CFM
    SSERR=(SSTOT-SSTRT)/20.
    SIGMA=SQRT(SSERR)
    FTEST=(SSTRT/9.0)/SSERR
    DO 39 M=1,10
    CONCO(M)=TFINE(M)/TVOL(M)
39  GANG(M)=CONCO(M)-CONC(M)
    WRITE(6,174)
174  FORMAT('0',25X,'CRUDE ISOTHERM DATA')
    WRITE(6,175)
    WRITE(6,176)
    WRITE(6,177)((DATA(J,K),K=1,10),J=1,11)
175  FORMAT('0','FINES  SAMPLE EX ST  FINES  SAMPLE EX ST  FINES  SAM,
176  IPLE EX ST  FINES')
176  FORMAT('VOL,ML  VOLUME RATIO  CONC.  VOLUME RATIO  CONC.  VOLUME
2RATIO  CONC.')
177  FORMAT(F6.2,F8.3,F6.2,F8.1,F7.3,F6.2,F8.1,F7.3,F6.2,F8.1)
    IF(INX-1)200,200,201
200  WRITE(6,210)
    GO TO 221
201  WRITE(6,220)
210  FORMAT('0',10X,'AVERAGE  RESULTS')
220  FORMAT('0','CORRECTED  AVERAGE  RESULTS')
221  WRITE(6,202)
    WRITE(6,205)
205  FORMAT('  INITIAL          FINAL          DIFFERENCE  VOLUME RETENTION')
    WRITE(6,203)(CONCO(M),CONC(M),GANG(M),TVOL(M),RET(M),M=1,10)
202  FORMAT('0','          FINES CONCENTRATION,CPM/ML          TOTAL  PERCENT ,
4  ')
203  FORMAT(F9.2,5XF8.2,6XF7.2,3XF7.2,2XF7.3)
    WRITE(6,204)SIGMA
204  FORMAT('RETENTION STANDARD DEVIATION =' ,F6.2)
C  FIRST ORDER REVERSIBLE CURVE FITTING
    SUMX=0.0
    XCSS=0.0
    DO 40 M=4,33
    SUMX=CPM(M) +SUMX
40  XCSS=(CPM(M) **2)+XCSS
    XSS=XCSS-((SUMX*SUMX)/30.)
    XKSS=XSS
    XSUMX=SUMX

```

```

SUMY=0.0
M=1
I=4
N=6
703 Y(I)= CONCO(M)-CPM(I)
    XNTH(I)=Y(I)
    YNTH(I)=CPM(I)
    I=I+1
    IF(I-N)703,703,704
704 N=N+3
    M=M+1
    IF(M-10)703,703,705
705 YCSS=0.0
    DO 41 M=4,33
    SUMY=Y(M)+SUMY
41 YCSS=(Y(M)**2)+YCSS
    YSS=YCSS-((SUMY*SUMY)/30.)
    SUMP=0.0
    DO 42 M=4,33
42 SUMP=(CPM(M) *Y(M))+SUMP
    PCFM=(SUMX*SUMY)/30.
    RCOEF=(SUMP-PCFM)/XSS
    CEPT=(SUMY/30.)-(RCOEF*(SUMX/30.))
    YBAR=SUMY/30.
    XBAR=SUMX/30.
    IF(INX-1)297,297,299
299 WRITE(6,304)
304 FORMAT('0','CORRECTED FIRST ORDER REVERSIBLE')
    GO TO 310
297 WRITE(6,305)
305 FORMAT('0','FIRST ORDER REVERSIBLE ANALYSIS')
    GO TO 310
310 WRITE(6,300)YBAR,XBAR
300 FORMAT('0','Y AVG=',F8.2,5X,'X AVG= ',F8.2)
    CORR=(SUMP-PCFM)/SQRT(XSS*YSS)
    SSREG=YSS-(((SUMP-PCFM)**2)/XSS)
    VAREG=SSREG/28.0
    SSREG=SQRT(VAREG/XSS)
    CONB=2.05*SSREG
    CONY=2.05*SQRT((1.0333*VAREG)+((VAREG/XSS)*(XBAR**2)))
    WRITE(6,211)RCOEF,CONB
    WRITE(6,212)CEPT,CONY
    WRITE(6,206)CORR
206 FORMAT('CORRELATION COEFFICIENT =',F6.4)
100 FORMAT(F8.2,1X12,A2,1XF10.6)
102 FORMAT(F6.3,1XF3.2)
101 FORMAT(F5.4,F3.2,F6.2)
C NTH ORDER REVERSIBLE CALCULATION
    SUMX=0.0
    XCSS=0.0
    DO 43 M=4,33
    Y(M)=ALOG10(XNTH(M))
    SUMX=Y(M)+SUMX
43 XCSS=(Y(M)**2)+XCSS
    XSS=XCSS-((SUMX*SUMX)/30.)
    XBAR=SUMX/30.
    SUMY=0.0
    YCSS=0.0
    DO 44 M=4,33
    CPM(M) =ALOG10(YNTH(M))

```

```

SUMY=CPM(M) +SUMY
44  YCSS=(CPM(M) **2)+YCSS
    YSS=YCSS-((SUMY*SUMY)/30.)
    YBAR=SUMY/30.
    IF(INX-1)340,340,341
340  WRITE(6,302)
    GO TO 306
341  WRITE(6,307)
307  FORMAT('0','CORRECTED NTH ORDER REVERSIBLE SLOPE ANALYSIS')
    GO TO 306
302  FORMAT('0','NTH ORDER REVERSIBLE SLOPE ANALYSIS')
306  WRITE(6,300)YBAR,XBAR
    SUMP=0.0
    DO 45 M=4,33
45   SUMP=(CPM(M) *Y(M))+SUMP
    PCFM=(SUMX*SUMY)/30.
46   RCOEF=(SUMP-PCFM)/XSS
    CEPT=(SUMY/30.)-(RCOEF*(SUMX/30.))
    CORR=(SUMP-PCFM)/SQRT(XSS*YSS)
    SSREG=YSS-(((SUMP-PCFM)**2)/XSS)
    VAREG=SSREG/28.0
    SSREG=SQRT(VAREG/XSS)
    CONB=2.05*SSREG
    YVAR=SQRT((1.0334*VAREG)+((VAREG/XSS)*(XBAR**2)))
    CONY=2.05*YVAR
    WRITE(6,211)RCOEF,CONB
    WRITE(6,212)CEPT,CONY
211  FORMAT('SLOPE = ',F6.4,5X,'LIMITS = ',F6.4)
212  FORMAT('INTERCEPT = ',F6.2,5X,'LIMITS = ',F6.2)
    WRITE(6,206)CORR
    GO TO 151
    END
```

APPENDIX VII

ELECTROPHORETIC MOBILITY DATA AND RESULTS

The electrophoretic mobility of the fines was determined with the Numinco electrophoretic mass transport unit in various electrolyte environments (75). The mobility was calculated using the following basic formula (76).

$$V_e = \Delta W \lambda / t i \phi (1 - \phi) (\rho_s - \rho_w) \quad (16)$$

where V_e = electrophoretic mobility cm.²/volt-sec.,

ΔW = mass transfer, g.,

$$= (C_F - C_0) \times V \times A,$$

C_F = final radioactivity concentration, c.p.m./ml.,

C_0 = initial radioactivity concentration, c.p.m./ml.,

V = volume of collection chamber = 5.672 ml.,

A = specific activity of fines = 4.166×10^7 , c.p.m./g.,

λ = specific conductance, mhos/cm.,

$$= k/\Omega,$$

k = conductivity cell constant = 0.10,

Ω = resistance, ohms.,

t = time, sec.,

i = current, amps.,

ϕ = volume fraction of the dispersed phase,

$$= \underline{m}/\underline{\rho}_s,$$

\underline{m} = concentration of fines suspension, g./cc.,

$\underline{\rho}_s$ = specific gravity of the particle = 1.5 g./cc., and

$\underline{\rho}_w$ = specific gravity of the water = 1.0 g./cc.

The zeta potential of the particle can be calculated from the mobility using the following formula for spherical particles (76).

$$\psi_{\zeta} = 4\pi\eta V_e/D \quad (17)$$

where ψ_{ζ} = zeta potential,

η = viscosity of suspending liquid,

D = dielectric constant, and

V_e = electrophoretic mobility, cm.²/volt-sec.

The data and calculated electrophoretic mobilities are summarized in Table XVII.

TABLE XVII

ELECTROPHORETIC MOBILITY OF RADIOACTIVE FINES^a

Sample Number	Electrolyte		Fines Conc.,		Ω , ohms.	$\frac{i}{ma.}$	$\frac{V_e}{cm.^2} \times 10^{-4}$, cm. ² /volt-sec.
	Species	Concn., mM/l.	c.p.m./ml.				
			Initial	Final			
11	Na	0.01	4130	17,602	29,000	0.5	5.74
3		0.01	4130	19,968	31,900	0.5	6.14
12		0.10	4130	9,606	6,790	1.0	4.99
1		0.10	4720	10,765	7,500	1.0	4.36
4		0.10	4130	10,498	6,790	2.0	5.80
2		0.60	4720	7,062	1,730	2.0	3.66
7		0.60	4130	6,287	1,780	3.0	3.74
13		1.00	4130	5,627	856	3.0	3.60
3		1.10	4720	6,405	879	3.0	3.46
9		2.00	4130	5,368	467	4.0	4.10
6		2.20	4361	4,579	428	2.0	1.49
10		3.00	4130	4,900	304	5.0	3.13
11		3.00	4130	5,051	304	5.0	3.74
4		3.30	4720	5,463	304	5.0	2.64
12	4.25	4130	4,472	232	5.0	1.82	
13	5.00	4130	4,272	180	5.0	0.98	
14	5.00	4130	4,212	180	5.0	0.56	
1	Ca	0.000	4130	6,456	45,590	0.05	6.31
2		0.000	4130	19,821	45,590	0.35	6.08
3		0.000	4130	15,364	32,950	0.50	4.22
4		0.02	4130	14,775	22,400	0.50	5.88
5		0.05	4130	15,550	6,915	2.00	5.10
6		0.08	4130	9,097	3,738	2.00	4.11
7		0.18	4130	11,668	1,985	5.00	4.70
17		0.20	4361	4,775	1,900	1.00	1.28
8		0.27	4130	5,080	1,360	3.00	1.44
9		0.39	4130	4,492	1,045	3.00	0.71
10	0.49	4130	4,481	826	3.00	0.88	
1	La	0.000	4361	21,456	54,500	0.40	4.59
2		0.002	4361	21,130	30,750	0.50	6.38
3		0.004	4361	16,824	28,600	0.50	5.10
4		0.006	4361	12,360	20,350	0.50	4.60
5		0.008	4361	15,533	17,000	0.80	4.81
6		0.010	4361	12,529	16,300	0.80	3.67
7		0.015	4361	14,999	12,750	1.00	4.88
8		0.020	4361	9,054	9,745	1.00	2.82
5		0.020	4720	12,509	11,250	1.00	3.74
9		0.025	4361	7,771	8,860	1.00	2.25
10		0.030	4361	7,475	7,345	1.00	2.48
6		0.040	4720	6,400	5,960	1.00	1.53
7		0.060	4720	5,396	4,105	1.00	0.89
8		0.080	4720	5,710	3,115	1.00	1.72

^aElectrophoretic time was 10.0 min. in each determination.