Settling and sedimentation behavior of fine-grained materials

By

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ABSTRACT

Channeling has already been an observed phenomenon that often occurs during settling and sedimentation processes of finer materials. However, it has been regarded as a minor factor affecting settling process, e.g. settling velocity or consolidation rate. In this study, settling behaviors of talcs, kaolins and attapulgite were reviewed by experiments with small and large settling columns with special focus on channel formation during sedimentation. The large settling column is equipped with twenty eight measuring points, which are connected to pressure transducers for measuring pore pressure changes during settling. Throughout the study, channel formation was observed and related to the experimental conditions affecting it. The excess pore pressure changes were measured during the large column tests. Channels occurred under flocculation in zone settling and also in consolidation zones; pressure drop was observed near channels in some cases. It is summarized that not only initial concentration but also the material properties, such as specific gravity and shape of particles, can affect the channel formation. It was apparent that channels work as a facilitator to dissipate the excess pore water pressure.
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List of Symbols

\( K \quad \text{Intrinsic permeability} \)
\( k \quad \text{Permeability} \)
\( \mu_w \quad \text{Kinematic viscosity of water} \)
\( e \quad \text{Void ratio} \)
\( \rho_s \quad \text{Density of solid} \)
\( \rho_w \quad \text{Density of water} \)
\( v_s \quad \text{Settling velocity} \)
\( \omega \quad \text{Settling rate = settling velocity} \)
\( \gamma_s \quad \text{Unit weight of solids} \)
\( \gamma_w \quad \text{Unit weight of water} \)
\( A_0 \quad \text{Gravity number} \)
\( LL \quad \text{Liquid limit} \)
\( PL \quad \text{Plastic limit} \)
\( G_s \quad \text{Specific gravity} \)
\( D_{50} \quad \text{Median grain size} \)
\( C_c \quad \text{Coefficient of curvature} \)
\( C_u \quad \text{Coefficient of uniformity} \)
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Abstract

Channeling has already been an observed phenomenon that often occurs during settling and sedimentation processes of finer materials. However, it has been regarded as a minor factor affecting settling process, e.g. settling velocity or consolidation rate. In this study, settling behaviors of talcs, kaolins and attapulgite were reviewed by experiments with small and large settling columns with special focus on channel formation during sedimentation. The large settling column is equipped with twenty eight measuring points, which are connected to pressure transducers for measuring pore pressure changes during settling. Throughout the study, channel formation was observed and related to the experimental conditions affecting it. The excess pore pressure changes were measured during the large column tests. Channels occurred under flocculation in zone settling and also in consolidation zones; pressure drop was observed near channels in some cases. It was apparent that channels work as a facilitator to dissipate the excess pore water pressure. It is summarized that not only initial concentration but also the material properties, such as specific gravity and shape of particles, can affect the channel formation.

Keywords: channeling, self-weight consolidation, flocculation, zone settling
1. INTRODUCTION

The settling phenomena of fine solid particles in liquid are affected by several factors, such as initial concentration, material type, and water salinity, as well as chemical and ionic characteristics. It is known that there are different zones in settling phenomena and each has different settling characteristics (Coe and Clevenger, 1916; Fitch, 1962, 1966; Holdich and Butt, 1995, 1996). As shown in Figure 1, settling behavior can be described with three regimes: clarification, zone settling, and compression (Holdich and Butt, 1995, 1996). In clarification, also known as the free settling zone, solid particles fall individually without hindering. Their settling velocity remains constant and could be explained by Stokes’ law (Fitch, 1962). The material characteristics in suspensions mostly depend on the physical properties of the particles. The bigger and heavier particles will settle faster than the others.

On the other hand, hindered settling is dominant in zone settling. In zone settling, the particles in the slurry settle “en masse” presenting two distinct interfaces: the mudline (interface between supernatant and suspension layers) and the sediment-layer suspension (interface between suspension and compression layers) (Diplas and Papanicolaou, 1997). The flocs, which are aggregated particles of plastic type structure, move at the same speed regardless of particle sizes (Svarovsky, 1979). The zone settling regime starts under various concentrations as well as degree of flocculation. After the particles or flocs touch the surface of the compression zone, the structures of the settled particles becomes firmer, supporting the load above mechanically, and the changes in volume of the zone become smaller (Svarovsky, 1979). This layer is called compression or consolidation zone. Even though the consolidation layer is much firmer and
causes less volume changes than zone settling layer, large amount of subsidence generally occurs by its self weight.

As a part of the settling and consolidation process, a common but not widely recognized phenomenon randomly occurs: the formation of small paths transporting water and solid particles upward. These are known as “channels”. Solid particles, moving through channels, often develop volcanoes or craters on the interface. The channels facilitate excess pore pressure dissipation from the bottom.

Coe and Clevenger (1916) observed that water channels occurred upward in intermittent, rapidly moving streams, which finally show up as volcanoes on the surface. Fitch (1962), also observed channels in pulps, and expected that these could facilitate higher settling rates. Dell and Kaynar (1968) did experiments using shale added with flocculant, and observed channels growing from the bottom upwards. Channeled and unchanneled zones were defined with fairly sharp boundary, and differences in dilution, specific resistance, flow rate and pressure gradient were compared. Harris et al (1975), added air bubbles and coarser materials intending to accelerate the settling rates. They observed channels propagating downward due to coarser materials. They also observed the water cavities in the slimes and micro volcanoes at the settling surface. Vesilind and Jones (1993) focused on the channeling phenomenon. Using calcium carbonate slurry during the gravity thickening, small channels were observed, mostly 4 cm or less in length and about 0.1 cm wide, moving upward slowly. Channeling zones occurred at the interface between the diluted slurry and the slurry in compression. The solids in the lower zones compressed and expelled water due to the accumulated load, and this caused the water to escape through the channels. However, no patterns could be discerned in the spacing of the channels and
volcanoes. Glasrud et al (1993), using needle-like particles of iron oxide suspended in mineral oil, observed that the entrained air bubbles moved upward to create paths filled with oil and to flocculate the suspensions as they passed. After the bubbles touched the oil/particle interface, holes were created at the surface, and flocs and oil were dragged with the bubbles to the surface. Druitt (1995) also observed channels in volcanological experimental research. The tests were performed using crushed silicon carbide. Hindered settling at intermediate concentrations generated normally graded deposits with elutriation pipes. The research performed by Holdich and Butt (1995, 1996, 1997a&b) were also mainly focused on the channeling and its formation. Channeling was observed with different initial concentrations of slurries of calcite, talc and aragonite in 330mm high columns. Slurry solid concentrations were measured by electrical conductivity in addition to visual observation. Considerable channels and volcanoes occurred in some ranges of concentration. Chen et al (1996) did settling tests with waste activated sludge in tubes which were 6cm in diameter and 42cm in height. In the high concentrations, channeling was observed to enhance the settling. When the solid concentration was low, flocs tended to agglomerate and the aggregates also enhanced the settling velocity. They explained that the channeling usually appears owing to the spatial unbalance between the fluid forces exerting on flocs and the associated binding forces acting between the flocs with both strongly dependent on the solid concentration. However, it was not possible to describe comprehensive concentration criteria of the occurrence of channeling due to the very different nature of various sludge systems. Maxwell et al (2003) recently observed channeling, which they called microventing, using kaolin clay with water in 540mm tall settling columns. They visually observed and determined the onset
of channeling. They hypothesized that gradients in the volume fraction of solids may be correlated to channel openings.

Although many studies have examined the problems of flocculation and solid/liquid separation, and have observed the formation of channels, experimental factors affecting channel formation are still not fully understood. Further, the effects of channel formation on settling behavior need to be better understood. Nevertheless, a channel, which can be visually recognized in many cases, is an important factor that affects settling and sedimentation characteristics as well as flocculation. Therefore, more accurate analysis of sedimentation and self-weight consolidation needs to be performed in order to improve our understanding of the fundamentals of the channeling phenomenon. If channeling can be controlled, the settling behavior of slurries encountered in various industrial applications could be significantly enhanced.

In this research, laboratory experiments were performed to examine the settling characteristics and channel formation exhibited by various slurries.

2. Experimental Setup

In this research, two different types of settling tests were performed. The small settling column test is the more observational one, whereas the large column test measures pressure changes in different locations and at different times. The experimental matrices are in Table 1. The small settling column tests were used to measure the change of interfaces with time, giving general characteristics of settling and sedimentation. The large settling column test can measure the pore pressure changes. Though the density profiles in consolidation zone cannot be directly derived from the measured values by the tests, the measurements at different locations are
important to determine any effects of channeling. Especially when the interfaces are not distinct, the pore pressure measurement could be used to identify the location of interfaces.

**Experimental equipment**

Settling and self-weight consolidation tests consist of using large and small settling columns. Small settling columns are of 1000 ml clear glass circular cylinders as shown in Figure 2. The inside diameter is 60mm and the height of the column is 450mm. A transparent ruler is attached on the surface of the column to measure the interface changes. With small columns, experimental tests were performed by changing material types, initial concentration, and salinity. The large settling column is built for measuring excess pore pressure changes as well as observing changes taking place within the slurry visually. Limited numbers of tests were performed in large column tests. As shown in Figure 3, it is a circular acrylic tube with an inside diameter of 101.6 mm and height of 1830 mm. Detailed specifications of the settling columns are shown in Table 2. On the large settling column, there are twenty eight measuring points connected to pressure transducers (Druck PDCR-4010). The censors have an accuracy of ±0.04 %, and available ranges of sensors are 34.5 kPa and 13.5 kPa. The first twenty points are located in the lower segment of the column and the rest are in the upper portion of the column. The typical distances among consecutive measuring points are 101.6 mm and 50.8 mm, except for the lower five points where they are spaced 12.7 mm and 25.4 mm apart to get more precise pressure changes in the consolidation zone. 5-way and 3-way switching valves were installed to connect the measuring point and the sensors for continuous measurement. All the measurements were acquired by Keithley 2000 multimeter. The data from the multimeter were recorded and saved in a personal computer.
Particle size distributions of the various materials were acquired using the Honeywell Microtrac X-100 particle size analyzer. Using an auto aligning laser system and a unified scatter technique, this equipment is capable of identifying particle sizes within the range 0.04 to 704 microns by employing a tri-laser diffraction analysis.

**Materials**

Six materials, a calcined kaolin and two hydrous kaolins, two talcs, and an attapulgite, were tested in the present study. The kaolins are all products of Imerys Groups, GA, U.S.A. The commercial brand of the calcined kaolin is Polestar-400, and the two others are Hydrite Flat D and Hydrite 121S. Hydrous kaolin is water washed and air dried kaolin, whereas calcined kaolin is produced by heating ultra-fine natural kaolin to high temperatures over 1000 °C. The calcination process alters the particle shape and size, increases whiteness and hardness, and improves electrical properties. Two talcs, Pioneer T-80 and Pioneer 2882, were obtained from Zemex Industrial Minerals Inc., TX, U.S.A. They have larger particles and skewed particle distribution curves (Figure 5). Talc is a hydrous magnesium silicate composed of stacks of 2:1 layers. Larger particle size and higher specific gravity make it settle fast. An attapulgite, Fertogel, is produced by Zemex Attapulgite LLC., GA, USA. It has very high liquid limits and plastic limits so that it can hold much water. Attapulgite is a crystalline hydrated magnesium aluminum silicate with a unique chain structure. Due to its elongate particle shape, which affects its absorption characteristics, it behaves like a coagulated structure even in the lower initial concentration so that it could not be used for large column testing. General characteristics and physical properties of these materials are summarized in Table 3 and Table 4 (Murray, 1999; Agnello and Morris, 1960; Haden and Schwint, 1967).
The mixed slurry samples were prepared 24 hours before the test. They were allowed to settle after frequent mixing for first 3 hours. The samples were finally mixed just before pouring into the settling columns. The column was filled from the bottom with the difference in hydraulic gradient by placing the mixed slurry container higher than the column. In order to find the effect of water salinity in settling and channeling behavior of fine materials, 3.5% of NaCl solution was used in small column tests. The solution was prepared before the test and added to pre-mixed slurries right before each test.

3. EXPERIMENTAL RESULTS

The objectives of this research are to learn the condition under which channeling occurs, how it affects the settling characteristics, and how to quantify the effects of channeling. The initial studies in this research focused on small column tests of different materials, salinities, and initial concentration. Visual observations were mainly performed with small settling column tests to learn the settling behavior of each of the factor combinations, and help identify the best combinations for follow up tests using the large column in which pressure change could be measured at 28 locations. The visually observed results were mostly from small column tests, whereas the pressure change measurements were exclusively from large settling column tests. The various and comparative detail results of each test such as initial and final heights of interfaces, local and average settling velocities, and void ratio and gravity number changes, are in figures and tables in Appendices.

As the objectives of this study are focused on the channeling and its effects, the following sections give the brief settling characteristics results found from each of the materials studied,
Then, the channeling findings are discussed, first based on the visual observations and then from the pore pressure changes.

**Settling behavior**

**Kaolins:** 3 kaolin types were used in the experiments. Due to the differences in particle size distribution, each of the kaolin materials showed unique results. Calcined kaolin settled much slower than any others. No channeling could be observed either in the consolidation or the settling zone. Particles remained suspended more than 5 weeks without flocculation. The lower interface (sediment layer-suspension interface) was hard to recognize and it changed very slowly. Particles didn’t flocculate even under higher concentration. The upper interface (supematant-suspension interface) was not distinct in any concentration either. Average settling rate, which is the changing rate of the upper interface, and sedimentation rate, which is the changing rate of the lower interface were almost same. The rates were around $5 \times 10^{-5} \text{mm/sec}$.

The two hydrous kaolins have different settling behaviors. The kaolin 121S tended to remain in suspension, while the other, kaolin Flat D, tended to remain in flocculation. Hydrous kaolin 121S showed similar results to calcined kaolin except for the weaker strength of consolidation zone. It also took more time to settle than the kaolin Flat D, and required NaCl in order to flocculate. However, no channeling was observed either with or without salinity effects. Slow settling of the kaolins seemed to prevent the generation of excess pore pressures. The average sedimentation rates of hydrous kaolin 121S were about $5 \times 10^{-4} \text{mm/sec}$, and the average settling rates were about $7 \times 10^{-6} \text{mm/sec}$, respectively. Considering the typical permeability of soils, those rates are very small close to the permeability of silty sand or silty clay. The suspended particles behaved like colloid without settling. The changes in the lower interface could be
observed when initial concentrations were low, but not visible with NaCl solution. Figure 6 shows the settling characteristics of each material when the initial concentration is 1.10 g/cm³. As it is seen, calcined kaolin did not change much in either the suspension or consolidation zones.

Hydrous kaolin Flat D is the material that shows concentration effects on settling behavior based on the results obtained by other researchers: free settling in the lowest initial concentration, zone settling in the intermediate density, and consolidation settling in the higher concentration. These typical settling behaviors are well described in Figure 7. When the initial concentration was 1.01 g/cm³, suspended particles remained at the top like the other kaolins. Those small suspended particles did not make flocs, and they were therefore small enough to remain suspended. The local settling velocities decreased gradually from start in lower initial concentration. However, for intermediate initial concentrations, the local settling velocities remained constant. Then, for higher concentrations, it increased until it hit peak point when the upper and lower interfaces meet as shown in Figure 8(b). Under these higher initial concentrations, flocs settled more like compressing structures rather than zone settling. Except when the initial concentration is 1.01 g/cm³, which settled in dispersed condition, average settling velocities decreased as the initial concentration increased with distilled water, and they were also reduced when added with NaCl.

Talc: The two talcs show settling characteristics different from the kaolins. They settled fast, due to their coarser particle size and higher specific gravity. Having both coarser and finer particles, they settled fast at the bottom but still remained suspended at top, and no flocs were formed. It took less than an hour to settle complete more than 90% of their total sedimentation, whereas, for example, hydrous kaolin took about 5 hours at the same concentration. Settling
behavior of talc was affected significantly by salinity. As NaCl was added, fast settlement occurred as before, but the suspended material settled down much faster, constituting flocs. The average settling rate increased about 30 to 100 times by adding NaCl, whereas the average sedimentation rate did not change much. The flocculation enhanced the settling rate of suspended particles.

**Attapulgite:** Attapulgite consists of elongated particles. The needle-shape of the particles makes attapulgite more flocculated even at lower initial concentrations (Haden and Schwint, 1967; Ciullo, 1996). Therefore, only a few tests with low initial concentration were feasible. When the initial concentration was greater than 1.10 g/cm³, samples were not available due to its uneven mixtures condition. In tests at the initial concentration of 1.10 g/cm³ or lower, the settling characteristics were very similar to other materials at higher concentration occurring flocculation. As it flocculated without adding NaCl, the effects by changing salinity were not important. Settling velocities did not change with salinity change. The settling velocity characteristics are in Table 5.

**Void ratio and gravity number**

Initial and final void ratios were calculated based on the initial concentrations and heights of slurry mixtures. As it is given by the relationships between void ratio and the height of suspension layer (Pane and Schiffman, 1997), initial density, or the initial concentration of slurry mixture can be expressed in terms of void ratio, as following:

\[
e_0 = \frac{\gamma_w G_z - \gamma_{ini}}{\gamma_{ini} - \gamma_w}
\]  

(1)
Here, $G_s$ is the specific gravity of materials, and $h_0, e_0$ and $h_s, e_s$ are the heights and void ratios at time $t = 0$ and $t = s$, respectively. The final void ratio $e_f$ can be calculated with the final heights of settled materials $h_f$ and total thickness of the solid manner $h_z$.

Each material showed different void ratio results. Hydrous kaolin Flat D showed linear decrease in void ratio as the initial concentrations increased using distilled water and the results were similar with NaCl. Hydrous kaolin 2882 and calcined kaolin showed very small final void ratios. Suspended particles still existed using these two kaolins, although the tests were performed until the final heights of settled layer did not show further significant changes. The smaller void ratios seemed to be the result of lower settling rate as well as the suspending particles. Attapulgite showed that void ratios decreased when initial concentration increased using distill water, and showed opposite characteristics in NaCl solution. Attapulgite showed much higher final void ratio. While the other materials showed the final void ratio ranged between 7-30% of their initial void ratio, the corresponding values for attapulgite were 25-70%. The reason for this higher final void ratio resulted from the higher magnitude of flocculation, which could be easily comparable by visual observation. It seemed much more like compressing rather than settling. The settling velocities also support this fact.

However, the average differences of final void ratios under different conditions varied less than 2. It is quite a small number considering the initial void ratios which range from 7 to 160. Considering the over all variations, final void ratios seemed to be independent of the material.
type and initial concentration, except for attapulgite. Void ratio changes for different conditions are summarized in Table 6.

In addition to void ratio, a gravity number $\Lambda_0$ is used to define the characteristics of settling layer. The gravity number is dimensionless, and gives the ratio of permeability to the sedimentation rate (Gutierrez and Wangen, 2005). It gives the idea of settling condition, i.e., the higher gravity number implies lower settling rate, a larger initial permeability or both.

$$\Lambda_0 = \frac{k_0 (\rho_s - \rho_w) g}{\mu \omega}$$  \hspace{1cm} (3)

Here, $k_0$ is the intrinsic permeability of the sediment at the surface, and $\rho_s$ and $\rho_w$ are the solid density of materials and the density of water respectively. $\mu$ is viscosity of water and $\omega$ is settling rate. However, it is hard to determine the permeability of young fine sediments by experiments. Therefore, substituting the permeability-void ratio equation (Eq(2)) into Eq(3), gravity number $\Lambda_0$ can be simplified. Then, permeability becomes no longer a factor in gravity number and it is much easier to calculate it.

Pane and Schiffman(1997) suggested an equation to calculate the permeability with initial settling velocity and void ratio.

$$k(e) = \frac{v_{si}(1+e)}{\gamma^*}$$  \hspace{1cm} (4)

Where $v_{si}$ is initial settling velocity of solid and $\gamma^*$ is given by
\[ \gamma^* = \frac{\gamma_s - \gamma_w}{\gamma_w} \]  

(5)

Initial void ratio can be estimated by Eq(1), and the initial settling velocity can be calculated by experiments.

Notes that the permeability in Eq.(3) is different to that in Eq.(4). It needs to be converted with Eq. (6)

\[ K_0 = k(e_0) \frac{\mu_w}{\gamma_w} \]  

(6)

Then, the gravity number is

\[ \Lambda_0 = (1 + e) \]  

(7)

However, application of the simplified gravity number is restricted to the hindered settling condition, where the settling velocity is constant.

**Channeling**

In this study, small settling column tests were performed mainly to find out the conditions under which channeling occurs, whereas large column test were mainly to do a quantitative comparison by measuring pore pressure changes.

**Visual observation**

Visual observation is the most common method used to characterize the channel formation. Channels could be easily observed under higher concentrations in most cases. When flocculation occurred, channels were more likely to form. Channels usually developed from the bottom and
propagated upward until they met the mudline interface. In some cases, channels propagated and maintained their length up to 10cm. Near the mudline interface, channels generally occurred with lengths less than 3cm. These channels usually disappeared in the end of settlement.

**Kaolins:** Calcined kaolin developed no channels at all. The reasons seemed to be that no flocculation occurred, so without contact there would be no pressure on water between the particles in the suspension. In addition, there was enough time to dissipate excess pore water pressure in the consolidation layer. Especially for calcined kaolin, the sediment layer was so stiff that a small sharp cone dropped on the layer would not penetrate, which is normally can not be observed during settling and sedimentation of natural soils. Even though further study has not been done to explain this unusual behavior of newly settled sediment, the consolidation zone of calcined kaolin is so firm that no channel could be formed. By increasing salinity, flocculation occurred and the settling rate increased significantly, but still no channeling occurred. When NaCl was added, resulting in increased flocculation and a distinct supernatant and suspension interface, there was no channeling. It was concluded that no favorable condition for channel formation could be found with calcined kaolin.

When hydrous kaolin 121S was tested with distilled water, it acted in a way similar to that of calcined kaolin. It settled very slowly and there was no flocculation. The thickness of the consolidation zone was small in distilled water. Thus, the overburden pressure was not high enough to generate excess pore pressure. Consequently, finer particles settled so slow that there was enough time to release the captured water. No channel formation was observed. However, when NaCl was added, flocculation actively occurred. Uprising bubbles were observed penetrating from the upper interface. Large volcanoes and craters were generated at the surface at
higher initial concentrations, leading to the conclusion that channeling was occurring in flocculated suspension zone.

Hydrous kaolin Flat D was the most channel prone material in the study. It showed many channels, even without adding NaCl, especially at the intermediate initial concentration. Channel openings and closings were repeatedly observed in the suspension zone. Volcanoes and craters were also observed as results of channels at the interface surface of settled layer (Figure 10). No flocculation occurred at 1.01 g/cm³, and the upper interface moved downward very slowly. Because the suspension layer remained unflocculated, no channeling was observed. Even in the consolidation layer, low initial concentration causes small thickness of consolidation layer so that not enough load could be applied to lower zone to develop channels.

Talc: In talc, channeling could not be observed at lower concentrations for the same reason as above. Channels were developed in the consolidation layer when initial concentrations were higher than 1.10 g/cm³. When the consolidation layer was 40-60mm high, small channels occurred, usually near the top of the layer. As the settling of the particles in suspension layer proceeded, channels of 2-5mm height still occurred, causing inconsistency of interface and creating horizontal cracks. Segregation of particles was observed in the consolidation layer with coarser particles on the bottom (Figure 11). Channels developed above the settled coarser particles layer, channels developed up to the surface. However, the effect of salinity in liquid was significant. NaCl solution enhanced the flocculation so that the upper interface became clear and settling rate increased, and channel formation was observed. The skewed particle size distribution of talcs made coarser particles settle very fast, having finer particles suspended in upper layer simultaneously. Upper interface was cloudy so that only the lower interface changes were
traceable. However, suspended finer particles flocculated by increasing salinity and their settling rate increased (Figure 12).

In large column tests, even in lower initial concentrations, channel occurred when the thickness of the consolidation layer was higher than 40mm. This shows that the channeling is more dependent on the actual applied load above the layer than on the initial concentration. NaCl forced flocculation within the suspension layer so that channel formed actively at all locations. However, channels in the suspension layer seemed to be the path that was developed more by uprising fluid rather than by excess pressure.

Holdich and Butt (1996) observed that channels occurred in talc when initial concentrations were between 7-15% by volume, equivalent to 1.13-1.25 g/cm³ in this study. They divided channeling zones into “hard” and “soft” zones, and compared the development of channels. Similar results were observed in this research, in that channels actively occurred in 1.10-1.25 g/cm³, even though the particle size distributions are different.

**Attapulgite:** Attapulgite tended to flocculate and compress immediately at the start of experiments, behaving much like the other materials did at higher concentration. However, channel formation was not visually observable. Instead, voids could be easily observed, which disappeared later leaving craters and holes. These seemed to be generated by channels, occurring at the compressing surface in early stages. When attapulgite was mixed with NaCl solution at lower concentration, it became more viscous but had clear supernatant above the upper interface with no suspending particles remaining. More active formation of wider channels was observed, resulting in upward movement of particles and fluid. Channels occurred throughout the material
below the upper interface and they were more clear and distinct on the surface of this interface. However, higher initial concentration of attapulgite were unaffected by the addition of NaCl.

Large volcanoes were created after the sedimentation was completed. The other research argued that those volcanoes formed by solid particles being transported through channels. However, the volcanoes in attapulgite were much larger than of other materials or by the previous research. It was observed that those large volcanoes were created not by solid particles from channels but by differential settlement, with a higher concentration of particles forming around the channels.

**Pressure measurement**

There are several sub-objectives for measuring the pressure induced at various points during the settling column tests. One is to establish the reliability of the experimental condition. Another is to reveal the effects of channeling by measuring the pressure fluctuations in the pressure in the column. The pressure measurement also can predict the interfaces between the settling and sedimentation zones, especially when the interfaces are not visually distinct. Moreover, they enable determining the time of the start of the self-weight consolidation process.

Pressure was measured at every point in the column and can be plotted for different times. As long as the prepared mixture has constant initial concentration, the first reading should be linear with column height with a slope predictable from the planned initial concentration. If suspended materials are under zone settling, which consists of different size of particles but behaves like a mass, which is settling with a constant velocity, they will give a straight line in the suspending zone. It is clear in Figures 14-16 that the pressure changes are linear in all suspending zones, except right above the channeling zones. These locally non-linear zones, however, have
another important implication in settling procedures. Due to the water expelled through channels, dilution occurred above the channels and the density was decreased. The channels mainly occurred both at “soft” and “hard” zones, into which previous research (Butt, 1997) divided the zone where channels were observed. The measured pressure in our research showed that the pressure at the soft zone and also above it was smaller then expected.

Another advantage of measuring pressure change is that it makes possible a prediction of location of interfaces. As observed by previous research (Lin, 1984) and confirmed in our results, interfaces are not easily visible when initial concentrations are high. Similarly, when the particles are too small, the colloidal suspended particles do not show a clear interface between supernatant and suspending zones. Other research have suggested several approaches to determining when the self weight consolidation starts and when the flocculation starts. Theoretically consolidation starts when the particles contact with each other, generating excess pore water pressures. Therefore, monitoring the excess pore pressure can determine the exact time when the self weight consolidation starts and where the suspending zone is located. The lower interfaces were not visually observable in hydrous kaolin Flat D and attapulgite. However, the locations of interfaces were traceable by measuring the excess pore water pressure changes.

The last advantage of measuring pressure in this study is that it is also another good method of characterizing the settling behavior. Figures 15 and 16 show the pressure changes of talc and hydrous kaolin at the same initial concentrations. Their settling behaviors were previously analyzed visually. However, those observed characteristics could not give a good picture of the settling process on how the characteristics changed with time. In talc, significantly higher excess pressure developed instantly and dissipated very fast. On the contrary, hydrous
kaolin settled slowly and the pore pressure increased very slowly and steadily. Its highest value was less than half of what talc had generated. It also took a long time to dissipate.

Using 28 measuring points on the large column, pressure changes were analyzed to provide a picture of the settling process and its interface changes that occurred. Pressures at different time are plotted in Figures 14, 15, and 16. A long-dash indicates the initial pressure to be expected if the material concentration were to remain constant throughout the column (theoretical). A solid line shows the actual pressures in the early stage of settlement (first measurement). Solid dots indicate the pressure after a specified time t. The horizontal shaded area shows the zone where the channel formations were visually observed. The dash-dot and dot lines are the location of upper and lower interfaces, respectively, as observed visually or estimated by pressure measurement.

Figure 14(a) shows the pressures of attapulgite after 2.3 hours. The upper interface is located at 1614mm. Below 80mm, pressure exceeded more than twice the theoretical, but higher locations showed pressure lower than the theoretical. Channeling was observed about 50mm above and below the interface. After 4.7 hours, channeling occurred more broadly. Even though the pressure changes below the interface did not seem to be strongly affected by channeling, the pressures above the interface were smaller than expected. It is speculated that this was due to the diluted zone by water exiting the channels. However, the excess pore pressure below the interface still evident after 140 hours.

Figure 15 shows the pressure changes of talcs. The actual pressure near the bottom was initially about three times higher than the theoretical. However, pressure changes in the consolidation zone were much smaller. Lower pressures were also found above the interface
where channeling occurred. After 88 hours, there still existed excess pore pressure of about 0.5 kPa below the interface, which is about 25-15% of its initial excess pore pressure. Below the lower interface, pore pressure did not change much with depth. Finally, the excess pore pressure became 0 in all location after 127 hours.

As a general observation of the materials studied in large column tests, channeling occurred and disappeared throughout the columns. The channels usually occurred disappeared randomly, but more concentrated near the interfaces. Channels near interfaces were more distinct and propagated as interfaces moved upward. The others were randomly occurred and disappeared. Even though the transport of particles and water were visually observed, the pressure changes did not seem to be affected by those random channels. However, the pressure dropped near interface as well as above channeling zones. Those pressure drops could not be solely the result of channels, significant pressure changes were observed when channels did occur. Some of those pressure changes were on the interface between the consolidation and suspension zones.

4. CONCLUSIONS

In our research, settling behaviors and channel formation characteristics of six different materials were analyzed. Calcined kaolin and hydrous kaolin 121S have similar settling characteristics, showing a long lasting suspending zone with lower settling rate. No flocculation or channel formations were observed. Two types of talcs settled fast because of their higher proportion of larger particles, although their suspending zone lasted much like the calcined kaolin. Excess pore pressure was developed by the overload from the quickly settling zones and channeling occurred at this layer. Attapulgite developed strong flocculation due to its elongated
particle shape. Under lower initial concentrations, it flocculated very actively and channeling occurred all over the zones. As described in the previous chapter, hydrous kaolin Flat D showed settling behaviors that were highly dependent on initial concentrations. Initial densities, ranging from intermediate to high, resulted in flocculation in the suspension zone, which resulted in the formation of channel in different locations and with different magnitudes.

Salinity had a major role in the settling characteristics. Suspending dominant materials such as calcined kaolin and hydrous kaolin 121S were very sensitive to the effects of salinity. In addition, some materials, particularly talcs and hydrous kaolin Flat D under lower initial concentration, also showed significant salinity effects. Suspended particles flocculated with a clear supernatant-suspension layer interface whenever NaCl was added. Channels easily developed in this flocculated zone, and were associated with faster settling into the consolidation zone. It showed that the flocculation during settling seems to be the prerequisite condition for channel formation in the suspension zone.

Pressure measurements in this study proved to be a very useful, reliable, and unique approach to study the effects of channeling as well as settling behavior. The concentration distribution throughout the suspension layer could be established. Measurement of excess pore pressures in the consolidation zone gave another method for comparing the consolidation behavior of the different materials revealing their self weight consolidation behaviors. Pressure changes near channels were often observed, and it was one of the significant findings of the research. It is concluded that the pressure drops near the channeling zones and diluted zones are related to the formation of channels.
As a general conclusion, the experimental results are used to develop useful pictures of the channeling process. When the initial concentrations are low, hindering among falling particles is not major. Each particle falls individually and the particles do not make an “en masse” zone, so that there can be no specific path for free flow of liquid. Thus, channels are not expected to form anywhere except in the consolidation zones. When the consolidation zones are thick enough, the accumulated load on their lower particles results in the generation of excess pore pressures. In order for channels to be formed, pressures higher than the hydrostatic pressure must be generated by contact of the particles in the consolidation zone. Contacting particles and captured water result in the development of excess pore developed excess pore pressure. As the load on the captured water between particles increases, excess pore pressure develops and the water tends to find the shortest way to dissipate the pressure. In doing so, the water develops channel.

Channels also can occur in the flocculation zones. Flocculation means increased development of matrix structures of the particles, which hindered the flow of water upward. As the flocs settle by their self-weight, an equal mass of water must be transported upward. However, due to the flocs, the water can not be delivered freely to the upper layer. The larger the matrices become, the more resistance to the upflow develops. Finally, upflowing water tends to seek the weakest paths to the supernatant-suspension layer interface. These paths are channels in the flocculation zones.

The settling behaviors associated with channel formation were observed, and the experimental results are analyzed. As guidance to the further research, it is suggested that future research focuses quantitatively on the dynamics of channel formation, particularly the flowing velocity and the solid flux in the channels.
REFERENCES


Lin, T.W., 1983 “Sedimentation and self weight consolidation of dredge spoil”, Department of Civil Engineering, Iowa State University, PhD thesis.


Papanicolaou, A.N., 1992, “Settling characteristics of particles in a suspension of medium to high solids concentration”, Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, MS thesis


Figure 1. Types of sedimentation behavior
Figure 2. Small settling column
Figure 3. Large settling column
Figure 4. Particle size distribution of kaolins
Figure 5. Particle size distribution of talcs and attapulgite
Figure 6. Settling behavior, including both upper and lower interfaces
Figure 7. Settling behavior of hydrous kaolin Hydrite Flat D in different initial concentrations
Figure 8. Average settling velocity and velocity profile of hydrous kaolin Hydrite Flat D in different initial concentrations
Figure 9. Salinity effect on settling characteristics (hydrous kaolin Hydrite Flat D)
Figure 10 Crater and ventilating holes at the surface
(Hydrous kaolin Flat D, D=1.20 g/cm³, NaCl solution)
Figure 11. Particle segregation in settle layer (Talc T-80, D=1.20 g/cm³, distilled water)
Figure 12. Salinity effects (Talc 2882, D=1.10 g/cm³, distilled water(left), NaCl solution(right))
Figure 13. Channel formation (Attapulgite Fertogel, D=1.05 g/cm³, Distilled water)
Figure 14. Pressure drops near channels (Attapulgite Fertogel, D=1.025 g/cm³)
Figure 15. Pressure drops near channels (Talc T-80, D=1.20 g/cm³)
Figure 16. Pressure drops near channels (Hydrous kaolin Hydrite Flat D, D=1.20 g/cm³)
<table>
<thead>
<tr>
<th>Column Size</th>
<th>Material</th>
<th>Product Name</th>
<th>Solution</th>
<th>Initial Concentration (g/cm³)</th>
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<tbody>
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<td>Hydrite Flat D</td>
<td>DW</td>
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<td></td>
<td></td>
<td>NaCl</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydrite 121S</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polestar 400</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Talc</td>
<td>T-80</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NaCl</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Attapulgite</td>
<td>Fertogel</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>NaCl</td>
<td>O</td>
</tr>
<tr>
<td>Large Column</td>
<td>Kaolin</td>
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<td>DW</td>
<td>O</td>
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<tr>
<td></td>
<td>Polestar 400</td>
<td></td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Talc</td>
<td>T-80</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Attapulgite</td>
<td>Fertogel</td>
<td>DW</td>
<td>O</td>
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Table 2. Settling columns

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<th>Type</th>
<th>Material</th>
<th>Diameter</th>
<th>Height</th>
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<tbody>
<tr>
<td>Large column</td>
<td>Acrylic</td>
<td>101.6 mm</td>
<td>1830 mm</td>
</tr>
<tr>
<td>Small column</td>
<td>Glass</td>
<td>60 mm</td>
<td>450 mm</td>
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### Table 3. General characteristic of materials

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<th>Material</th>
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<th>Talc</th>
<th>Attapulgite (Palygorskite)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td>1:1 Layer</td>
<td>2:1 Layer</td>
<td>2:1 Layer inverted</td>
</tr>
<tr>
<td><strong>Particle shape</strong></td>
<td>Platy</td>
<td>Platy</td>
<td>Elongate</td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td>White/Gray-white</td>
<td>White/Gray-white/Pale green</td>
<td>White/Gray/Brownish white</td>
</tr>
<tr>
<td><strong>Surface area</strong></td>
<td>Low surface area</td>
<td>Low surface area</td>
<td>High surface area</td>
</tr>
<tr>
<td><strong>Sorptivity</strong></td>
<td>Very low absorption capacity</td>
<td>Low absorption capacity</td>
<td>High absorption capacity</td>
</tr>
<tr>
<td><strong>Effect of electrolytes</strong></td>
<td>Flocculates</td>
<td>Flocculates</td>
<td>Little or none</td>
</tr>
<tr>
<td><strong>Chemical Formula</strong></td>
<td>$\text{Al}_2\text{Si}_2\text{O(OH)}_4$ / $\text{Al}_2\text{Si}_2\text{O}_3\text{(OH)}_4$</td>
<td>$\text{Mg}_3\text{Si}<em>4\text{O}</em>{10}\text{(OH)}_2$</td>
<td>$(\text{Mg,Al})_2\text{Si}<em>8\text{O}</em>{22}\text{(OH)}_4$</td>
</tr>
</tbody>
</table>
Table 4. Physical properties of materials

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<tr>
<th>Tested Materials</th>
<th>Product Name</th>
<th>LL</th>
<th>PL</th>
<th>Gs</th>
<th>D_{50} (µm)</th>
<th>C_c</th>
<th>C_u</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcined kaolin</td>
<td>Polestar- 400</td>
<td>N/A</td>
<td>N/A</td>
<td>2.6</td>
<td>4.7</td>
<td>0.61</td>
<td>6.08</td>
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<td>Hydrous kaolin A</td>
<td>Hydrite Flat D</td>
<td>37</td>
<td>15</td>
<td>2.6</td>
<td>10</td>
<td>1.05</td>
<td>3.53</td>
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<tr>
<td>Hydrous kaolin B</td>
<td>Hydrite 121S</td>
<td>25</td>
<td>18</td>
<td>2.6</td>
<td>8.1</td>
<td>1.02</td>
<td>3.03</td>
</tr>
<tr>
<td>Talc A</td>
<td>Pioneer T-80</td>
<td>28</td>
<td>19</td>
<td>2.98</td>
<td>33</td>
<td>0.95</td>
<td>6.83</td>
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<tr>
<td>Talc B</td>
<td>Pioneer 2882</td>
<td>33</td>
<td>17</td>
<td>2.7</td>
<td>23</td>
<td>0.88</td>
<td>4.62</td>
</tr>
<tr>
<td>Attapulgite</td>
<td>Fertogel</td>
<td>239</td>
<td>84</td>
<td>2.36</td>
<td>14</td>
<td>0.82</td>
<td>2.79</td>
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Table 5. Settling velocity for different materials and their conditions

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<thead>
<tr>
<th>Materials</th>
<th>Distilled water</th>
<th>NaCl solution</th>
<th>Salinity</th>
<th>Settling Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concentration</td>
<td>Settling Velocity</td>
<td>Concentration</td>
<td>Settling Velocity</td>
</tr>
<tr>
<td>Calcined kaolin</td>
<td>↗</td>
<td>→</td>
<td>↗</td>
<td>N/A*</td>
</tr>
<tr>
<td>Hydrous kaolin A</td>
<td>↗</td>
<td>↘</td>
<td>↗</td>
<td>↘</td>
</tr>
<tr>
<td>Hydrous kaolin B</td>
<td>↗</td>
<td>→</td>
<td>↗</td>
<td>↘</td>
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<tr>
<td>Talc A</td>
<td>↗</td>
<td>→</td>
<td>↗</td>
<td>↘</td>
</tr>
<tr>
<td>Talc B</td>
<td>↗</td>
<td>→</td>
<td>↗</td>
<td>↘ →</td>
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<td>Attapulgite</td>
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* Single data only
Table 6. Void ratio and gravity number change

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<th>Material</th>
<th>Solution</th>
<th>$\rho_{i,conc.}$ g/cm³</th>
<th>$e_0$</th>
<th>$h_0$ (mm)</th>
<th>$h_y$ (mm)</th>
<th>$e_f$</th>
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<th>Remarks</th>
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<td>Hydrous</td>
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<td>3.17</td>
</tr>
<tr>
<td></td>
<td>Talc</td>
<td>1.025</td>
<td>67.0</td>
<td>300.0</td>
<td>4.41</td>
<td>25.8</td>
<td>4.85</td>
<td>5.85</td>
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<td>1.100</td>
<td>16.0</td>
<td>350.0</td>
<td>20.59</td>
<td>92.5</td>
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<td></td>
<td></td>
<td></td>
<td>1.200</td>
<td>7.5</td>
<td>361.0</td>
<td>42.47</td>
<td>160.0</td>
<td>2.77</td>
</tr>
<tr>
<td>Pioneer</td>
<td>DW</td>
<td>1.025</td>
<td>78.2</td>
<td>355.0</td>
<td>4.48</td>
<td>18.5</td>
<td>3.13</td>
<td>4.13</td>
</tr>
<tr>
<td>T-80</td>
<td></td>
<td></td>
<td>1.050</td>
<td>38.6</td>
<td>350.0</td>
<td>8.84</td>
<td>38.5</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.100</td>
<td>18.8</td>
<td>364.5</td>
<td>18.41</td>
<td>75.0</td>
<td>3.07</td>
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<td>NaCl</td>
<td></td>
<td></td>
<td>1.200</td>
<td>8.9</td>
<td>363.0</td>
<td>36.67</td>
<td>132.2</td>
<td>2.61</td>
</tr>
<tr>
<td></td>
<td>LC</td>
<td>1.050</td>
<td>38.6</td>
<td>1734.0</td>
<td>43.79</td>
<td>161.5</td>
<td>2.69</td>
<td>3.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.150</td>
<td>12.2</td>
<td>1796.0</td>
<td>136.06</td>
<td>500.0</td>
<td>2.67</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td>1.100</td>
<td>18.8</td>
<td>365.0</td>
<td>18.43</td>
<td>83.5</td>
<td>3.53</td>
<td>4.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.200</td>
<td>8.9</td>
<td>371.0</td>
<td>37.47</td>
<td>154.5</td>
<td>3.12</td>
</tr>
</tbody>
</table>
Table 7. Summary of the results

<table>
<thead>
<tr>
<th>Material</th>
<th>Channeling</th>
<th>Flocculation</th>
<th>Interface</th>
<th>Salinity effect on settling</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcined kaolin</td>
<td>N/A</td>
<td>X</td>
<td>Unclear Interfaces</td>
<td>♦♦♦</td>
<td>Very slow settlement</td>
</tr>
<tr>
<td>Hydrous kaolin A</td>
<td>Random</td>
<td>O</td>
<td>Sharp upper interface</td>
<td>♦ ♦</td>
<td>Easy to flocculate</td>
</tr>
<tr>
<td>Hydrous kaolin B</td>
<td>N/A</td>
<td>X</td>
<td>Unclear interface</td>
<td>♦♦♦</td>
<td>Similar to C.K</td>
</tr>
<tr>
<td>Talc A</td>
<td>Near surface, consolidation zone</td>
<td>X</td>
<td>Sharp lower interface</td>
<td>♦♦♦</td>
<td>Fast settlement, Particle segregation</td>
</tr>
<tr>
<td>Talc B</td>
<td>Near surface, consolidation zone</td>
<td>X</td>
<td>Sharp lower interface</td>
<td>♦♦♦</td>
<td>Fast settlement, Particle segregation</td>
</tr>
<tr>
<td>Attapulgite</td>
<td>Random</td>
<td>O</td>
<td>Sharp upper interface</td>
<td>♦</td>
<td>Easy to flocculate</td>
</tr>
</tbody>
</table>
APPENDIX

A1. Experimental Matrices

A2. Experimental Equipment

A3. Material Properties

A4. Small Settling Column Test

A5. Large Settling Column Test
## A1. Experimental Matrices

### (1) Small Column Tests

<table>
<thead>
<tr>
<th>Material</th>
<th>Product Name</th>
<th>Solution</th>
<th>Initial Concentration (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolinit</td>
<td>Hydrite Flat D</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Hydrite 121S</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Polestar 400</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>T-80</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>2882</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td></td>
<td>O</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Product Name</th>
<th>Solution</th>
<th>Initial Concentration (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fertogel</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>NaCl</td>
<td></td>
<td>O</td>
</tr>
</tbody>
</table>

### (2) Large Column Tests

<table>
<thead>
<tr>
<th>Material</th>
<th>Product Name</th>
<th>Solution</th>
<th>Initial Concentration (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolin</td>
<td>Hydrite Flat D</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Polestar 400</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td>Talc</td>
<td>T-80</td>
<td>DW</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>Fertogel</td>
<td>DW</td>
<td>O</td>
</tr>
</tbody>
</table>

51
A2. Experimental Equipment

(1) Small settling column

<table>
<thead>
<tr>
<th>Material</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>450 mm</td>
</tr>
<tr>
<td>Inner diameter</td>
<td>60 mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>69 mm</td>
</tr>
<tr>
<td>Color</td>
<td>Clear</td>
</tr>
<tr>
<td>Remarks</td>
<td>Measuring tape on the cylinder surface</td>
</tr>
</tbody>
</table>
(2) Large settling column

<table>
<thead>
<tr>
<th>Material</th>
<th>Acrylic tube</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>765 mm</td>
</tr>
<tr>
<td>Lower</td>
<td>865 mm</td>
</tr>
<tr>
<td>Total</td>
<td>1,830 mm</td>
</tr>
<tr>
<td>Inner diameter</td>
<td>101.6 mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>127 mm</td>
</tr>
<tr>
<td>Color</td>
<td>Clear</td>
</tr>
</tbody>
</table>
| **Remarks**       | 30 quick connectors  
|                   | - 28 for measurement 
|                   | - 2 for drain      |
(3) Particle size analyzer

<table>
<thead>
<tr>
<th>Model</th>
<th>Honeywell Microtrac X-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>0.04 ~ 704 microns</td>
</tr>
<tr>
<td>Phase</td>
<td>Wet or Dry Measurements</td>
</tr>
<tr>
<td>Measurement Technique</td>
<td>Tri-laser diffraction analysis using auto aligning laser system and unified scatter technique</td>
</tr>
<tr>
<td>Optics</td>
<td>One primary (on-axis) laser diode and two secondary (off-axis) laser diodes with one forward and one high-angle photo detector array</td>
</tr>
</tbody>
</table>
(4) Data Acquisition System

<table>
<thead>
<tr>
<th>Model</th>
<th>Keithley Multimeter 2700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built in function</td>
<td>DCV, ACV, DCI, ACI, Resistance, Temperature, Frequency, Continuity</td>
</tr>
<tr>
<td>Channels</td>
<td>Max. 80 channels</td>
</tr>
<tr>
<td>Resolution</td>
<td>6 and 1/2 digit (22-bit)</td>
</tr>
<tr>
<td>Scanning rate</td>
<td>Max. 500 channels/sec</td>
</tr>
</tbody>
</table>
### Pressure transducers and switching panel

<table>
<thead>
<tr>
<th>Type</th>
<th>Qt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching panel for 5psi pressure transducer</td>
<td></td>
</tr>
<tr>
<td>5-way switching valve</td>
<td>2</td>
</tr>
<tr>
<td>3-way switching valve</td>
<td>1</td>
</tr>
<tr>
<td>5-psi pressure sensor</td>
<td>1</td>
</tr>
<tr>
<td>Model</td>
<td>Capacity</td>
</tr>
<tr>
<td>Druck PDCR-4010</td>
<td>34.5 kPa</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Qt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching panel for 2psi pressure transducer</td>
<td></td>
</tr>
<tr>
<td>3-way switching valve</td>
<td>3</td>
</tr>
<tr>
<td>2-psi pressure sensor</td>
<td>1</td>
</tr>
<tr>
<td>Model</td>
<td>Capacity</td>
</tr>
<tr>
<td>Druck PDCR-4010</td>
<td>13.8 kPa (2 psi)</td>
</tr>
</tbody>
</table>
(6) Switching valves

<table>
<thead>
<tr>
<th>Model</th>
<th>Swagelok Switching 3-way/5-way valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Brass Multiport Ball Valve Female NPT</td>
</tr>
<tr>
<td>Inflow / outflow</td>
<td>1/8 inches, female NPT</td>
</tr>
</tbody>
</table>
A3. Material Properties
   A3.1 Particle size distribution

Figure A3.1 Particle distribution curve of calcined kaolin

Figure A3.2 Particle distribution curve of hydrous kaolin Flat D
Figure A3.3 Particle distribution curve of hydrous kaolin 121S

Figure A3.4 Particle distribution curve of talc T80
Figure A3.5 Particle distribution curve of talc 2882

Figure A3.6 Particle distribution curve of attapulgite
A3.2 Atterberg Limits Tests

Figure A3.7 Atterberg limits of hydrous kaolin Flat D
Figure A3.8 Atterberg limits of hydrous kaolin 121S
**Liquid Limit Determination**

<table>
<thead>
<tr>
<th>Can No.</th>
<th>S-1</th>
<th>S-2</th>
<th>S-3</th>
<th>S-4</th>
<th>S-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. of wet soil + can</td>
<td>9.83</td>
<td>9.41</td>
<td>8.42</td>
<td>12.86</td>
<td>10.2</td>
</tr>
<tr>
<td>Wt. of dry soil + can</td>
<td>9.0</td>
<td>8.8</td>
<td>8.01</td>
<td>12.33</td>
<td>9.46</td>
</tr>
<tr>
<td>Wt. of can</td>
<td>6.35</td>
<td>6.78</td>
<td>6.61</td>
<td>10.41</td>
<td>6.63</td>
</tr>
<tr>
<td>Wt. of dry soil</td>
<td>2.65</td>
<td>2.02</td>
<td>1.4</td>
<td>1.92</td>
<td>2.63</td>
</tr>
<tr>
<td>Wt. of water</td>
<td>0.83</td>
<td>0.61</td>
<td>0.41</td>
<td>0.53</td>
<td>0.74</td>
</tr>
<tr>
<td>Water content, w%</td>
<td>31.3</td>
<td>30.2</td>
<td>29.3</td>
<td>27.6</td>
<td>26.1</td>
</tr>
<tr>
<td>No. of Blows</td>
<td>14</td>
<td>17</td>
<td>22</td>
<td>30</td>
<td>35</td>
</tr>
</tbody>
</table>

**Plastic Limit Determination**

<table>
<thead>
<tr>
<th>Can No.</th>
<th>S-6</th>
<th>S-7</th>
<th>S-8</th>
<th>S-9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. of wet soil + can</td>
<td>5.07</td>
<td>7.54</td>
<td>5.07</td>
<td>5.03</td>
</tr>
<tr>
<td>Wt. of dry soil + can</td>
<td>4.97</td>
<td>7.42</td>
<td>4.95</td>
<td>4.9</td>
</tr>
<tr>
<td>Wt. of can</td>
<td>4.33</td>
<td>6.78</td>
<td>4.39</td>
<td>4.29</td>
</tr>
<tr>
<td>Wt. of dry soil</td>
<td>0.64</td>
<td>0.64</td>
<td>0.57</td>
<td>0.61</td>
</tr>
<tr>
<td>Wt. of water</td>
<td>0.1</td>
<td>0.12</td>
<td>0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Water content (PL)</td>
<td>15.6</td>
<td>16.6</td>
<td>21.1</td>
<td>21.3</td>
</tr>
</tbody>
</table>

**Liquid Limit**

![Liquid Limit Graph]

- Liquid Limit = 28
- Plastic Limit = 19.2
- Plastic Index = 9.1

Figure A3.9 Atterberg limits of talc T80
### Atterberg Limits Determination

**Soil description**: Talc 2882

<table>
<thead>
<tr>
<th>Can No.</th>
<th>D-1</th>
<th>D-2</th>
<th>D-3</th>
<th>D-4</th>
<th>D-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. of wet soil + can</td>
<td>17.96</td>
<td>7.96</td>
<td>7.39</td>
<td>7.07</td>
<td>10.7</td>
</tr>
<tr>
<td>Wt. of dry soil + can</td>
<td>17.04</td>
<td>7.01</td>
<td>6.64</td>
<td>6.42</td>
<td>9.8</td>
</tr>
<tr>
<td>Wt. of can</td>
<td>14.61</td>
<td>4.3</td>
<td>4.37</td>
<td>4.33</td>
<td>6.65</td>
</tr>
<tr>
<td>Wt. of dry soil</td>
<td>2.43</td>
<td>2.71</td>
<td>2.27</td>
<td>2.09</td>
<td>3.15</td>
</tr>
<tr>
<td>Wt. of water</td>
<td>0.94</td>
<td>0.97</td>
<td>0.75</td>
<td>0.69</td>
<td>0.9</td>
</tr>
<tr>
<td>Water content, w%</td>
<td>38.7</td>
<td>35.8</td>
<td>33</td>
<td>31.1</td>
<td>28.6</td>
</tr>
<tr>
<td>No. of Blows</td>
<td>12</td>
<td>17</td>
<td>24</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>

### Plastic Limit Determination

<table>
<thead>
<tr>
<th>Can No.</th>
<th>D-1</th>
<th>D-2</th>
<th>D-3</th>
<th>D-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. of wet soil + can</td>
<td>7.76</td>
<td>5.26</td>
<td>7.12</td>
<td>7.23</td>
</tr>
<tr>
<td>Wt. of dry soil + can</td>
<td>5.59</td>
<td>5.11</td>
<td>/</td>
<td>5.17</td>
</tr>
<tr>
<td>Wt. of can</td>
<td>6.61</td>
<td>4.27</td>
<td>6.34</td>
<td>6.77</td>
</tr>
<tr>
<td>Wt. of dry soil</td>
<td>0.97</td>
<td>0.84</td>
<td>0.66</td>
<td>0.4</td>
</tr>
<tr>
<td>Wt. of water</td>
<td>0.18</td>
<td>0.14</td>
<td>0.12</td>
<td>0.06</td>
</tr>
</tbody>
</table>

![Liquid Limit Graph](image)

- Liquid Limit = 32.6
- Plastic Limit = 17.2
- Plastic Index = 15.4

Figure A3.10 Atterberg limits of talc 2882
Figure A3.11 Atterberg limits of attapulgite
Table A3.1 Void ratio and gravity number changes

<table>
<thead>
<tr>
<th>Material</th>
<th>Solution</th>
<th>Init. Conc. g/cm³</th>
<th>e₀</th>
<th>h₀ (mm)</th>
<th>h₁ (mm)</th>
<th>h₂ (mm)</th>
<th>e₁</th>
<th>Δ₀</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrous Kaolinite</td>
<td>DW</td>
<td>1.010</td>
<td>159.0</td>
<td>345.0</td>
<td>2.16</td>
<td>11.0</td>
<td>4.10</td>
<td>5.10</td>
<td></td>
</tr>
<tr>
<td>Hydrous Hydrite</td>
<td>LC</td>
<td>1.050</td>
<td>31.0</td>
<td>1751.0</td>
<td>54.72</td>
<td>209.0</td>
<td>2.82</td>
<td>3.82</td>
<td></td>
</tr>
<tr>
<td>Flat D</td>
<td>DW</td>
<td>1.010</td>
<td>159.0</td>
<td>341.0</td>
<td>2.13</td>
<td>10.0</td>
<td>3.69</td>
<td>4.59</td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>1.025</td>
<td>63.0</td>
<td>332.0</td>
<td>5.19</td>
<td>26.0</td>
<td>4.01</td>
<td>5.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.200</td>
<td>7.0</td>
<td>366.0</td>
<td>45.75</td>
<td>162.0</td>
<td>2.54</td>
<td>3.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrous Kaolinite</td>
<td>LC</td>
<td>1.100</td>
<td>15.0</td>
<td>356.0</td>
<td>22.90</td>
<td>50.0</td>
<td>1.25</td>
<td>2.25</td>
<td>still suspending</td>
</tr>
<tr>
<td>Hydrous Hydrite 121S</td>
<td>LC</td>
<td>1.100</td>
<td>15.0</td>
<td>360.0</td>
<td>22.50</td>
<td>156.5</td>
<td>5.96</td>
<td>6.96</td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>1.200</td>
<td>7.0</td>
<td>354.0</td>
<td>44.26</td>
<td>248.5</td>
<td>4.62</td>
<td>5.62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcined Kaolinite</td>
<td>DW</td>
<td>1.010</td>
<td>159.0</td>
<td>361.0</td>
<td>2.19</td>
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<td>31.0</td>
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<td>15.0</td>
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<td>DW</td>
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<td>53.4</td>
<td>357.0</td>
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<td>1751.0</td>
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<td>LC</td>
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<td>67.0</td>
<td>300.0</td>
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A4. Small settling column test

A4.1 Settling curves

Figure A4.1 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.01 \text{g/cm}^3$, Distilled Water)
Figure A4.2 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi}=1.025$g/cm$^3$, Distilled Water)
Figure A4.3 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.05 $g/cm$^3$, Distilled Water)
Figure A4.4 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{\text{ini}} = 1.10$ g/cm$^3$, Distilled Water)
Figure A4.5 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{mi} = 1.15 \, \text{g/cm}^3$, Distilled Water)
Figure A4.6 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{im}$ =1.20 g/cm$^3$, Distilled Water)
Figure A4.7 Settling curve of hydrous kaolin Hydrite Flat D \((\gamma_{\text{omi}} = 1.01 \text{ g/cm}^3, 3.5\% \text{ NaCl Solution})\)
Figure A4.8 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{\text{ini}} = 1.025$ g/cm$^3$, 3.5% NaCl Solution)
Figure A4.9 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{mi} = 1.20 \text{ g/cm}^3$, 3.5% NaCl Solution)
Figure A4.10 Settling curve of hydrous kaolin Hydrite 121S (\(\gamma_{imi} =1.10 \text{ g/cm}^3\), Distilled water)
Figure A4.11 Settling curve of hydrous kaolin Hydrite 121S ($\gamma_{ini} = 1.20$ g/cm$^3$, Distilled water)
Figure A4.12 Settling curve of hydrous kaolin Hydrite 121S ($\gamma_{omi} = 1.10$ g/cm$^3$, 3.5% NaCl Solution)
Figure A4.13 Settling curve of hydrous kaolin Hydrite 121S \( (\gamma_{omi} = 1.20 \text{ g/cm}^3, 3.5\% \text{ NaCl Solution}) \)
Figure A4.14 Settling curve of calcined kaolin Polestar 400 ($\gamma_{\text{imi}} = 1.01 \text{ g/cm}^3$, Distilled water)
Figure A4.15 Settling curve of calcined kaolin Polestar 400 ($\gamma_{ini} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.16 Settling curve of calcined kaolin Polestar 400 ($\gamma_{mi}$ = 1.10 g/cm$^3$, Distilled water)
Figure A4.17 Settling curve of calcined kaolin Polestar 400 ($\gamma_{\text{mi}}$ =1.15 g/cm$^3$, Distilled water)
Figure A4.18 Settling curve of calcined kaolin Polestar 400 ($\gamma_{mi} = 1.10 \text{ g/cm}^3$, NaCl Solution)
Figure A4.19 Settling curve of attapulgite Fertogel ($\gamma_{\text{omi}} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.20 Settling curve of attapulgite Fertogel ($\gamma_{ini} = 1.05 \text{ g/cm}^3$, Distilled water)
Figure A4.21 Settling curve of attapulgite Fertogel ($\gamma_{ini}=1.10$ g/cm$^3$, Distilled water)
Figure A4.22 Settling curve of attapulgite Fertogel ($\gamma_{\text{ini}}=1.05$ g/cm$^3$, NaCl Solution)
Figure A4.23 Settling curve of attapulgite Fertogel (ρ_{ini} = 1.10 g/cm³, NaCl Solution)
Figure A4.24 Settling curve of talc Pioneer T80 ($\gamma_{\text{imp}} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.25 Settling curve of talc Pioneer T80 ($\gamma_{\text{talc}} = 1.05$ g/cm², Distilled water)
Figure A4.26 Settling curve of talc Pioneer T80 ($\gamma_{\text{solid}} = 1.10$ g/cm$^3$, Distilled water)
Figure A4.27 Settling curve of talc Pioneer T80 ($\gamma_{\text{solid}} = 1.20$ g/cm³, Distilled water)
Figure A4.28 Settling curve of talc Pioneer T80 ($\gamma_{\text{ini}}=1.10$ g/cm$^3$, NaCl Solution)
Normalize Height \( \left( \frac{H_i}{H_t} \right) \)

(a) Arithmetic scale

(b) Logarithmic scale

Figure A4.29 Settling curve of talc Pioneer T80 \((\gamma_{\text{ini}} = 1.20 \text{ g/cm}^3, \text{NaCl Solution})\)
Figure A4.30 Settling curve of talc Pioneer 2882 ($\gamma_{\text{ini}} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.31 Settling curve of talc Pioneer 2882 ($\gamma_{imi} = 1.10 \text{ g/cm}^3$, Distilled water)
Figure A4.32 Settling curve of talc Pioneer 2882 ($\gamma_{\text{ini}}=1.20 \text{ g/cm}^3$, Distilled water)
Figure A4.33 Settling curve of talc Pioneer 2882 (γ_{ini} = 1.025 g/cm³, NaCl Solution)
Figure A4.34 Settling curve of talc Pioneer 2882 ($\gamma_{\text{imi}} = 1.10 \text{ g/cm}^3$, NaCl Solution)
Figure A4.35 Settling curve of talc Pioneer 2882 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, NaCl Solution)
A4.2 Settling velocities

Figure A4.36 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi}=1.025\text{g/cm}^3$, Distilled Water)

Figure A4.37 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi}=1.05\text{g/cm}^3$, Distilled Water)
Figure A4.38 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{ini} = 1.10$ g/cm³, Distilled Water)

Figure A4.39 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{ini} = 1.15$ g/cm³, Distilled Water)
Figure A4.40 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi}=1.20$ g/cm$^3$, Distilled Water)

Figure A4.41 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi}=1.20$ g/cm$^3$, Distilled Water)
Figure A4.42 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.01 \text{ g/cm}^3$, 3.5% NaCl Solution)

Figure A4.43 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.025 \text{ g/cm}^3$, 3.5% NaCl Solution)
Figure A4.44 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{\text{ini}}=1.20 \text{ g/cm}^3$, 3.5% NaCl Solution)

Figure A4.45 Settling curve of hydrous kaolin Hydrite 121S ($\gamma_{\text{ini}}=1.10 \text{ g/cm}^3$, Distilled water)
Figure A4.46 Settling curve of hydrous kaolin Hydrite 121S ($\gamma_{\text{ini}}=1.20$ g/cm$^3$, Distilled water)

Figure A4.47 Settling curve of hydrous kaolin Hydrite 121S ($\gamma_{\text{ini}}=1.10$ g/cm$^3$, 3.5% NaCl Solution)
Figure A4.48 Settling curve of hydrous kaolin Hydrite 121S ($\gamma_{\text{omi}} = 1.20 \, \text{g/cm}^3$, 3.5% NaCl Solution)

Figure A4.49 Settling curve of calcined kaolin Polestar 400 ($\gamma_{\text{omi}} = 1.01 \, \text{g/cm}^3$, Distilled water)
Figure A4.50 Settling curve of calcined kaolin Polestar 400 ($\gamma_{ini}=1.025$ g/cm$^3$, Distilled water)

Figure A4.51 Settling curve of calcined kaolin Polestar 400 ($\gamma_{ini}=1.10$ g/cm$^3$, Distilled water)
Figure A4.52 Settling curve of calcined kaolin Polestar 400 ($\gamma_{ini} = 1.15$ g/cm$^3$, Distilled water)

Figure A4.53 Settling curve of calcined kaolin Polestar 400 ($\gamma_{ini} = 1.10$ g/cm$^3$, NaCl Solution)
Figure A4.54 Settling curve of attapulgite Fertogel ($\gamma_{imi}$ = 1.025 g/cm$^3$, Distilled water)

Figure A4.55 Settling curve of attapulgite Fertogel ($\gamma_{imi}$ = 1.05 g/cm$^3$, Distilled water)
Figure A4.56 Settling curve of attapulgite Fertogel ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled water)

Figure A4.57 Settling curve of attapulgite Fertogel ($\gamma_{ini} = 1.05$ g/cm$^3$, NaCl Solution)
Figure A4.58 Settling curve of attapulgite Fertogel ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, NaCl Solution)

Figure A4.59 Settling curve of talc Pioneer T80 ($\gamma_{ini} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.60 Settling curve of talc Pioneer T80 (\(\gamma_{\text{int}} = 1.05\) g/cm\(^3\), Distilled water)

Figure A4.61 Settling curve of talc Pioneer T80 (\(\gamma_{\text{int}} = 1.10\) g/cm\(^3\), Distilled water)
Figure A4.62 Settling curve of talc Pioneer T80 ($\gamma_{ini}=1.20$ g/cm$^3$, Distilled water)

Figure A4.63 Settling curve of talc Pioneer T80 ($\gamma_{ini}=1.10$ g/cm$^3$, NaCl Solution)
Figure A4.64 Settling curve of talc Pioneer T80 ($\gamma_{\text{ini}}=1.20 \text{ g/cm}^3$, NaCl Solution)

Figure A4.65 Settling curve of talc Pioneer 2882 ($\gamma_{\text{ini}}=1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.66 Settling curve of talc Pioneer 2882 ($\rho_{\text{ini}} = 1.10 \text{ g/cm}^3$, Distilled water)

Figure A4.67 Settling curve of talc Pioneer 2882 ($\rho_{\text{ini}} = 1.20 \text{ g/cm}^3$, Distilled water)
Figure A4.68 Settling curve of talc Pioneer 2882 ($\gamma_{ini}=1.025 \text{ g/cm}^3$, NaCl Solution)

Figure A4.69 Settling curve of talc Pioneer 2882 ($\gamma_{ini}=1.10 \text{ g/cm}^3$, NaCl Solution)
Figure A4.70 Settling curve of talc Pioneer 2882 ($\gamma_{imi}=1.10$ g/cm$^3$, NaCl Solution)
A4.3 Experiments pictures

Figure A4.71 Hydrous kaolin Hydrite Flat D \((\gamma_{\text{imi}} = 1.01 \text{g/cm}^3, \text{Distilled Water})\)

Figure A4.72 Hydrous kaolin Hydrite Flat D \((\gamma_{\text{imi}} = 1.01 \text{g/cm}^3, \text{Distilled Water})\)
Figure A4.73 Hydrous kaolin Hydrite Flat D (γ_{im Jos}=1.01 g/cm³, Distilled Water)

Figure A4.74 Hydrous kaolin Hydrite Flat D (γ_{im Jos}=1.01 g/cm³, Distilled Water)
Figure A4.75 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{imi}} = 1.025\text{g/cm}^3$, Distilled Water)

Figure A4.76 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{imi}} = 1.025\text{g/cm}^3$, Distilled Water)
Figure A4.77 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{omi}} = 1.025 \text{g/cm}^3$, Distilled Water)

Figure A4.78 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{omi}} = 1.025 \text{g/cm}^3$, Distilled Water)
Figure A4.79 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled Water)

Figure A4.80 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled Water)
Figure A4.81 Hydrous kaolin Hydrite Flat D ( $\gamma_{imi} = 1.05 \text{g/cm}^3$, Distilled Water)

Figure A4.82 Hydrous kaolin Hydrite Flat D ( $\gamma_{imi} = 1.05 \text{g/cm}^3$, Distilled Water)
Figure A4.83 Hydrous kaolin Hydrite Flat D (γ_{imi} = 1.05 g/cm³, Distilled Water)
Figure A4.84 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.10$ g/cm$^3$, Distilled Water)

Figure A4.85 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.10$ g/cm$^3$, Distilled Water)
Figure A4.86 Hydrous kaolin Hydrite Flat D (γ_{\text{imi}} = 1.10g/cm^3, Distilled Water)

Figure A4.87 Hydrous kaolin Hydrite Flat D (γ_{\text{imi}} = 1.10g/cm^3, Distilled Water)
Figure A4.88 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{imi}} = 1.10 \text{g/cm}^3$, Distilled Water)
Figure A4.89 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.15\text{g/cm}^3$, Distilled Water)

Figure A4.90 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.15\text{g/cm}^3$, Distilled Water)
Figure A4.91 Hydrous kaolin Hydrite Flat D (γ_{imi} = 1.15 g/cm^3, Distilled Water)

Figure A4.92 Hydrous kaolin Hydrite Flat D (γ_{imi} = 1.15 g/cm^3, Distilled Water)
Figure A4.93 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.15\text{g/cm}^3$, Distilled Water)

Figure A4.94 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.15\text{g/cm}^3$, Distilled Water)
Figure A4.95 Hydrous kaolin Hydrite Flat D (γ_{imi} =1.20 g/cm³, Distilled Water)

Figure A4.96 Hydrous kaolin Hydrite Flat D (γ_{imi} =1.20 g/cm³, Distilled Water)
Figure A4.97 Hydrous kaolin Hydrite Flat D (\( \gamma_{imi} = 1.20 \text{g/cm}^3 \), Distilled Water)

Figure A4.98 Hydrous kaolin Hydrite Flat D (\( \gamma_{imi} = 1.20 \text{g/cm}^3 \), Distilled Water)
Figure A4.99 Hydrous kaolin Hydrite Flat D (γ_{imi} =1.20g/cm^3, Distilled Water)

Figure A4.100 Hydrous kaolin Hydrite Flat D (γ_{imi} =1.20g/cm^3, Distilled Water)
Figure A4.101 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{im}} = 1.01\text{g/cm}^3$, NaCl solution)

Figure A4.102 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{im}} = 1.025\text{g/cm}^3$, NaCl solution)
Figure A4.103 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{ini}} = 1.25 \text{g/cm}^3 \rightarrow 1.20 \text{g/cm}^3$, NaCl solution)

Figure A4.104 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{ini}} = 1.25 \text{g/cm}^3 \rightarrow 1.20 \text{g/cm}^3$, NaCl solution)
Figure A4.105 Hydrous kaolin Hydrite Flat D ($\gamma_{ini}=1.25\text{g/cm}^3 \rightarrow 1.20\text{g/cm}^3$, NaCl solution)

Figure A4.106 Hydrous kaolin Hydrite Flat D ($\gamma_{ini}=1.25\text{g/cm}^3 \rightarrow 1.20\text{g/cm}^3$, NaCl solution)
Figure A4.107 Hydrous kaolin Hydrite Flat D($\gamma_{\text{init}} = 1.25 \text{g/cm}^3 \Rightarrow 1.20 \text{g/cm}^3$, NaCl solution)

Figure A4.108 Hydrous kaolin Hydrite Flat D($\gamma_{\text{init}} = 1.25 \text{g/cm}^3 \Rightarrow 1.20 \text{g/cm}^3$, NaCl solution)
Figure A4.109 Hydrous kaolin Hydrite Flat D ($\gamma_{ini} = 1.25\text{g/cm}^3 \rightarrow 1.20\text{g/cm}^3$, NaCl solution)

Figure A4.110 Hydrous kaolin Hydrite Flat D ($\gamma_{ini} = 1.25\text{g/cm}^3 \rightarrow 1.20\text{g/cm}^3$, NaCl solution)
Figure A4.111 Hydrous kaolin Hydrite Flat D(\( \gamma_{\text{w}} = 1.25 \text{g/cm}^3 \rightarrow 1.20 \text{g/cm}^3 \), NaCl solution)

Figure A4.112 Hydrous kaolin Hydrite Flat D(\( \gamma_{\text{w}} = 1.25 \text{g/cm}^3 \rightarrow 1.20 \text{g/cm}^3 \), NaCl solution)
Figure A4.113 Hydrous kaolin Hydrite 121S ($\gamma_{imi} = 1.10g/cm^3$, Distilled water)

Figure A4.114 Hydrous kaolin Hydrite 121S ($\gamma_{imi} = 1.10g/cm^3$, Distilled water)
Figure A4.115 Hydrous kaolin Hydrite 121S ($\gamma_{omi} = 1.10$g/cm$^3$, Distilled water)

Figure A4.116 Hydrous kaolin Hydrite 121S ($\gamma_{omi} = 1.10$g/cm$^3$, Distilled water)
Figure A4.117 Hydrous kaolin Hydrite 121S ($\gamma_{imi}$ =1.20g/cm³, Distilled water)

Figure A4.118 Hydrous kaolin Hydrite 121S ($\gamma_{imi}$ =1.20g/cm³, Distilled water)
Figure A4.119 Hydrous kaolin Hydrite 121S (\(\gamma_{\text{im}}\) =1.20g/cm³, Distilled water)

Figure A4.120 Hydrous kaolin Hydrite 121S (\(\gamma_{\text{im}}\) =1.20g/cm³, Distilled water)
Figure A4.121 Hydrous kaolin Hydrite 121S (\( \gamma_{\text{min}} = 1.10 \text{g/cm}^3 \), NaCl solution)

Figure A4.122 Hydrous kaolin Hydrite 121S (\( \gamma_{\text{min}} = 1.10 \text{g/cm}^3 \), NaCl solution)
Figure A4.123 Hydrous kaolin Hydrite 121S ($\gamma_{\text{lim}} = 1.10\text{g/cm}^3$, NaCl solution)

Figure A4.124 Hydrous kaolin Hydrite 121S ($\gamma_{\text{lim}} = 1.10\text{g/cm}^3$, NaCl solution)
Figure A4.125 Hydrous kaolin Hydrite 121S ($\gamma_{\text{limit}} = 1.10 \text{g/cm}^3$, NaCl solution)
Figure A4.126 Hydrous kaolin Hydrite 121S ($\gamma_{\text{ms}} = 1.20 \text{g/cm}^3$, NaCl solution)

Figure A4.127 Hydrous kaolin Hydrite 121S ($\gamma_{\text{ms}} = 1.20 \text{g/cm}^3$, NaCl solution)
Figure A4.128 Hydrous kaolin Hydrite 121S ($\gamma_{imi} = 1.20g/cm^3$, NaCl solution)

Figure A4.129 Hydrous kaolin Hydrite 121S ($\gamma_{imi} = 1.20g/cm^3$, NaCl solution)
Figure A4.130 Calcined kaolin Polestar 400 (From left $\gamma_{ini} = 1.15, 1.10, 1.025,$ and $1.01\text{g/cm}^3$, D.W.)

Figure A4.131 Calcined kaolin Polestar 400 ($\gamma_{ini} = 1.10\text{ g/cm}^3$, NaCl solution)
Figure A4.132 Calcined kaolin Polestar 400 ($\gamma_{im} = 1.10$ g/cm$^3$, NaCl solution)
Figure A4.133 Talc T-80 ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled water)

Figure A4.134 Talc T-80 ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.135 Talc T-80 ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled water)

Figure A4.136 Talc T-80 ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.137 Talc T-80 ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled water)

Figure A4.138 Talc T-80 ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.139  Talc T-80 (\(\gamma_{\text{jmi}} = 1.05 \text{ g/cm}^3\), Distilled water)

Figure A4.140  Talc T-80 (\(\gamma_{\text{jmi}} = 1.05 \text{ g/cm}^3\), Distilled water)
Figure A4.141  Talc T-80 ($\gamma_{ini} = 1.05$ g/cm$^3$, Distilled water)

Figure A4.142  Talc T-80 ($\gamma_{ini} = 1.05$ g/cm$^3$, Distilled water)
Figure A4.143  Talc T-80 ($\gamma_{\text{int}} = 1.05 \text{ g/cm}^3$, Distilled water)

Figure A4.144  Talc T-80 ($\gamma_{\text{int}} = 1.05 \text{ g/cm}^3$, Distilled water)
Figure A4.145  Talc T-80 (\(\gamma_{\text{ini}} = 1.05 \text{ g/cm}^3\), Distilled water)
Figure A4.146  Talc T-80 (\(\gamma_{\text{imi}} = 1.10 \text{ g/cm}^3\), Distilled water)

Figure A4.147  Talc T-80 (\(\gamma_{\text{imi}} = 1.10 \text{ g/cm}^3\), Distilled water)
Figure A4.148  Tale T-80 ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled water)

Figure A4.149  Tale T-80 ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled water)
Figure A4.150  Tale T-80 (\(\gamma_{\text{ini}} = 1.10\ \text{g/cm}^3\), Distilled water)

Figure A4.151  Tale T-80 (\(\gamma_{\text{ini}} = 1.10\ \text{g/cm}^3\), Distilled water)
Figure A4.152  Talc T-80 (γ_{imi} = 1.20 g/cm³, Distilled water)

Figure A4.153  Talc T-80 (γ_{imi} = 1.20 g/cm³, Distilled water)
Figure A4.154  Talc T-80 ($\gamma_{\text{ini}} = 1.20 \text{ g/cm}^3$, Distilled water)

Figure A4.155  Talc T-80 ($\gamma_{\text{ini}} = 1.20 \text{ g/cm}^3$, Distilled water)
Figure A4.156  Talc T-80 ($\gamma_{\text{ini}} = 1.10$ g/cm$^3$, NaCl solution)

Figure A4.157  Talc T-80 ($\gamma_{\text{ini}} = 1.10$ g/cm$^3$, NaCl solution)
Figure A4.158  Talc T-80 (γ_{ini} = 1.10 g/cm^3, NaCl solution)

Figure A4.159  Talc T-80 (γ_{ini} = 1.10 g/cm^3, NaCl solution)
Figure A4.160  Talc T-80 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, NaCl solution)

Figure A4.161  Talc T-80 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, NaCl solution)
Figure A4.162  Talc T-80 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, NaCl solution)

Figure A4.163  Talc T-80 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, NaCl solution)
Figure A4.164  Talc T-80 ($\gamma_{\text{ini}} = 1.20 \, \text{g/cm}^3$, NaCl solution)

Figure A4.165  Talc T-80 ($\gamma_{\text{ini}} = 1.20 \, \text{g/cm}^3$, NaCl solution)
Figure A4.166  Talc T-80 ($\gamma_{imi} = 1.20$ g/cm$^3$, NaCl solution)

Figure A4.167  Talc T-80 ($\gamma_{imi} = 1.20$ g/cm$^3$, NaCl solution)
Figure A4.168  Talc T-80 ($\gamma_{\text{ini}} = 1.20 \text{ g/cm}^3$, NaCl solution)

Figure A4.169  Talc T-80 ($\gamma_{\text{ini}} = 1.20 \text{ g/cm}^3$, NaCl solution)
Figure A4.170  Talc 2882 ($\gamma_{\text{imm}} = 1.025$ g/cm$^3$, Distilled water)

Figure A4.171  Talc 2882 ($\gamma_{\text{imm}} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.172  Tale 2882 ($\gamma_{\text{ml}} = 1.025 \text{ g/cm}^3$, Distilled water)

Figure A4.173  Tale 2882 ($\gamma_{\text{ml}} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.174  Tale 2882 ($\gamma_{\text{mix}} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A4.175  Talc 2882 ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled water)

Figure A4.176  Talc 2882 ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled water)
Figure A4.177  Talc 2882 ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled)

Figure A4.178  Talc 2882 ($\gamma_{ini} = 1.10$ g/cm$^3$, Distilled water)
Figure A4.179  Talc 2882 ($\gamma_{\text{ini}} = 1.10$ g/cm$^3$, Distilled water)

Figure A4.180  Talc 2882 ($\gamma_{\text{ini}} = 1.10$ g/cm$^3$, Distilled water)
Figure A4.181  Talc 2882 \( (\gamma_{\text{ini}} = 1.10 \text{ g/cm}^3, \text{Distilled water}) \)

Figure A4.182  Talc 2882 \( (\gamma_{\text{ini}} = 1.10 \text{ g/cm}^3, \text{Distilled water}) \)
Figure A4.183  Tale 2882 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, Distilled water)

Figure A4.184  Tale 2882 ($\gamma_{ini} = 1.10 \text{ g/cm}^3$, Distilled water)
Figure A4.185  Talc 2882 (\( \gamma_{\text{ini}} = 1.10 \text{ g/cm}^3 \), Distilled water)

Figure A4.186  Talc 2882 (\( \gamma_{\text{ini}} = 1.10 \text{ g/cm}^3 \), Distilled water)
Figure A4.187  Tale 2882 ($\gamma_{\text{init}} = 1.10 \text{ g/cm}^3$, Distilled water)

Figure A4.188  Tale 2882 ($\gamma_{\text{init}} = 1.10 \text{ g/cm}^3$, Distilled water)
Figure A4.189  Talc 2882 ($\gamma_{\text{int}} = 1.10$ g/cm$^3$, Distilled water)

Figure A4.190  Talc 2882 ($\gamma_{\text{int}} = 1.10$ g/cm$^3$, Distilled water)
Figure A4.191  Tale 2882 ($\gamma_{\text{ini}} = 1.10 \text{ g/cm}^3$, Distilled water)

Figure A4.192  Tale 2882 ($\gamma_{\text{ini}} = 1.10 \text{ g/cm}^3$, Distilled water)
Figure A4.193  Tale 2882 ($\gamma_{wtr} = 1.20$ g/cm$^3$, Distilled water)

Figure A4.194  Tale 2882 ($\gamma_{wtr} = 1.20$ g/cm$^3$, Distilled water)
Figure A4.195  Talc 2882 ($\gamma_{\text{mat}} = 1.20 \text{ g/cm}^3$, Distilled water)

Figure A4.196  Talc 2882 ($\gamma_{\text{mat}} = 1.20 \text{ g/cm}^3$, Distilled water)
Figure A4.197  Talc 2882 \( \gamma_{\text{int}} = 1.025 \text{ g/cm}^3 \), NaCl solution

Figure A4.198  Talc 2882 \( \gamma_{\text{int}} = 1.025 \text{ g/cm}^3 \), NaCl solution
Figure A4.199  Talc 2882 ($\gamma_{\text{ini}} = 1.025$ g/cm³, NaCl solution)

Figure A4.200  Talc 2882 ($\gamma_{\text{ini}} = 1.025$ g/cm³, NaCl solution)
Figure A4.201  Talc 2882 \( (\gamma_{\text{mi}} = 1.10 \text{ g/cm}^3, \text{NaCl solution}) \)

Figure A4.202  Talc 2882 \( (\gamma_{\text{mi}} = 1.10 \text{ g/cm}^3, \text{NaCl solution}) \)
Figure A4.203  Talc 2882 ($\gamma_{\text{wt}} = 1.10$ g/cm$^3$, NaCl solution)

Figure A4.204  Talc 2882 ($\gamma_{\text{wt}} = 1.10$ g/cm$^3$, NaCl solution)
Figure A4.205  Talc 2882 ($\gamma_{\text{ini}} = 1.10 \text{ g/cm}^3$, NaCl solution)

Figure A4.206  Talc 2882 ($\gamma_{\text{ini}} = 1.10 \text{ g/cm}^3$, NaCl solution)
Figure A4.207  Talc 2882 ($\gamma_{\text{mi}} = 1.10 \text{ g/cm}^3$, NaCl solution)

Figure A4.208  Talc 2882 ($\gamma_{\text{mi}} = 1.10 \text{ g/cm}^3$, NaCl solution)
Figure A4.209  Talc 2882 ($\gamma_{\text{wai}} = 1.10 \text{ g/cm}^3$, NaCl solution)

Figure A4.210  Talc 2882 ($\gamma_{\text{wai}} = 1.10 \text{ g/cm}^3$, NaCl solution)
Figure A4.211  Talc 2882 ($\gamma_{\text{ini}} = 1.20$ g/cm$^3$, NaCl solution)

Figure A4.212  Talc 2882 ($\gamma_{\text{ini}} = 1.20$ g/cm$^3$, NaCl solution)
Figure A4.213  Talc 2882 ($\gamma_{\text{air}} = 1.20$ g/cm$^3$, NaCl solution)

Figure A4.214  Talc 2882 ($\gamma_{\text{air}} = 1.20$ g/cm$^3$, NaCl solution)
Figure A4.215  Talc 2882 ($\gamma_{ini} = 1.20$ g/cm$^3$, NaCl solution)

Figure A4.216  Talc 2882 ($\gamma_{ini} = 1.20$ g/cm$^3$, NaCl solution)
Figure A4.217  Talc 2882 ($\gamma_{\text{ini}} = 1.20 \text{ g/cm}^3$, NaCl solution)
Figure A4.218 Attapulgite Fertogel ($\gamma_{\text{mi}} = 1.025$ g/cm$^3$, Distilled water)

Figure A4.219 Attapulgite Fertogel ($\gamma_{\text{mi}} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.220 Attapulgite Fertogel ($\gamma_{\text{mi}} = 1.025$ g/cm$^3$, Distilled water)

Figure A4.221 Attapulgite Fertogel ($\gamma_{\text{mi}} = 1.025$ g/cm$^3$, Distilled water)
Figure A4.222 Attapulgite Fertogel ($\gamma_{mi} = 1.025$ g/cm³, Distilled water)

Figure A4.223 Attapulgite Fertogel ($\gamma_{mi} = 1.025$ g/cm³, Distilled water)
Figure A4.224 Attapulgite Fertogel ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled water)

Figure A4.225 Attapulgite Fertogel ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled water)
Figure A4.226 Attapulgite Fertogel ($\gamma_{imi} = 1.05 \text{ g/cm}^3$, Distilled water)

Figure A4.227 Attapulgite Fertogel ($\gamma_{imi} = 1.05 \text{ g/cm}^3$, Distilled water)
Figure A4.228 Attapulgite Fertogel ($\gamma_{imi} = 1.05 \text{ g/cm}^3$, Distilled water)

Figure A4.229 Attapulgite Fertogel ($\gamma_{imi} = 1.05 \text{ g/cm}^3$, Distilled water)
Figure A4.230 Attapulgite Fertogel ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled water)

Figure A4.231 Attapulgite Fertogel ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled water)
Figure A4.232 Attapulgite Fertogel ($\gamma_{\text{imi}} = 1.05$ g/cm$^3$, Distilled water)

Figure A4.233 Attapulgite Fertogel ($\gamma_{\text{imi}} = 1.05$ g/cm$^3$, Distilled water)
Figure A4.234 Attapulgite Fertogel ($\gamma_{imi} = 1.05 \text{ g/cm}^3$, Distilled water)

Figure A4.235 Attapulgite Fertogel ($\gamma_{imi} = 1.05 \text{ g/cm}^3$, Distilled water)
Figure A4.236 Attapulgite Fertogel ($\gamma_{mi} = 1.01 \rightarrow 1.10$ g/cm$^3$, Distilled water)

Figure A4.237 Attapulgite Fertogel ($\gamma_{mi} = 1.01 \rightarrow 1.10$ g/cm$^3$, Distilled water)
Figure A4.238 Attapulgite Fertogel ($\gamma_{ml} = 1.05$ g/cm$^3$, NaCl solution)

Figure A4.239 Attapulgite Fertogel ($\gamma_{ml} = 1.05$ g/cm$^3$, NaCl solution)
Figure A4.240 Attapulgite Fertogel ($\gamma_{im} = 1.05$ g/cm$^3$, NaCl solution)

Figure A4.241 Attapulgite Fertogel ($\gamma_{im} = 1.05$ g/cm$^3$, NaCl solution)
Figure A4.242 Attapulgite Fertogel ($\gamma_{\text{ml}} = 1.05$ g/cm$^3$, NaCl solution)

Figure A4.243 Attapulgite Fertogel ($\gamma_{\text{ml}} = 1.05$ g/cm$^3$, NaCl solution)
Figure A4.244 Attapulgite Fertogel ($\gamma_{iml} = 1.05 \text{ g/cm}^3$, NaCl solution)

Figure A4.245 Attapulgite Fertogel ($\gamma_{iml} = 1.05 \text{ g/cm}^3$, NaCl solution)
Figure A4.246 Attapulgite Fertogel (\( \gamma_{ml} = 1.05 \text{ g/cm}^3 \), NaCl solution)

Figure A4.247 Attapulgite Fertogel (\( \gamma_{ml} = 1.05 \text{ g/cm}^3 \), NaCl solution)
Figure A4.248 Attapulgite Fertogel ($\gamma_{imi} = 1.01 \rightarrow 1.10$ g/cm$^3$, NaCl solution)

Figure A4.249 Attapulgite Fertogel ($\gamma_{imi} = 1.01 \rightarrow 1.10$ g/cm$^3$, NaCl solution)
Figure A4.250 Attapulgite Fertogel ($\gamma_{imi} = 1.01 \rightarrow 1.10$ g/cm$^3$, NaCl solution)

Figure A4.251 Attapulgite Fertogel ($\gamma_{imi} = 1.01 \rightarrow 1.10$ g/cm$^3$, NaCl solution)
A5. Large settling column test

A5.1 Settling curves

Figure A5.1 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{mi} =1.05$g/cm$^3$, Distilled Water)
Figure A5.2 Settling curve of hydrous kaolin Hydrite Flat D \((\gamma_{mi} = 1.20 \text{ g/cm}^3, \text{ Distilled Water})\)
Figure A5.3 Settling curve of calcined kaolin Polestar 400 ($\gamma_{ini} = 1.05 \text{ g/cm}^3$, Distilled water)
Figure A5.4 Settling curve of attapulgite Fertogel ($\gamma_{ini}=1.025$ g/cm$^3$, Distilled water)
Figure A5.5 Settling curve of talc Pioneer T-80 (\( \gamma_{imi} = 1.05 \text{ g/cm}^3 \), Distilled water)
Figure A5.6 Settling curve of talc Pioneer T-80 ($\gamma_{\text{sol}} = 1.15 \text{ g/cm}^3$, Distilled water)
Figure A5.7 Settling curve of talc Pioneer T-80 ($\gamma_{imi} = 1.20$ g/cm$^3$, Distilled water)
A5.2 Settling velocities

Figure A5.8 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.05$ g/cm$^3$, Distilled Water)

Figure A5.9 Settling curve of hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.20$ g/cm$^3$, Distilled Water)
Figure A5.10 Settling curve of calcined kaolin Polestar 400 ($\gamma_{\text{ini}} = 1.05 \text{ g/cm}^3$, Distilled water)

Figure A5.11 Settling curve of attapulgite Fertogel ($\gamma_{\text{ini}} = 1.025 \text{ g/cm}^3$, Distilled water)
Figure A5.12 Settling curve of talc Pioneer T-80 ($\gamma_{ini} = 1.05$ g/cm$^3$, Distilled water)

Figure A5.13 Settling curve of talc Pioneer T-80 ($\gamma_{ini} = 1.15$ g/cm$^3$, Distilled water)
Figure A5.14 Settling curve of talc Pioneer T-80 ($\gamma_{\text{omi}} = 1.20 \text{ g/cm}^3$, Distilled water)
A5.3 Pressure changes

Figure A5.15 Pore pressure measurement of hydrous kaolin Hydrite Flat D at \(t=5,287\) sec 
\[\gamma_{init} = 1.05\text{g/cm}^3\text{, Distilled Water}\]

Figure A5.16 Pore pressure measurement of hydrous kaolin Hydrite Flat D at \(t=19,891\) sec 
\[\gamma_{init} = 1.05\text{g/cm}^3\text{, Distilled Water}\]
Figure A5.17 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=34,340$ sec
($\gamma_{\text{ini}} = 1.05\text{g/cm}^3$, Distilled Water)

Figure A5.18 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=127,413$ sec
($\gamma_{\text{ini}} = 1.05\text{g/cm}^3$, Distilled Water)
Figure A5.19 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=249,027$ sec
($\gamma_{ini}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.20 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=324,504$ sec
($\gamma_{ini}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.21 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=522,081$ sec
($\gamma_{\text{ini}} = 1.05$ g/cm$^3$, Distilled Water)

Figure A5.22 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=599,590$ sec
($\gamma_{\text{ini}} = 1.05$ g/cm$^3$, Distilled Water)
Figure A5.23 Pore pressure measurement of hydrous kaolin Hydrite Flat D at different times
($\gamma_{ini}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.24 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=1,440$ sec
($\gamma_{\text{ini}} = 1.20 \text{g/cm}^3$, Distilled Water)

Figure A5.25 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=7,557$ sec
($\gamma_{\text{ini}} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.26 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=18,382\text{sec}$ ($\gamma_{\text{ini}} = 1.20\text{g/cm}^3$, Distilled Water)

Figure A5.27 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=30,550\text{sec}$ ($\gamma_{\text{ini}} = 1.20\text{g/cm}^3$, Distilled Water)
Figure A5.28 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=50,640$ sec
($\gamma_{\text{ini}} = 1.20 \text{g/cm}^3$, Distilled Water)

Figure A5.29 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=70,126$ sec
($\gamma_{\text{ini}} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.30 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=83,203$ sec
($\gamma_{ini}=1.20\text{g/cm}^3$, Distilled Water)

Figure A5.31 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=98,781$ sec
($\gamma_{ini}=1.20\text{g/cm}^3$, Distilled Water)
Figure A5.32 Pore pressure measurement of hydrous kaolin Hydrite Flat D at t=107,208sec
($\gamma_{int}$ = 1.20g/cm$^3$, Distilled Water)

Figure A5.33 Pore pressure measurement of hydrous kaolin Hydrite Flat D at t=115,227sec
($\gamma_{int}$ = 1.20g/cm$^3$, Distilled Water)
Figure A5.34 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=231,288$ sec
($\gamma_{\text{ini}} = 1.20\text{g/cm}^3$, Distilled Water)

Figure A5.35 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=372,231$ sec
($\gamma_{\text{ini}} = 1.20\text{g/cm}^3$, Distilled Water)
Figure A5.36 Pore pressure measurement of hydrous kaolin Hydrite Flat D at $t=455,268$ sec
($\gamma_{\text{m}} = 1.20 \text{g/cm}^3$, Distilled Water)

Figure A5.37 Pore pressure measurement of hydrous kaolin Hydrite Flat D at different times
($\gamma_{\text{m}} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.38 Pore pressure measurement of attapulgite Fertogel at $t=753\,\text{sec}$

\[ \gamma_{\text{im}} = 1.05\,\text{g/cm}^3, \text{Distilled Water} \]

Figure A5.39 Pore pressure measurement of attapulgite Fertogel at $t=2,556\,\text{sec}$

\[ \gamma_{\text{im}} = 1.05\,\text{g/cm}^3, \text{Distilled Water} \]
Figure A5.40 Pore pressure measurement of attapulgite Fertogel at $t=4,806\text{sec}$

($\gamma_{imi}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.41 Pore pressure measurement of attapulgite Fertogel at $t=8,276\text{sec}$

($\gamma_{imi}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.42 Pore pressure measurement of attapulgite Fertogel at $t=17,016$ sec
($\gamma'_{mi}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.43 Pore pressure measurement of attapulgite Fertogel at $t=26,676$ sec
($\gamma'_{mi}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.44 Pore pressure measurement of attapulgite Fertogel at t=39,136sec 
($\gamma_{imi}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.45 Pore pressure measurement of attapulgite Fertogel at t=51,916sec 
($\gamma_{imi}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.46 Pore pressure measurement of attapulgite Fertogel at $t=72,986$ sec
($\gamma_{\text{imi}} = 1.05 \text{g/cm}^3$, Distilled Water)

Figure A5.47 Pore pressure measurement of attapulgite Fertogel at $t=117,020$ sec
($\gamma_{\text{imi}} = 1.05 \text{g/cm}^3$, Distilled Water)
Figure A5.48 Pore pressure measurement of attapulgite Fertogel at \( t=213,273 \) sec
\\( (\gamma_{\text{ini}} = 1.05 \text{g/cm}^3, \text{Distilled Water}) \)

Figure A5.49 Pore pressure measurement of attapulgite Fertogel at \( t=294,595 \) sec
\\( (\gamma_{\text{ini}} = 1.05 \text{g/cm}^3, \text{Distilled Water}) \)
Figure A5.50 Pore pressure measurement of attapulgite Fertogel at $t=385,338$ sec 
($\gamma_{\text{ini}}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.51 Pore pressure measurement of attapulgite Fertogel at $t=472,563$ sec 
($\gamma_{\text{ini}}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.52 Pore pressure measurement of attapulgite Fertogel at $t=506,350$ sec
($\gamma_{\text{ini}}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.53 Pore pressure measurement of attapulgite Fertogel at different times
($\gamma_{\text{ini}}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.54 Pore pressure measurement of talc Polestar T-80 at t=4,756 sec
($\gamma_{ini} = 1.15\text{g/cm}^3$, Distilled Water)

Figure A5.55 Pore pressure measurement of talc Polestar T-80 at t=39,550 sec
($\gamma_{ini} = 1.15\text{g/cm}^3$, Distilled Water)
Figure A5.56 Pore pressure measurement of talc Polestar T-80 at $t=87,166$sec
($\gamma_{\text{ini}} = 1.15\text{g/cm}^3$, Distilled Water)

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Figure A5.57 Pore pressure measurement of talc Polestar T-80 at $t=121,563$sec
($\gamma_{\text{ini}} = 1.15\text{g/cm}^3$, Distilled Water)
Figure A5.58 Pore pressure measurement of talc Polestar T-80 at $t=298,940$sec
($\gamma_{ini}=1.15$g/cm$^3$, Distilled Water)

Figure A5.59 Pore pressure measurement of talc Polestar T-80 at $t=459,774$sec
($\gamma_{ini}=1.15$g/cm$^3$, Distilled Water)
Figure A5.60 Pore pressure measurement of talc Polestar T-80 at t=528,048sec
\( (\gamma_{\text{ini}} = 1.15\text{g/cm}^3, \text{Distilled Water}) \)

Figure A5.61 Pore pressure measurement of talc Polestar T-80 at t=642,427sec
\( (\gamma_{\text{ini}} = 1.15\text{g/cm}^3, \text{Distilled Water}) \)
Figure A5.62 Pore pressure measurement of talc Polestar T-80 at t=818,746 sec
($\gamma_{\text{ini}} = 1.15 \text{g/cm}^3$, Distilled Water)

Figure A5.63 Pore pressure measurement of talc Polestar T-80 at different times
($\gamma_{\text{ini}} = 1.15 \text{g/cm}^3$, Distilled Water)
Figure A5.64 Pore pressure measurement of talc Polestar T-80 at t=600sec
$\gamma_{\text{init}} = 1.20\text{g/cm}^3$, Distilled Water

Figure A5.65 Pore pressure measurement of talc Polestar T-80 at t=3,140sec
$\gamma_{\text{init}} = 1.20\text{g/cm}^3$, Distilled Water
Figure A5.66 Pore pressure measurement of talc Polestar T-80 at t=8,540sec
\( \gamma_{\text{ini}} = 1.20 \text{g/cm}^3 \), Distilled Water

Figure A5.67 Pore pressure measurement of talc Polestar T-80 at t=12,565sec
\( \gamma_{\text{ini}} = 1.20 \text{g/cm}^3 \), Distilled Water
Figure A5.68 Pore pressure measurement of talc Polestar T-80 at t=22,432sec
($\gamma_{\text{ini}}=1.20\text{g/cm}^3$, Distilled Water)

Figure A5.69 Pore pressure measurement of talc Polestar T-80 at t=30,931sec
($\gamma_{\text{ini}}=1.20\text{g/cm}^3$, Distilled Water)
Figure A5.70 Pore pressure measurement of talc Polestar T-80 at t=50,700sec
\( \gamma_{\text{ini}} = 1.20 \text{g/cm}^3 \), Distilled Water

Figure A5.71 Pore pressure measurement of talc Polestar T-80 at t=84,529sec
\( \gamma_{\text{ini}} = 1.20 \text{g/cm}^3 \), Distilled Water
Figure A5.72 Pore pressure measurement of talc Polestar T-80 at t=121,500 sec
($\gamma_{\text{ini}} = 1.20$ g/cm$^3$, Distilled Water)

Figure A5.73 Pore pressure measurement of talc Polestar T-80 at t=316,371 sec
($\gamma_{\text{ini}} = 1.20$ g/cm$^3$, Distilled Water)
Figure A5.74 Pore pressure measurement of talc Polestar T-80 at \( t=454,784 \text{sec} \)
\( (\gamma_{\text{ini}} = 1.20 \text{g/cm}^3, \text{Distilled Water}) \)

Figure A5.75 Pore pressure measurement of talc Polestar T-80 at \( t=567,280 \text{sec} \)
\( (\gamma_{\text{ini}} = 1.20 \text{g/cm}^3, \text{Distilled Water}) \)
Figure A5.76 Pore pressure measurement of talc Polestar T-80 at different times
($\gamma_{ini} = 1.20\text{g/cm}^3$, Distilled Water)
A5.4 Experiments pictures

Figure A5.77 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{omi}}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.78 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{omi}}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.79 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{imi}} = 1.05\ \text{g/cm}^3$, Distilled Water)

Figure A5.80 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{imi}} = 1.05\ \text{g/cm}^3$, Distilled Water)
Figure A5.81 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{omi}} = 1.05\text{g/cm}^3$, Distilled Water)

Figure A5.82 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{omi}} = 1.05\text{g/cm}^3$, Distilled Water)
Figure A5.83 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{smi}} = 1.05$ g/cm$^3$, Distilled Water)

Figure A5.84 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{smi}} = 1.05$ g/cm$^3$, Distilled Water)
Figure A5.85 Hydrous kaolin Hydrite Flat D ($\gamma_{ini} = 1.20\text{g/cm}^3$, Distilled Water)

Figure A5.86 Hydrous kaolin Hydrite Flat D ($\gamma_{ini} = 1.20\text{g/cm}^3$, Distilled Water)
Figure A5.87 Hydrous kaolin Hydrite Flat D ($\gamma_{omi} = 1.20\,\text{g/cm}^3$, Distilled Water)

Figure A5.88 Hydrous kaolin Hydrite Flat D ($\gamma_{omi} = 1.20\,\text{g/cm}^3$, Distilled Water)
Figure A5.89 Hydrous kaolin Hydrite Flat D ($\gamma_{omi} =$1.20g/cm$^3$, Distilled Water)

Figure A5.90 Hydrous kaolin Hydrite Flat D ($\gamma_{omi} =$1.20g/cm$^3$, Distilled Water)
Figure A5.91 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.20$g/cm$^3$, Distilled Water)

Figure A5.92 Hydrous kaolin Hydrite Flat D ($\gamma_{imi} = 1.20$g/cm$^3$, Distilled Water)
Figure A5.93 Hydrous kaolin Hydrite Flat D ($\gamma_{\text{ini}} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.94 Calcined kaolin Polestar 400 ($\gamma_{\text{mix}} = 1.05 \text{g/cm}^3$, Distilled Water)

Figure A5.95 Calcined kaolin Polestar 400 ($\gamma_{\text{mix}} = 1.05 \text{g/cm}^3$, Distilled Water)
Figure A5.96 Calcined kaolin Polestar 400 ($\gamma_{\text{imi}}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.97 Calcined kaolin Polestar 400 ($\gamma_{\text{imi}}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.98 Calcined kaolin Polestar 400 ($\gamma_{\text{imi}} = 1.05\text{g/cm}^3$, Distilled Water)

Figure A5.99 Calcined kaolin Polestar 400 ($\gamma_{\text{imi}} = 1.05\text{g/cm}^3$, Distilled Water)
Figure A5.100 Calcined kaolin Polestar 400 ($\gamma_{imi} =1.05\text{g/cm}^3$, Distilled Water)

Figure A5.101 Calcined kaolin Polestar 400 ($\gamma_{imi} =1.05\text{g/cm}^3$, Distilled Water)
Figure A5.102 Calcined kaolin Polestar 400 ($\gamma_{mi} = 1.05\text{g/cm}^3$, Distilled Water)

Figure A5.103 Calcined kaolin Polestar 400 ($\gamma_{mi} = 1.05\text{g/cm}^3$, Distilled Water)
Figure A5.104 Calcined kaolin Polestar 400 (γ_{\text{mi}} = 1.05\text{g/cm}^3, \text{Distilled Water})

Figure A5.105 Calcined kaolin Polestar 400 (γ_{\text{mi}} = 1.05\text{g/cm}^3, \text{Distilled Water})
Figure A5.106 Talc T-80 ($\gamma_{int} = 1.05\text{g/cm}^3$, Distilled Water)

Figure A5.107 Talc T-80 ($\gamma_{int} = 1.05\text{g/cm}^3$, Distilled Water)
Figure A5.108 Talc T-80 (γ_{int} =1.05\text{g/cm}^3, Distilled Water)

Figure A5.109 Talc T-80 (γ_{int} =1.05\text{g/cm}^3, Distilled Water)
Figure A5.110 Talc T-80 ($\gamma_{\text{mat}}=1.05\text{g/cm}^3$, Distilled Water)

Figure A5.111 Talc T-80 ($\gamma_{\text{mat}}=1.05\text{g/cm}^3$, Distilled Water)
Figure A5.112 Talc T-80 (\( \gamma_{\text{int}} = 1.05 \text{g/cm}^3 \), Distilled Water)

Figure A5.113 Talc T-80 (\( \gamma_{\text{int}} = 1.05 \text{g/cm}^3 \), Distilled Water)
Figure A5.114 Talc T-80 ($\gamma_{\text{int}} = 1.05$ g/cm$^3$, Distilled Water)

Figure A5.115 Talc T-80 ($\gamma_{\text{int}} = 1.05$ g/cm$^3$, Distilled Water)
Figure A5.116 Talc T-80 ($\gamma_{int} = 1.05\text{g/cm}^3$, Distilled Water)

Figure A5.117 Talc T-80 ($\gamma_{int} = 1.05\text{g/cm}^3$, Distilled Water)
Figure A5.118 Talc T-80 \( (\gamma_{\text{int}} = 1.15\,\text{g/cm}^3, \text{Distilled Water}) \)

Figure A5.119 Talc T-80 \( (\gamma_{\text{int}} = 1.15\,\text{g/cm}^3, \text{Distilled Water}) \)
Figure A5.120 Talc T-80 (γ_{m} = 1.15 g/cm³, Distilled Water)

Figure A5.121 Talc T-80 (γ_{m} = 1.15 g/cm³, Distilled Water)
Figure A5.122 Talc T-80 (γ_{int} = 1.15 g/cm³, Distilled Water)

Figure A5.123 Talc T-80 (γ_{int} = 1.15 g/cm³, Distilled Water)
Figure A5.124 Talc T-80 ($\gamma_{\text{int}} = 1.15\text{g/cm}^3$, Distilled Water)

Figure A5.125 Talc T-80 ($\gamma_{\text{int}} = 1.15\text{g/cm}^3$, Distilled Water)
Figure A5.126 Talc T-80 (γ\textsubscript{int} = 1.15 g/cm\textsuperscript{3}, Distilled Water)

Figure A5.127 Talc T-80 (γ\textsubscript{int} = 1.15 g/cm\textsuperscript{3}, Distilled Water)
Figure A5.128 Talc T-80 (\( \gamma_{\text{int}} = 1.15 \text{g/cm}^3 \), Distilled Water)

Figure A5.129 Talc T-80 (\( \gamma_{\text{int}} = 1.15 \text{g/cm}^3 \), Distilled Water)
Figure A5.130 Talc T-80 ($\gamma_{\text{int}} = 1.15\text{g/cm}^3$, Distilled Water)
Figure A5.131 Talc T-80 (\( \gamma_{\text{imm}} = 1.20\text{g/cm}^3 \), Distilled Water)

Figure A5.132 Talc T-80 (\( \gamma_{\text{imm}} = 1.20\text{g/cm}^3 \), Distilled Water)
Figure A5.133 Talc T-80 ($\gamma_{imm} = 1.20 \text{g/cm}^3$, Distilled Water)

Figure A5.134 Talc T-80 ($\gamma_{imm} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.135 Talc T-80 ($\gamma_{\text{int}} = 1.20 \text{g/cm}^3$, Distilled Water)

Figure A5.136 Talc T-80 ($\gamma_{\text{int}} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.137 Talc T-80 ($\gamma_{\text{int}} = 1.20 \text{g/cm}^3$, Distilled Water)

Figure A5.138 Talc T-80 ($\gamma_{\text{int}} = 1.20 \text{g/cm}^3$, Distilled Water)
Figure A5.139 Talc T-80 ($\gamma_{im} = 1.20\text{g/cm}^3$, Distilled Water)

Figure A5.140 Talc T-80 ($\gamma_{im} = 1.20\text{g/cm}^3$, Distilled Water)
Figure A5.141 Attapulgite Fertogel ($\gamma_{imi} = 1.025 \text{ g/cm}^3$, Distilled Water)

Figure A5.142 Attapulgite Fertogel ($\gamma_{imi} = 1.025 \text{ g/cm}^3$, Distilled Water)
Figure A5.143 Attapulgite Fertogel (\(\gamma_{\text{imi}} = 1.025\) g/cm\(^3\), Distilled Water)

Figure A5.144 Attapulgite Fertogel (\(\gamma_{\text{imi}} = 1.025\) g/cm\(^3\), Distilled Water)
Figure A5.145 Attapulgite Fertogel (\(\gamma_{im} = 1.025\) g/cm\(^3\), Distilled Water)

Figure A5.146 Attapulgite Fertogel (\(\gamma_{im} = 1.025\) g/cm\(^3\), Distilled Water)
Figure A5.147 Attapulgite Fertogel ($\gamma_{\text{imi}} = 1.025 \text{ g/cm}^3$, Distilled Water)

Figure A5.148 Attapulgite Fertogel ($\gamma_{\text{imi}} = 1.025 \text{ g/cm}^3$, Distilled Water)
Figure A5.149 Attapulgite Fertogel ($\gamma_{mi} = 1.025$ g/cm$^3$, Distilled Water)

Figure A5.150 Attapulgite Fertogel ($\gamma_{mi} = 1.025$ g/cm$^3$, Distilled Water)
Figure A5.151 Attapulgite Fertogel ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled Water)

Figure A5.152 Attapulgite Fertogel ($\gamma_{mi} = 1.025 \text{ g/cm}^3$, Distilled Water)
Figure A5.153 Attapulgite Fertogel (\(\gamma_{\text{im}} = 1.025\) g/cm\(^3\), Distilled Water)

Figure A5.154 Attapulgite Fertogel (\(\gamma_{\text{im}} = 1.025\) g/cm\(^3\), Distilled Water, 23 11:46 AM)
Vita

The author was born in August 21, 1973 in Seoul, Korea. He graduated from Baemyung High school and attended Ajou University in Korea from 1992. He started his academic and engineering career as a research assistant at IGUA (Institut of Geotechnik Universität Ajou) from 1993. In 1998, he received his first M.S. degree on the behavior of reinforced earth wall with passive resistance using finer particles. After getting M.S. degree, he joined the Republic of Korea Marine Corps and was commissioned as a second lieutenant. He served as an engineering officer for three and a half years. He retired as a first lieutenant and joined the IGUA as a researcher in 2001. After one year, the author entered Virginia Tech. and is completing his second master’s degree in Civil Engineering.