DESIGN AND TESTING OF A HYPERBARIC HORIZONTAL BELT FILTER FOR FINE COAL DEWATERING

Jeffrey A. Salomon

Thesis submitted to the Faculty of
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Mining and Minerals Engineering

Committee Members:

Dr. Gerald Luttrell, Chairman
Dr. Roe-Hoan Yoon
Dr. Greg Adel
Dr. Thomas Novak

June 1, 2007
Blacksburg, Virginia

Keywords: Dewatering, Filtration, Pressure Filter, Belt Filter, Coal Preparation

DESIGN AND TESTING OF A HYPERBARIC HORIZONTAL BELT FILTER FOR FINE COAL DEWATERING

by

Jeffery Salomon

Committee Chairman: Gerald H. Luttrell
Department of Mining and Minerals Engineering

ABSTRACT

This objective of this project was to develop a new dewatering device that could produce a lower moisture content and better fine particle recovery than current technology. To meet this goal, a hyperbaric horizontal belt filter was designed and constructed over the course of 18 months. Once built, the filter was then thoroughly tested to determine operational capabilities. The test data showed that the lowest moisture content that could be achieved with a coarse feed (minus 1 mm screen-bowl centrifuge feed) was 8.8%. This value could be further reduced to 8.2% and capacity increased with the use of dewatering aids. When testing with a fine feed (minus 0.15 mm column product feed), the lowest moisture content was 35% without chemicals and 29% with chemicals. A 50/50 mixture by volume of coarse and fine feeds was artificially created and provided a moisture of 10.8%, which was reduced using reagents to 8.4%. The machine provided a very high recovery rate for all feed materials. Of the coal input, no less than 94% of it reported to the dry product. The pressure used to dewater the coal was the controlling factor for the air consumption of the unit. The data from these tests suggest that a full size production unit is feasible, although the power requirements for gas compression would be high.

ACKNOWLEDGMENTS

It is with a much appreciation that I would like to thank my advisor Dr. Gerald Luttrell for all of his support and encouragement.

Also, my wife Rachel Salomon has been an inspiration to me through some of the difficult times of all of this research. With that I would also like to add my parents Roy and Cyndie Salomon for all of the monetary and emotional support that they have provided me over the years.

In addition, many thanks to my many colleagues here at Virginia Tech all of whom have helped me in many ways during the course of my research Selahattin Baris Yazgan, Todd Burchett, Christopher Barbee, Brain Parker, and Mert Kerem Eraydin.

Finally, I owe the highest appreciation of all to the man that made everything that this research accomplished possible Mr. James Waddell. Without his steadfast assistance and know-how this project would simply not have been possible.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1:
GENERAL INTRODUCTION

1.1 Preamble

Coal is a major energy resource in both the United States and world wide. The extraction of this resource from the earth requires methods that often mix impurities that do not contain heating value in with the valuable coal. Removal of this excess material requires that the coal be washed in a preparation plant to separate the clean coal from the refuse material. Most known methods for accomplishing this for the fine particle size range (less than 1 mm) are wet processes. Water, when mixed with coal, also reduces its BTU (British Thermal Unit) value, thus creating a need to remove it from the final product.

Traditionally, coal producers have handled fine waste slurries in two different ways. The first is to pump the slurry to an impoundment pond where the valuable coal is wasted and creates an environmental hazard. This is done because it becomes increasingly difficult and costly to dewater coal as particle size decreases. The other option is to install thermal dryers. Thermal dryers, however, have high capital and operating costs. It is also difficult to get a permit to install thermal dryers due to air pollution problems.

Thus, there is a need for a third option. An attractive alternative would involve the use of a filtration unit that greatly reduces the cost and improves the effectiveness of fine coal dewatering. This cost is reduced because the energy input needed to evaporate water is high compared to the cost of mechanically removing water. The use of displacement filters combined with surface tension reducing reagents can create a high volume filtration unit that would allow for the economical recovery of these fine coal slurries. Unfortunately, a piece of equipment that takes advantage of all of these factors in a cost effective way does not currently exist.

The impact of such a unit, if developed, should not be underestimated. It would help reduce the size of hazardous impoundments, reduce the air pollution currently caused by thermal drying, and increase the available energy supply in the world by creating more usable BTUs with less energy input.

1.2 Literature Review

1.2.1 Definition of Filtration

Filtration is the separation of two forms of matter by passing one of them through a porous medium. This study is limited to the principles relating to the separation between solid particles and liquids. In addition, the primary liquid that is being separated in this case is water, allowing the distinction to be made that this is a dewatering process.

1.2.2 Filtration Methods

Dewatering is primarily concerned with removing water that is bound in the capillaries between solid particles. This can be achieved using three basic known methods. The first is to compact the slurry by adding stress to the perimeter of the slurry with a roller, pistons, screw presses, or other mechanical means. The second method is to displace the water using a gas that is applied through either vacuum or pressure. The third method can be achieved by adding an electrical field to a slurry of charged particles. Each of the methods has its advantages and limitations.

Dewatering that uses mechanical compression is limited to the compressibility of the filter cake. Once the cake has been compressed to the point of virtual incompressibility, no further dewatering is possible since the water has been fully compacted into the capillaries and pores.

In dewatering by gas displacement, the important factors are the pressure difference across the filter cake and the kinetic dewatering characteristics. This process results in an exchange between water volume and gas volume in the filter cake.

Dewatering using electrical fields creates charged ions to generate the pressure required to force the water out of the capillaries. This process is called electro-osmosis. The primary difference in this method of dewatering is that rather than the driving force being generated from outside the capillaries, it is formed from the electrical forces within the capillaries.

1.2.3 Filtration Theory

Scientists and engineers have been working to develop the fundamental theory behind filtration for over 150 years. Despite this large time frame and much attention, the theory regarding filtration is not complete. Most of the work that has been done is in regard to cake formation rates. The ability to predict the moisture content of a cake is beyond the current knowledge of filtration theory. Most work that has been done on this topic is empirical in nature.

The filtration theory that is known is an extension of fluid mechanics. The rate of filtration is directly proportional to the pressure drop across the cake and inversely proportional to the resistance. It is known that the pore sizes in the filter cake are small and the liquid's velocity through the cake is also slow, the filtrate flow maybe considered laminar. Since these assumptions can be made Poiseuille's law is applicable. From this it can be seen that the variable rate of filtration may be expressed as:

$$u = \frac{dV}{Adt} \tag{1}$$

where V = volume of filtrate

A = area of filtration

t = time

u = filtration rate

By making the laminar flow assumption and by applying Poiseuille's Law the basic filtration equation, it is possible to show that:

$$\frac{dV}{Adt} = \frac{\Delta P}{\frac{\mu(awV + r)}{A}} \tag{2}$$

where ΔP = pressure drop across the filter (including the cloth and drainage system)

μ = liquid viscosity

a = specific cake resistance

w = weight of the dry cake solids per unit volume of filtrate

r = resistance of the filter cloth and drainage system

Rearranging Equation (2) yields,

$$\mu awV\frac{dV}{A^2} + r\frac{dV}{A} = \Delta P dt \tag{3}$$

It can then be assumed for a thick cake that r ≈ 0 since the resistance of the cake is much greater than that of the filter cloth and drainage system. This expression can be integrated between the limits of 0 and t_f (where t_f is the cake formation time per cycle) and 0 and V_f where V_f is volume of filtrate in time t_f. From these limits, it is possible to show that:

$$\mu aw\int_0^{V_f}\frac{VdV}{A^2} = \Delta P\int_0^{t_f} dt \tag{4}$$

The result of the integration gives:

$$\frac{\mu a w}{2A^2} V_f^2 = \Delta P t_f \quad (5)$$

When both sides are divided by t_f^2, rearranged, and square root taken, it can be shown that:

$$\frac{V_f}{At_f} = \sqrt{\frac{2\Delta P}{\mu a w t_f}} \quad (6)$$

The final step is to get the equation in the form Z_s. Z_s is measured in weight of dry solids per unit area per unit time of cake formation. If t_f is the time involved in the cake formation, this variation of the equation is realized by multiplying Equation (6) by w, i.e.:

$$Z_s = \frac{wV_f}{At_f} = \sqrt{\frac{2w\Delta P}{\mu a t_f}} \quad (7)$$

This expression shows that the cake production rate is proportional to the square root of the pressure and inversely proportional to the square root of time.

1.2.4 Cake Filtration Using Displacement

The most critical aspect of any filtration process is the source of the driving force. The importance of this force is shown in Equation (2), the fundamental relationship for filtration. In that equation, ΔP is a critical term and this pressure difference is often referred to as the driving force. In all of the equipment that was studied and analyzed, the driving force is provided by air pressure applied to the filter cake. The filtration theory states that the higher the ΔP the greater will be the cake formation rate. Other empirical evidence also shows that the higher the ΔP the lower will be the final cake retained moisture (Cheremisinoff, 1995).

1.2.5 Filtration Equipment

There are several types of equipment that are commercially available for fine particle dewatering. The most prolific of these are disc filters, drum filters, and belt filters. All of these units are currently used in a vacuum mode and some are used in a pressure mode. Each of these units has some advantages over the others. There are other novel pieces of dewatering equipment that are made in various places, but these three are the most prevalent.

1.2.5.1 Disc Filters

Disc filters are used in both a vacuum mode and a pressure mode. Pressurized disc filters work on the same principal only the disks are contained within a pressure vessel. Disc filters use a multitude of rotary discs that are vertically mounted on a horizontal shaft, which are suspended in a slurry reservoir. This has the advantage of having greater floor space utilization than other filters. Each disc is divided into separate sectors often ranging from 12 to 30 per disc. The disc must be mostly submerged because cake formation occurs while the sector is still submerged in the slurry.

Disc filters do have some major disadvantages due to the vertical nature of the disks this limits the thickness of the cake since too thick of a cake will not stick to the filter. This limits the capacity for the filters. Also, it is difficult to wash the filter media thus plugging can be a major problem. Since the cake is submerged through much of the rotating cycle of the filter it can result in too high moisture content due to too short of dewatering time.

1.2.5.2 Drum Filters

Drum filters are the most commonly used air displacement filter. This is a device that has a large drum that rotates slowly about the horizontal axis. The drum is similar to the disc filter in that part of the drum is submerged in the slurry. The drum has multiple sections, each containing a separate vacuum chamber. This filter like the disc filters can be enclosed in a pressure vessel and operated under pressure. The disadvantage of the drum filter is the relatively poor use of space. The entire volume of the drum contributes little to the dewatering process and yet consumes much space. Otherwise, the operating principal of the drum filter is similar to the disc filter.

1.2.5.3 Belt Filters

Horizontal belt filters are the third prevalent type of displacement filtration equipment. The operation of the horizontal belt filter is quite different from that of the disc filter or drum filter. In this unit, a filter belt is continuously rolled across two rollers much like a conveyor belt. The slurry is feed onto one end and then slowly turned across the length of the belt. While traversing the length of the belt, a vacuum is applied to the underside of the belt. This type of unit has an advantage of lower capitol costs than the other filters and it has a high area available for dewatering. Also, the speed and feed rate of the belt can be easily controlled. The primary disadvantage is that the unit has a poor dewatering rate per square footage of floor space. These units are not made in a pressurized version at this time.

1.3 Objectives

A variety of mechanical processes are available for dewatering fine particles in the coal and mineral processing industries. Most of these units have major problems associated with them. All of the units currently available suffer from one or more of a number of difficulties, such as poor dewatering performance, low throughput capacity, high capital costs, and high operating costs. Primarily, the vacuum units suffer from the poor performance and low capacity, while the pressurized units suffer from high capital and operating costs.

The first aspect of this research was to develop a new type of dewatering process that combines the operational flexibility of a continuous horizontal belt filter with the dewatering efficiency of a batch pressure filter. As such, the project involved the design, construction, testing, and evaluation of a pilot-scale prototype unit. The prototype hyperbaric belt filter can be used as a model to assist in the design of a full-size commercial unit. The project demonstrated that the unit is physically feasible and provided critical operating information such as throughput capacity, moisture capabilities, power requirements, etc.

CHAPTER 2: DEVELOPMENT OF A HYPERBARIC BELT FILTER

2.1 Introduction

The final stage of a coal processing operation involves the separation of liquid water from the useful coal particles. For very fine material, this is commonly done using a vacuum filtration method, a practice that is inherently limiting. One of the primary factors in any filtration process is the pressure drop across the filter cake. Vacuum methods are limited to a theoretical maximum of one atmosphere of pressure. By utilizing pressure filtration, the amount of pressure can be increased much higher.

Research was done to determine how effective pressure filtration would be on fine particle dewatering of coal. The ultimate goal is to develop a process that, inexpensively, is effective at reducing cake moisture content to levels that are currently unattainable in coal processing equipment.

The mining industry is infamous for handling massive amounts of material. To accommodate this inherent requirement in the industry it is critical that any filtration device have a large capacity to be of any practical use. This large capacity is one of the major shortcomings of vacuum filters. Although it is possible to create a high capacity vacuum filter, this is impractical due to the massive size that would be required. This is due to the low pressure differential that causes cake formation times to be long and extended dry cycle times. To understand the relationship between cake formation time and various operating parameters is imperative to the design of a filter unit. The higher the cake formation rate is, the higher the capacity of the full size unit. This overall dewatering capacity is of extreme importance to the success of the project.

2.2 Hyperbaric Belt Filter Design

The first step in the design process was to determine what type of filter was going to be developed to dewater coal. It was determined, that currently, a pressurized belt filter does not exist. This unit has unique advantages over other types of pressure filters. The primary advantage is that it has the potential to have high capacity since the length of the belt can be increased and yet run at a relatively high velocity.

2.2.1 Concept of the Design

Once the decision was made to design a hyperbaric filter, the specific details of the design needed to be worked out. One of the objectives was to make a low cost unit. To this end, the basic components were considered. The lab tests showed that for the unit to physically do what was necessary, the top of the belt would need to be exposed to positive pressure while the bottom of the belt would need be open to atmospheric pressure. This pressure difference across the belt is the key item to a pressure filter. All of the parts of the unit are designed to allow this to occur. Figure 2.1 shows what a pressure difference across the belt looks like.

The most feasible approach to achieve a large pressure differential across a moving belt was one that had the entire filter device enclosed in a pressure vessel. That would create the large positive pressure on the top of the belt. To support the pressure differential across the belt, a rigid pressure plate was devised that was capable of handling a large force load.

The other major requirement that this project set out to overcome is that the pressure filter had to be a continuously operating unit. This is something that virtually all of the existing pressure filters are not. Most of them are batch processes that simulate continuous operation by having multiple units operating side by side. This creates numerous difficulties by presenting a

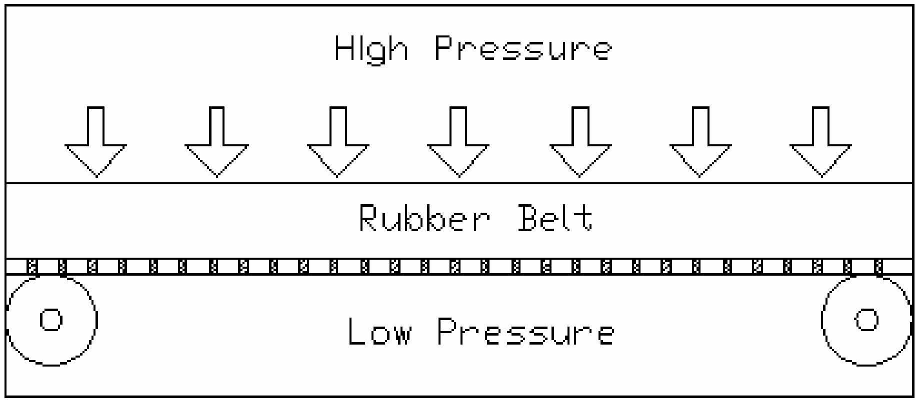

Figure 2.1. Pressure differential across a horizontal belt filter.

situation where material has to both enter and leave a pressurized chamber while maintaining a pressurized environment.

2.2.2 Design of the Filter Device

From the general concept of having a belt filter contained in a pressure vessel, it is clear that the project should be separated into two major designs, the filter device and the pressure vessel. Each of the parts of the filter device is discussed in detail in the following sections.

2.2.2.1 Frame

The purpose of the frame is to support all of the other components that are required to make the unit operate. This was designed to be as inexpensive as possible while still minimizing weight and still having the strength characteristics that would be required. The frame was constructed out of carbon steel tubing. Figure 2.2 provides a scale technical drawing of the filter device frame. Additionally, the frame had to be conducive to material handling for maintenance purposes. For this purpose, hooks were added to allow the unit to be handled using an overhead

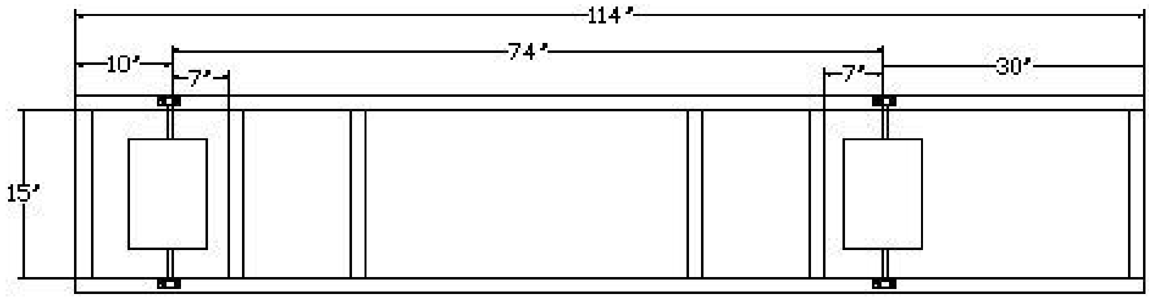

Figure 2.2. Design of the filter device frame.

crane. The unit also has wheels that can roll along a track to allow easy access to the unit inside the pressure filter. Figure 2.3 shows the track wheel mounted to the filter device frame.

To assist in the handling of the unit an a-frame attachment was made to fit into the end of the support structure to assist in removing the filter from the pressure vessel. Figure 2.4 is a picture of the A-frame structure inserted into the end of the filter device to support the structure when removing it from the pressure vessel.

2.2.2.2 Filter Cloth

The filter cloth is the medium that allows the water to pass while holding most of the solids on the top of the belt. The filter cloth that is being used on the unit has openings of 80 microns. Thus, any material that is larger than 80 microns is retained on the filter belt as is a large percentage of finer material. The pressure differential across this

Figure 2.3. Wheel on the filter device.

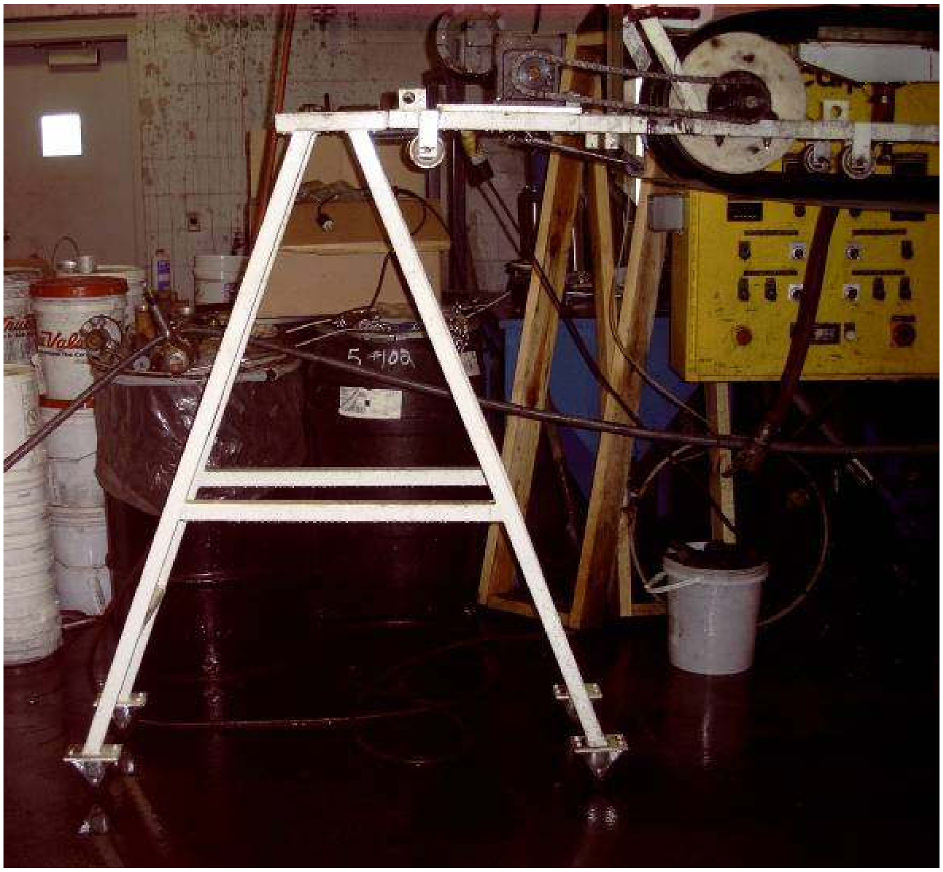

Figure 2.4, A-frame attachment for the filter device.

medium provides the driving force that allows for the filtration to occur.

One of the major concerns of the filter cloth is that over time the cloth would become blinded (plugged) with near size particles. This would cause a situation where water would not be allowed to pass through the cloth and no more filtration would be possible. To prevent this, a high pressure water spray was installed to force water through the back side of the filter cloth to push out any trapped particles. The water spray is located just before the fresh feed is put on the belt to ensure that each run of slurry has a clean cloth to filter through.

Another design concern that had to be addressed in regard to the filter cloth is the tensioning of the filter cloth. This tensioning had to be done separate of the rubber belt so that the water spray would be able to spray the back side of the belt to effectively remove any trapped

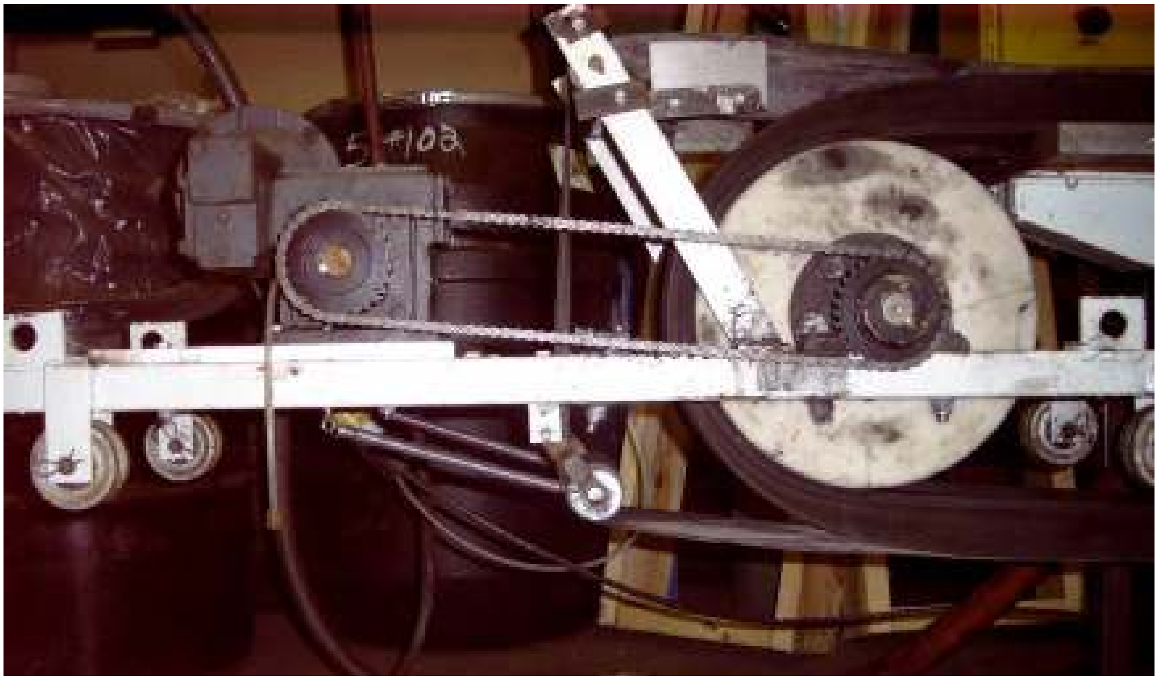

Figure 2.5. Tensioning roller and water spray on the filtering device.

particles. This tensioning is done just behind the drive roller. The roller in the center of Figure 2.5 is the tensioning roller.

The tension is provided by a pair of springs that pull an idler roller back to create the tension on the filter cloth. The filter cloth is in contact with the rubber belt during its entire travel around the non-drive primary roller and the length of the dewatering stage as well as the trip to the drive roller. This means that to tension the filter cloth and allow washing, the amount of distance the filter cloth is apart from the rubber belt is minimized.

To keep the slurry from running off the feed end of the filter, a trough was built to provide a reservoir of slurry to ensure continuous feed to the dewatering section of the belt. This was accomplished using two Teflon guiders for the filter cloth and a roller. A picture of this apparatus is shown in Figure 2.6.

Figure 2.6. Trough apparatus used to hold slurry on the filter cloth.

2.2.2.3 Pressure Plate

The pressure plate is the part of the filter device that creates the seal necessary to separate the high pressure region from the low (atmospheric) pressure region. The pressure plate consists of an aluminum plate, which has had some machine work done to it, along with a steel box that collects the water. Figure 2.7 shows an isometric view of the pressure plate.

The plate has a slot machined down the center that allows the notch in the rubber belt to fit inside of it. Also, there are holes drilled in a slightly lower slot to allow the water and air to pass through both the pressure plate and the rubber belt. At the ends of the pressure plate, two ¾ inch rubber strips are mounted. The rubber strips also have a slot machined in them to help seal the ends of the belt and pressure plate as the belt travels across the plate. Also, mounted to the pressure plate are two V-shaped plastic strips that help the length of the belt to seal. Commercial

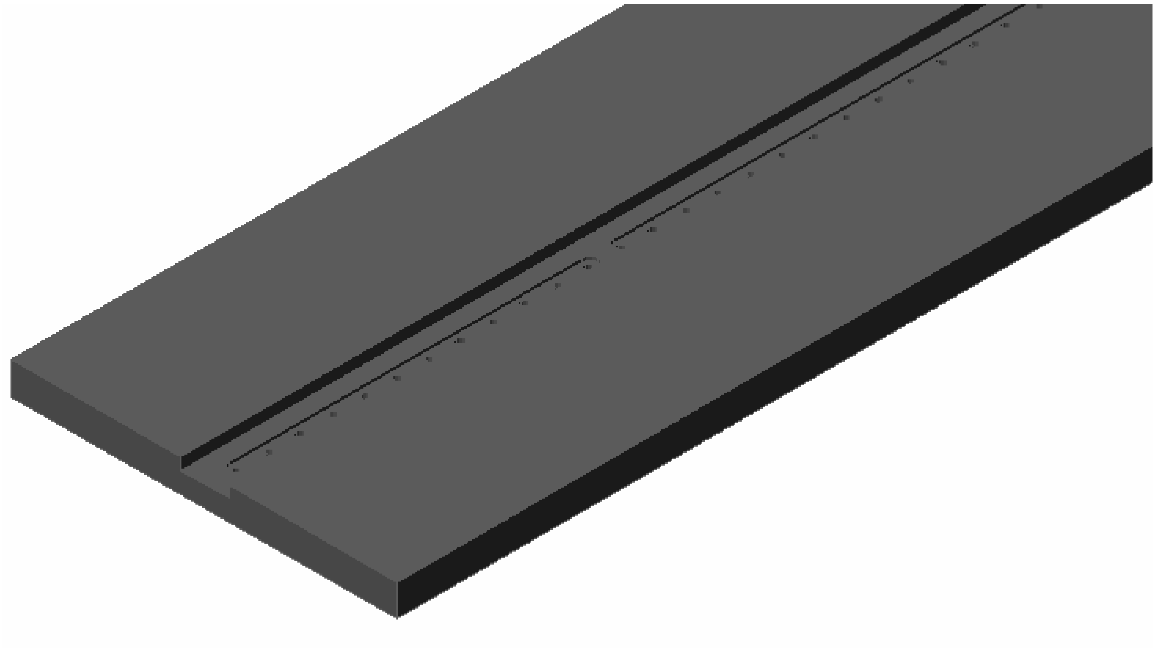

Figure 2.7. Design used for the pressure plate.

weather stripping attached with silicone was found to be ideally suited for sealing the underside of the belt (see Figure 2.8).

On the bottom of the pressure plate is the discharge box that collects the air and water in a central location and sends it to a drain pipe to leave the pressure vessel. The pressure plate is attached to the frame by four one-inch diameter bolts that have a ten-inch adjustment on them. This allows the pressure plate to be pushed against the belt with varying degrees of force. Figure 2.9 shows how the bolts are screwed through four steel blocks that are welded to the frame.

2.2.2.4 Belt and Drive System

One of the key aspects of the filtration device is the rubber belt that carries the filter cloth over the pressure plate. The rubber belt provides a material with the strength properties needed to take the filter cloth across the pressure plate. The rubber belt supplies the drive to overcome the force that the pressure differential creates to hold the filter cloth in place. The belt has a notch in

Figure 2.8. Plastic strips used to seal the underside of the belt.

Figure 2.9. Bolts attaching frame to the pressure plate.

the center that contains holes for the air and water to pass through. Also, the belt has slots across it that allow for the pressure to be applied across the entire width of the belt. These attributes are shown in Figures 2.10 and 2.11. The belt has two raised angular rubber pieces on each side to prevent the slurry and cake from falling off the sides of the belt.

The rubber belt is mounted on two nylon rollers. The drive roller is on the same side as the feed is put on the belt. This roller is chain driven by a DC electric motor that has been speed reduced to increase the torque needed to pull the belt across the pressure plate. Both of the nylon rollers are mounted on the frame by two pillow block ball bearings. A diagram of one of the pillow block bearings used to support the two nylon rollers is shown in Figure 2.12.

2.2.2.5 Filter Cloth Scraper

After studying a lab batch unit that was developed at Virginia Tech, it was determined that to remove the filter cake from the filter cloth after all of the dewatering has been completed

Figure 2.10. Top of the rubber carrier belt.

Figure 2.11. Bottom of the rubber carrier belt.

would require some sort of scraper. The best location for the placement of the scraper was determined to be just over the hopper so that the bulk of the cake would fall into the product discharge chamber. This means that the scraper would have to scrape over a portion of the filter cloth while it is traveling across the nylon roller. Since the scraping site is not flat the scraper needed to be constructed of a material that is soft enough that it would not damage the filter cloth. To meet this requirement, it was determined that a soft rubber would be stiff enough to effectively scrape the cloth and not damage it.

The other issue that had to be overcome was how to position the scraper in an orientation that the cake would not excessively build up on the scraper. This was accomplished by scraping at an angle with two separate scrapers to cover the entire width of the belt. Figure 2.13 shows the scrapers used to remove fine material coming off of the filter device. Each of the scrapers is adjustable to change the amount of force with which each of the scrapers presses against the belt. The angle of scrape can be adjusted also.

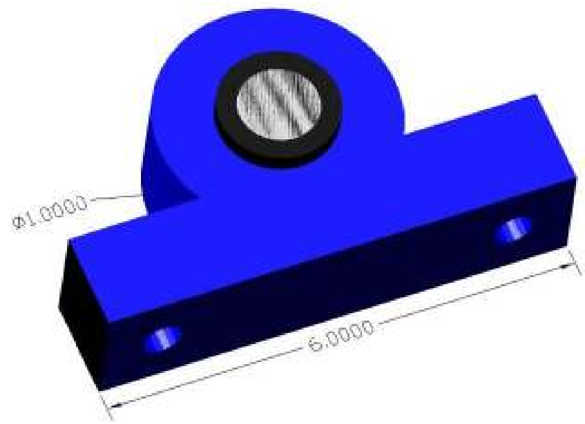

Figure 2.12. Pillow block bearing for the primary drive.

Figure 2.13. Scrapers used to remove fines from the filter cloth.

2.2.3 Pressure Vessel Design

The pressure vessel was designed with two primary concerns in mind. The first was to construct a structure that could safely hold 60 PSI of air pressure for a long period of time. The second concern that had to be addressed was it must be sufficiently large to contain the filtration apparatus. Both of these conditions had to be addressed before the smaller technical issues could be resolved.

To form the body of the pressure vessel, a cylindrical steel pipe made the most sense. First, it would be easy to find a pipe that was rated to hold more than 60 PSI of pressure. The second reason for using a steel pipe would be that it is easy to attach accessories to it since it can be welded. The final motivation for using steel is that it is relatively inexpensive. The only major drawbacks to using steel for the pressure vessel is that it is heavy and that there is the potential for corrosion due to the wet environment that exists on the inside of the unit. The other type of material that was seriously considered to form the pressure filter was polyvinyl chloride (PVC). This type of pipe is less accessible but is still widely manufactured. PVC is lighter than steel and has better corrosion resistance. It is more expensive and it would be difficult to cap off the ends. Also, adding a structure to the inside of the pipe to hold the filtration apparatus would present a challenge. After much consideration, the decision was made to use steel pipe. The steel pipe that was used is a schedule 40 pipe that is rated to hold 150 PSI. Figure 2.14 shows the steel pipe in the condition it was in when it was received.

Figure 2.14. Pipe used to construct the pressure chamber (as received).

The second major concern was to get a vessel that would be large enough to hold the filtration apparatus. From the design specifications it was determined that the smallest circle that could practically hold the entire unit would have to be 30 inches in diameter. From this plan the pipe that was acquired is 30 inches in diameter and 10 feet long.

2.2.3.1 Supporting Frame

Before the pressure vessel could be assembled, a frame had to be built to hold the vessel and filtration apparatus. This frame was built out of tubular steel. Figure 2.15 shows the dimensions on the tubular steel that was used to construct the frame shown in Figure 2.16. To support the weight of the pressure vessel and all of its components, it was decided that a simple box frame would be sufficient to hold the pressure vessel. This frame was welded together and

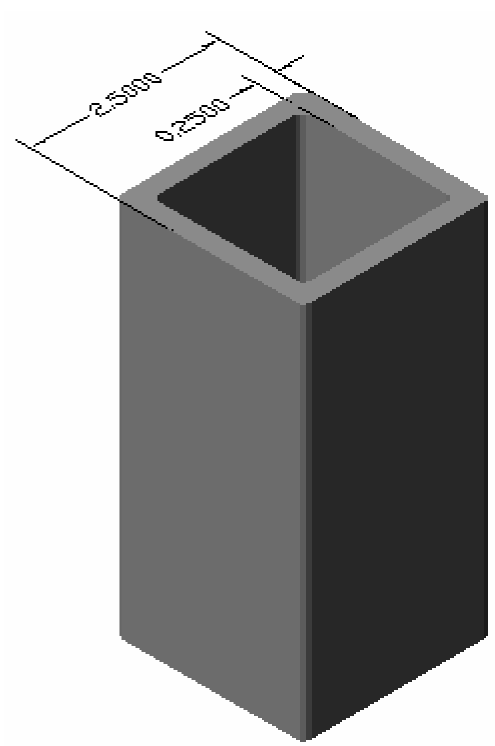

Figure 2.15. Steel used to construct the main frame.

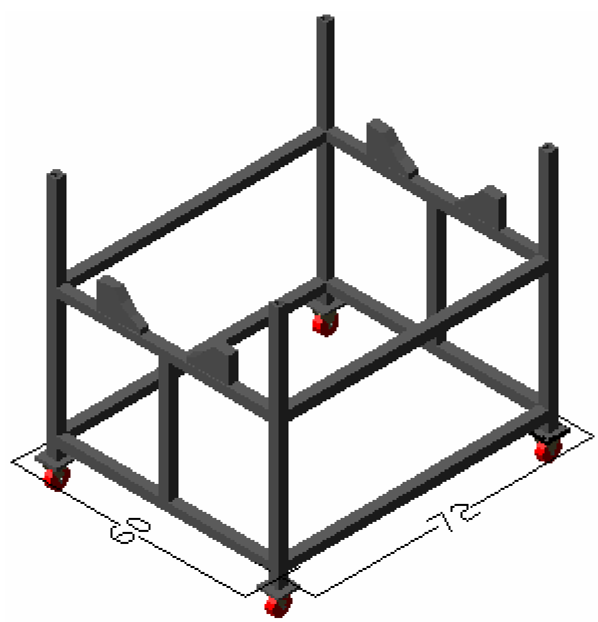

Figure 2.16. Schematic of the primary support frame.

then painted. The primary frame was then placed on wheels so that entire hyperbaric belt filter could be easily moved.

In addition to holding the pressure vessel, the frame also supports a grate walkway that allows access to the sight glasses that were put into the pressure vessel. Figure 2.17 shows the walkway that was built on the frame and the safety handrails.

2.2.3.2 End Caps

To seal the ends of the steel pipe, some sort of capping device had to be employed. To create the end caps two possibilities were considered. The first was to make the end caps out of Plexiglas. This would have the great advantage of being transparent. The other possibility was to make the ends out of steel in either a flat cap or a domed structure. The Plexiglas was the first

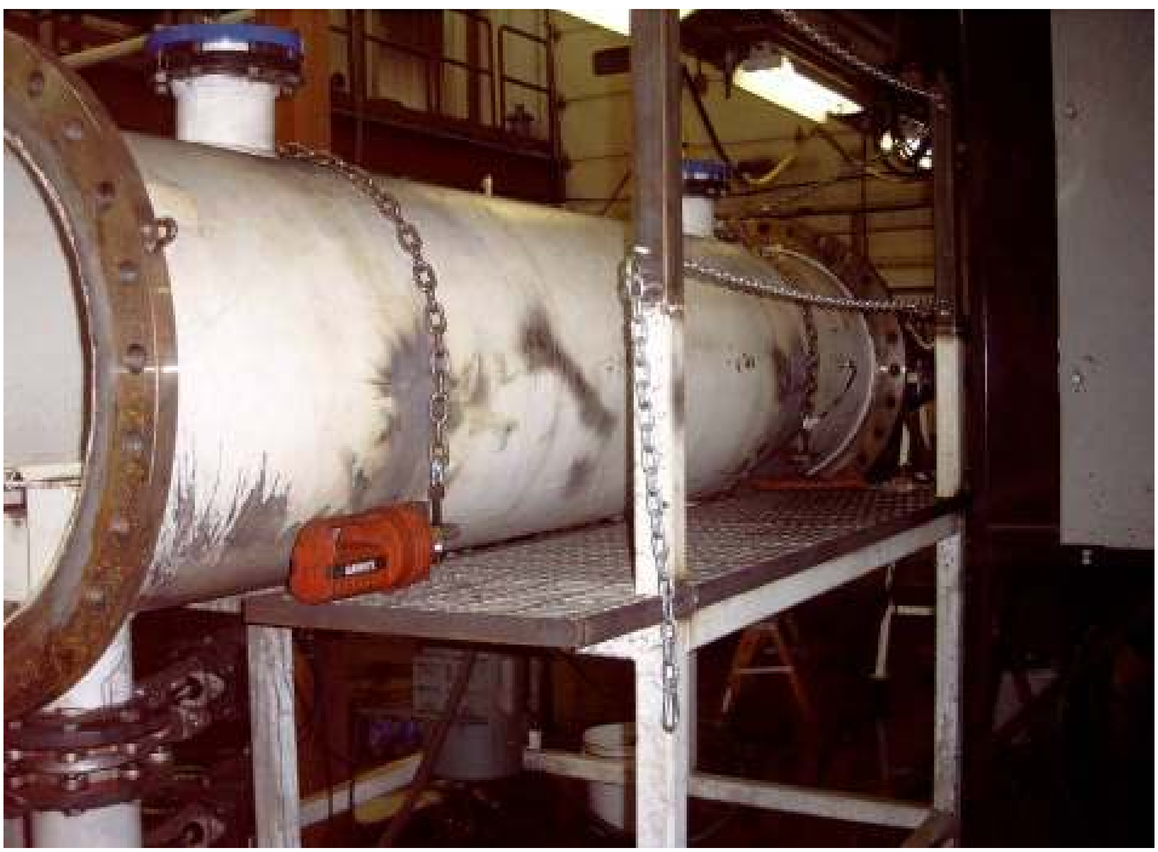

Figure 2.17. Walkway on the support frame.

choice because of its great visibility. This option was tried until it was determined that to seal a 30 inch flat plate against the pipe holding back 60 PSI of pressure would result in over 42,000 lbs of force. To get a piece of Plexiglas that could withstand these forces would require a 12 inch thick plate. This was determined to be impractical.

That left the steel plate or dome option. Since a blank flanged plate option is simple and these items are fairly commonly produced that was determined to be the best option. Though to have used a dome structure would have allowed the caps to use less steel and thus weight less. The blank flanges would be attached to the pipe using 28 hole flanges that were welded to the pipe. Figure 2.18 shows one of the flanges attached to the pressure vessel.

Figure 2.18. Flange attached to the ends of the pressure vessel.

2.2.3.3 Feed System

The pressure vessel had to allow for material to be continuously fed to the filter device. Since the input stream to the filter is slurry the only option was to pipe in a line and to pump the slurry onto the filter belt. The main challenge that this presented was that the filter device and pressure vessel where designed to allow operation at various pressures. This means that a normal centrifugal pump could be optimized to create flow at a given pressure but it would be hard to operate the same pump under different conditions. Also, most centrifugal pumps could not produce the pressure required to overcome the back pressure caused by the pressurized tank at a low feed rate. These deficiencies lead to the search for some form of positive displacement pump that could suit the requirements. Since a positive displacement pump could function and get various feed rates with little reaction to the changing back pressure caused by the air. A progressive cavity pump seemed to be the best option for the combination of factors that this situation required. It could generate a low flow rate pulse less flow against high pressure and could handle abrasive slurry. Figure 2.19 shows a picture of the progressive cavity pump that was used with this hyperbaric belt filter unit.

2.2.3.4 Discharge System

The discharge system is required to allow a large amount of solids to exit the pressure vessel and to not lose air pressure. For this system, two basic concepts were considered. The first was to use a rotary star valve. This is a valve that has several compartments in it that rotate around an axis. While some of the compartments are exposed to the inside of the pressure vessel, others are facing the outside allowing the material to pass but not depressurizing the vessel. This system has the advantage of only requiring one valve. The disadvantage is that these valves are

Figure 2.19. Progressive cavity pump used to feed the pressure filter.

known to have maintenance problems from the solids getting stuck in the rotary portion of the valve preventing it from sealing.

The alternative to this is to use a system of two valves that would act as an air lock. This mean that at no time would both valves be open at the same time. But, one could be opened at a time to allow material to pass through the system. For the pressure vessel, it was decided to use knife gate valves that are pneumatically actuated. These valves are operated on two timers that allow the unit to be fully automated. Figure 2.20 shows one of the knife gate valves prior to being installed. Figure 2.21 shows the entire airlock system after it has been assembled.

Figure 2.20. Knife gate value used for the air-lock pressure seal.

2.2.3.5 Rail System

The filter device is supported in the pressure vessel by a rail system. The rail system is a set of angle iron tracks that is supported by steel supports that have been precisely cut to fit into the radius of the pressure vessel. Then the steel supports were welded into place inside the vessel. The tracks were built to fit the wheels on the filter device. Inside the pressure vessel the filter device is free rolling with only its inertia to keep it in place. Although a locking device has not yet been deemed necessary to keep the pressure vessel stationary several have been considered. Figure 2.22 contains a picture of the rail system that was built to allow access to the filter device and to support it inside the pressure vessel.

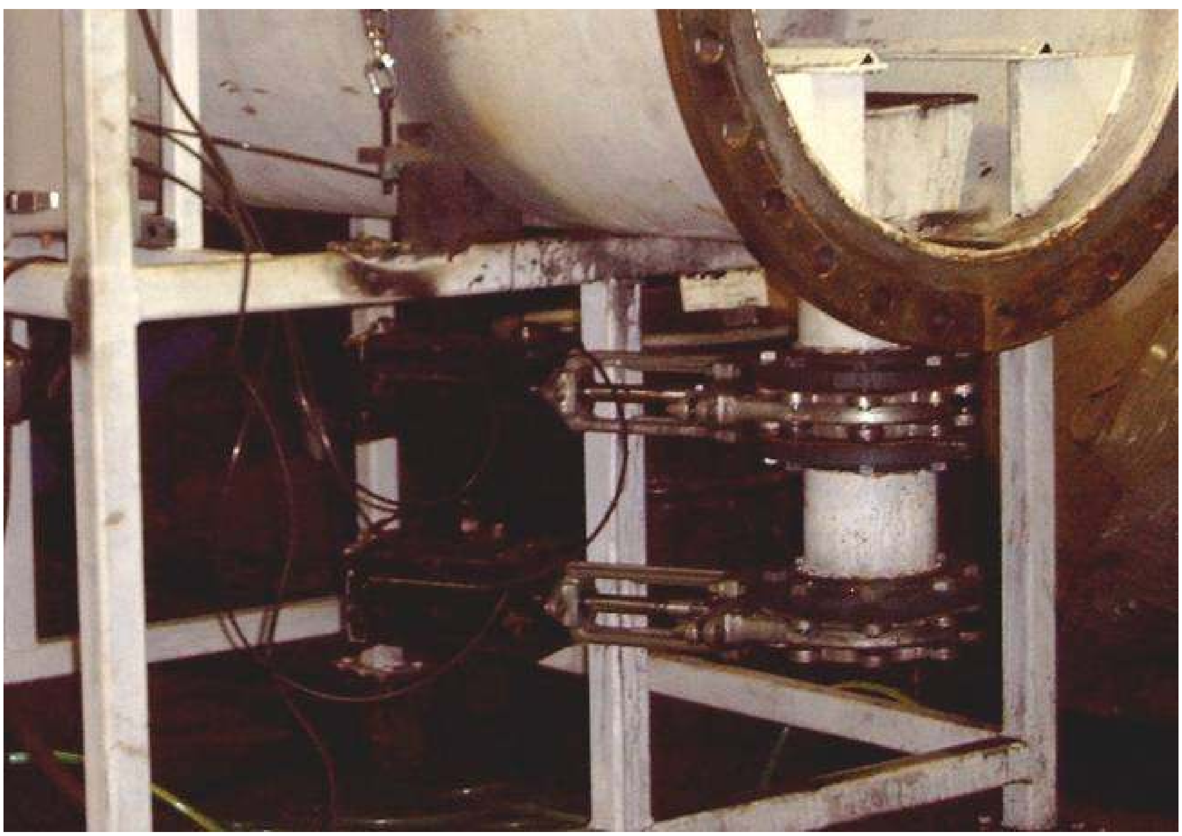

Figure 2.21. Twin values used for the airlock system (as installed).

Figure 2.22. Rails and support system for the belt filter mechanism.

2.3 Hyperbaric Belt Filter Construction

Once the designs for the filtration device and pressure vessel were completed, it took almost one year to complete the construction of both units. A vast array of equipment was used to construct the hyperbaric belt filter. Appendix A provides a list of equipment that was used.

2.3.1 Filter Device Construction

Construction on the filter device started with the tubular steel frame construction. It was then followed by adding the rollers and the tensioning apparatus for the rubber belt. Once that was completed the wheels to slide along the track were added. Then, the screws holding the pressure plate were machined and added. While the screws were being made the discharge box was constructed from sheet steel. Next, the hooks were attached to the frame to allow easier handling of the unit. After that, the chain and sprockets were installed to attach the drive motor to the rollers. The roller system for the filter cloth was then made and the filter cloth was added to the unit. The final additions to the filter device were the feed trough, water spray, and scrapers. Once all of the components were added, the unit was painted with epoxy paint. Figure 2.23 shows a picture of the completely assembled filter device.

Figure 2.23. Completely assembled belt filter mechanism.

2.3.2 Pressure Vessel Construction

The pressure vessel portion of the unit took longer to construct. The construction began with making the frame to hold the pressure vessel. Then, the pipe was placed on the frame. Once on the frame the rail system was added to the inside of the pressure vessel. Then, there was a long break in construction while bids were taken for some work to be done by outside contractors. This work included welding on the pipe fittings for all of the input and output system on the vessel. Also, welded on were the flanges for the end caps and knife gate valves. Once this was done, the end caps were put on and the unit was hydrostatically tested at 100 PSI for one hour. The unit was then returned to the plantation road facilities and painted with water resistant epoxy paint. Figure 2.24 shows a picture of the fully assembled pressure vessel.

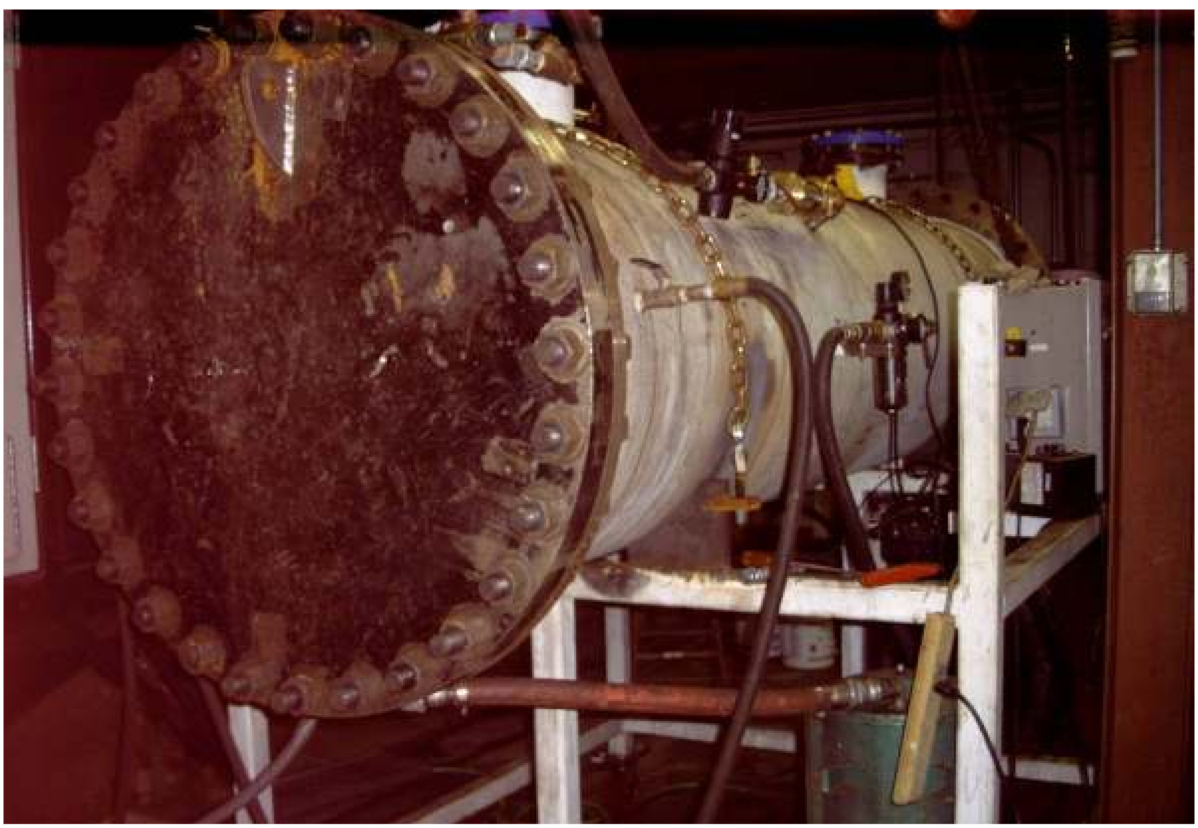

Figure 2.24. Completely assembled pressure vessel.

2.4 Shake-Down Testing

When construction of the unit was completed it was necessary to test the hyperbaric belt filter for its mechanical operation. These tests lead to two primary discoveries.

2.4.1 Air Requirement

The first operational discovery was that for the unit to operate effectively it would need more volume of air than could be provided by the air compressor at plantation road. The lack of an appropriate air compressor, lead to renting a 185 CFM unit from RSC Rental in Christiansburg, Virginia. Once the air requirement for the unit was met the unit began to perform as expected.

2.4.2 Start-Up Procedure

The second important discovery during shake-down testing was that the unit like most complex machinery has a start up procedure that must be followed to ensure that the unit will perform as expected. The steps to properly start up the unit are listed below.

1. Check to see that all of the valves on the unit are closed.
2. Start the water spray.
3. Start the belt at the desired speed.
4. Pressurize the vessel to the desired pressure (not to exceed 60 PSI).
5. Check the pressure vessel to ensure that there are no leaks.
6. Start the pump to allow slurry to flow on the belt.
7. Open the valve to allow the dewatering to begin.
8. Open the water discharge valve to ensure that water level in the waste tank is brought to zero.

If these steps are followed the unit has operated effectively with little maintenance required. Once the optimal start up procedure was determined, the unit was ready to be tested to determine the operating parameters.

CHAPTER 3:
HYPERBARIC BELT FILTER OPTIMIZATION

3.1 Introduction

The experimental testing of the hyperbaric belt filter was initiated after the design and construction activities were completed. This work is the final phase of the process for developing the hyperbaric belt filter. During this phase, the performance of the prototype unit was tested, analyzed and calculated. The performance was measured on several different aspects. Some of these measures focused on the functionality of the unit, while others focused on the dewatering capabilities.

The test program included both batch laboratory tests as well and continuous tests conducted with the new prototype. Because of the importance of particle size in determining filter performance, the tests were conducted using coal feeds that were coarse, fine and intermediate (mixed coarse and fine). Several sets of tests were also performed with dewatering chemicals in order to further enhance the dewatering performance of the unit. Once these tests were completed, the optimal operating conditions for the new hyperbaric belt filter were established. This data was used to develop empirical correlations that could be used to predict the performance of the filter under other conditions not tested in the current study.

3.2 Experimental

Described in this section are the precise procedures that were necessary to complete the test work for the filtration device. This is recorded to ensure that proper scientific procedures were followed and to allow these experiments to be replicated elsewhere if desired.

3.2.1 Feed Material

To test the operation of the filter, feed coal material is needed. It was decided to perform the tests under three primary conditions. The first is to have the filter tested under good filtration conditions. For these tests, the size distribution of the particles in the filter was 1 mm x 0. This material was obtained as screen-bowl feed for the Alpha Natural Resources Tom's Creek Mine in southwestern Virginia. From filtration theory (Gregory, 1984), it is known that larger particles are easier to dewater than smaller ones. This higher moisture is primarily due to the increased surface area associated with fine and ultrafine particles.

The second set of tests was also run using fine material that was obtained from Tom's Creek Mine. This material is column flotation overflow material; it is much finer and has low percent solids (less than 10%). This material was nominally minus 0.15 mm (minus 100 mesh).

The third series of tests was done with a mixture of the two feeds. The mixture is 50% coarse and 50% fine material by volume. This results in a feed that is 1 mm x 0, but has a much more even size distribution due to the greatly increased amount of fine particles compared to the coarse tests.

Due to the dramatic difference that has been reported in filter performance due to particle size, the unit was tested with both extremes of materials to see how the unit would perform under difficult conditions (Dickenson, 1997). From these tests it should be possible to predict the performance of the filter under a wide range of operating conditions.

3.2.2 Procedure

All of the procedures used in testing the unit were considered and used for the purposes of functionality and repeatability. In the following sections, each step in the testing process is described in detail to show how the testing was done.

3.2.2.1 Maintaining the Sample

The samples were obtained in 55 gallon drums and hauled on a trailer to the Plantation Road processing facilities at Virginia Tech. When it was ready to be used, it was dumped from the drum into a sump. While in the sump, the sample was mixed and aerated by a two horsepower mixer/aerator. Also, it was recirculated from the bottom of the sump back to the top by a pneumatic powered double diaphragm pump to minimize settling. After each had pumped and mixed for size hours, it was not used again to avoid fines generate via attrition. The pumping and mixing was done to help ensure that the sample was as uniform as possible during testing. The sample is meant to be representative of what conditions exist in the processing plant.

3.2.2.2 Percent Solids

The measurement of percent solids was done by pumping the entire sample through a sample splitter numerous times until it was reduced to approximately 100 ml of sample. Then, the 500 ml beaker was weighed while dry. The 100 ml of sample slurry was placed into it and weighed wet. It was then placed in an oven at 80^oC overnight and weighed dry. From these numbers, it is a simple calculation to determine the percent solids in the feed.

3.2.2.3 Air Flow

The air flow input into the pressure filter was determined using a spring loaded flow meter. This meter was located after the pressure regulator in the air input line. This allowed it to measure all of the air that went into the unit so that the air requirements at each operating condition would be known.

3.2.2.4 Moisture Content

The moisture content of the discharge material is of prime importance. Each of the tests was conducted over a five minute period. After five minutes, all of the material that the filter produced was collected by discharging it through the knife gate valve system. Since some of the tests produce a large amount of filter cake it was necessary to take a sample of the discharge. This was done by cutting the sample using a Jones Riffler to reduce to sample to a manageable amount that could be weighed, dried, and reweighed. The sample was reduced in size to less than 50 grams. It was then weighed and placed in an oven at $80^{o}C$ for five hours. This was to ensure that all of the moisture had been removed. Once dried, it was weighed again to determine how much of the original weight could be attributed to moisture.

3.2.2.5 Effluent Characterization

The effluent from the filtration device was also analyzed. This was to determine how much material was being lost through the filter cloth. This material was collected at the bottom of a stainless steel tank. Once the test was completed, the tank was drained into a container and the contents weighed. This material was also dried to see the weight of the solid material that was being lost during the separation process. From this process, it is not possible to determine how much water is being released since much of it is carried with the air to the atmosphere.

3.2.2.6 Bench Scale Batch Testing

To conduct a batch test each sample is prepared separately. The sample is cut from a five gallon bucket to produce an accurate sample of the bucket's contents. Then, it is placed inside the unit shown in Figure 3.1. This is a pressure vessel that has a filter cloth in the bottom of it. Under the filter cloth there are a series of grooves that lead to a hole which lets air and water escape through the filter media. The process is timed, which varies depending on the conditions of the test. Once the allotted time has elapsed, the bottom is removed from the batch unit and the cake is discharged. It is then carefully placed into an aluminum pan, weighed, and dried. From this process, the cake formation time, total drying time, cake thickness, air consumption, and total moisture are all determined and recorded.

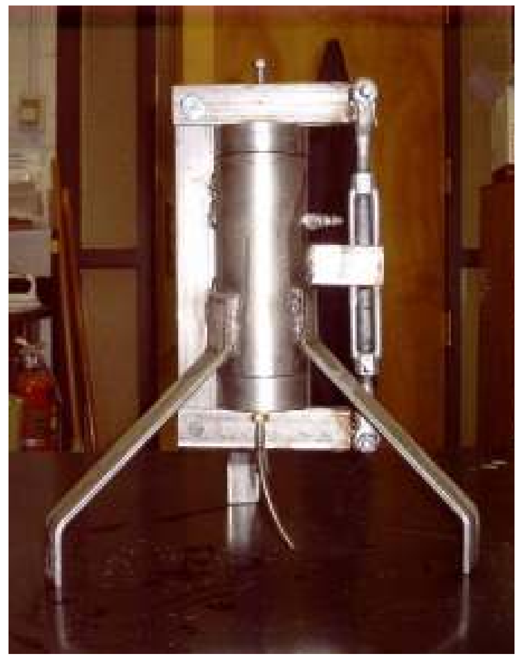

Figure 3.1. Batch pressure filter.

3.3 Experimental Results

The results that are described below were arrived at using the methods explained in the experimental section of this chapter. The results are primarily divided into three sections coarse feed, fine feed, and mixed feed. This segregation is due to the different behavior caused by the different feed material.

3.3.1 Lab Batch Testing

The batch testing was done for two primary reasons. The first was to set a baseline for what types of moisture percentages are possible if conditions in the batch tests could be duplicated in a continuous filter. The second reason for the batch testing was to determine the best possible reagents and dosages for the coal that was to be used for filtration. These optimal reagents would then be tested on the prototype unit.

From the filtration theory described by Equation (2), it is known that one of the controlling factors in dewatering is the driving force created by a ΔP across the filter cake. For this reason, all of the tests that conducted were done at 60 PSI. Over fifty tests were done to create each of the charts in this section. The data obtained from the batch tests are plotted in Figures 3.2 and 3.3. The difference between these two charts is the amount of material that was used for each. The later chart shows data from tests run with more slurry, thus increasing the dewatering time and increasing the cake thickness. The tests were conducted using proprietary dewatering reagents provided by Nalco Chemical. In this work, these proprietary reagents have been designated as Reagent RU and RV.

From these charts, it is clear that for this coal sample, which was cut from the larger sample being used to test the continuous unit, that the best reagent combination is RV at an active ingredient ratio of 1:10. It can also be seen that the effect of the reagents in greatly increased for the thicker filter cake. Thus, if the continuous unit is run with a thick cake, the reagents should provide a substantial benefit compared to that of a very thin cake. Also, from these tests, it is clearly possible to achieve a moisture content less than 9% if the conditions in the batch test can be replicated in a continuous filter.

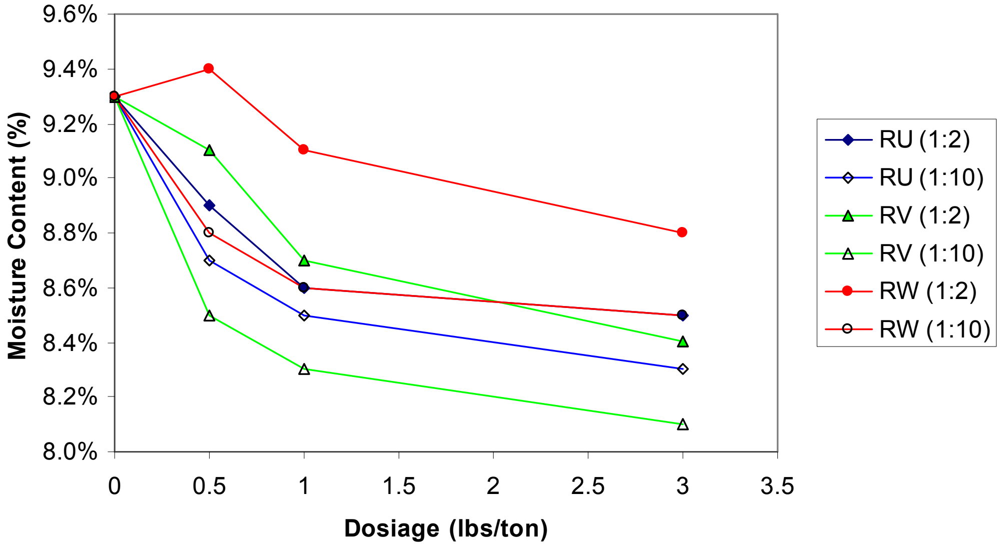

Figure 3.2. Batch test data for 20 ml of coarse feed (60 PSIG).

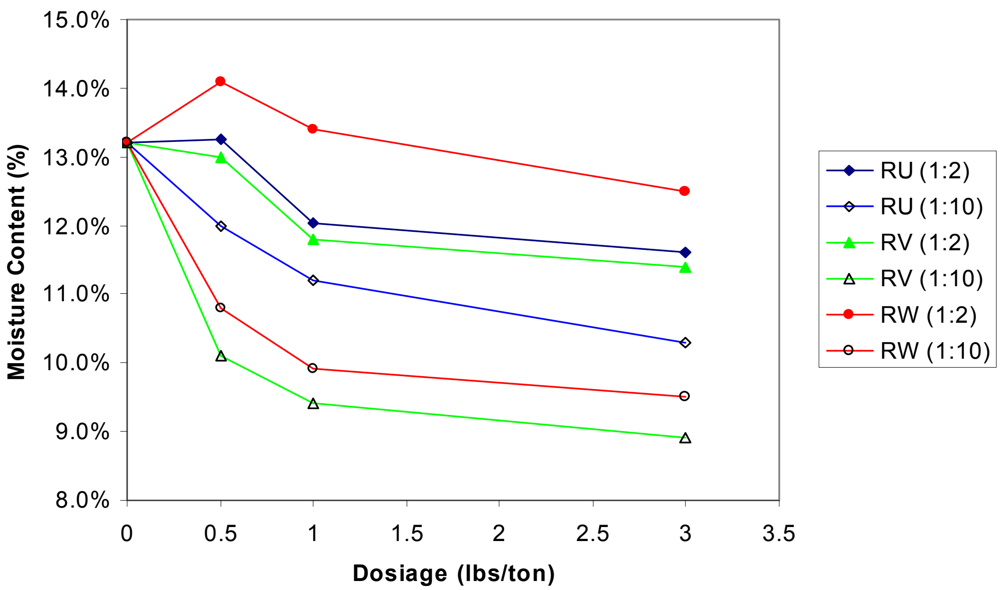

Figure 3.3. Batch test data for 50 ml of coarse feed (60 PSIG).

Also tested to determine performance was a fine feed from the same plant. The results of these tests are shown in Figure 3-4 and Figure 3-5. Just as in the coarse feed tests, all of these tests were conducted at 60 PSI. This fine material is 61% minus 325 mesh. The high percentage of slimes in the feed necessitates the need to use flocculants on all tests. All of the tests have a

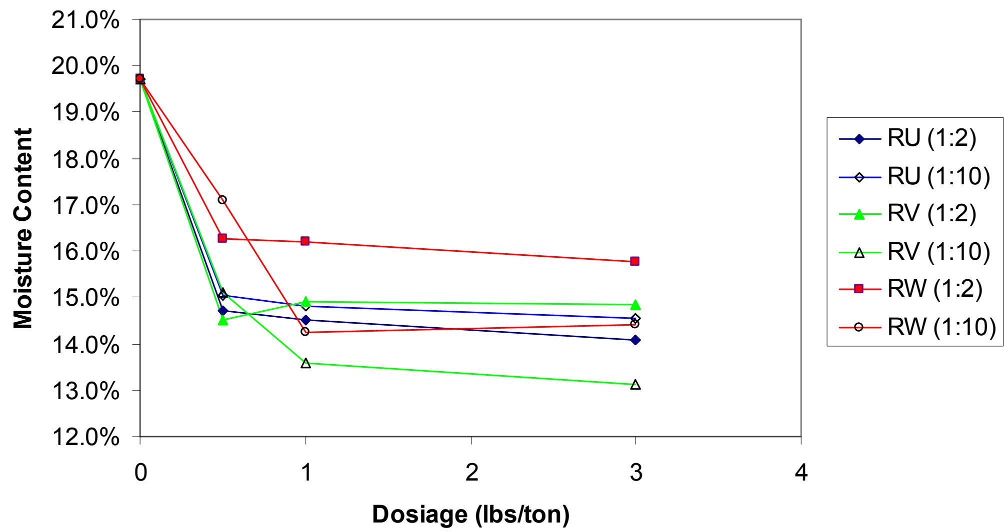

Figure 3.4. Batch test data for 20 ml of fine feed (60 PSIG).

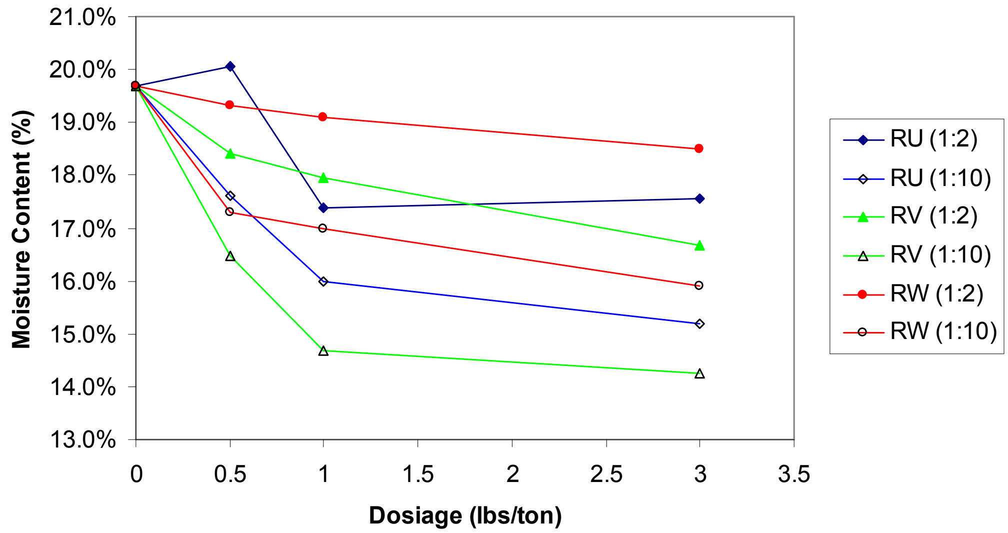

Figure 3.5. Batch test data for 50 ml of fine feed (60 PSIG).

dosage equivalent to 1 gallon of flocculant per 70 tons of material. This is similar to the amount of flocculants that is used in the preparation plant.

From the charts, it can be observed that the best reagent is RV with a dosage of active ingredient of 1:10. Also, it can be seen that once again as in the coarse material the less slurry that is on the filter the lower the moisture content of the filtrate. For this fine material, the batch unit was able to produce a moisture content of approximately 14%.

3.3.2 Coarse Feed

On the continuous filter there were four primary controllable parameters that were considered to affect the moisture content of the product. The first has already been mentioned and that is the size of the feed particles. The second is the pressure across the filtrate. Third is the speed that the belt moves and the fourth is the speed at which the material is added to the filter or the mass flow rate. Using these four parameters, it is possible to affect the air flow rate, cake thickness, production rate, and the moisture content of the product. Each of these responses will be addressed separately as they each have their own unique impact on the overall performance of the filter device. The analysis has also been broken down by size class.

This section concerns feed material which is screen-bowl feed from the Tom's Creek Mine. The size of the material is 1 mm x 0. This material has some spiral material mixed in with it. About 15% of this material is minus 325 mesh. Thus, it contains a wide range of sizes of particles.

3.3.2.1 Moisture Content

There are several factors that affect the moisture content of the product. First is the size of the material as mentioned before, second the cake thickness, third the ΔP across the cake, fourth is the dewatering time, and fifth is the water's affinity to remain attached to the water. With this filter it is possible to affect all of these primary factors but not all of them directly.

Since some of these factors cannot be controlled directly it makes sense to focus on inputs that can be controlled. These are feed rate, belt speed, pressure, and chemical reagents which affect surface tension.

The first thing that was examined was how consistent the filter's product is when all of the external factors are held constant. The results of these tests are shown in Figure 3.6. The average value of these tests is 11.4%. These tests were conducted at an operating pressure of 60 PSIG. The percent solids for all of the coarse material tests were approximately 24% solids by weight.

The standard deviation of this data is 0.0074. This is showing that while the range of the data is 1.1% by moisture percentage the actual difference between the numbers is small. There are some likely causes for this variation. One unlikely possibility is that the feed material is changing. As described in the procedure section the feed it highly mixed and is also recirculated in the sump. The feed pump is a progressive cavity pump that even with high solids contents and large particles delivers a steady pulseless flow.

Some likely causes of this variation have to do with the moisture in the compressed air itself. The compressor while compressing the air heats it to a temperature of approximately 60^{o}C. The air is not conditioned in any way - it is straight from the atmosphere in Blacksburg, Virginia. This means that there is a significant amount of moisture in the air. This hot air rises to the top of

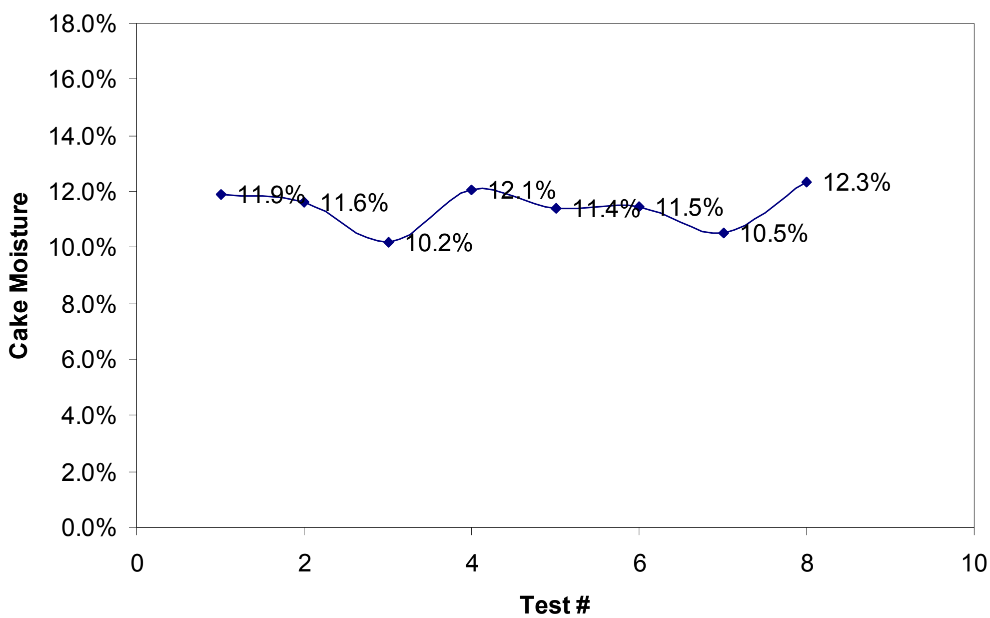

Figure 3.6. Variability of the coarse data (30% feed pump speed).

the pressure vessel and condenses when it meets the cooler exterior wall of the pressure vessel. This causes random droplets of water to periodically fall onto the filtered material. If a few of these drops fall on the filtered material before it is discharged for the pressure vessel it would account for some of the variability. Also, there is the potential for random periodic cracking of the filter cake. When this happens the pressure drop locally across the filtrate material is reduced, which retards the effectiveness of the filtration equipment. Due to this noticeable variability, all of the subsequent data points are actually an average value of three individual data points. By taking an average value, the confidence of each point is significantly improved.

After the variance of the data was determined, Design Expert was used to create a testing matrix of conditions that should be tested to determine the effect of each of the input variables on moisture content. The Design Expert tool analysis method chosen was a Box-Behnken response surface. Given the three parameters that could be changed for each test scenario, the program created a testing schedule that was used. This schedule is shown if Appendix B. Four different response surfaces were created to accommodate the five parameters that were discussed. Since only three are truly controllable by the filter device itself those where the variables in each of the different scenarios.

Two of the response surfaces are related to the coarse feed material. The first is the material with no additives and the second is one where the feed material has been conditioned with RV (1:10) based on the results from the batch testing. Figure 3.7 shows the response surface from the base case test with no additives.

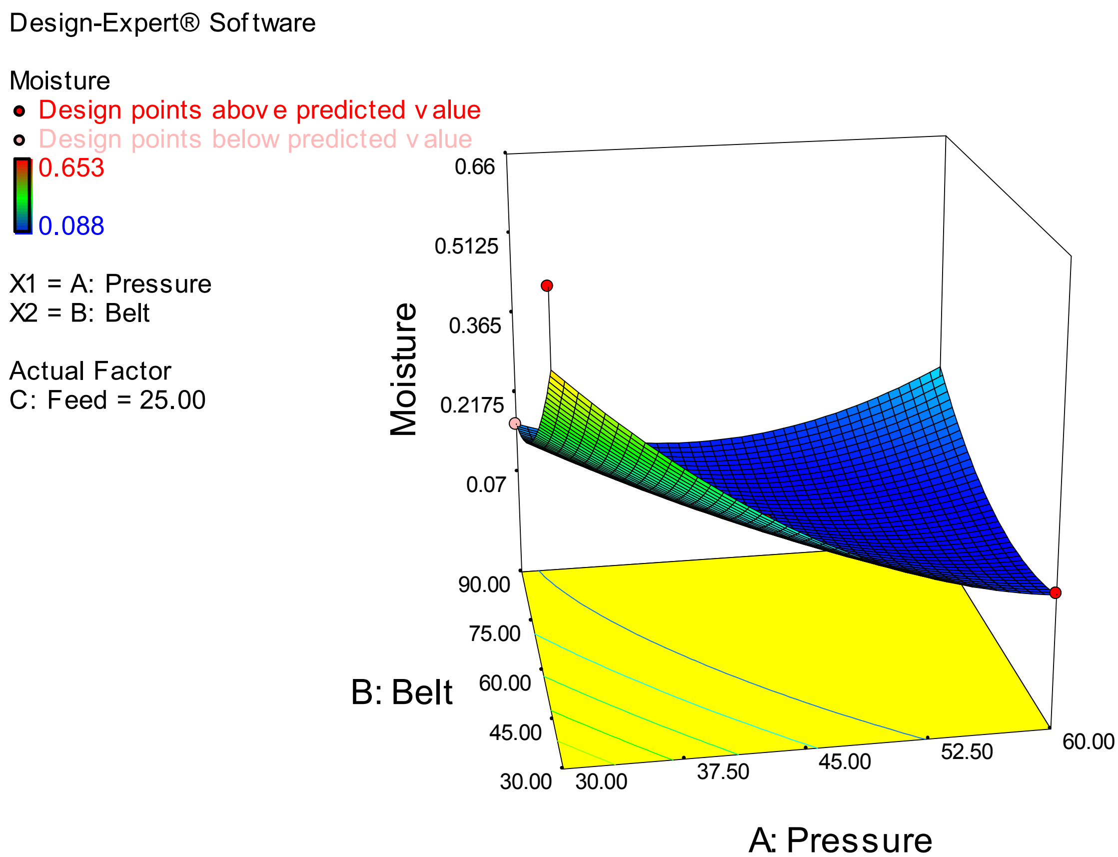

Figure 3.7. Response surface with coarse feed and no chemicals.

The chart shows the pressure on the x-axis and it is measured in PSI. The y-axis is the belt speed and it is shown as a percentage of the maximum speed of the belt, and the z-axis displays the moisture content at a given operating condition expressed as a decimal. Table 3.1 shows the conversion factors between the belt speed as a percentage and feet per minute.

Figure 3.7 shows how the filter device performs at every operating point in the given set. For each input of pressure and belt speed, it shows how the filter will respond. In this case, it is showing that at a low pressure and slow belt speed the moisture content is very high. This is because of the slurry being too deep and not enough dewatering time is available due to the short length of the filter belt. With thick slurry, the cake formation time is greatly increased (see cake

Table 3-1. Belt speed conversion chart.

Dial Setting (%)	Belt Speed (ft/min)
20	0.2
30	0.8
40	1.5
50	2.1
60	2.7
70	3.4
80	3.9
90	4.4
100	4.7

formation times of batch tests in Appendix E). Also, from the surface it can be seen that the best operating point is a 60 PSI and lies between a belt speed of 45% and 75%. Finally, it is interesting to note that while moisture content typically drops as cake thickness drops, that is not the case for the 90% belt speed and the 60 PSI operating point. The reason for this is simply that the belt is moving to rapidly for the dry cake to form in this situation.

That situation changes, however, once the dewatering reagent is added. This chemical, in addition to helping produce lower moisture contents overall, also has the effect of increasing the rate of dewatering. Figure 3.8 shows the response surface generated by the data from the continuous filter using chemical additives. This response surface is for the material that has been conditioned for five minutes with RV (1:10) at a dosage of 3 lbs/ton. This surface shows even more clearly how strong the effect of pressure is on the moisture content of the product. What is different about this surface is that the edges do not flare up in the same manner that they did with the chemicals. This is due to the increased rate of filtration associated with the reagents. The thicker cake at the low belt speed can now be dewatered as well as the thin cake that moves

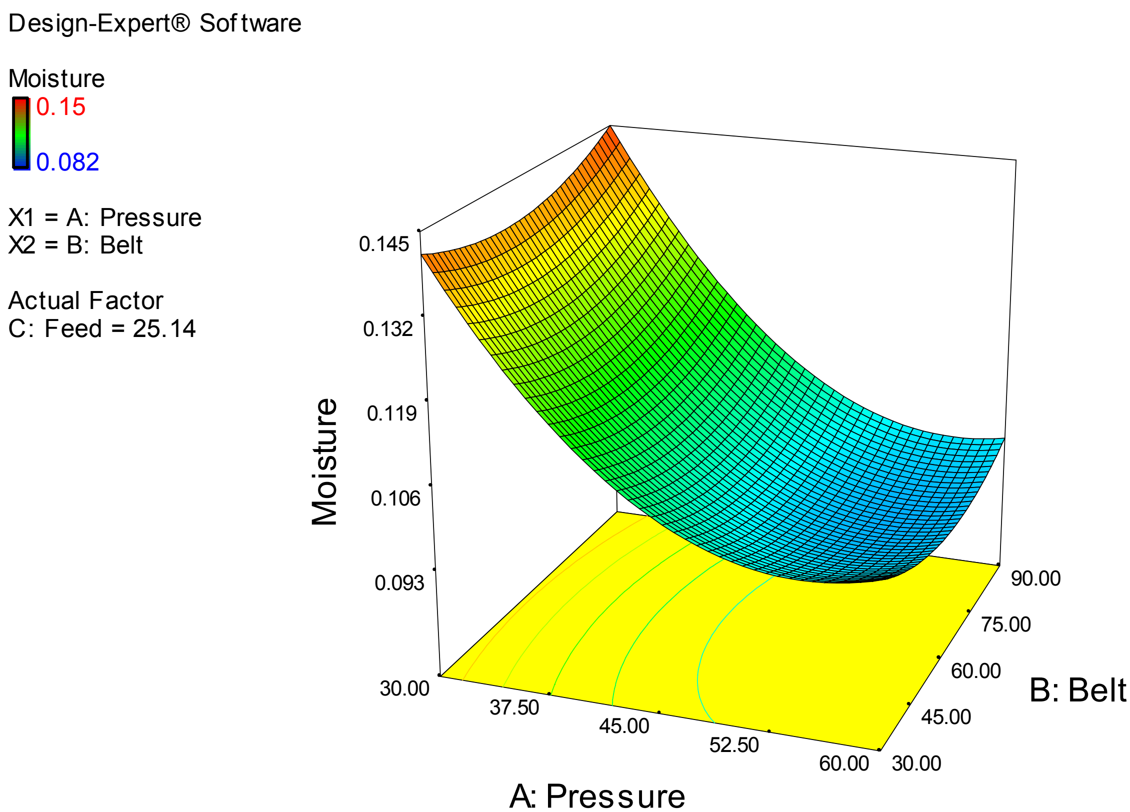

Figure 3.8. Response surface with coarse feed and 3 lb/ton reagent RV (1:10).

quickly across the belt at high speed. It is a little difficult to see, but also the lowest point on the curve is slightly lower than it was without the reagents. Since the scales are different, it is hard to see but the low pressure tests performed much better with the reagents than they did without them. This is also for the same reason. With the lowered surface tension, the filtrate did not require as great a ΔP to achieve the same moisture.

3.3.2.2 Air Requirements

The air requirements for the filter device are important to understanding the cost of operating a production unit. This is without a doubt the most expensive part of the filtration process since it is here that the energy to do the dewatering is applied.

There were several factors that were investigated to see if they had a significant effect on the air requirements of the filter device. These were cake thickness, pressure, feed size, and chemical additions. The other factor that affects the air required is the amount of losses in the air. These losses are the result of air leaking from the pressure vessel into to the discharge without passing through the filtrate.

To approximate how much of the air was being lost, the filter belt was completely sealed off with plastic and then pressurized at the operating pressures to determine how much of the air was being lost. The results of this study are shown in Table 3.2. This loss is a result of an imperfect seal that exists between the rubber belt and the pressure plate. All of the airflow measurements that are shown below have been corrected based on this table.

Table 3-2. Air losses due to imperfect seal.

Pressure (PSI)	Consumption (CFM)	Losses (CFM)	Percentage Loss
30	88	4	4.5%
45	103	8	7.7%
60	109	12	11.0%

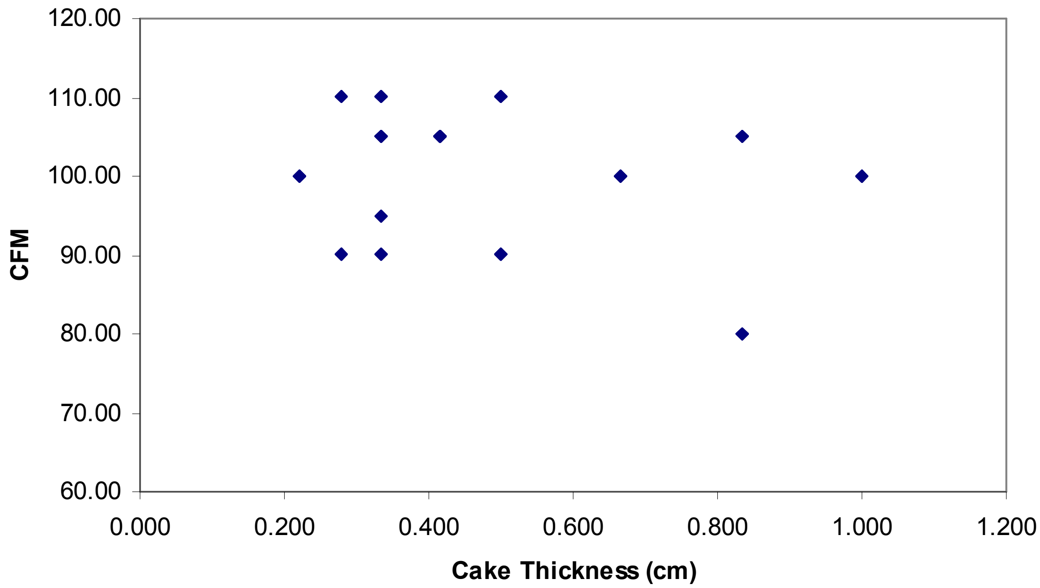

Figure 3.9. Cake thickness vs. air flow rate for coarse feed.

Based on the speed of the belt with the corresponding pumping speed, it is possible to construct an estimate of the cake thickness. After comparing the cake thickness vs. CFM requirements graph, it has been determined that there is only a slight correlation between them. This chart is shown on Figure 3.9.

The pressure vs. CFM chart is shown in Figure 3.10. This chart shows a strong correlation between the two factors. There is clearly a direct relationship between these two. It isn't clear on the chart, there are many more points than it appears, but they are often overlapping.

The last factor that was thought to control the air requirements was reagents. The plot of pressure vs. CFM of both the base tests and the RV tests are shown on Figure 3-11. From this chart it is clear to see that both are directly related and that the coal conditioned with the reagents required more air than the corresponding base test conditions.

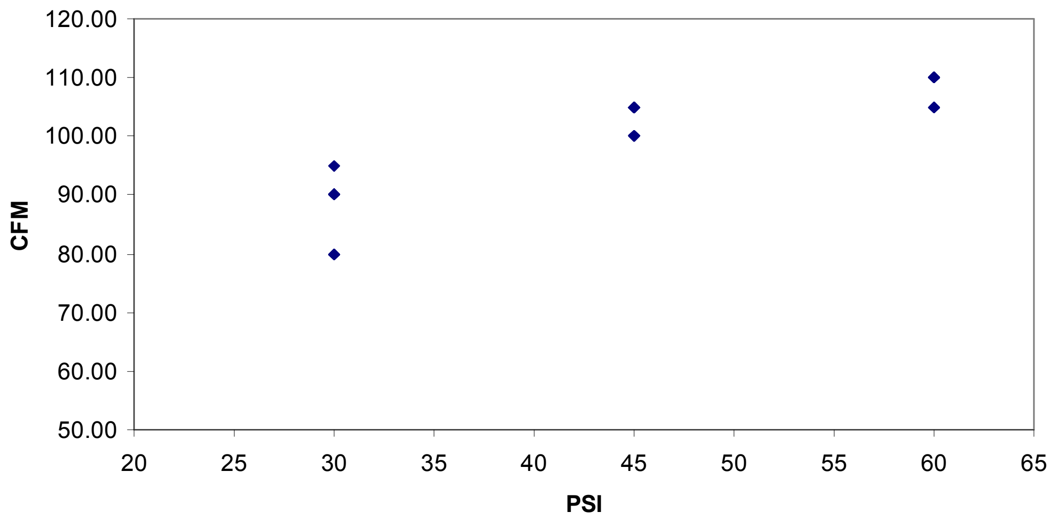

Figure 3.10. Pressure vs. air flow rate for coarse feed.

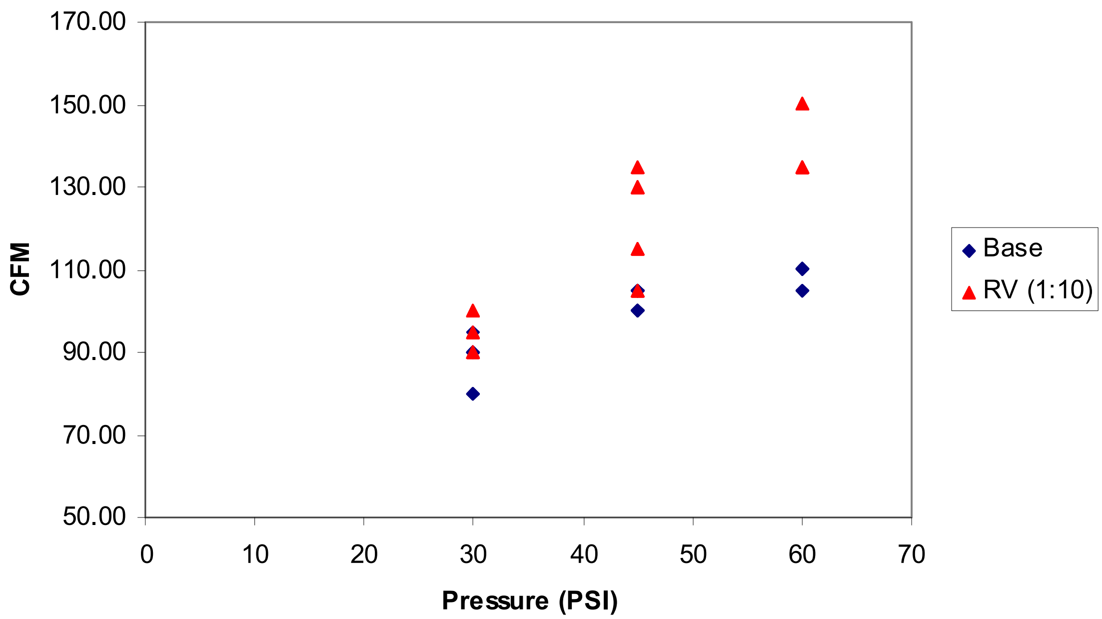

Figure 3.11. Pressure vs. air flow rate for coarse feed (base vs. reagent RV).

From these tests, it is clear that the controlling factor is the pressure in the pressure vessel. The chemical additions also have an effect on the process that causes a wider spread in the air flow and a shift upward in the requirements. This greater variability is caused primary by cake cracking and the increased air requirements are caused by an increase in cake porosity.

3.3.2.3 Mass Flow Rate

The mass flow rate is important to know since it will show what the production capacity of a full size unit would be. This factor is clearly controlled by two factors. That is the percent solids in the feed and the pump speed. This is due to the fact that the amount of material put on the filter directly controls how much comes out as product. The amount of material lost through the filter cloth is important to know. Figure 3.12 shows the mass flow rate into the filter on the horizontal axis and the amount of losses on the vertical axis. It has been found that although losses do increase with more material they increase at a rate slower than the input. This is due to the formation of a bed at the bottom of the filter. This bed once formed greatly reduces the amount of material lost. It is formed at both low and high feed rates.

Figure 3.13 is informative with regard to how the filter is truly performing. It shows the

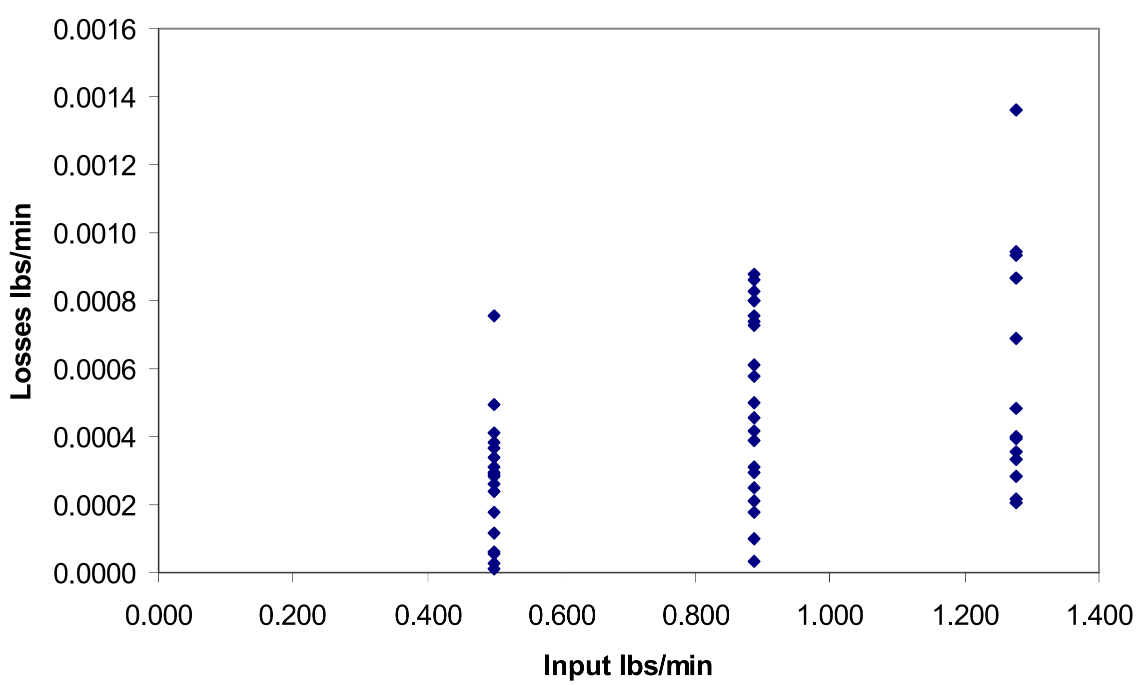

Figure 3.12. Material input vs. losses for coarse feed.

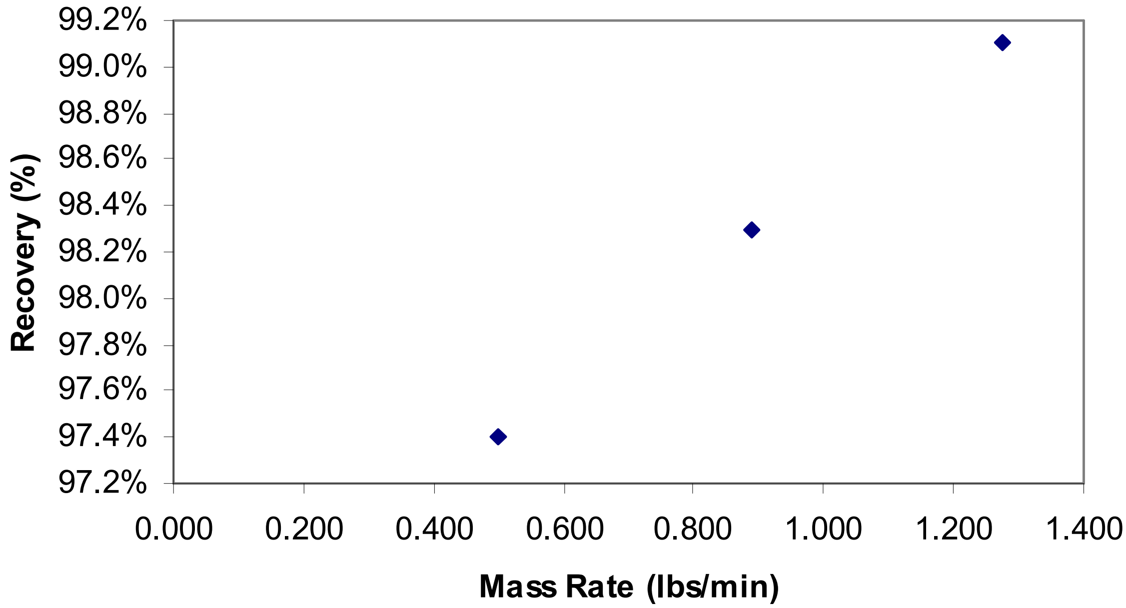

Figure 3.13. Mass rate vs. recovery for coarse feed.

mass cake rate vs. recovery of the filter as an average of all of the values at each mass rate for clarity. The data shows a very slight increase in the recovery of the filter with more material on the filter. If it were possible to put more material on the belt, it is expected that the recovery would asymptotically approach 100%.

3.3.3 Fine Feed

All of the tests and analysis that was done for the coarse material was also duplicated for the fine material. This material is column product (minus 0.15 mm) from Tom's Creek mine. It was tested to see how the belt filter would perform under poor conditions for dewatering. The feed material contains 8% solids by weight. This material contains 61% minus 325 mesh. For this reason, all of the tests were conducted with flocculant at a concentration of 1 gallon per 70 tons of coal. The flocculant addition was done by a small pump used to produce very small drops at a slow speed.

3.3.3.1 Moisture Content

The first tests conducted were designed to see how much variability exists in the filter using the same feed and settings on the pressure filter. The results of these tests are shown on Figure 3.14. It can be seen that the variability is less than that of the coarse feed material on Figure 3.6. The standard deviation of this data is 0.0044. To keep the testing procedures consistent, it was decided that each data point for the fine feed would also be an average of three test points.

Then same testing schedule was used which is shown in Appendix B. The data from these tests was entered into Design Expert to produce a Box-Behnken response surface. This is a model of how the filter behaves given a set of input conditions. The generated response surface is shown below in Figure 3.15.

The filter in this case performs in much the same manner as it did for the coarse material.

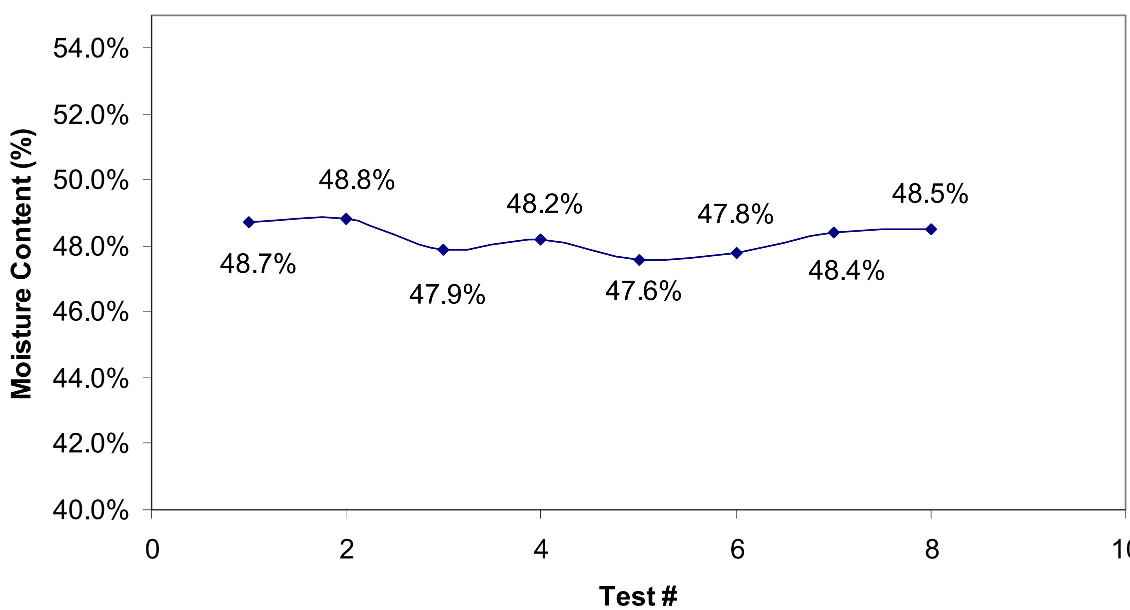

Figure 3.14. Variability of the fine feed data (25% feed pump speed).

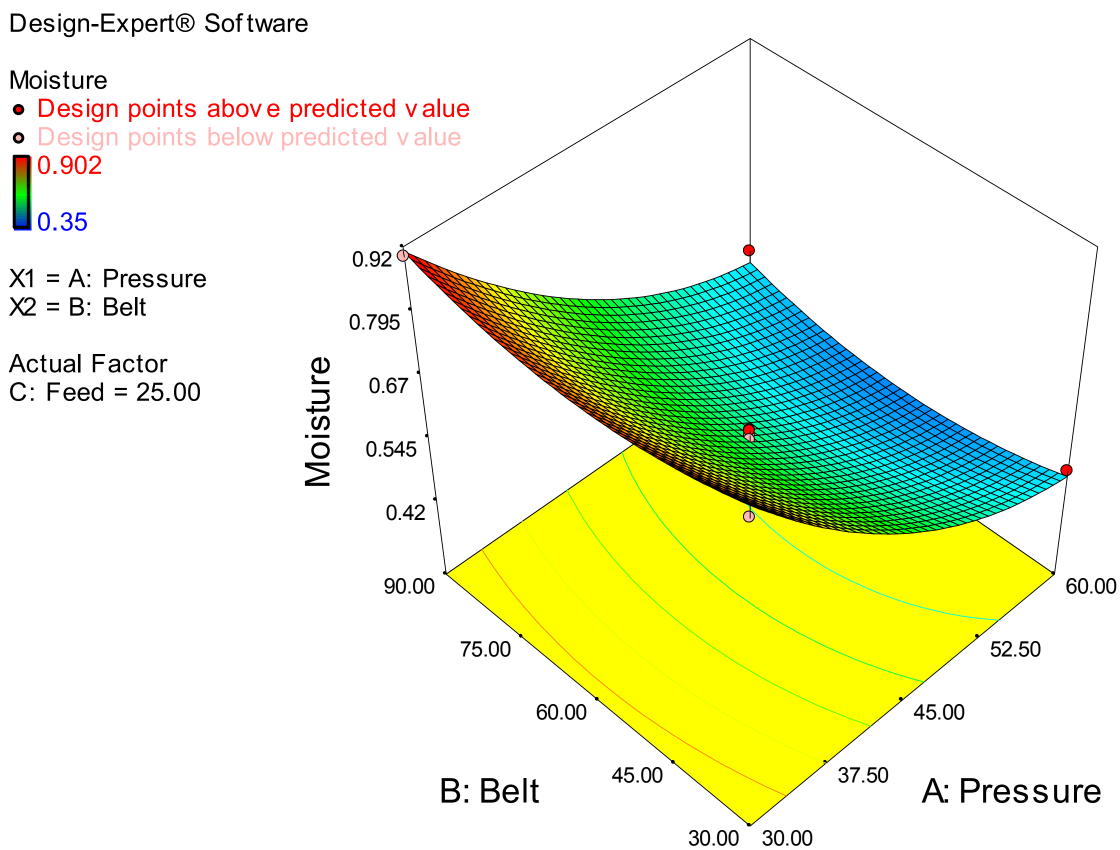

Figure 3.15. Response surface for fine feed and no chemicals.

The most noticeable difference is that the moisture content is much higher than for the fine material. This is due to the fact that it takes more force over a longer period of time to dewater this material. The belt filter was not long enough to give this material sufficient time to fully dewater. From the response surface it is easy to see that the best operating point for moisture was at 60 PSI of pressure and a belt speed of 60 percent.

Based on the results found in the batch testing of this material it was determined that the best reagent to use is the RV (1:10) at 3 lbs/ton. This was then added to the sample and tested.

The results were input into Design Expert which created the response surface shown in Figure 3.16.

The response surface shows how the filter behaved in this situation. This material has a lower moisture at every operating point compared to the results without the dewatering chemicals. Most of this gain was realized because of the greatly improved rate of dewatering that was realized. The worst point occurred when the pressure was low and the belt ran slow. This created a situation where the driving force was low and the cake thickness was high. This situation simply did not produce cake formation rates that were fast enough. The best operating point was at high pressure and high belt speed. This was because this had the thinnest cake which realized the greatest moisture reduction. The other corners of the design also exhibit the same

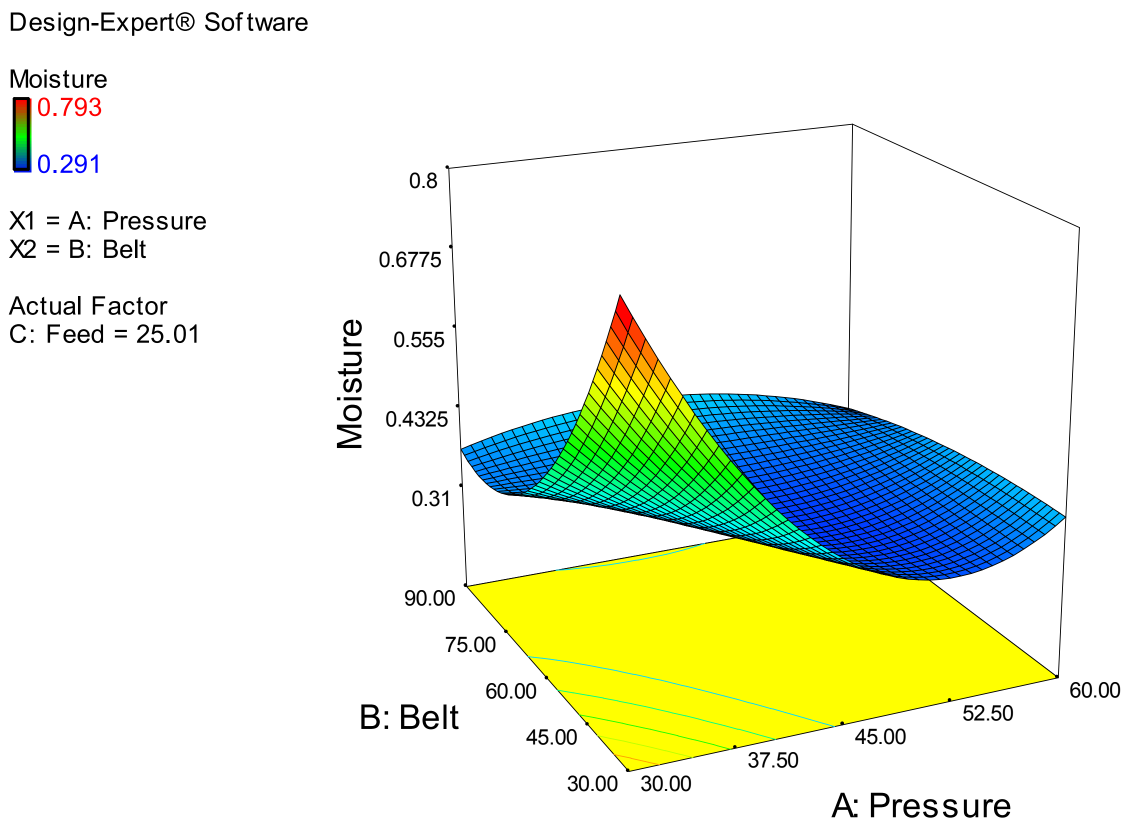

Figure 3.16. Response surface of fine feed with 3 lb/ton reagent RV (1:10).

behavior only with more moderate results.

3.3.3.2 Air Requirements

The air requirements for the fine feed are important to understand the cost of operating the belt filter. Just as in the coarse feed there are several possible factors that affect the air requirement these are, cake thickness, pressure, chemical additions, and size of the feed.

Figure 3.17 shows the plot of cake thickness vs. air requirements. This chart, like the one for coarse feed, shows that that cake thickness in the filter is not a major determining factor for air consumption.

Pressure was a major controlling factor in the air consumption in the coarse feed material. The addition of chemical reagents also had a shifting effect on the air consumption of the unit. Figure 3.18 shows both the feed with no reagent and that with reagent. From Figure 3.18 it is

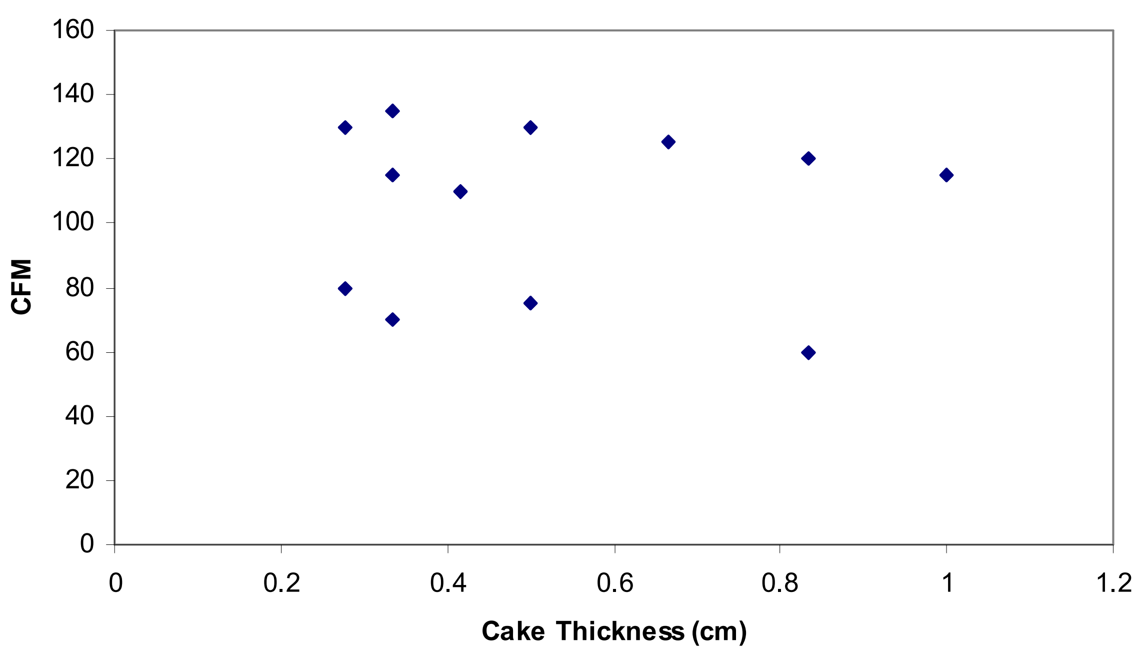

Figure 3.17. Cake thickness vs. air flow rate for fine feed.

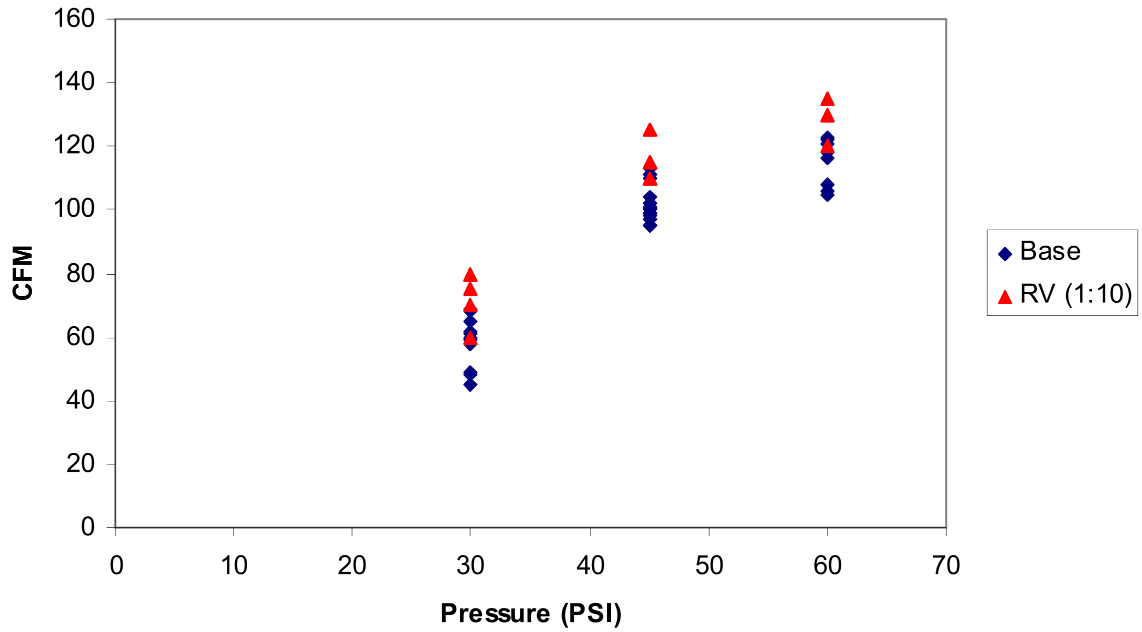

Figure 3.18. Pressure vs. air flow rate for fine feed (base vs. reagent RV).

seen that pressure is a controlling factor for air requirements and that the use of the reagent also increases the requirement.

The comparison between the air requirements for the two different feed types is shown on Figures 3.19 and 3.20. On the chart with no reagent it is difficult to discern any meaningful difference in air flow from the two types of feed. This is not true on the material with RV. On this diagram, it shows that the coarse material has a higher airflow than the fine material. This is most due to the greater size in the cracks in the and due to the higher porosity that is created in the cake that contains large particles compared to the small ones.

3.3.3.3 Mass Flow Rate

The mass flow rates are essential for developing a scale up model for this pressure filter. Figure 3.21 shows the mass flow rate vs. losses rate. From this plot, it is shown that the loss rate

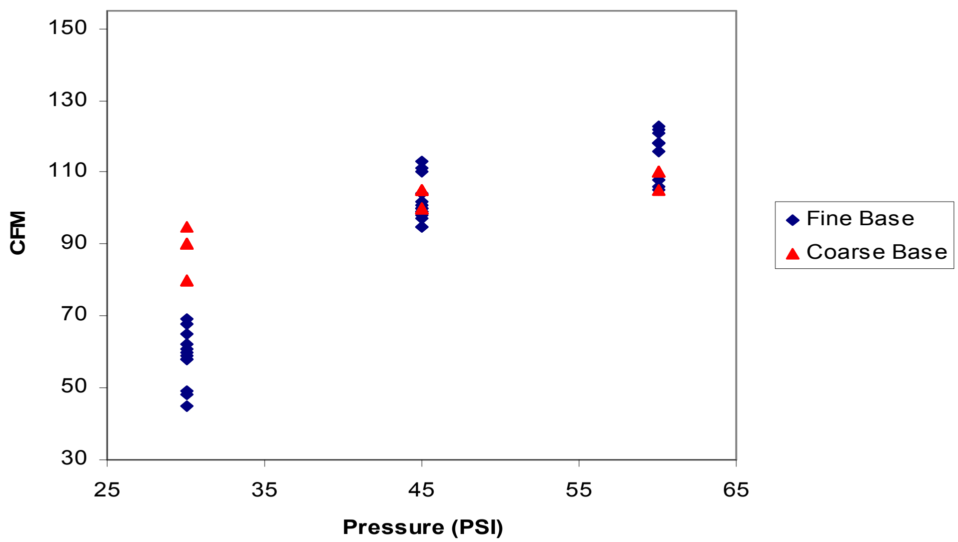

Figure 3.19. Pressure vs. air flow rate for coarse and fine feeds with no chemicals.

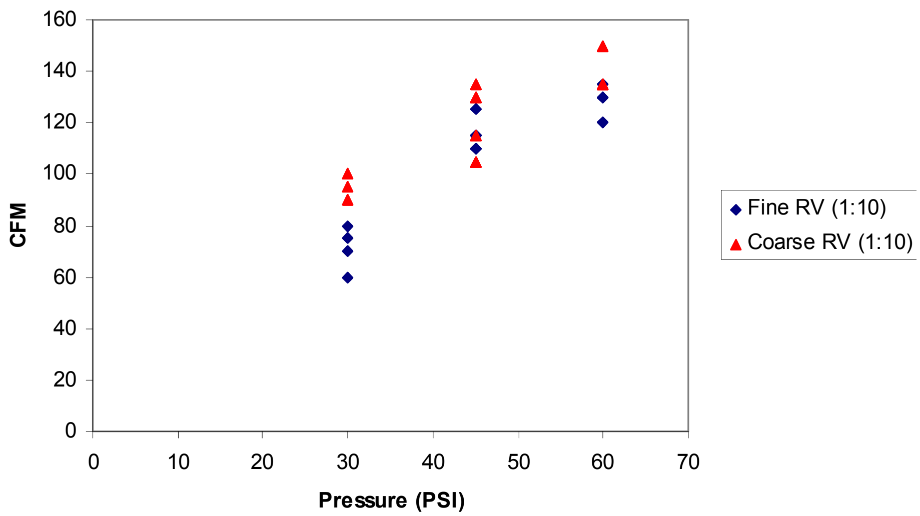

Figure 3.20. Pressure vs. air flow rate for coarse and fine feed with reagent RV.

increases when the feed rate is increased. This is not unexpected since there is more ultrafine material in this feed.

Figure 3.22 shown below is of the input mass rate vs. recovery. This chart shows that there is little change in the recovery of the filter as the mass rate is increased. This is due to the large amount of ultra fine material in that belt that helps slow the rate of dewatering. The time

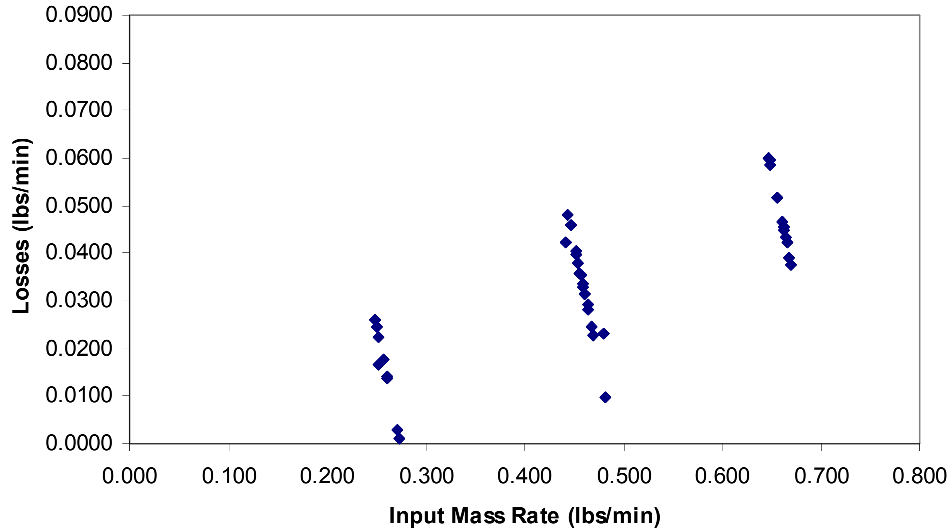

Figure 3.21. Mass rate vs. losses for fine feed.

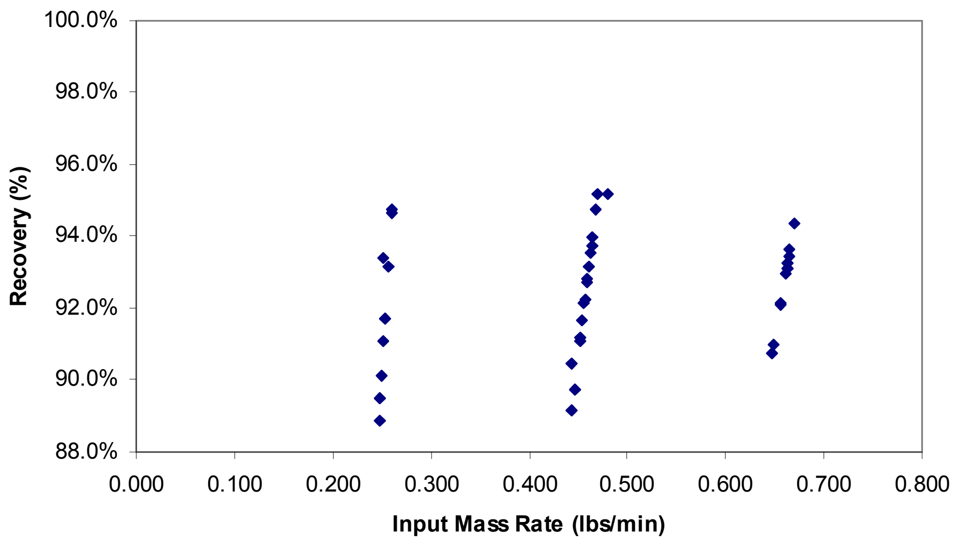

Figure 3.22. Mass flow rate vs. recovery for fine feed.

for the cake to form is increased by a large amount which gives much of the ultra fine material time to escape through the filter cloth before the cake forms to provide a barrier.

3.3.4 Mixed Feed

A mixed feed was the final type of feed that was researched. In this group, the coarse material is mixed with the fine material to produce a feed that has a more evenly dispersed size distribution. The size range is still 1 mm x 0 as with the coarse feed but it has more minus 325 mesh material. This material is 38% minus 325 mesh, compared to the coarse feed which was 16% and the fine feed which was 61%. Figure 3.23 show the consistency of the product obtained using the mixed feed. For this group of tests, the standard deviation is 0.0048.

3.3.4.1 Moisture Content

Once the variability of the data was established, the same series of tests was once again run for mixed sample. The results were then put into Design Expert and analyzed. From this analysis, it was possible to generate a response surface. Figure 3.24 shows the response surface for the mixed data without any chemical additions.

From the surface, the optimal operating point for this material is with a high belt speed and high pressure. This would result in shorter drying times and thinner cake. Also, for this particular feed, the thin cake helps prevent a layer of slimes from coating the surface and

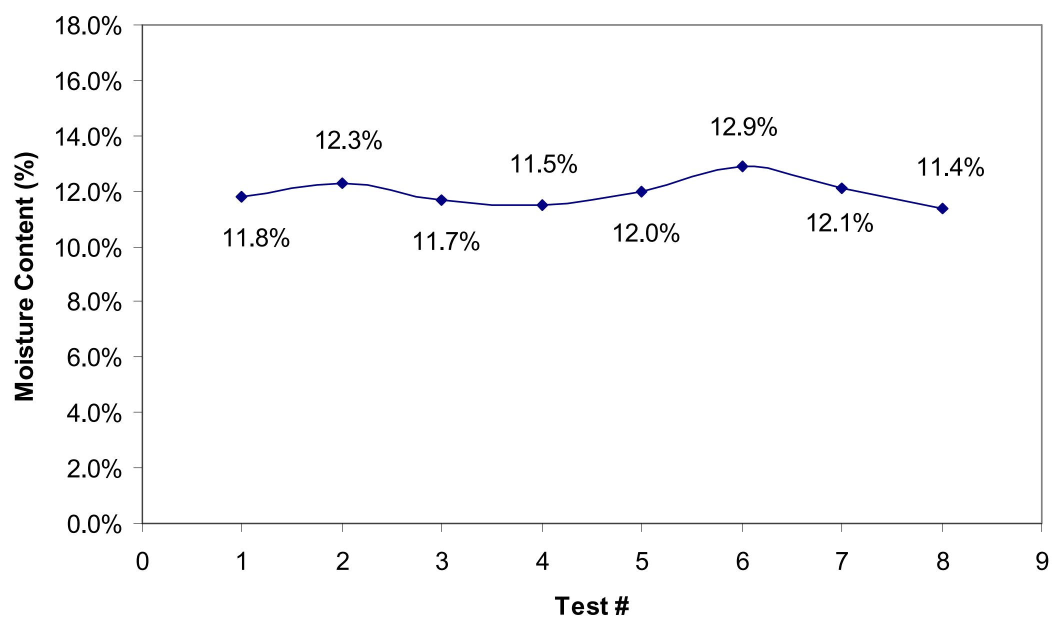

Figure 3.23. Variability of the mixed feed data (30% feed pump speed).

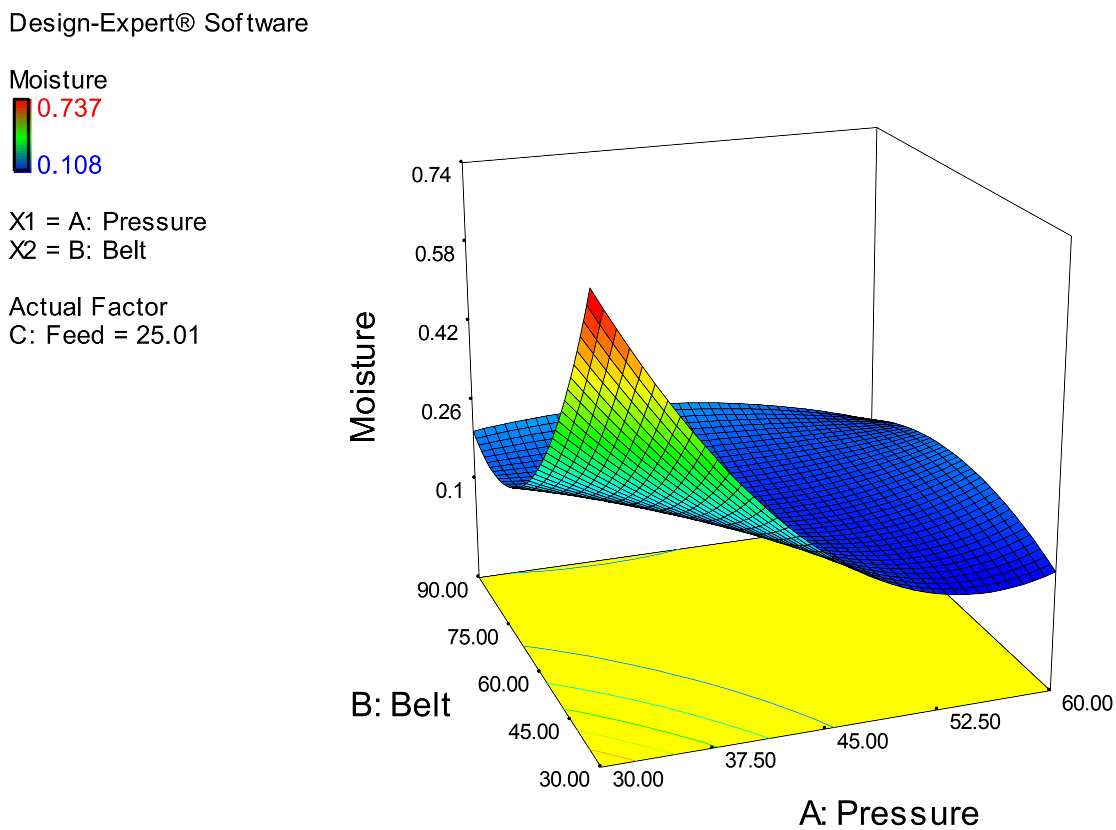

Figure 3.24. Response surface for mixed without chemicals.

blocking the air from penetrating the cake. The very high moisture that is shown at a slow belt speed and low pressure is the result of the belt flooding due to a cake thickness that is too great and not a long enough time for it to dewater.

Also done were tests on the unit with chemical additions that had been made. These were also completed with RV (1:10) at 3lbs/ton. The resulting response surface is shown in Figure 3.25. This chart indicates that the moisture content can be lowered by a significant amount from those done without the reagents. The moisture reduction is approximately 2-3 percentage points. The best operating conditions for the material under these conditions is with a high pressure and a moderate ranging belt speed. This is a normal optimal condition which is expected.

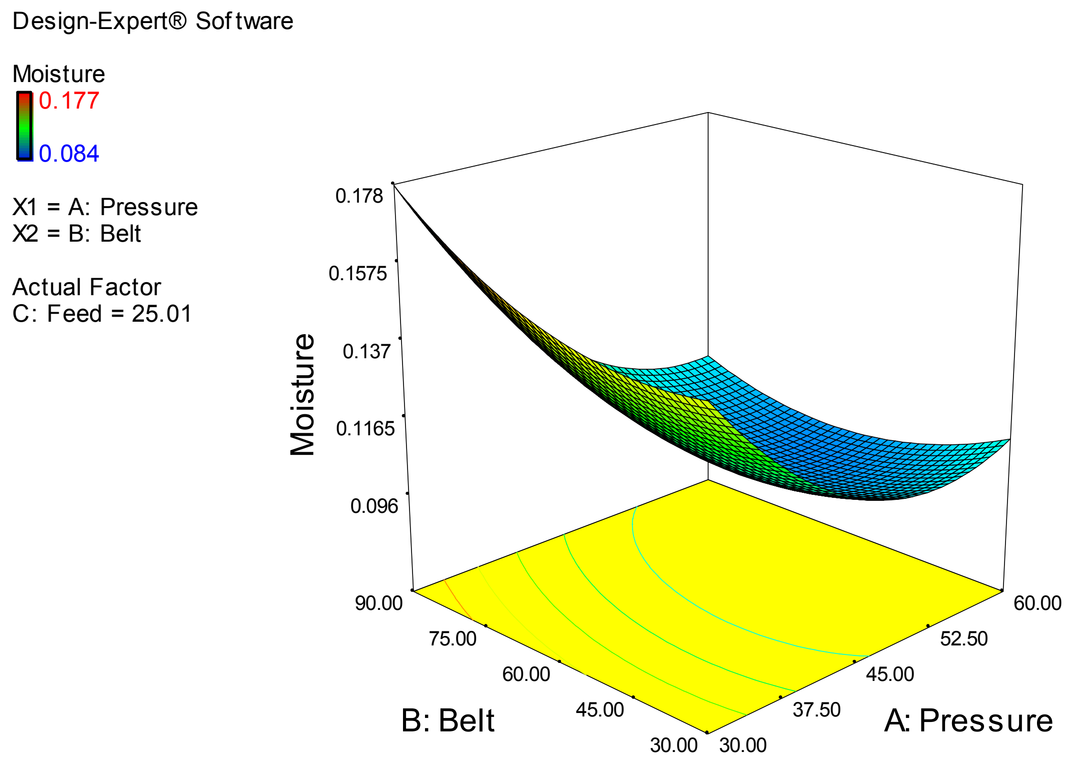

Figure 3.25. Response surface for mixed with 3 lb/ton reagent RV (1:10).

The amount of air consumed by the pressure filter during the tests changes depending on the conditions of the test. The amount of air consumption varies primarily with the amount of pressure in the pressure vessel. This can be seen on Figure 3.26.

The amount of air consumed is similar to that of both the fine feed material and the coarse feed material. It largely fits between the two as is seen on Figure 3.27 and Figure 3.28. One of the plots is of the reagent treated material, while the other is with no chemicals material. This further indicates that as the size of the material to be filtered increases, so does the amount of air required for effective filtration.

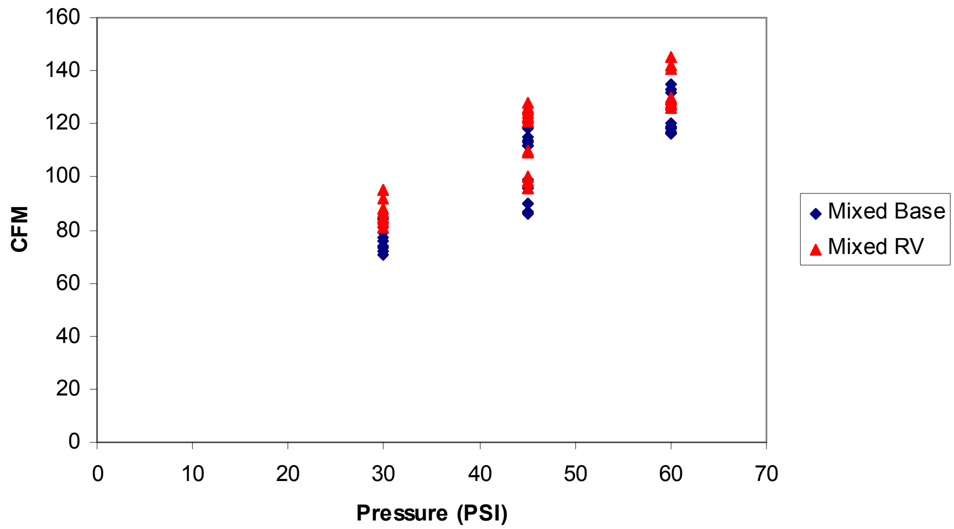

Figure 3.26. Air requirement for mixed feed.

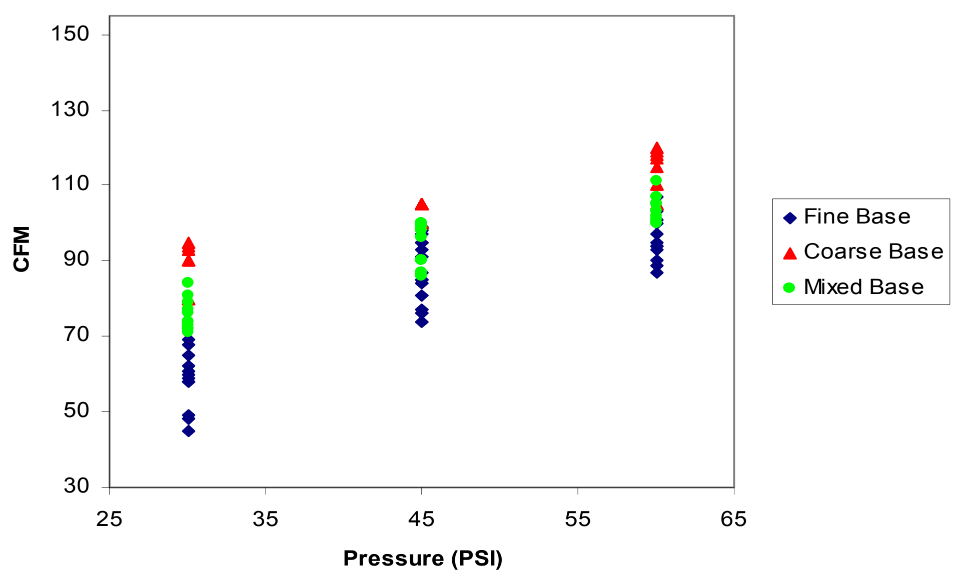

Figure 3.27. Base air flow requirements for mixed feed.

3.3.4.3 Mass Flow Rate

The mass flow rate of this material is of importance in scaling up the equipment to determine how large, a production capacity unit would have to be. The mass flow rate vs. recovery chart is shown on Figure 3.29. This shows that as the amount of material on the belt increases so does the recovery of the filter. For this reason there are advantages to creating a filter with high capacity since it will also result in a higher recovery.

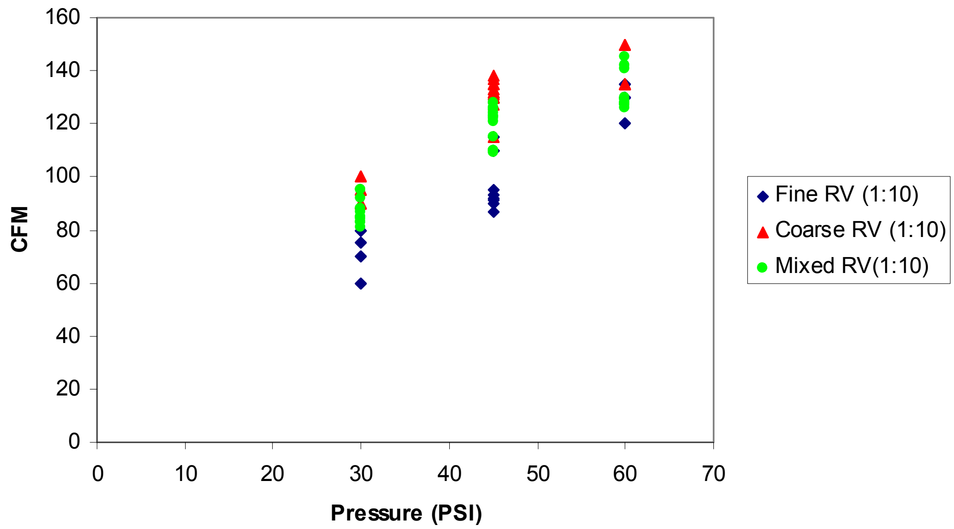

Figure 3.28. Air flow comparisons for chemically treated feeds.

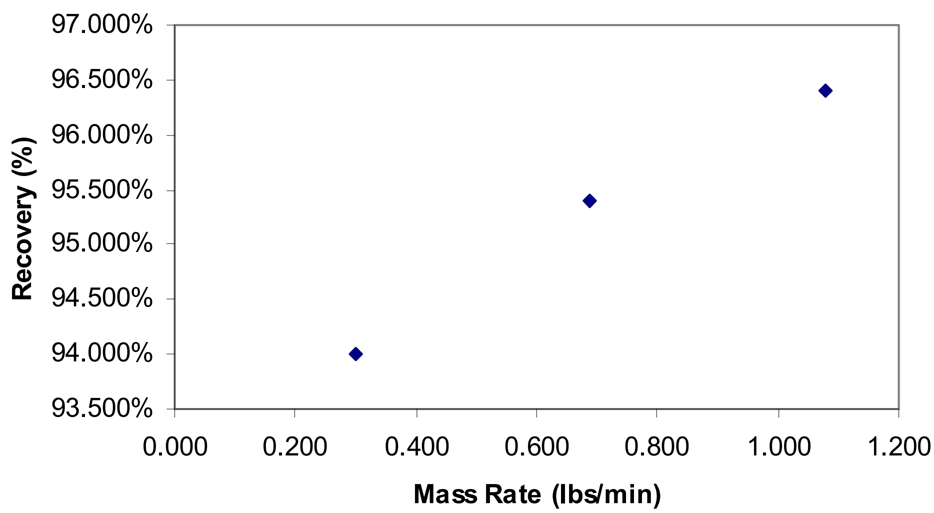

Figure 3.29. Mass rate vs. recovery for mixed feed.

3.4 Discussion

From these results it is possible to scale up this unit and to predict the behavior and requirements of a larger full production capacity unit. This process has several assumptions that must be made and can therefore only provide an estimate as to the performance of such a unit.

3.4.1 Discrepancies

In terms of scale up, most of the discrepancies exist in the fine feed batch testing compared to that of the continuous filter. The lowest moisture numbers for the batch test are approximately 14%, while the lowest moisture numbers for the continuous unit are approximately 29%. The primary reason for this difference is the dewatering time. In the batch unit, the total time can at times be almost 3.5 minutes. Across the belt the longest time that is has is only 2.5 minutes. Also, the slower the belt moves the greater the cake thickness thus making dewatering even more difficult. If the belt were longer, it would be possible to maintain a thin cake and allow the proper amount of dewatering time. If this occurred, then it is possible that it would produce similar moistures to the batch unit.

The coarse material did not respond in the same manner on the continuous unit as it did on the batch unit. It was not successful at significantly reducing the moisture content of the product. It did, however, increase the rate of dewatering thus allowing greater throughput on the machine. This rate change can be seen from comparing Figure 3.7 and Figure 3.8, where the great improvement was made when the pressure was 30 PSI. The value of this addition will be further explored in the scale up section.

3.4.2 Scale-Up Analysis

To do a meaningful scale up the results of two different size machines should so a relationship. The most important factor in this design is the moisture content of the product. For this reason, the scale up analysis will be done primarily based on the coarse feed material since its findings can be confirmed more definitely with those of the batch unit. The computer models also suggest that if the dimensions of the filter belt were altered to increase the dewatering time that the fine material would more closely correspond to the lab results.

The scale up analysis will look into determining approximately how much energy would be required to operate a unit with a capacity similar to that of other dewatering equipment. Finally, there are some major design modifications that are suggested for a full time operating unit.

3.4.2.1 Horsepower Requirements

To build a full size capacity unit, the optimal operating point will be used as the design criteria to design for. This is the best that a unit built just like this one could achieve. There are two processes that occur in this unit that require power. The first is turning the rubber belt. This requirement is essential but its overall power requirements are dwarfed by the second requirement. Second is the air compressor that will need to produce large amounts of compressed air continuously.

The optimal operating point produces a cake with 10.7% moisture required 110 CFM of air, while producing 1½ pounds of coal per minute. Assuming that the air consumption has a linear relationship with capacity as it scales up, a unit capable of handling 50 tons per hour would require approximately 120,000 CFM. To produce this much air would require approximately18,360 horsepower. Calculations of this value are shown in Appendix D. The cost associated with load can be calculated as:

Cost = [18,360 HP x 0.747 kW/HP x \$0.04/kW-hr] / [50 ton/hr] = \$10.97/ton

Using the dewatering reagent, it is possible to obtain the same moisture content but with the same amount of air to produce 2½ pounds of coal per minute. By making the same assumptions, it would require 73,000 CFM of air. That would require 11,169 horsepower to operate. This would reduce the gas compression cost to only \$6.67/ton (i.e., \$10.97 x 11,169/18360 = \$6.67).

3.4.2.2 Suggested Design Modifications for a Production Unit

A full size production unit will make some design changes to increase reliability and maintenance. The most significant change will be to move the belt drive motor outside of the pressure vessel. This is because inside the pressure vessel is a wet and corrosive environment that would cause the motor to decay at a rapid pace. This new design would most likely involve a sealed bearing connecting a shaft to the outside of the vessel to allow the motor to sit on the outside.A full production unit would also include a way to easily access the water sprays used to clean the belt. This would be done because these water sprays are notorious for getting plugged.

Also, a production unit would design a more robust tracking control system for the filter cloth. At present the filter cloth does not move more than a few inches in either direction. If the tracking did get off it would require the machine to be shut down and disassembled to fix it. A unit designed to be run for more than 100 hours a week would include a way to shift the tracking on the filter cloth without shutting down the equipment.

Finally, for a unit that is built to dewater the fine material, the dimensions of the unit need to be modified. This modification will include an increase in the length of the dewatering section of the belt relative to all the other dimensions. This will allow for longer dewatering times and not increase the thickness of the cake. If this design modification were employed the lab data from the coarse material suggests that it should be possible to produce cake moistures that are similar in value to those of the batch unit.

3.5 Conclusions

This research set out with two objectives. The first was to design and build and operating pilot scale hyperbaric belt filter. The second was to test such a device to determine its operating parameters. The primary purpose of these tests was to determine how low of a moisture content could be achieved and what would be the work input to deliver this separation.

The first objective was completed in May 2006 when the unit successfully demonstrated a significant moisture reduction with a coal slurry feed. Once this was accomplished and shown that it could be achieved repeatedly, the shake-down tested period came to a close and the unit was declared operational. When this happened, the first goal of constructing an operating device was completed.

The second objective of testing the unit to determine its operating parameters was also completed. The results of these tests indicate several key points in the operation of the hyperbaric filter. The first is that the unit consumes more air at higher pressure. Secondly, the moisture content of the product depends on many factors including, belt speed which operates best in the mid-ranges between 40% and 75%. The fine feed material takes significantly longer to dewater than does the coarse material. Also, pressure across the filtrate has a large impact particularly in the fine feed material. The chemical additions had the ability to reduce the moisture content of the mixed material and fine material in a significant way. The reagents had the ability to increase the rate of dewatering for the fine material. For the fine material, this increase in dewatering rate resulted in greatly reduced moisture contents for the product material. The lowest moisture content that was recorded for the fine feed material was 29.1% by weight, for the mixed material 8.4%, and for the coarse material it was 8.2%. Finally, it was determined that if a production capacity unit operated with the same ratio of feed to air consumption it would use between

73,000 CFM and 120,000 CFM, requiring 11,169 to 18,360 horsepower for the air compressor, respectively. As such, the gas compression cost for dewatering would range from $10.97 per ton of dry coal when no dewatering aide is used and $6.67 per ton of dry coal when using 3 lb/ton of dewatering aide.

CHAPTER 4:
GENERAL SUMMARY

In the United States there is a great need for energy. To help supply this need, coal is one of the primary resources. The coal processing industry has a need for a solid-liquid separation between coal particles and liquid water. This process is currently expensive and often sacrifices many tons of fine coal particles. To address this need, this project seeks two goals. The first is to design and construct an operating pilot scale version of a piece of equipment to improve dewatering performance. The second goal is to test this new piece of equipment to determine how effect it is at removing water from coal slurry.

The first stage of achieving the goal of building a unit was to decide what type of unit to construct. It was decided after much literature research that a hyperbaric horizontal belt filter had much promise. So the unit was designed and constructed. This process took approximately 18 months to complete. At the conclusion of this phase of the project the belt filter was capable of consistently operating and causing significant moisture reduction.

The second stage began once the first stage was completed and it involved testing the unit to determine how it would perform under a series of operating conditions. From these tests, it was determined that the belt speed that produced the best results was in the mid-range of the machine's capability. Also, it was much more effective at dewatering the coarse particle material than it was the fine particle material. The lowest moisture reduction that was achieved was in the coarse material where the feed contained 76% moisture and the product 9%. This was even further reduced by adding dewatering aids which brought the final moisture down to 8%. The fine feed material realized a moisture reduction from 92% moisture to 35%. This was also enhanced by the presence of dewatering aids to 29%. Then a mixed material was created and it moisture was reduced from 84% to 8% when dewatering aids were used. For this mixed material it was shown that the chemical additions did lower the moisture content of the product material.

It was also determined that the operating pressure of the belt filter was by far the dominate factor in controlling the air consumption of the unit. This is an important consideration in the planning of a production capacity unit.

The test results suggest that if the belt's length were increased it would possible to realize lower moisture contents from the fine material than what was recorded with these tests.

References

1. Atak Sunna and Celik Mehmet, *Innovations in Mineral and Coal Processing*, Rotterdam: A. A. Balkema, 1998.

2. Canbazoglu Mehmet, *Changing Scopes in Mineral Processing*, Rotterdam: A. A. Balkema, 1996.

3. Cheremisinoff Nicholas P. and Azbel David, *Liquid Filtration*, Woburn: Ann Arbor Science Publishers, 1983.

4. Cheremisinoff Nicholas P., *Pocket Handbook for Solid-Liquid Separations*. Houston: Gulf Publishing Company, 1984.

5. Cheremisinoff Paul N., *Solid-Liquid Separations*. Lancaster: Technomic Publishing Company, 1995.

6. Chuse Robert and Carson Bryce, *Pressure Vessels The ASME Code Simplified 7th Edition*, New York: McGraw-Hill, 1993.

7. Cummins Arthur and Givens Ivan, *SME Mining Engineering Handbook*. New York: Port City Press, 1973. p. 27-1 – 27-94

8. Dahlstrom D. A., *Challenges in Mineral Processing*, Littleton: Society of Mining Engineers, 1989. p. 467-475.

9. Demirel Halim and Ersayin Salih, *Progress in Mineral Processing Technology*, Rotterdam: A. A. Balkema Publishers, 1994.

10. Dickenson T. C., *Filters and Filtration Handbook 4th Edition*, New York: Elsevier Science Ltd, 1997.

11. Ellenberger Phillip and Chuse Robert, *Pressure Vessels 8th Edition*, New York: McGraw-Hill, 2004.

12. Filtration Dictionary, Croydon: Uplands Press Ltd., 1975.

13. Green Robert E., *Machinery's Handbook 25th Edition*. New York: Industrial Press Inc, 1996.

14. Gregory J. *Solid-Liquid Separation*, New York: Ellis Horwood Limited, 1984.

15. Harvey John, *Theory and Design of Pressure Vessels 2nd Edition*, New York: Van Nostrand Reinhold, 1991.

16. Hicks Tyler G., *Handbook of Mechanical Engineering Calculations 2nd Edition*. New York: McGraw-Hill, 2006.

17. Hudson Clayton, *Filter Cloth Resistance in Constant Pressure Filtration*, Thesis. Virginia Tech, 1941.

18. Kutz Myer, *Mechanical Engineers' Handbook*. New York: John Wiley & Sons, 1986.

19. Loving James, *The Design, Constriction, & Operation of a Pressure Continuous Filter*, Thesis. Virginia Tech, 1947.

20. Malek Mohammad, *Pressure Relief Devices*, New York: McGraw-Hill, 2006.

21. Merrit Paul*, Book of Flowsheets*, New York: McGraw Hill Inc., 1984.

22. Mohanty M.K., *Performance Evaluation of a New Fine Coal Dewatering Technology.* 2003: p. 1-3.

23. Moss Dennis, *Pressure Vessel Design Manual 3rd Edition*, Boston: Gulf Professional Publishing, 2004.

24. Myers Drew*, Surfactant Science and Technology*. Hoboken: John Wiley & Sons, 2006.

25. Osborne, D.G., *Rotary-vacuum filtration of coal flotation concentrates.* International Journal of Mineral Processing, 1976. **3**(2): p. 175-191.

26. Purchas Derek, *Industrial Filtration of Liquids 2nd Edition*, London: Leonard Hill Books, 1971.

27. Ritcey Gordon, *Tailings Management*, Amsterdam: Elsevier Science Publishing Company, 1989.

28. Ruthven D.M., *Encyclopedia of Separation Technology Vol. 1*. New York: John Wiley & Sons, 1997. p.487-513

29. Ruthven D.M., *Encyclopedia of Separation Technology Vol. 2*. New York: John Wiley & Sons, 1997. p.829-893

30. Svarovsky L., *Solid-Liquid Separation 2nd Edition*. London: Butterworth & Co, 1981.

31. Wade David, *The Design, Construction, and Operation of a High Pressure Filter*, Thesis. Virginia Tech, 1943.

32. Wang Ching, *A Study of the Fine Coal Dewatering by High Temperature and Pressure Filtration*, Thesis. Virginia Tech, 1966.

33. Weiss Norman, *SME Mineral Processing Handbook*. New York: Society of Mining Engineers, 1985.

APPENDIX

Appendix A

A list of tools used in the construction of the hyperbaric pressure filter.

Table A-1: List of tools used in the construction of the hyperbaric belt filer.

Number	Tools
1	3/4 Inch Chuck Power Drill
2	Acetylene Torch
3	Ball Pin Hammer
4	Band Saw
5	Belt Sander
6	Bottle Jack
7	Box End Wrenches
8	Calipers
9	C-Clamps
10	Chain Pullers
11	Channel Locks
12	Compound Square
13	Cordless Drill
14	Crescent Wrench
15	Dies
16	Drill Press
17	Flat Head Screw Driver
18	Grinder
19	Hack Saw
20	Impact Wrench 1/2 inch Drive
21	Impact Wrench 3/4 inch Drive
22	Lathe
23	Leather Gloves
24	Mig Welder
25	Mill
26	Miter Saw
27	Paint Brush
28	Paint Roller
29	Phillips Head Screw Driver
30	Pipe Wrench
31	Plainer
32	Sand Blasters
33	Shearer
34	Socket Set and Driver
35	Square
36	Tape Measure
37	Taps
38	Tube Clamps
39	Vice

Appendix B

This is a table showing the inputs to the Design Expert analysis program.

Table B-1: Input data for Design Expert test runs.

STD	Run	Belt %	Feed %	Pressure	Coarse Moisture	Coarse Moisture w/ RV (1:10)	Fine Moisture w/ Floc	Fine Moisture w/ Floc & RV (1:10)
1	15	30	20	45	10.8%	11.0%	60.4%	32.7%
2	7	30	30	45	11.2%	10.6%	61.1%	31.8%
3	8	90	20	45	11.4%	11.1%	58.9%	33.0%
4	3	90	30	45	11.8%	11.3%	60.7%	36.3%
5	16	60	20	30	14.1%	15.0%	86.3%	38.9%
6	14	60	30	30	16.6%	14.2%	88.0%	35.3%
7	10	60	20	60	8.8%	8.2%	45.0%	35.2%
8	4	60	30	60	11.3%	10.7%	35.0%	29.1%
9	17	30	25	30	65.3%	14.0%	89.1%	79.3%
10	9	90	25	30	16.1%	13.9%	90.2%	37.0%
11	11	30	25	60	10.9%	10.8%	48.2%	39.0%
12	5	90	25	60	9.9%	10.0%	50.1%	33.6%
13	12	60	25	45	10.0%	9.7%	55.7%	31.7%
14	2	60	25	45	10.3%	10.5%	54.7%	33.9%
15	6	60	25	45	10.2%	10.1%	54.8%	32.5%
16	13	60	25	45	10.3%	10.4%	56.6%	32.9%
17	1	60	25	45	9.8%	9.9%	56.8%	31.0%

Table B-1: Input data for Design Expert test runs (continued).

STD	Run	Belt %	Feed %	Pressure	Mixed	Mixed w/ RV (1:10)
1	15	30	20	45	13.9%	10.3%
2	7	30	30	45	13.2%	11.6%
3	8	90	20	45	13.6%	12.4%
4	3	90	30	45	14.1%	12.6%
5	16	60	20	30	16.8%	14.9%
6	14	60	30	30	18.9%	15.7%
7	10	60	20	60	10.8%	8.4%
8	4	60	30	60	12.1%	11.7%
9	17	30	25	30	73.7%	15.3%
10	9	90	25	30	20.0%	17.7%
11	11	30	25	60	12.1%	11.2%
12	5	90	25	60	11.8%	10.4%
13	12	60	25	45	13.4%	10.2%
14	2	60	25	45	13.7%	10.8%
15	6	60	25	45	14.2%	10.4%
16	13	60	25	45	13.7%	11.4%
17	1	60	25	45	11.8%	10.2%

Appendix C

This section shows the results of the hyperbaric belt filter in graphical form showing some of the input factors graphed versus moisture content.

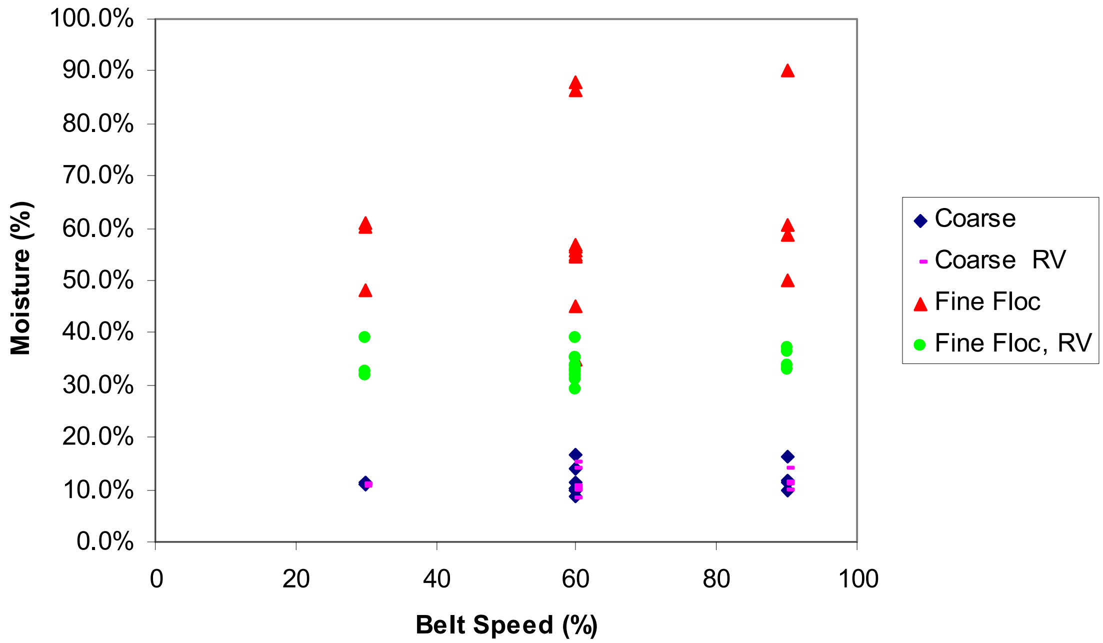

Figure C-1: Belt speed vs. moisture content.

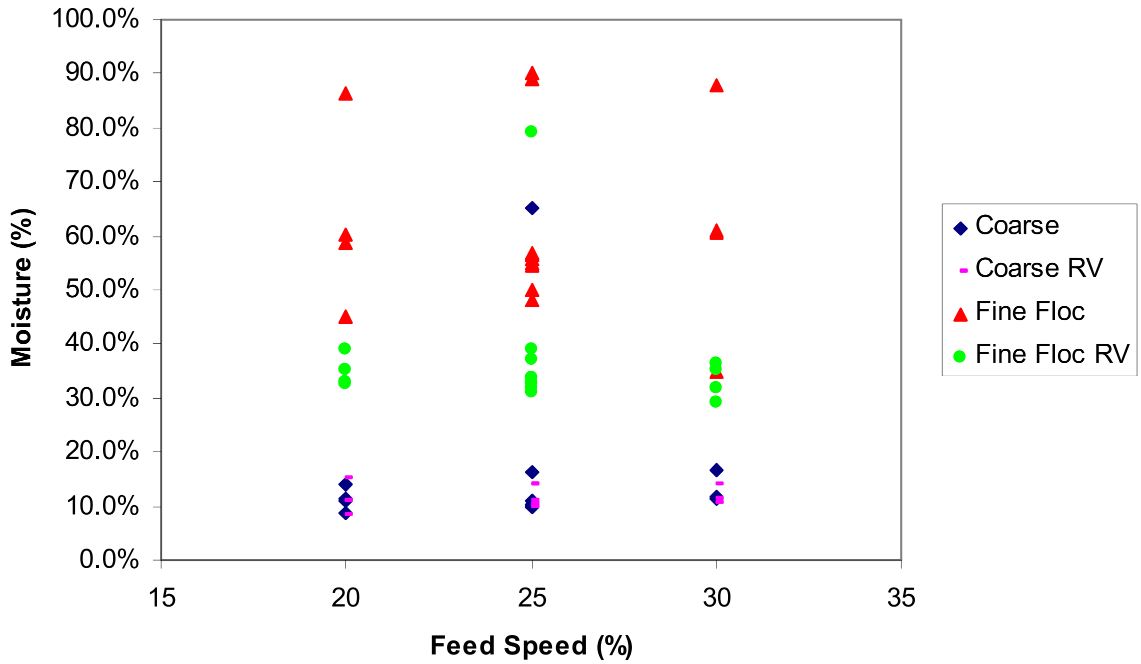

Figure C-2: Feed rate vs. moisture content.

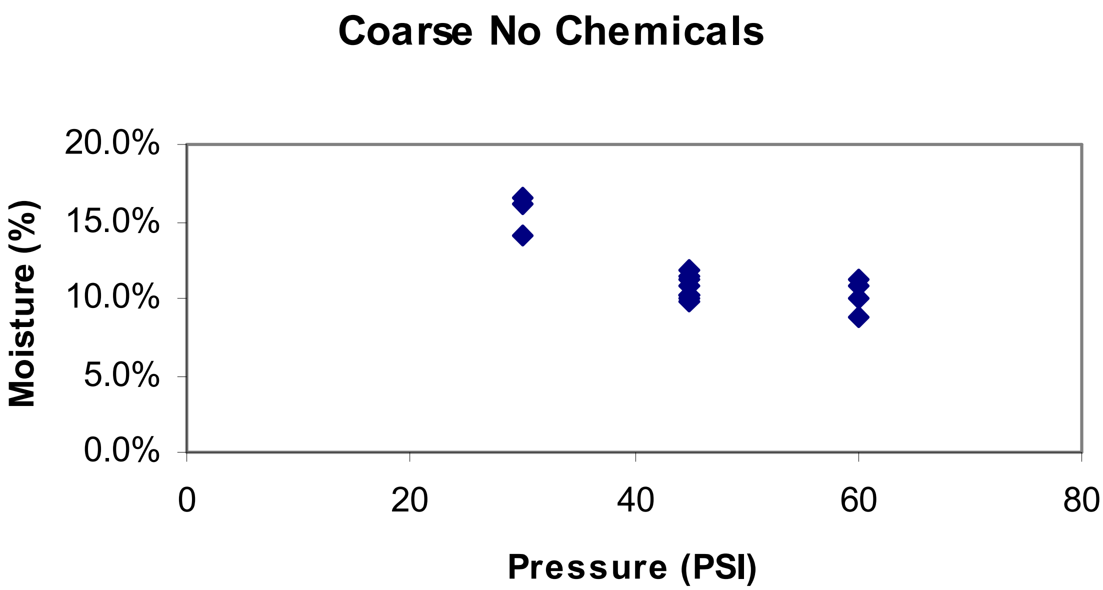

Figure C-3: Pressure vs. moisture content (coarse feed with no chemicals).

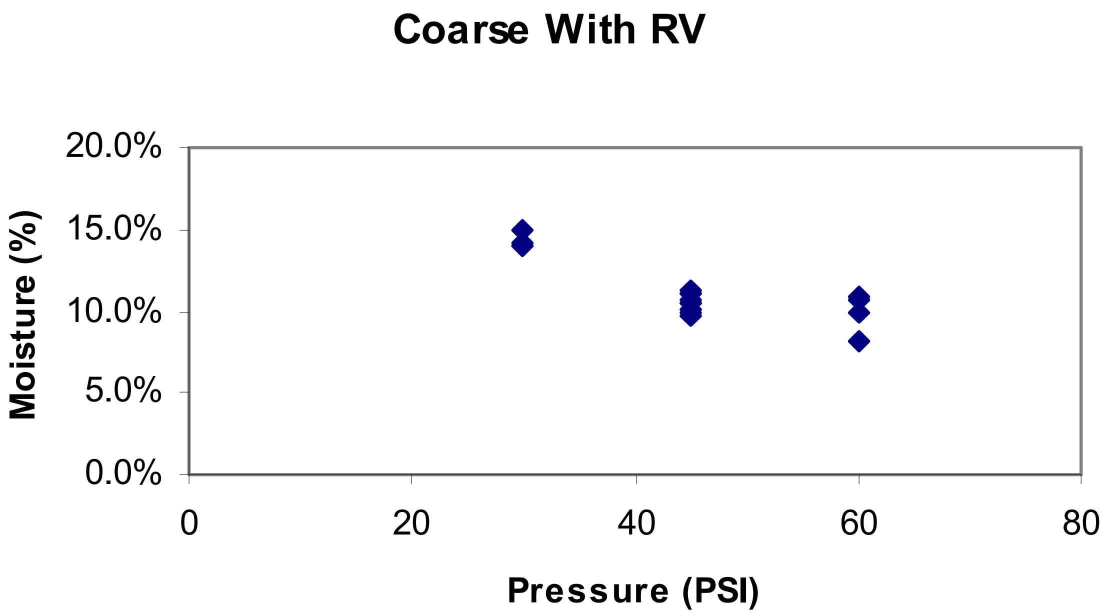

Figure C-4: Pressure vs. moisture content (coarse feed with reagent RV).

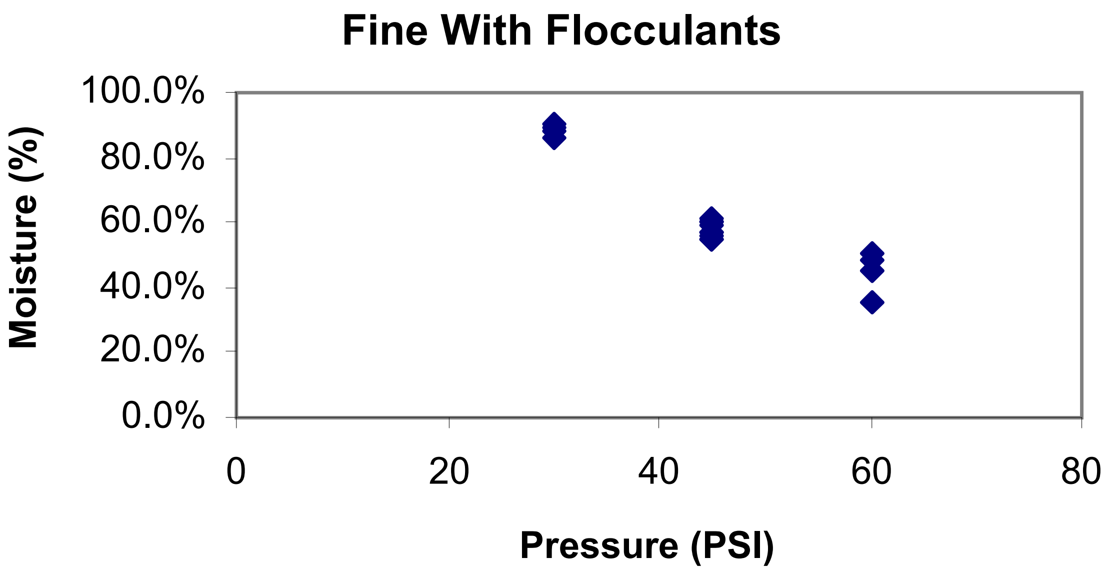

Figure C-5: Pressure vs. moisture content (fine feed with flocculant).

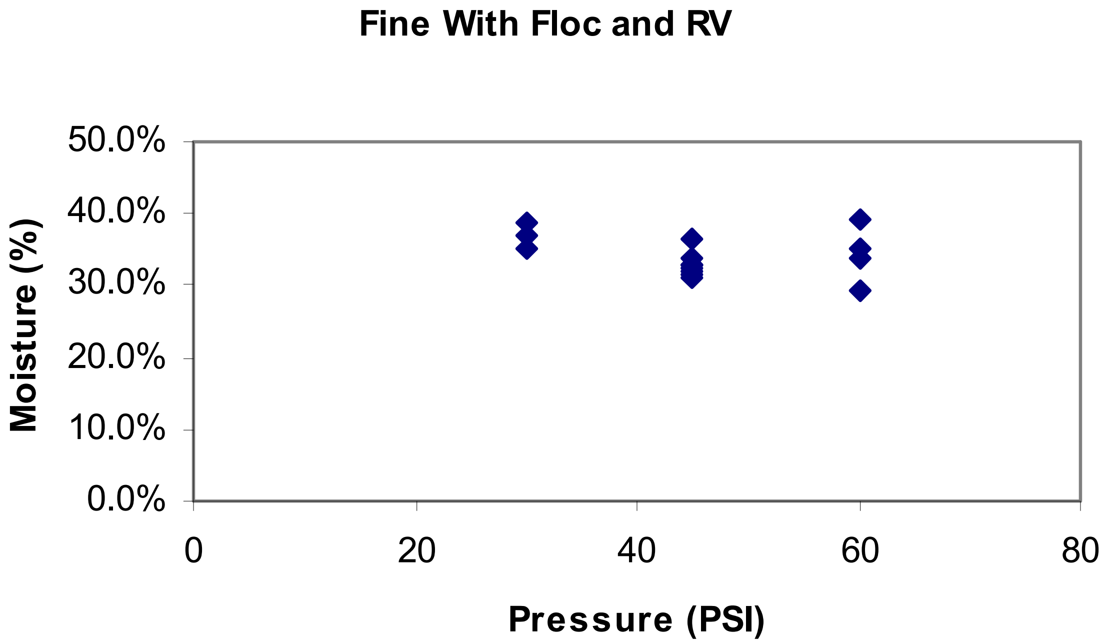

Figure C-6: Pressure vs. moisture content (fine feed with flocculant and reagent RV).

Appendix D

This section shows the calculations made to determine the horsepower requirements of the production capacity hyperbaric belt filter. The equation listed below is used of determining the horsepower required to compress atmospheric air to various gauge pressures (Green, 1996). This compression can be done in one, two, three, or four stages. The formula will allow any amount of volume of air that is required to be compressed, adiabatically. Adiabatically is an assumption, but one that holds relatively well for most air compression operations (Hicks, 2006).

$$H.P. = \frac{144NPVn}{33000(n-1)}\left[\left(\frac{P_2}{P}\right)^{\frac{n-1}{Nn}} - 1\right] \qquad \text{(D-1)}$$

H.P. = Horsepower

N = Number of stages of compression

P = Atmospheric pressure in PSI

P_2 = Absolute terminal pressure in PSI

V = Volume of air to be compressed expressed in CFM

n = Exponent of the compression curve = 1.41 for adiabatic compression

To calculate the horsepower required to compress the amount of air that is required for a production capacity unit it will be assumed that the number of stages of compression will be one. From the equation above it would require 15,960 horsepower to compress 120,000 CFM of air at 60 PSIG. However, if the friction and other losses are considered it results in a 15% loss thus the horsepower required is 18,360. Similarly to generate 73,000 CFM of air at 60 PSIG with the losses included is 11,169 horsepower.

Appendix E

In Figure E-1, the cake thickness vs. cake formation times is plotted for the batch tests.

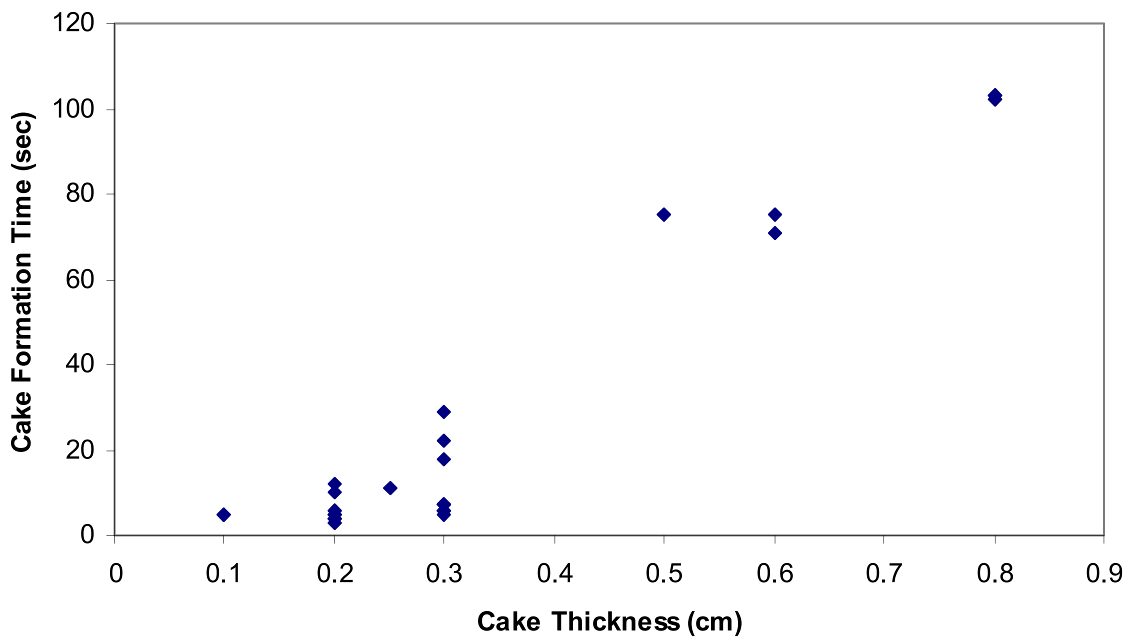

Figure E-1: Batch tests with fine feed.

VITA

Jeffrey Allen Salomon is the son of Roy and Cyndie Salomon. While growing up, his father was a career US Air Force Officer. This permitted him the opportunity to live in many different places and experience lots of different people in his childhood. He graduated from Lake Braddock High School in Burke, Virginia in June 2001. Afterward, he attended Virginia Tech and was awarded a Bachelors of Science in Mining and Minerals Engineering in December 2004. Upon completing his Bachelors degree, he enrolled in the Masters of Mining Engineering program at Virginia Tech where he has studied under the tutelage of Dr. Gerald Luttrell.

On May 29th, 2005, he was happily married to Rachel Salomon. Following his studies at Virginia Tech, he moved on into industry as a consultant.