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Determination Of Optimum Polymer Dose For Grand Forks Wastewater Treatment Plant Lagoon Sludge Dewatering

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DETERMINATION OF OPTIMUM POLYMER DOSE FOR GRAND FORKS WASTEWATER TREATMENT PLANT LAGOON SLUDGE DEWATERING

By

Dipesh Das

A Thesis

Submitted to the Graduate Faculty

of the

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This thesis, submitted by Dipesh Das in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done, and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements for the Graduate School of the University of North Dakota, and is hereby approved.

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Dean's name

Dean of the Graduate School

December 19, 2012

Date

PERMISSION

Title	Determination of Optimum Polymer Dose for Grand Forks Wastewater Treatment Plant Lagoon Sludge Dewatering
Department	Civil Engineering
Degree	Master of Science

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Signature Dipesh Das___________

Date 12/19/2012____________

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LIST OF ACRONYMS

APF: Air Pressure Filtration

APLR: Annual Pollutant Loading Late

AWA: Australian Water Association

BOD_5: 5-Day Biochemical Oxygen Demand

CFR: Code of Federal Regulations

CFU: Colony Forming Units

CPLR: Cumulative Pollutant Loading Rate

CST: Capillary Suction Time

DAF: Dissolved Air Floatation

EPA: Environmental Protection Agency

EQ: Exceptional Quality

g: Gram

GFWWTP: Grand Forks Waste Water Treatment Plant

ha: Hectare

INC.: Incorporated

Kg: Kilograms

KPa: Kilopascal

l: Litre

lb: Pound

mg: Milligram

ml: Milliliter

mm: Millimeter

MGD: Millions Gallons per Day

MPN: Most Probable Number

NDSU: North Dakota State University

PC: Pollutant Concentration

PC2: Primary Cell 2

PFRP: Process to Further Reduce Pathogen

PFU: Plaque-Forming Units

PRV: Pressure Reducing Valve

Psi: Pressure per Square Inch

PSRP: Process to Significantly Reduce Pathogen

RAS: Return Activated Sludge

rpm: Rotations per Minute

TSS: Total Suspended Solid

TTF: Time to Filter

USEPA: United States Environmental Protection Agency

VS: Volatile Solid

Vs: Versus

WAS: Waste Activated Sludge

wt.: Weight

yr.: Year

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ABSTRACT

The Grand Forks Waste Water Treatment Plant (GFWWTP) is currently sending its waste activated sludge (WAS) from the activated sludge treatment process to an existing on-site wastewater treatment lagoon which has been in operation since 2003. The plant produces approximately 65,000 gallons of WAS per day. Because of this high level of loading, the existing lagoon system is no longer considered as a treatment option for the produced sludge. The Plant Authority is trying to find a sustainable solution for sludge disposal and for this reason the GFWWTP is interested in introducing screw press system for the dewatering process. As a part of this upgrade plan, the existing lagoon will be decommissioned. Biosolids from this lagoon will be dewatered and will be used beneficially. Polymers are used for coagulating sludge solid particles for better dewatering and bear a major part of cost associated with the dewatering process. So, choice of the appropriate polymer for dewatering and determining the optimum dose is very important from an economic point of view. Two bench top tests- Time to filter (TTF) and Air Pressure Cell Test were performed for determining the best usable polymer and optimum polymer dose. Polymers of four cationic concentrations(C 6210, C 6237, C 6257 and C 6285) were used as polymer samples. Sludge samples were collected from the Primary Cell 2 (PC2). From both test results, it was determined that C 6257 with cationic concentration of 50% is the best usable polymer out of the four. From these tests it was recommended that polymer concentration of 0.1% and solid concentration of 4.5~5.5% be used while dewatering sludge obtained from decommissioned lagoon. Polymer required from TTF test was 7.5~8.5 lbs/dry ton of solids and 4~5.5 lbs/dry ton on solids for air pressure cell test. Maximum cost for polymer associated with decommissioning of PC2 was estimated to be approximately 1.1 million USD.

CHAPTER I

INTRODUCTION

Wastewater treatment is the process of removing contaminants from wastewater. It includes different processes to remove physical, chemical and biological contaminants. Its objective is to produce an environmentally-safe fluid stream (or treated effluent) and a solid by-product (or treated sludge) suitable for disposal or reuse (usually as farm fertilizer). Using advanced technology, it is now possible to re-use sewage effluent for drinking water, although Singapore is the only country to implement such technology on a production scale in its production of NEWater (History of NEWater, 2011).

Solids collected from the wastewater treatment process which have not undergone further treatment are called sewage sludge. Once sewage sludge is treated further to significantly reduce disease causing pathogens and volatile organic matter, producing a stabilized product suitable for beneficial use, it is called biosolids. Biosolids normally contain between 3% and 90% solids (AWA, Australian & New Zeland Biosolids Partnership, 2009). Biosolids are carefully treated and monitored and they must be used in accordance with regulatory requirements.

The United States Environmental Protection Agency (USEPA) has certain regulation regarding biosolids management and these regulations are contained in USEPA 40 CFR Part 503.

The city of Grand Forks is also developing a sustainable management plan for the biosolds from the lagoon system. Dewatering the biosolids plays an important role in successful management of biosolids both environmentally and economically. This thesis has studied dewatering of biosolids. Chemical conditioning is one of the important factors that affect the dewatering. The conditioners bring the solid particles together by forming solid flocs so that dewatering becomes easier. As these conditioners are expensive, it is necessary to choose the appropriate conditioner and also to find out the optimum dose for the biosolids that need to be dewatered.

This thesis mainly focuses on the choice of a chemical conditioner for Grand Forks Wastewater Treatment Plant (GFWWTP) biosolids and determining the optimum dose based on two different laboratory procedures. One of these procedures is a standard test method and the other is a pressure based method. Both test results were used for a competitive cost analysis of polymer use for the GFWWTP lagoon sludge.

CHAPTER II

BACKGROUND

2.1 Grand Forks Wastewater Treatment Plant

The Grand Forks Waste Water Treatment Plant (GFWWTP) is the only wastewater treatment facility in the city of Grand Forks. It serves a population of nearly 55,000. It was first in operation in the year 2003. From that time, the GFWWTP has served the people of Grand Forks with wastewater treatment.

Figure 2.1: Aerial Photo of GFWWTP
Source: (Kistner, Brian T, 2011)

According to Mr. Donald Tucker, the GFWWTP superintendent, the plant is designed to handle a load of 10MGD with a peaking factor of 3 and the plant is expandable to a capacity of 15 MGD with a 35 MGD peak flow. The design rating for TSS and BOD is 1040 mg/l TSS and 480 mg/l BOD_5 respectively at the headworks. The current wastewater flow in the plant is around 5-8 MGD with 252 mg/l BOD_5 and 537 mg/l of TSS (Kistner, Brian T, 2011).

In the GFWWTP, the raw wastewater undergoes preliminary treatment through 10 mm rotary mechanical screens and vortex grit removal. After the wastewater goes through the grit chamber, 20% of this wastewater is bypassed to the lagoon and the rest moves through the remaining headwork processes by open concrete channels which are designed to have the water flow under the force of gravity. The wastewater drops down a forty-eight inch diameter steel pipe which transports the wastewater over to the distribution building. In the distribution building wastewater enters into a distribution channel. From the distribution channel, the water is transported by gravity to the biological reactors. In the reactor tanks, the wastewater gets mixed and treated by aerobic biological processes. There are different microorganisms in each tank which consume and digest various organic materials. The sludge that is produced is a combination of these microorganisms and other inert matter that is found in the wastewater.

The wastewater is sent to the flocculation basin and then to the post-aeration chambers in the distribution building after going through all in-service bioreactors. From the post-aeration chambers the wastewater then flows to the main treatment building and runs through six parallel dissolved air flotation (DAF) units. The solids are skimmed off the top of the DAF units at about 3-4 percent concentrations and collected in aerated sludge holding tanks located on the lower level of the main treatment building.

Around 85% of this sludge is pumped back to the biological processes as return activated sludge (RAS) and the rest of the sludge is pumped to the Primary Cell 2 (PC2) lagoon as waste activated sludge (WAS). The lagoon currently provides WAS volatile solids destruction through aerobic and anoxic biological processes simultaneously with treatment of the 20% raw wastewater which is bypassed to the lagoon from the headworks processes.

The schematic diagram of the GFWWTP processes is shown in figure 2.2

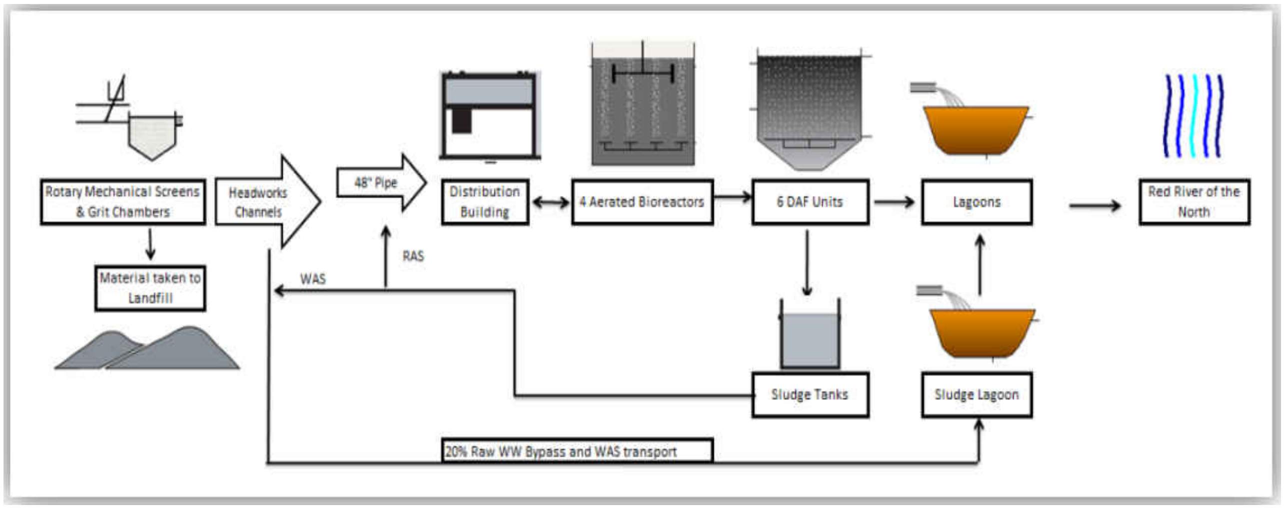

Figure 2.2: Current Schematic of GFWWTP Processes
(Source: Kistner, Brian T. 2011)

The city of Grand Forks has been operating a wastewater stabilization lagoon system since the 1970s. Although they have started the GFWWTP in 2003, they are still using the lagoon system for treating the produced sludge and discharging the wastewater effluent. The capacity of the lagoons is approximately 1.3 billion gallons at 3.5 ft depth and 1.9 billion gallons at 5 ft depth. The approximate detention time for the water is about 0.9 to 1.1 years and then the water is released to the Red River of the North to return it to the hydrological cycle. The required detention time according to the Ten State Standards is 90 - 120 days (Recommended Standards for Wastewater Facilities, 2012) for a treatment pond. In winter time, the lagoon water cannot be discharged into the river below the ice. So, a particular time is chosen to discharge the wastewater when the water is not frozen. About 2-2.5 billion gallons from the lagoons are discharged between April and November (Kistner, Brian T, 2011). This time period was chosen to avoid a high ratio of treated wastewater to freshwater because the flow of the river is medium to high during that time of the year.

As the GFWWTP is pumping around 65,000 to 125,000 GPD of WAS into the lagoon system, it is classified as a high-level activated sludge plant. To comply with the regulations of Environmental Protection Agency (EPA), the city may decommission some or all the lagoon cells and find a sustainable disposal plan for these biosolids. After decommissioning the lagoon, the biosolids might need to be dewatered depending on the management plan. Dewatering of these biosolids will involve significant cost while decommissioning the lagoon and cost estimation for dewatering prior to decommissioning the lagoon will be important. This thesis tried to estimate the cost of polymer use for the biosolids that will be produced from Primary Cell 2 (PC2).

2.2 Biosolids Management

Normally biosolids are a mix of water and organic materials which are obtained as a by-product of municipal wastewater treatment processes. Municipal wastewater comes from household kitchens, laundries and bathrooms. Biosolids may contain:

- Organic matter
- Macronutrients, such as nitrogen, phosphorus, potassium, sulphur and
- Micronutrients, such as copper, zinc, calcium, magnesium, iron, boron, molybdenum and manganese

Biosolids may also contain trace inorganic compounds, including arsenic, cadmium, chromium, lead, mercury, nickel and selenium. The USEPA has certain regulations to limit the extent of these nutrients and inorganics present in biosolids prior to use for various purposes.

Biosolids are produced by stabilizing sewage sludge. There are various ways to stabilize sewage sludge:

- Aerobic and anaerobic digestion
- Lime stabilization
- Composting
- Heat treatment

Biosolids are used for various purposes. These include:

- Co-generation/power production/energy recovery
- Land application in agricultural fields
- Land application in forestry

- Road base
- Landfill
- Daily cover in landfills
- Landscaping and topsoil
- Composting
- Incineration
- Mine reclamation

Not all boisolids can be used for all purposes. The use of biosolids depends on its nutrient level. Biosolids with a higher nutrient level are commonly used as fertilizers in the agricultural lands. Biosolids, enriched with nitrogen (N), phosphorus (P) and lime (after lime stabilization), are the best to be used as fertilizers. Biosolids also supply essential plant nutrients such as sulfur (S), manganese (Mn), Zinc (Zn), copper (Cu), iron (Fe), molybdenum (Mo) and boron (B). Biosolids lacking in these nutrients are often used for other purposes than fertilizing soil. These purposes include use of biosolids as road base, as daily cover in landfills, for landscaping and topsoil on dams, for incineration and mine reclamation. For Example, the Fargo Wastewater Treatment Plant send their biosolids to the Fargo landfill and these biosolids are used for producing methane which is used for commercial purpose. (History of Fargo Wastewater Treatment Plant, 2011).

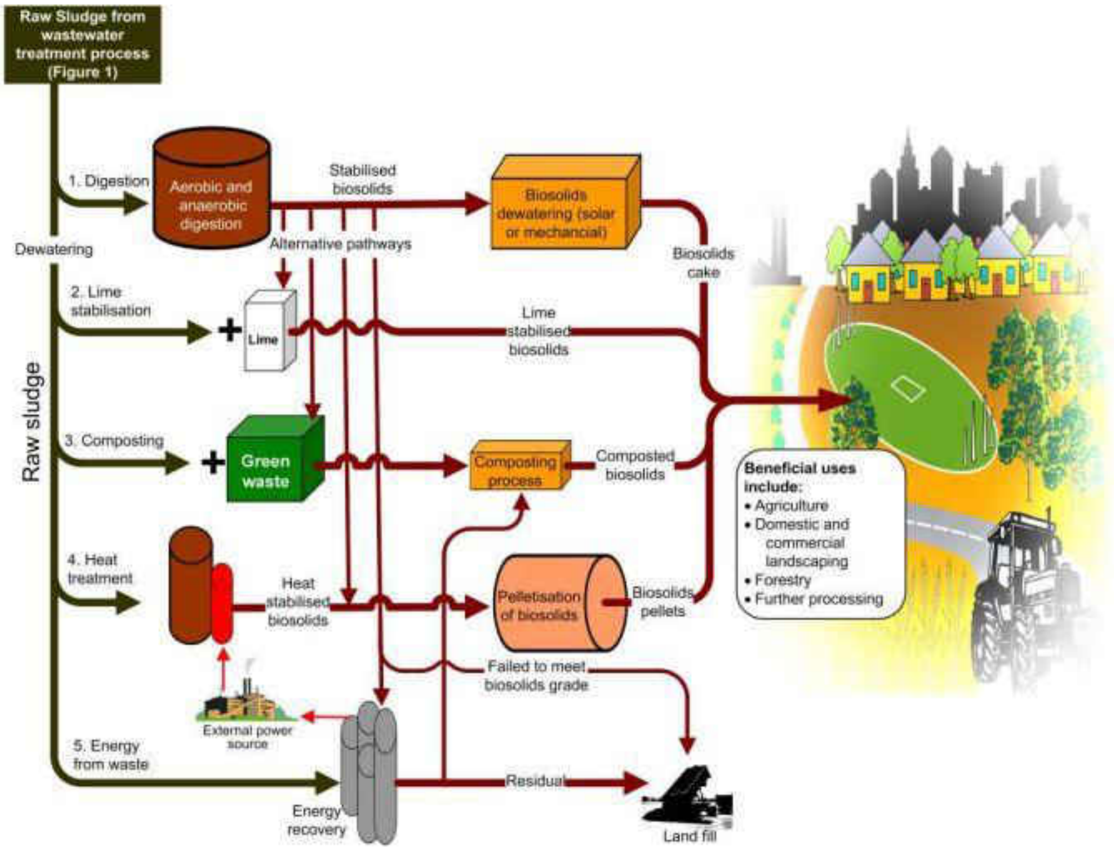

Figure 2.3: Typical Production Systems for Biosolids with Possible Alterative Production Pathways

The USEPA developed regulations to protect public health and environment from the adverse effects of specific pollutants that might be present in biosolids as a requirement of the Clean Water Act Amendments of 1987. The EPA does not have any regulations for the sewage sludge treatment process. They only regulate the disposal or utilization methods. These regulations are cited in Title 40 of the Code of Federal regulations (CFR) Part 503.

Title 40 CFR Part 503 defined the management practices and numerical criteria for the three major use and disposal options for biosolids – land application, incineration and surface disposal – that will protect public health and the environment. In addition to limiting where and when biosolids can be applied, the rule requires processes to kill pathogens and strictly limits amounts of metals that can be applied to any piece of land.

Federal, state and local governments play crucial roles in enforcing the Part 503 rule. Local government is also responsible for addressing related local concerns. North Dakota does not have any permitting laws regarding biosolids; therefore, the permit would come from the EPA. However, the North Dakota Department of Health receives a copy of the permit. Compliance with the permit would consist of monitoring and recording of sludge quantity, quality, distribution rates, and other information.

2.3 Regulations for Land Application

When biosolids are applied to land for either conditioning the soil or fertilizing crops or other vegetation growth in the soil, the process is called land application. Normally two types of land are benefited by the application of biosolids- nonpublic contact sites (areas not frequently visited by people) and public contact sites (areas where people are likely to come into contact with biosolids applied to land).

Biosolids are generally applied to land using various techniques. They may be spread above the soil surface. They also may be incorporated into the soil after being spread on the surface or injected directly below the soil surface. Liquid biosolids can be applied using tractors, tank wagons or other special application vehicles. Dryer biosolids are applied using equipment similar to that used for applying limestone, animal manures or commercial fertilizers. (A Plain Guide to the EPA Part 503 Biosolids Rule, 2012) Biosolids must meet the land application requirement before being land applied. These requirements are discussed below:

1. All biosolids applied to land must meet the ceiling concentrations for pollutants. These pollutant concentration limits are listed in Table 2.1, page 12.
2. Land applied biosolids also needs to meet either pollution concentration limits or cumulative pollutant loading rate limits or annual pollutant loading rate limits.
3. Before land application of biosolids, one of Class A and Class B requirements and site restrictions must be met. The two classes differ based on the level of pathogen reduction obtained after treatment.
4. Vector attraction requirements must be met before land application of biosolids.

The EPA guide for Part 503 has four different options for meeting pollutant limits and pathogen and vector attraction requirements. These options are:

- The Exceptional Quality (EQ) option
- The Pollutant Concentration (PC) option
- The Cumulative Pollutant Loading Rate (CPLR) option
- The Annual Pollutant Loading Rate (APLR) option

Table 2.1: Pollutant Concentration Limits for Land Application of Biosolids

Pollutant Name	Ceiling Concentration Limits for All Biosolids Applied to Land (mg/kg)	Pollutant Concentration Limits for EQ and PC Biosolids (mg/kg)	Cumulative Pollutant Loading Rate Limits for CPLR Biosolids (kg/ha)	Annual Pollutant Loading Rate Limits for APLR Biosolids (kg/ha/yr)
Arsenic	75	41	41	2
Cadmium	85	39	39	1.9
Chromium	3,000	1,200	1,200	150
Copper	4,300	1,500	1,500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum	75	--	--	--
Nickel	420	420	420	21
Selenium	100	36	36	5
Zinc	7,500	2,800	2,800	140
Limits applies to	All land applied biosolids	Biosolids in bulk and bagged biosolids	Biosolids in Bulk	Bagged biosolids

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

The EQ and APLR biosolids are Class A biosolids and have no site restrictions for land application while PC and CPLR biosolids can be either Class A or Class B biosolids and may have site restrictions depending on their class. PC, CPLR and APLR biosolids need general requirements and management practices while the EQ biosolids do not.

EPA categorizes biosolids as either Class A or Class B depending on the pathogenic organisms in it. EPA also describes specific processes to reduce pathogens to these levels.

2.4 Class A Biosolids

Class A biosolids contain minute levels of pathogens. To achieve Class A certification, biosolids must undergo heating, composting, digestion or increased pH that reduces pathogens to below detectable levels. Some treatment processes change the composition of the biosolids to a pellet or granular substance, which can be used as a commercial fertilizer. Once these goals are achieved, Class A biosolids can be land applied without pathogen-related restrictions at the site. Class A biosolids can be bagged and marketed to the public for application to lawns and gardens.

2.5 Class B Biosolids

Class B biosolids have less stringent standards for treatment and contain small, but compliant amounts of bacteria. Class B requirements ensure that pathogens in biosolids have been reduced to levels that protect public health and the environment and include certain restrictions for crop harvesting, grazing animals and public contact for all forms of Class B biosolids. As is true of their Class A counterpart, Class B biosolids are treated in a wastewater treatment facility and undergo heating, composting, digestion or increased pH processes before leaving the plant. This semi-solid material can receive further treatment when exposed to the natural environment as a fertilizer, where heat, wind and soil microbes naturally stabilize the biosolids.

There are six alternatives for meeting Class A pathogen requirements. For being classified as Class A biosolids, one of these six alternatives should be met. These alternatives are listed in table 2.2 and 2.3:

Table 2.2: Summary of Class A Pathogen Reduction Requirements

Alternative 1: Thermally treated Biosolids

Biosolids must be subjected to one of four time-temperature regimes. These regimes are listed in Table 2.3.

Alternative 2: Biosolids treated in a high pH-High Temperature Process

Biosolids need to meet specific pH, temperature and air drying requirements.

Alternative 3: Biosolids treated in other processes

Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration after the demonstration is completed.

Alternative 4: Biosolids Treated in Unknown Processes

Biosolids must be tested for *Salmonella* sp. or fecal coliform bacteria, enteric viruses, and viable helminth ova at the time the biosolids are used or disposed

Alternative 5: Biosolids Treated in PFRP

Biosolids must be treated in one of the Processes to Further Reduce Pathogens (Table 2.5)

Alternative 6: Biosolids Treated in a Process Equivalent to a PFRP

Biosolids must be treated in a process equivalent to one of the PFRPs as determined by the permitting authority.

Table 2.3: Time-Temperature Regimes for Meeting Class A Requirements

Regime	Applies to	Requirement	Time-Temperature Relationship
A	Biosolids with 7% solids or greater (Except those covered by Regime B	Temperature of Biosolids must be 50°C or higher for 20 minutes or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
B	Biosolids with 7% solids or greater in the form of small particles and heated by contact with either warmed gases or an immiscible liquid	Temperature of Biosolids must be 50°C or higher for 15 seconds or longer	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
C	Biosolids with less than 7% solids	Heated for at least 15 seconds but less than 30 minutes	$D = \frac{131{,}700{,}000}{10^{0.14t}}$
D	Biosolids with less than 7% solids	Temperature of sludge is 50°C or higher with at least 30 minutes or longer contact time	$D = \frac{50{,}070{,}000}{10^{0.14t}}$

*D=time in days and t= temperature in degree Celsius
(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Also the pathogen requirements must be met for all the alternatives to be considered as Class A biosolids. As per the pathogen requirement either the density of fecal coliform must be less than 1,000 most probable numbers (MPN) per gram total solids (dry-weight basis) (A Plain Guide to the EPA Part 503 Biosolids Rule, 2012) or the density of *Salmonella* sp. bacteria must be less than 3 MPN per 4 grams of total solids (dry-weight basis) (A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

For being considered as Class B, biosolids need to meet one of the three alternatives listed in table 2.4.

Table 2.4: Summary of Class B Pathogen Reduction Requirements

Alternative 1: The monitoring of Indicator Organism

Test for fecal coliform density as an indicator for all pathogens. The geometric mean of seven samples shall be less than 2 million MPNs per gram per total solids or less than 2 million CFUs per gram of total solids at the time of use or disposal.

Alternative 2: Biosolids treated in a PSRP

Biosolids need to be treated in one of the Processes to Significantly Reduce pathogens (PSRP) Table: 2.6

Alternative 3: Biosolids treated in a Process Equivalent to PSRP

Biosolids must be treated in a process equivalent to one of the PSRPs, as determined by the permitting authority.

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

2.6 Pathogen and Vector Attraction Reduction Requirements

Biosolids need to meet pathogen and vector reduction requirements prior to land application. Pathogens are organisms causing diseases such as specific types of bacteria, viruses and parasites. Vectors are rodents, birds and insects that can spread disease by carrying and transferring pathogens. For counting the microorganisms in the sludge sample, different methods exist for different types of pathogens. Helminth ova are counted as individuals, viruses are counted in plaque-forming units (PFU), and bacteria are counted in colony-forming units (CFU) or most probably number (MPN).

In 40 CFR Part 257 two processes are documented for pathogen reduction-

1. Process to further reduce pathogens (PFRP)
2. Process to significantly reduce pathogens (PSRP)

Class A biosolids are associated with PFRP and Class B biosolids are associated with PSRP. These processes are described in Table 2.5 and 2.6 respectively.

Table 2.5: Processes to Further Reduce Pathogens (PFRP)

Process No.	Process Name	Description
1	Composting	Temperature should be maintained at 55°C or higher for 3 days with either in-vessel composting or static aerated pile composting. For windrow composting the temperature should be maintained at 55°C or higher for 15 days and the windrow is turned a minimum of 5 times
2	Heat Drying	Biosolids are dried by direct or indirect contact with hot gases to reduce the moisture content to 10% or lower. The temperature of the solid particle should exceed 80°C
3	Heat Treatment	Liquid biosolids are heated to 180°C for 30 minutes
4	Thermophilic Aerobic Digestion	Liquid biosolids are agitated with air or oxygen to maintain aerobic conditions and the mean cell residence time will be 10 days between 55°C to 60°C
5	Beta Ray Irradiation	Biosolids are irradiated with beta ray at a dosage of at least 1 megarad at room temperature
6	Gamma Ray irradiation	Biosolids are irradiated with gamma ray from certain isotopes at room temperature
7	Pasteurization	The temperature of biosolids is maintained at 70°C or higher at a time period of 30 minutes or longer

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Table 2.6: Processes to Significantly Reduce Pathogens (PSRP)

Process No.	Process Name	Description
1	Aerobic digestion	Biosolids are agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time at a specific temperature. The Mean cell residence time should be between 40 days at 20°C and 60 days at 15°C.
2	Air drying	Biosolids are dried for at least 3 months on sand beds or paved or unpaved basins. The ambient temperature should be more than 0°C for more than 2 months.
3	Anaerobic digestion	Biosolids are treated in absence of air for a specific mean cell residence time at a specific temperature. Mean cell residence time should be 15 days at 35°C to 55°C and 60days at 20°C.
4	Composting	Biosolids may be composted by using either in-vessel, static aerated pile or windrow piling method. The temperature should be 40°C or higher for 5 days and within those 5 days temperature should exceed 55°C for 4 hours.
5	Lime stabilization	The pH of the biosolids should be raised to 12 with sufficient lime after 2 hours of contact

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

2.7 Vector Attraction Reduction Requirements

When the pathogens in the biosolids come into contact with human or other susceptible hosts as plant or animal, they pose a significant amount of risk of spreading diseases. Pathogens can be transmitted to human and other sources by vectors such as birds, flies, mosquitoes, flea and rodents. So, chances for transmitting diseases from pathogens in biosolids decreases if vectors are less attracted to it.

40 CFR Part 503 contains 12 options for vector attraction reduction which are summarized in table 2.7. These requirements are designed to either reduce the attractiveness of biosolids to vector contact with the biosolids.

Table 2.7: Summary of Options for Meeting Vector Attraction Reduction

Option No.	Description
1	Meet the 38% volatile solids content reduction
2	Demonstration of vector attraction reduction with additional anaerobic digestion in a bench scale unit
3	Demonstration of vector attraction reduction with additional aerobic digestion in a bench scale unit
4	Meet a specific oxygen uptake rate for aerobically digested biosolids
5	Use the anaerobic process at 40°C for 14 days or longer
6	Alkali addition under specified conditions
7	Dry biosolids with no unstabilized solids to at least 75% solids
8	Dry biosolids with unstabilized solids to at least 90% solids
9	Inject biosolids beneath the soil surface
10	Incorporate biosolids into the soil within 6 hours of application to or placement on a land
11	Cover biosolids placed on a surface disposal site with soil or other material by the end of each operating day
12	Alkaline treatment of domestic septage to pH 12 or above for 30 minutes without adding more alkaline material

(Source: A Plain Guide to the EPA Part 503 Biosolids Rule, 2012)

Among these options, No. 12 is only for domestic septage. For fulfilling the vector attraction reduction requirements, one of the first eleven options should be met.

2.8 Surface Disposal of Biosolids

When biosolids are placed on a certain area of land, the practice is called surface disposal of biosolids. Surface disposal sites may be used for beneficial purposes as well as for final disposal. Surface disposal sites include monofills, surface impoundments, lagoons, waste piles, dedicated disposal sites and dedicated beneficial use sites.

There are some other requirements for surface disposal of biosolids. The part 503 standard for surface disposal of biosolids includes:

- General requirements
- Pollutant limits
- Management practices
- Operational standards for pathogen and vector attraction reduction
- Frequency of monitoring requirements
- Record keeping requirements and
- Reporting requirements.

CHAPTER III

LITERATURE REVIEW

3.1 Sludge Dewatering

Sludge dewatering refers to reduction of moisture content from sludge. The general objectives of sludge dewatering are to reduce the volume of sludge by removing the water content, to produce a material which is semi-solid not a liquid and to reduce the cost of subsequent treatment and disposal processes. There are no lower limits for the percent solids content in dewatered sludge. Normally the lower limit is set by the authority responsible for the management of sludge.

3.2 Sludge Dewatering Processes

Dewatering processes are usually divided into natural and mechanical methods. Natural dewatering methods include those methods in which moisture is removed by evaporation or gravity or induced drainage such as sand beds, biosolids lagoons, paved beds, vacuum assisted beds, wedge water beds and dewatering via freezing. These natural processes are less controllable than the mechanical processes.

Mechanical dewatering equipments are-

- Belt filter presses
- Centrifuges

- Rotary disc press
- Inclined screw press
- Horizontal screw press

3.2.1 Belt Filter Press

Belt filter presses have been the industry standard for many years and continue to be a suitable alternative for many plants. There are many manufacturers of presses and there have been many improvements with these systems over the years. While these systems are relatively simple to operate and most plant operators are familiar with them, they are more difficult to control for odor mitigation.

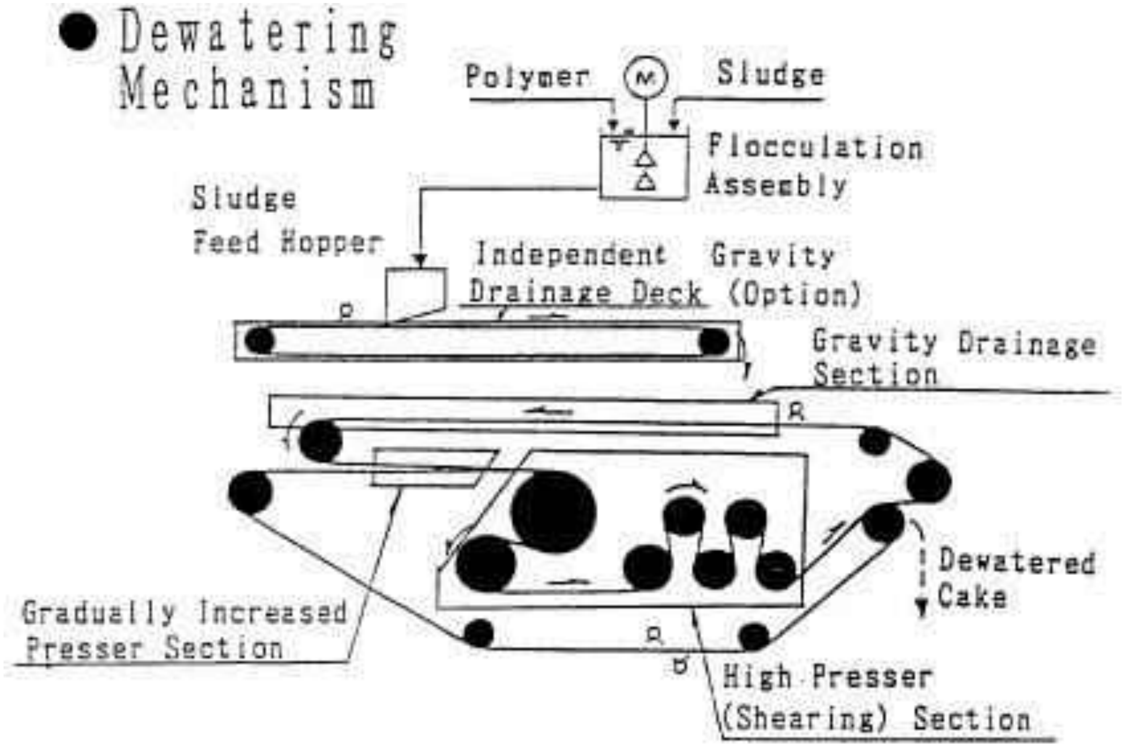

Figure: 3.1 Cross Section of a Belt Filter Press

3.2.2 Centrifuges

Centrifuges have been around for a long time and the latest generation of equipment is vastly superior to early generations of centrifuges. There are several reliable manufacturers of centrifuges. While they are a speed dewatering device (typically about 3000 rpm) (Atherton, Peter C., 2012) requiring the need for regularly scheduled maintenance work, these systems are remarkably reliable and operator friendly. Their flexibility handles changing sludge conditions and they perform well in straight activated sludge applications. Centrifuges often produce the driest sludge cake. They are also self-contained, making odor control easier. Wright Pierce has recently designed centrifuge systems for a number of large plants with incinerators and for several smaller and mid-sized plants that do not have primary sludge.

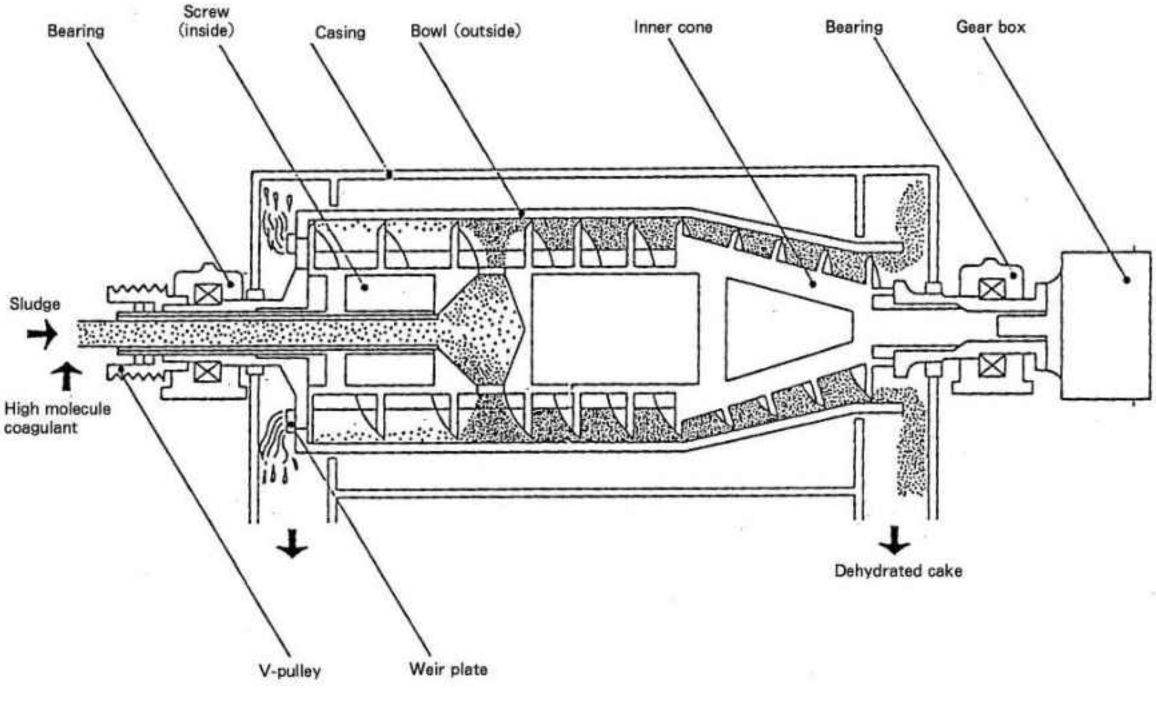

Figure: 3.2 Cross Section of a Dewatering Centrifuge

3.2.3 Rotary Disc Press

The rotary disc press technology is a relatively new technology introduced numbers of years ago by Fournier Industries, a Canadian manufacturer. The technology has been recently modified and other manufacturers have been introduced to the market. This system involves feeding flocculated sludge between two parallel, rotating screens within each disc assembly which rotate very slowly on a single shaft (typically between 1 and 3 rpm) (Atherton, Peter C., 2012). The dewatering equipment can contain from 1 to 6 discs assemblies per unit. Operators of these systems like the slow rotational speed and the fact that they are self contained. These systems work best with a significant primary sludge fraction.

Figure: 3.3 Rotary Disc Press

3.2.4 Inclined Screw Press

The inclined screw press technology was introduced to the treatment plant market in Europe well over a decade ago by Huber Technology, a German manufacturer (Atherton, Peter C., 2012). This system involves feeding flocculated sludge into an inclined screw rotating inside a stainless steel wedge wire screen. Like the rotary disc press, the screw press is self contained and operates at a very slow operational speed.

Figure: 3.4 Inclined Screw Press

3.2.5 Horizontal Screw Press

The horizontal screw press is very similar to the inclined screw press, except that it is configured in a horizontal arrangement. Generally, the horizontal press is considered where there are higher capacity requirements and a need for a custom designed press to match anticipated sludge quantities. FKC, a Japanese manufacturer (Atherton, Peter C., 2012), had marketed these for years in the pulp and paper industry as well as other industrial sectors, and more recently they have been marketing these to municipal treatment plants. The FKC press can also be configured to stabilize the sludge with quick lime and steam to produce a Class A Biosolids. Huber also makes a horizontal screw press. Wright Pierce is currently designing the first municipal application of a horizontal screw press in New England for Merrimack, NH (Atherton, Peter C., 2012).

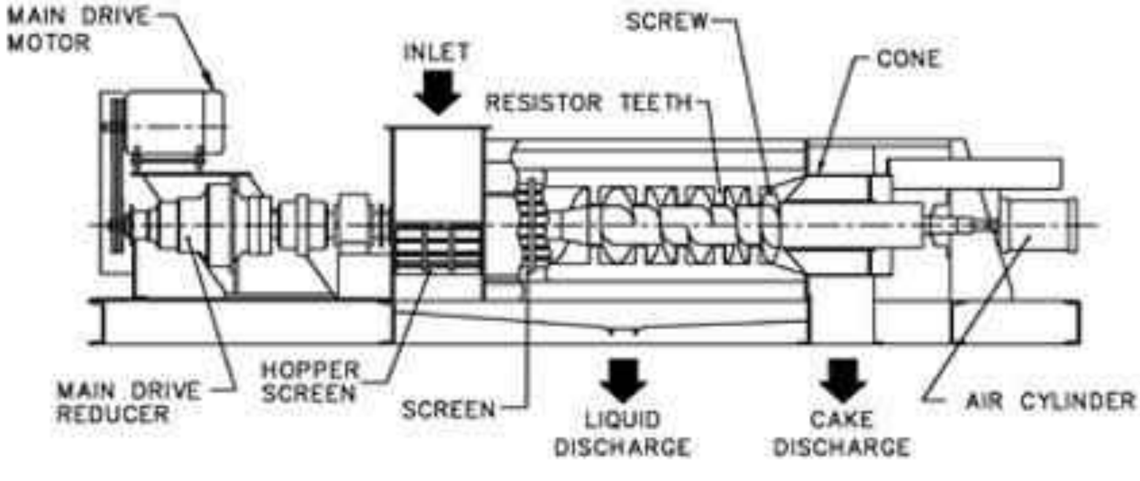

Figure: 3.5 Cross Section of a Horizontal Screw Press

The best dewatering solution for a facility is a function of many variables such as the sludge quantity and characteristics, the sludge disposal methodology, available space to house the equipment, the dewatering time period, the desire for containment to minimize odors and operator preferences. Often it is desirable to pilot test the various alternatives and then perform a life cycle cost analysis to select the best solution for the treatment facility. The wastewater treatment authorities should also visit other plants with the technology they are considering to check out the equipment and gain a first-hand understanding of the operational requirements. Upgrading antiquated dewatering equipment can pay big dividends in terms of operational and disposal cost savings, reduced operator attention, and improved odor control.

3.3 Distribution of water in sludge

Water in sludge may be divided into a number of moisture types which are defined in terms of moisture to solids bond strength. The knowledge of this distribution is very important in cost effective sludge volume reduction process. On the basis of experimental data, Smollen (1986) defined the following municipal sludge moisture contents.

3.3.1 Free Moisture

This type of moisture is minimally bound to solids and it can be separated by gravity.

3.3.2 Immobilized Moisture

This type of moisture is floc-entrapped and it is characterized by a low amount of binding energy. It can be removed by the application of energy in the form of mechanical dewatering.

3.3.3 Bound Moisture

This type of moisture is strongly absorbed into sludge particles and requires processes like electro-osmotic dewatering and, or thermal drying.

3.3.4 Chemically Bound Moisture

This type of moisture is bound to sludge particles by strong chemical bond and can be removed by thermal drying at a temperature higher than 105°C.

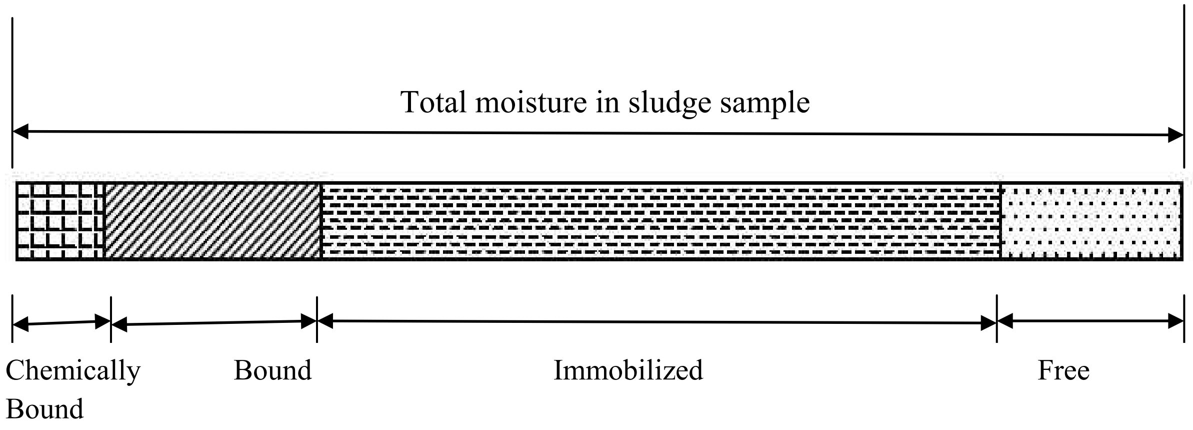

Figure 3.6: Categories of Moisture in Municipal Sludge

Figure 3.6 shows a typical distribution of moisture types in sludge. Free moisture in a sludge sample is normally 8-10% of the total water content. (Smollen,1986). Immobilized water, which can be separated from the solids through mechanical dewatering systems, is the largest among the four types of moisture content. The percentage varies from 20-85% depending on the sludge quality and the conditioning chemical used. Bound water holds a small percentage and this type of moisture cannot be removed by mechanical systems with or without the help of chemical conditioning. The last type of moisture is the smallest in percentage. This type of moisture is chemically attached with the solid particles and can only be separated by a temperature above 105°C.

Before the selection of dewatering process, it’s really important to determine the percentage of moisture types in the sludge that needs to be dewatered.

3.4 Different Types of Municipal Wastewater Sludge

The choice of dewatering aid is also dependent on the sludge type. Sludge types are categorized based on their origin and treatment processes.

3.4.1 Primary Sludge

Primary sludge is the outcome of a settling process in a primary clarifier. It is made of large and/or dense particles which is easy to dewater. The level of volatile solids in this type of sludge is low, around 55% to 60% (Sludge dewatering, SNF). This type of sludge is very easy to thicken prior to dewatering.

3.4.2 Biological Sludge

If the sludge is treated biologically, the sludge is called biological sludge. It is a mixture of microorganisms. These microorganisms, mainly bacteria, form bacterial flocs. These flocs can easily be taken out from the treated water by a simple decantation. This type of sludge is normally recirculatd to the reactor to maintain the bacterial population. The main properties of biological sludge are:

- High volatile solids (VS) content (around 70% to 80%) (SNF- Sludge dewatering, 2011)
- Low dry solids content (7g/l to 10g/l) (SNF-Sludge dewatering, 2011)
- Medium dewaterability. Generally, sludge with higher volatile solids content exhibits lower dewaterability.

3.4.3 Mixed Sludge

This type of sludge is a mixture of primary and biological sludge. Normally mixed sludge is preferred for dewatering. The mixing ratio for the mixed sludge is often as follows:

- 35% to 45% primary sludge
- 55% to 65% biological sludge

3.4.4 Digested Sludge

Digested sludge is obtained by a biological stabilizing step in the digestion process. Typically the biological or the mixed sludge is stabilized to get the digested sludge. Different temperatures might be used for digestion. Oxygen may or may not be present in this process.

3.5 Sludge Characteristics Affecting Dewaterability

Dewaterability of waste sludge is influenced by many factors. The sludge source, its treatment procedure and storage, which can change the sludge characteristics, are among those factors. But to be specific, all characteristics are related to the difficulty of forcing sludge solids closer together or to the difficulty of separating the water from the solid cell bodies. The sludge characteristics that influence the dewaterability most significantly are:

- Surface charge and hydration
- Particle size distribution
- Compressibility of the cell body
- Temperature of the sludge
- Ratio of volatile solids to fixed solids
- Sludge pH
- Septicity

3.5.1 Surface Charge and Hydration

As the sludge particles have a negative surface charge, they repel each other when they are forced together. Exponential increase of this repulsive force is observed when they are forced even closer together. Moreover, sludge particles attract water molecules to their surface either by adsorption or by capillary action between particles. This water interferes with dewatering although it is only weakly held at the particle surface.

To overcome the effects of surface charge and hydration, conditioning chemicals are used. Typically organic polymers, lime and ferric chloride are used as conditioning chemicals. These chemicals allow the particles to come together by reducing or eliminating the repulsive force.

3.5.2 Particle Size

The most important factor that influences dewaterability is the particle size. The surface area for a given sludge mass increases with a decrease in particle size. The increased surface area also influences some other things. These include

- Higher electrical repulsion between sludge particles because of a larger area of negatively charged surface
- Greater frictional resistance to the movement of water
- Higher attraction of water to the particle surface due to more adsorption sites

Both the sludge source and treatment process influence the particle size. Typically primary sludge has a larger average particle size than secondary sludge. Sludge treatment prior to dewatering by aerobic or anaerobic digestion also decreases the average particle size. For these reasons digested sludge is more difficult to dewater than raw sludge. Other conditions which can decrease the particle size are mixing, storage and sludge transport. These conditions should be minimized in order to maximize the dewaterability.

3.5.3 Compressibility

For idealized incompressible solids, the solids do not deform under pressure and the void area between particles remains the same during mechanical dewatering. In this ideal situation resistance to filtration is proportional to the depth of sludge and no increase in resistance is observed during the dewatering process. But municipal sludge particles are compressible to a degree, which results in particular deformation and reduction in void area between particles. The movement of water is inhibited through the void area by this reduction in volume and thus dewaterability is reduced.

Proper conditioning improves dewaterability by producing a flocculant matrix of solids in relatively clear water prior to initiation of filtration (EPA-Sludge dewatering manual, 1987). Conditioning causes rapid removal of water through the pores of the sludge particles.

3.5.4 Sludge Temperature

The viscosity of the water present in the sludge mass decreases with an increase in the sludge temperature. In the centrifugal dewatering process viscosity is an important factor as sedimentation is a key component of this process. From stokes law, we know that the terminal settling velocity during centrifugal acceleration varies according to an inverse linear relationship with viscosity of the water. Dewatering processes using the filtration principle are not that much affected by the sludge temperature.

3.5.5 Ratio of Volatile solids to Fixed Solids

Sludge with higher fixed solids content is easier to dewater considering all other factors to be equivalent (EPA-Sludge dewatering manual, 1987).

3.5.6 Sludge pH

Sludge pH affects the surface charge on sludge particles and also influences the type of polymer needed for proper conditioning. If the sludge has a high pH, anionic polymers are most useful. On the other hand, cationic polymers are most used when the pH range of the sludge is very near to neutral (EPA-Sludge dewatering manual, 1987).

3.5.7 Septicity

Septic sludge is more difficult to dewater than fresh sludge and requires higher dosage of conditioning polymer (Sludge dewatering manual, EPA). This is most likely because of a reduction in the size of the sludge particles and generation of gases that remain entrained in the sludge (EPA-Sludge dewatering manual, 1987).

3.6 Sludge Conditioning

Chemical conditioners are used to improve sludge dewaterability by acting as coagulants as well as flocculants. Normally, ferric chloride ($FeCl_3$), lime (CaO) and organic polymers are used as chemical conditioners. The application of conditioning chemicals is very much dependent on sludge characteristics and the parameters of the conditioning chemical. Experiments should be performed for selecting the appropriate chemical and its optimum dosage for sludge dewatering, taking all other factors into consideration.

3.6.1 How Conditioning Chemicals Work on Sludge Particles

There are mainly four types of microscopic forces that act on sludge particles

- Electrostatic repulsive force
- Brownian motion
- Van Der Waals attraction force
- Gravitation force

Sludge particles act as small colloidal particles in water. These particles are generally negatively charged. So, these particles are surrounded by an equal number of positive counter ions. As a result of that, the particles repel each other because of the electrostatic force. When a cationic polymer comes into contact with the sludge particles, it neutralizes the negative charge on the particles. The Van Der Waals force of attraction then becomes stronger than the electrostatic repulsive force and the particles come closer to each other and coagulate. As the sludge particles are colloidal, they have a tendency to move around with Brownian motion. After coagulation, the particles tend to settle under the effect of gravity. The settling rate of the particles can be measured using Stoke's law.

$$v = 2Gr^2(\rho - \rho_o)/9\eta$$

Here,

v= Settling rate

G= Gravitational Constant

r= Radius of particles

ρ= Density of particle

ρ_o= Density of liquid

η= Viscosity of liquid

After coagulation, the polymers start bridging the microflocs and the particles get bigger in size. With the increase in floc size, sludge particles become easier to dewater.

3.6.2 Parameters of the Conditioning Chemical that Influence Dewatering

The conditioning chemicals are characterized by five main parameters:

- The type of charge
- Charge density
- Molecular weight
- Molecular structure
- Type of Monomer

3.6.2.1 The Type of Charge

The type of charge of a conditioning polymer is selected based on the type of particles. Normally an anionic chemical is used to catch mineral particles and a cationic chemical is used to catch organic particles (SNF-Sludge dewatering, 2011).

3.6.2.2 Charge Density

The charge density of a chemical is represented by the quantity of negative or positive charge required to get the best flocculation at the lowest possible dose. The charge density depends on the type of sludge that needs to be treated. For municipal sludge, the charge density is a function of organic matter which is related to the volatile solids content. Need of cationic charge increases with an increase in the volatile solids content. Figure 3.7 shows different polymer charge used for different types of sludge.

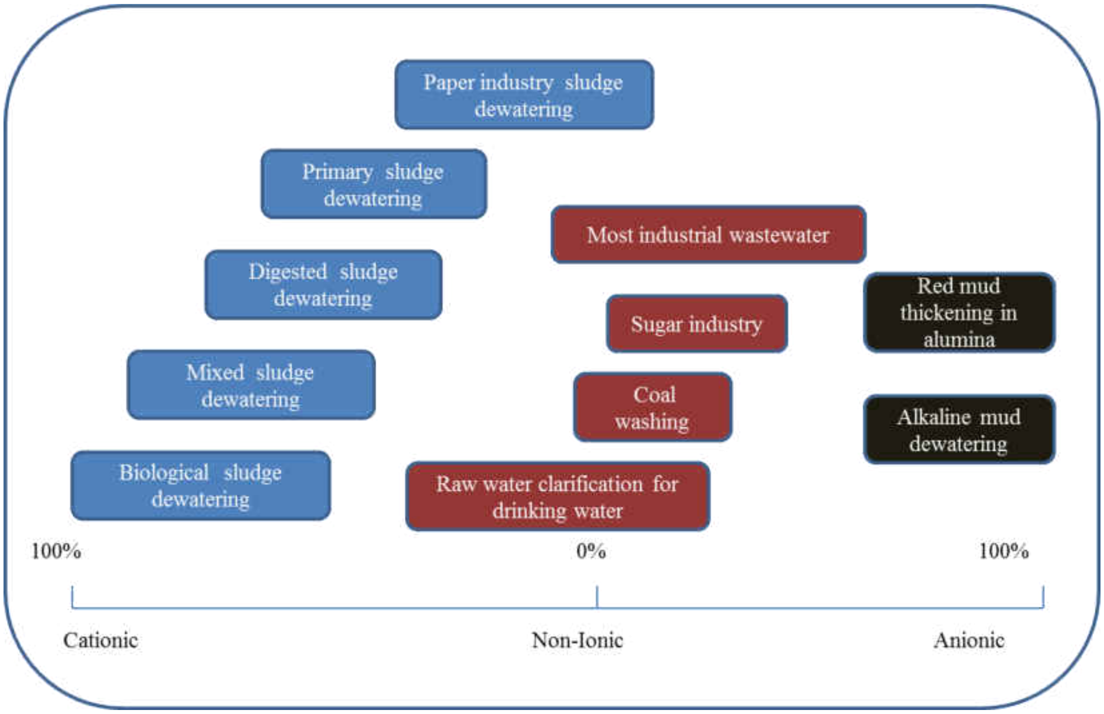

Fig 3.7: Charge Density for Different Types of Sludge

Figure 3.7 explains the effect of polymer charge density on different types sludge dewatering. For thickening of red mud and alkaline mud in water, polymers of higher anionic charge are best to use. Most industrial wastewater sludge, sugar industry sludge and coal washing sludge require lower anionic charged polymer. Polymer of neutral charge density or lower anionic or cationic charge is needed for clarification of raw water. Polymer of lower cationic charge density works best for dewatering paper industry sludge. Cationic charge density of 10~40% should work better on primary sludge while cationic charge density of 20~50%, 35~70% and 50~100% should work better for digested sludge, mixed sludge and biological sludge respectively. (SNF- Sludge dewatering, 2011)

3.6.2.3 Molecular Weight

Selection of molecular weight of a conditioning chemical and polymer chain length depends on the type of equipment used for dewatering. As high shearing is applied to the flocs in a centrifuge, a high to very high molecular weight is preferred. For the filtration process, a low to medium molecular weight is more suitable (SNF-Sludge dewatering, 2011).

3.6.2.4 Molecular Structure

The molecular structure of the conditioning chemical is selected based on the dewatering performance required. There are three types of structure for cationic conditioners:

- Linear structure: When the correct molecular weight is chosen, this type of structure works with low dosage. The drainage condition is good for this type of structure. (SNF-Sludge dewatering, 2011)
- Branched structure: This structure provides excellent drainage performance with medium dosage. (SNF-Sludge dewatering, 2011)
- Crossed linked structures: This type of structure provides exceptional drainage performance and shear resistance. (SNF-Sludge dewatering, 2011)

3.6.3 Sludge Conditioning Before Flotation Separation

Sludge conditioning before flotation separation is strongly recommended although it is not necessary. Polymers are used to ensure better flotation of the sludge particles. There are some key parameters that need to be considered in selecting the best usable conditioner before flotation. For laboratory testing these key parameters are:

- ✓ Floc size
- ✓ Overflow quality
- ✓ Floc formation speed
- ✓ Shear resistance of the flocs (SNF-Sludge dewatering, 2011)

For plant trials the key parameters are:

- ✓ Sludge flow
- ✓ Polymer flow
- ✓ Injection point of the polymer
- ✓ Capture rate of the sludge
- ✓ Floating sludge concentration (SNF-Sludge dewatering, 2011)

CHAPTER IV

SOLID-LIQUID SEPERATION

4.1 Filtration Theory

Filtration is a fluid-solid mixture separation process in which a porous barrier permits the fluid to pass through it and retains most of the solid particulates contained in the mixture. Filtration is a unit operation with a filter medium used as a barrier which lets the liquid pass while retaining most of the solids. A screen, cloth, paper or bed of solids is mainly used as a filter media. The liquid that passes through the filter media is called filtrate.

Scientists has developed a significant and detailed filtration theory over the years but a solid-liquid system which is both fast and accurate to determine filter requirements with small scale tests is hard to find with this theory. However, filtration theory shows how the small scale test data can be correlated and extrapolated for use in scale-up calculation.

As filtration proceeds, a porous cake of solid particles is built up on a porous medium, usually a filter paper or filter cloth. As the pores of the medium are very fine, the flow of the liquid is laminar and it can be represented by the equation

$$Q = \frac{dV}{dt} = \frac{A\Delta P}{\mu R} \qquad 4.1$$

The resistance R combines the resistance of the filter paper or cloth R_f and that of the cake R_c which may be assumed proportional to the mass of the cake. Accordingly,

$$Q = \frac{dV}{dt} = \frac{A\Delta P}{\mu(R_f + R_c)} = \frac{A\Delta P}{\mu(R_f + \alpha cV/A)} \qquad 4.2$$

α= Specific resistance of the cake (m/kg of solids)

c= Wt of solids/volume of liquid (kg of solids/m^3 of filtrate)

μ= Viscosity (N sec/m^2)

P= Pressure difference (N/m^2)

A= Filtering surface (m^2)

V= Volume of filtrate (m^3)

Q= Rate of filtrate accumulation (m^3/sec)

R_f and α are constants of the sludge and equipment and must be evaluated from experimental data. The simplest data to analyze are those obtained from constant pressure or constant rate tests for which the equation will be developed. At constant pressure equation 4.2 is integrated as

$$\frac{A\Delta P}{\mu} t = R_f V + \frac{\alpha c}{2A} V^2 \qquad 4.3$$

And is recast into linear form as

$$\frac{t}{V/A} = \frac{\mu}{\Delta P} R_f + \frac{\mu \alpha c}{2\Delta P} \frac{V}{A} \qquad 4.4$$

The constant R_f and α are derivable from the intercept and slope of the plot of t/V against V. If the constant pressure period sets in when $t=t_o$ and $V=V_o$, equation 4.4 becomes

$$\frac{t - t_0}{V - V_o} = \frac{\mu}{A\Delta P} R_f + \frac{\mu \alpha c}{2A^2 \Delta P}(V + V_o) \qquad 4.5$$

A plot of the left hand side against $V+V_o$ should be linear.

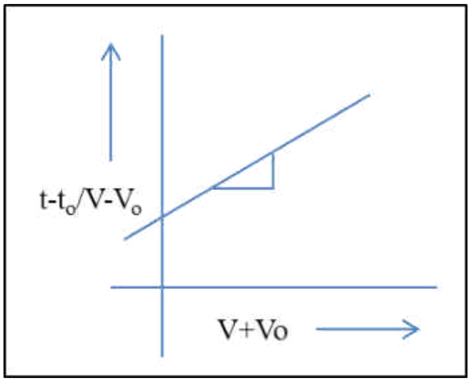

Figure 4.1: t-t_o/V-V_o Vs V+V_o Graph

In Figure 4.1, if the values of t-t_o/V-Vo is put on the Y axis and the values of V+V_o are put in X axis, $\frac{\mu}{A\Delta P}R_f$ will be the Y intercept and $\frac{\mu\alpha c}{2A^2\Delta P}$ will be the slope.

At constant rate of filtration, equation 4.2 can be written as

$$Q = \frac{V}{t} = \frac{A\Delta P}{\mu(R_f + \alpha cV/A)} \qquad 4.6$$

And rearranged into the linear form

$$\frac{\Delta P}{Q} = \frac{\Delta P}{V/t} = \frac{\mu}{A}R_f + \frac{\mu\alpha c}{A^2}V \qquad 4.7$$

The constants are again found from the intercept and slope of the linear plot of Δ*P/Q* against *V*.

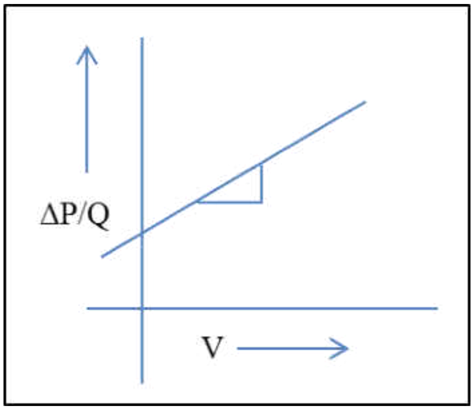

Figure 4.2: ΔP/Q Vs V Graph

Likewise Figure 4.1, if the values of t-t_o/V-Vo is put on the Y axis and the values of V+V_o are put in X axis, $\frac{\mu}{A}R_f$ will be the Y intercept and $\frac{\mu\alpha c}{A^2}$ will be the slope.

After the constants have been determined, eq. 4.7 can be employed to predict filtration performance under a variety of constant rate conditions.

The time required for a specified amount of filtrate is found by the following equation

$$t = \int_0^V dV/Q \qquad 4.8$$

CHAPTER V

METHODOLOGY

For determining the optimum polymer dose, two types of bench-top laboratory tests were performed. The dewatering tests had several steps-

- Sludge sample collection
- Sludge sample storage and preparation
- Polymer sample collection
- Polymer sample preparations
- Performing tests

5.1 Sludge Sample Collection

Samples for the bench-top dewatering tests were collected from three different locations in primary cell 2 (PC2). These three locations are shown in figure 5.1. All three locations in the lagoon were randomly selected. Certain areas of the lagoon were avoided while selecting the spots because of the formation of a 'Sludge Island' on the northern part of the lagoon and pipe-works in the south-west corner.

For collecting sludge samples a sludge judge was used. After taking the boat in the selected place, the sludge judge was placed vertically into the lagoon. As the lagoon has clay lining at its bottom, the sludge judge was placed carefully into the lagoon so that it does not reach the bottom. Samples were 2-3 feet thick depending on the locations. As fresh sludge were added into the lagoon everyday, it is expected that the top layer of the accumulated sludge in the lagoon contained fresh biological sludge and the lower layer of it contained digested sludge. So the sludge samples were a blend of fresh and digested sludge. Almost 2 gallons of sludge samples were taken in large jars from each three locations.

Figure 5.1: Sample Collection Locations

5.2 Sludge Sample Storage and Preparation

Sludge samples were collected in three big jars and were put in an incubator at 5°C. At first the sludge samples were kept at rest for 4 days for thickening. After 4 days, the thickened sludge was separated from the supernatant. Digestion of sludge in those 4 days was not taken into count. This sludge was then mixed thoroughly as the top and bottom layers did not have the same consistency. Samples were taken from the mixed sludge for all three locations and were put in the oven for calculating total solids in the samples. Solids concentrations for all three locations are shown in Table 5.1

Table 5.1: Solids Concentration for All Three Locations

Location No.	Total Solids Concentration
1	12.6%
2	10.9%
3	7.8%

5.3 Polymer Sample Collection

Tests were performed with polymers from Polydyne, INC. with different cationic concentrations. Polymers of four different cationic concentrations were used. Those are-

1. CLARIFLOC® C-6210 Polymer
2. CLARIFLOC® C-6237 Polymer
3. CLARIFLOC® C-6257 Polymer
4. CLARIFLOC® C-6285 Polymer

All these polymers are cationic polyacrylamide in emulsion form that is used as a flocculant in a wide variety of municipal and industrial wastewater treatment applications. These polymers have been successfully applied in all liquid/solids separation systems including clarification, thickening, and dewatering.

5.4 Typical Properties and Manufacturing Specifications of Polymer Samples

CLARIFLOC® C-6210 Polymer-

Physical Form	Clear to milky white liquid
Density	8.6 – 8.7 Lbs/Gal
Cationic Concentration	10%
Freezing Point	7 F. (-14°C)
Flash Point	>200 F (>93°C)
Specific Gravity	1.032 – 1.044
Total Solids	39.5 – 46.5 %
Net Viscosity	300 – 2000 cPs
Molecular Weight	High

CLARIFLOC® C-6237 Polymer-

Physical Form	Clear to milky white liquid
Density	8.6 – 8.7 Lbs/Gal
Cationic Concentration	30%
Freezing Point	7 F. (-14°C)
Flash Point	>200 F (>93°C)
Specific Gravity	1.032 – 1.044
Total Solids	41 – 48 %

Net Viscosity	300 – 2000 cPs
Molecular Weight	High

CLARIFLOC® C-6257 Polymer-

Physical Form	Clear to milky white liquid
Density	8.6 – 8.7 Lbs/Gal
Cationic Concentration	50%
Freezing Point	7 F. (-14°C)
Flash Point	>200 F (>93°C)
Specific Gravity	1.032 – 1.044
Total Solids	43 – 50 %
Net Viscosity	300 – 2000 cPs
Molecular Weight	High

CLARIFLOC® C-6285 Polymer-

Physical Form	Clear to milky white liquid
Density	8.6 – 8.7 Lbs/Gal
Cationic Concentration	80%
Freezing Point	7 F. (-14°C)
Flash Point	>200 F (>93°C)
Specific Gravity	1.032 – 1.044
Total Solids	N/A
Net Viscosity	300 – 2000 cPs
Molecular Weight	Structured

5.5 Polymer Sample Preparation

Polymer samples were prepared on a weight basis. For all four cationic concentrations 1%, 0.5%, 0.25% and 0.1% solutions were prepared. 1% solution means 1mg of polymer in 100mg of solution. Likewise, 0.5% solution means 0.5 mg of polymer in 100 mg of solution, 0.25% solution means 0.25 mg of polymer in 100 mg of solution and 0.1% solution means 0.1 mg of polymer in 100 mg of solution. Distilled water was used as the solvent while preparing these polymer solutions. According to the manufacturer, polymer solutions start losing effectiveness within a few seconds after it is prepared and it was also said that prepared solutions can also be used within 6 hours after preparing, at the latest. So, for the bench-top tests no solution was used which was more than 6 hours old. Because of the precise measurement and the size of the containers in which polymer solutions were prepared, solutions of nearly 100 mgs were prepared at a time.

Figure 5.2: Polymer Samples

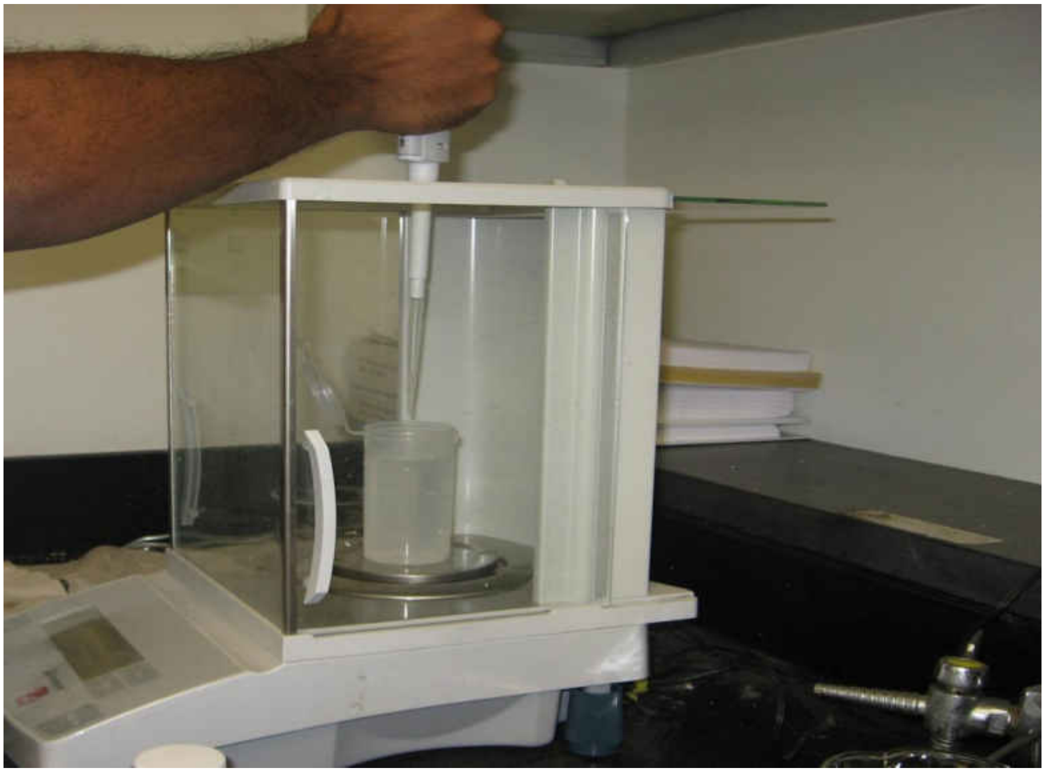

Figure 5.3: Polymer Samples Preparation

5.6 Test Methods

Two types of bench-top dewatering tests were performed. These tests were-

1. Time to filter test (TTF)
2. Air Pressure Filtration test (APF)

Test data obtained from these tests were analyzed, and based these test results, the optimum dose for the polymer was determined. The effect of polymer cation concentration and pressure was also determined. The two tests produced two different types of data and the optimum polymer dose was determined using test data from both tests.

5.6.1 Time to Filter Test

Time to filter test (TTF) is a standardized test for water and wastewater (Standard Methods for Examination of Water and Wastewater, 2012). It correlates with the capillary suction time (CST) test and is similar to the specific resistance to filtration test. As per the standard method book, the test requires approximately 200 mL sludge and can be used to assist in the daily operation of sludge dewatering processes or to evaluate the effectiveness of sludge-conditioning polymers and dosage. For this test, the sludge sample is placed in a Buchner funnel with a paper support filter. With the application of vacuum, the time required for 100 mL filtrate from 200 mL sludge is measured. For small apparatus, a smaller volume of sludge sample can also be taken and the time to get 50% filtrate out of it can be measured.

Apparatus for time to filter test

a. Buchner funnel
b. Side arm adopter
c. Graduated cylinder
d. Hollow pipe
e. Flask
f. Suction vacuum
g. Filter paper (Whatman #1, diameter- 9 cm)
h. Stopwatch

Figure 5.4: Apparatus Assembly for Time to Filter Test

Procedure:

For the TTF, first the filter paper was put on the Buchner funnel and some water was used with vacuum pressure to make the funnel-top airtight with the filter paper. As the TTF test equipment was small, 100mL of sludge sample was taken for each test. Sludges from all the lagoon locations were refrigerated at 5°C. Before testing, sludge samples were brought to the room temperature. Polymer was added to the sample with pipette tips and mixed thoroughly. A manual mixing blade was used for mixing the polymer with the sludge sample. The mixing blade was operated at a higher speed at the beginning of the mixing procedure. After some time, the speed was reduced to observe the formation of solid flocs. Once flocs started to form, the sludge sample was put on the funnel and pressure was applied to dewater the sample. Time to collect 50% of total liquid (sludge volume+ polymer solution volume) out of the sludge sample was measured with a stopwatch and was listed in a spreadsheet. A vacuum pressure of 380 mmHg (51Kpa, standard for TTF Test) was maintained with a pressure gauge. Six different polymer dosages were used for determining the optimum polymer dose required for effective dewatering. The polymer dose, for which the shortest time to filter was required for the sludge sample, was determined to be the optimum polymer dose. Test with this same dose was replicated to validate its reliability.

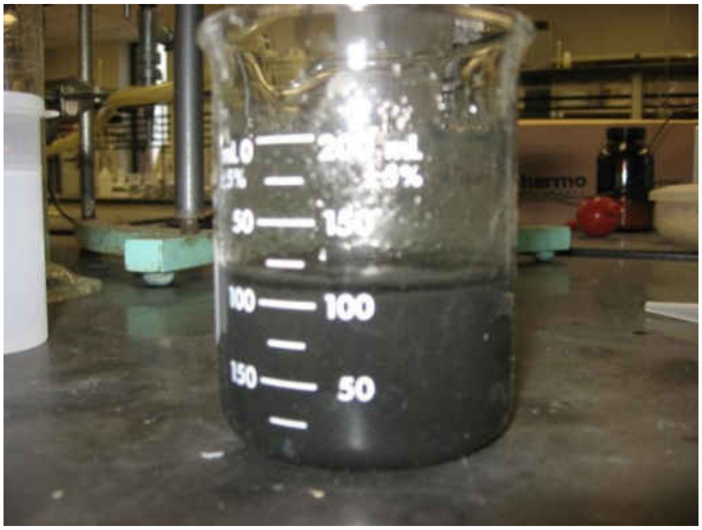

Figure 5.5: Sludge Sample before Adding Polymer

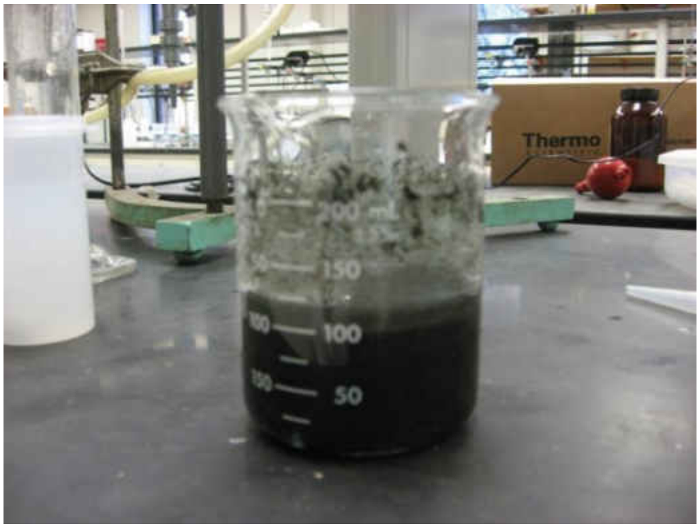

Figure 5.6: Sludge Sample after Mixing with Polymer

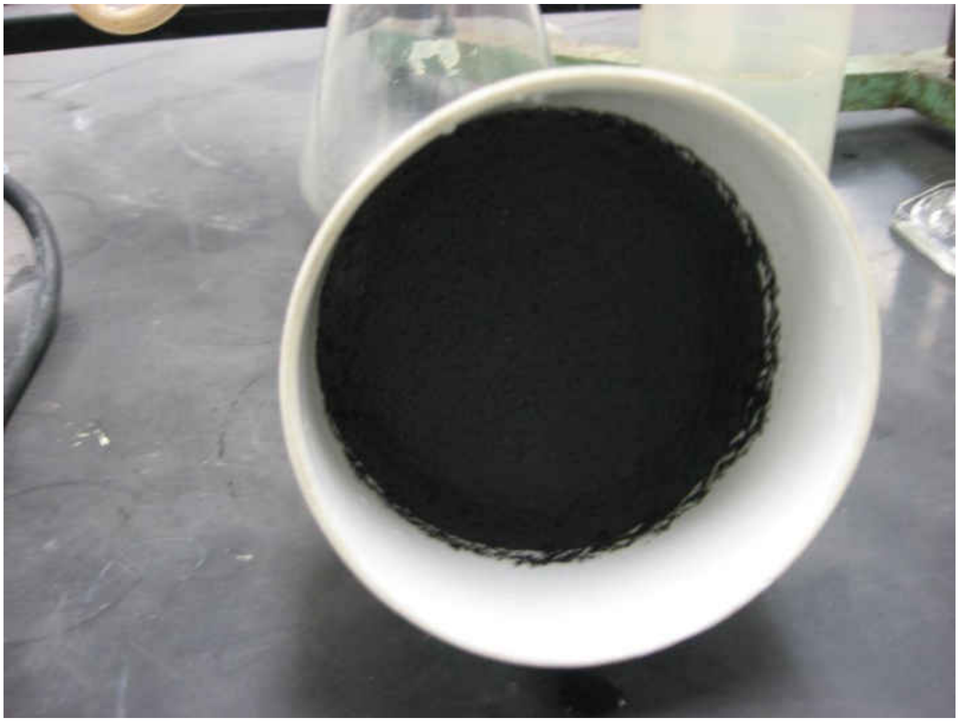

Figure 5.7: Formation of Dry Cake after Applying Vacuum Suction

5.6.2 Air Pressure Filtration (APF) Test

An APF test is also used to characterize sludge dewatering. With this test optimum polymer dose can be determined for a sludge sample and the effect of pressure on sludge dewatering can be understood. This test was used to analyze sludge dewatering rate pattern with different polymer dosages and different pressures.

Apparatus for Air Pressure Filtration test

a) Air Pressure Filtration
b) Pressure gauge
c) Air source
d) Control valve

e) Hollow reinforced tubing

f) Pipe clamp

g) Graduated cylinder

h) Filter paper (Whatman #1, diameter- 12.5 cm)

i) Stopwatch

Figure 5.8: Apparatus Assembly for Air Pressure Filtration Test

Procedure:

For the APF test, test equipment was set up on a laboratory bench. Because of the high pressure of the air, reinforced hollow tubing was needed for connecting to the air source. Pipe clamps were used so that the pipe doesn't come out from the air source. The other end of the tubing was connected with a pressure reducing valve (PRV). Another tubing section connected the PRV and a pressure gauge. The last tubing section connected the pressure gauge and the APF chamber. Water (filtrate) coming out from the APF chamber was collected through a tube to a graduated cylinder which was placed on the floor. The graduated cylinder was placed on the floor so that water can flow through the tube with minimum resistance. After setting up the equipment, a filter paper was placed on the metal mesh in the APF chamber. For this test 160 mL of sludge sample was used to make a half-inch sample according to the size of the pressure cell. A pressure of 80 pounds per square inch (psi) was maintained for all the tests. Volume of water coming out from the sludge sample every 10 seconds was measured and listed in a spreadsheet. These data was analyzed to see the effect of residence time of sludge in the APF chamber.

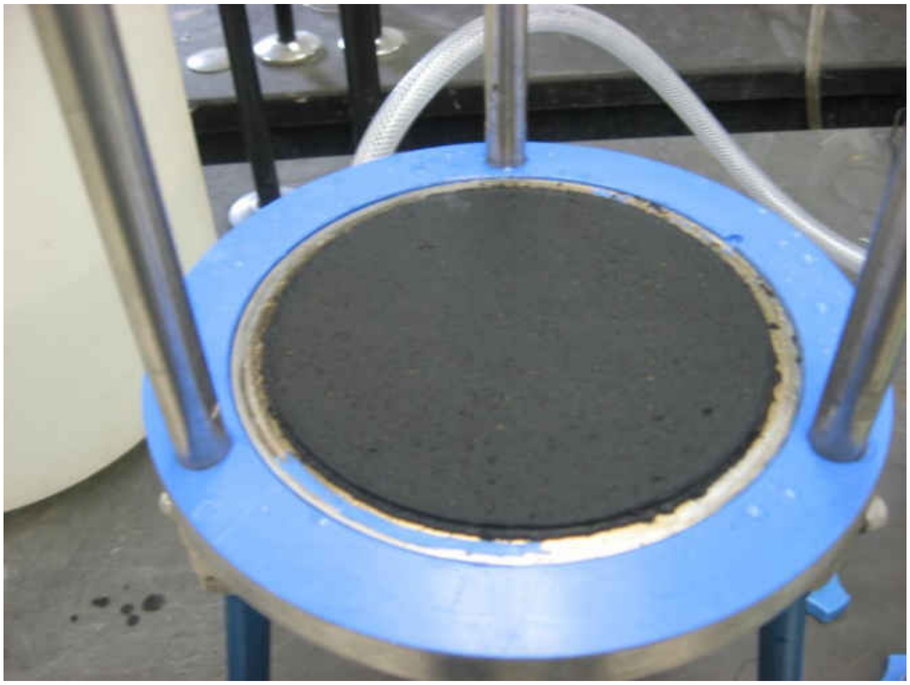

Figure 5.9: Dry Solids' Cake after Air Pressure Filtration Test

CHAPTER VI

RESULTS AND CALCULATIONS

6.1 Effect of Solids Concentration on Dewatering

For determining optimum polymer dose, the TTF test was used. Before starting the test, it was necessary to dilute polymer samples. All four polymer samples were diluted to 1%, 0.5%, 0.25% and 0.1% on a polymer wt. /solution wt. basis. Four different dilutions were evaluated in terms of effectiveness for dewatering. These dilutions were tested for different solids concentrations of sludge samples, ranging from 4.78% to 12.6%, from all three locations. Tables and graphs showing time to filter for different solids concentration from 3 different locations are given below.

Table 6.1: Time to Filter for Different Solids Concentration for C 6210

Polymer No.	Polymer concentration	Location No.	Initial solids concentration	Polymer dosage (ml of solution)/ 100 ml of sludge	Time to Filter (seconds to collect 50% of liquid volume)
C 6210	0.108%	1	12.6%	45	56
		2	10.9%	45	35
		3	7.8%	45	23
		1	4.78%	28	11.87

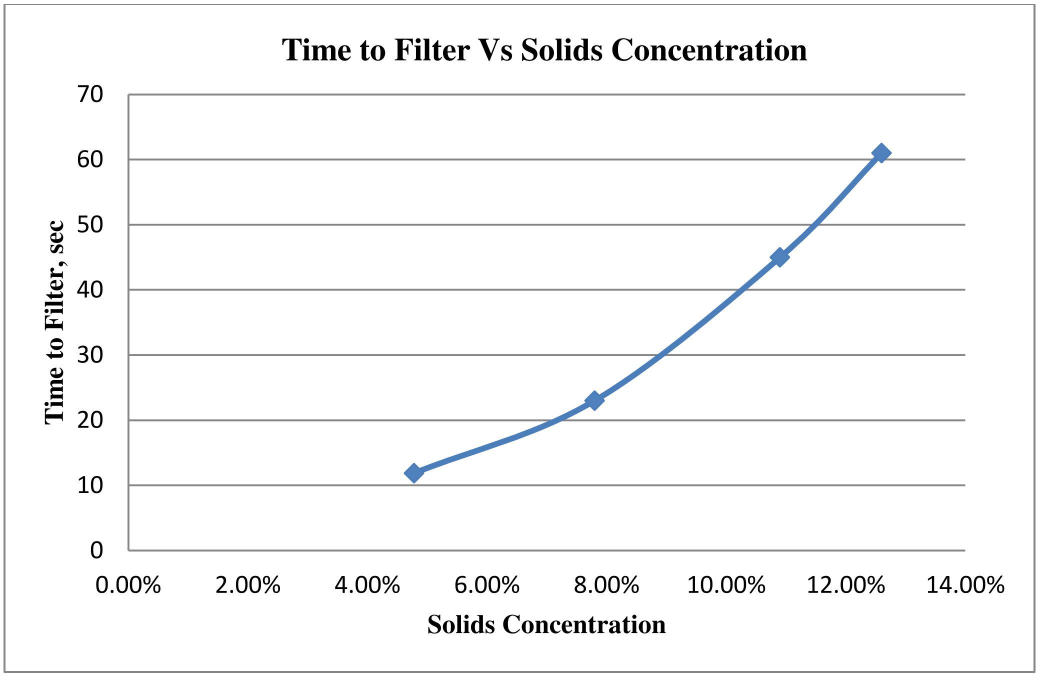

Figure 6.1: Time to Filter Vs Solids Concentration for C 6210

Table 6.1 and Figure 6.1 are for C 6210. Time to filter started decreasing with decreasing solids concentration for other polymers as well. Sludge samples with higher solids concentration was difficult to dewater. In order to dewater samples with a higher solids concentration, higher polymer dosage was required. With the higher polymer dosage, solids got separated from the liquid easily but it created islands of solids on the filter paper. So, there were some empty spots on top of the filter paper and vacuum suction was not able to work properly because of those empty places. Moreover, uniform dry cakes of solids did not form for sludge samples with higher solids concentration and higher polymer dosage. With lower solids concentration and lower polymer dosage, almost 85~90% of moisture was sucked out by vacuum, while with higher solids concentration, only 70~75% of moisture could be separated from the sludge solids. So, obviously a lower solids concentration of sludge solids is preferable for ease of dewatering. Based on the results from Table 6.1 and Graph 6.1, solids concentrations of 4.5~5.5% were preferred for the rest of the tests for ease of dewatering.

6.2 Effect of Polymer Concentration on Dewatering

Sludge samples were tested with four different polymer concentrations for all types of polymers to see the effect of polymer dilution on dewatering. Four different polymer dilutions were chosen on a polymer wt/wt of solution basis. The polymer concentrations of 1%, 0.5%, 0.25% and 0.1% were used for the tests. Results showed that .1% concentration was the best dilution to use for dewatering. Table 6.2 and Figure 6.2 are shown below in support of this observation.

Table 6.2: Polymer Dosage Required to Achieve Effective Dewatering for Different Polymer Dilutions (C 6210)

Polymer No.	Location No.	Polymer conc. wt/wt	Polymer dosage (mls/ 100 mls of sludge* sample)	Gram of Polymer required /Gram dry of dry solid	Time to Filter (seconds to collect 50% of total liquid)
C 6210	1	0.108%	28	0.0063	11.87
		0.25%	17	0.0089	12.08
		0.5%	13	0.014	11.98
		1%	7	0.015	14.56

*Sludge solids concentration was 4.78%

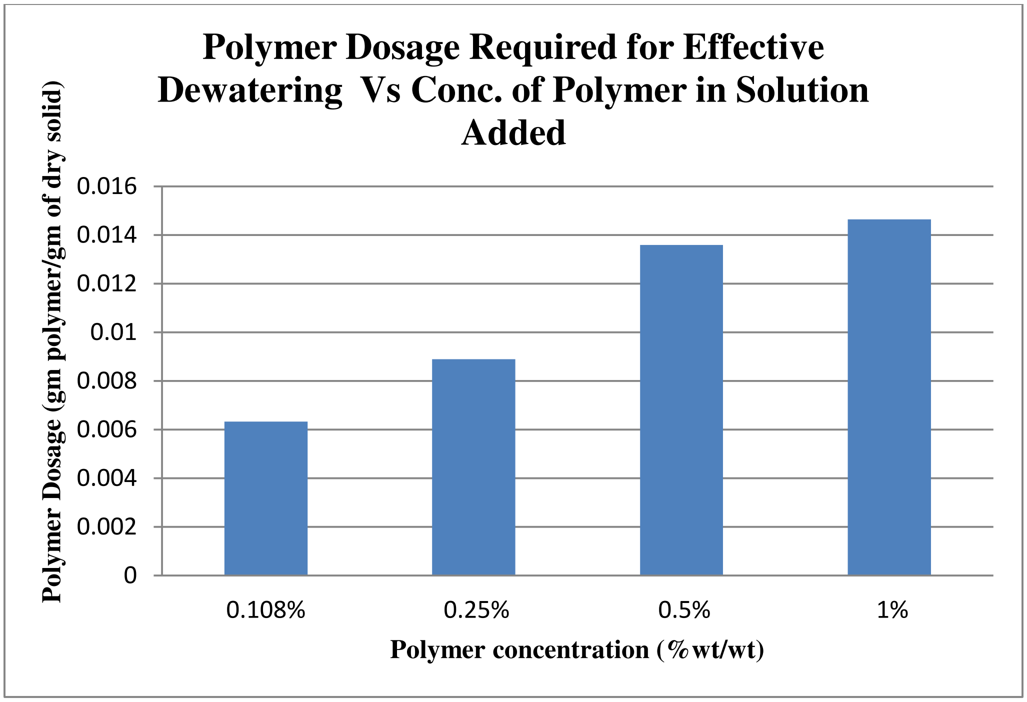

Figure 6.2: Polymer Dosage Vs Polymer Conc. for C 6210, location 1

Figure 6.2 explains that lower polymer concentration (0.108% in solution) allow the lowest polymer dosage to achieve effective dewatering. The order of effectiveness of polymer solution concentrations based on polymer dosage (gm polymer/ gm of dry solids) requirement for effective dewatering is: 0.1%>0.25%>0.5%>1%.

At lower concentration, polymers can more easily be distributed to make bonds with solid particles of sludge and help solids to coagulate better. At higher polymer concentrations, polymers are more difficult to disburse, get wasted, and fail to make bonds with solid particles. The extra portion of polymers creates a thin layer coating outside of the coagulated solid, which makes sludge harder to dewater.

All four types of polymer were used to see the polymer concentration effects for lagoon location 1sludge. Results of those results were pretty much the same as Figure

6.2. These results are shown in Table 6.3, 6.4 and 6.5. Table 6.3, 6.4 and 6.5 represents test results for C 6237, C 6257 and C 6285 respectively. For lagoon location 2 and 3 sludges, only the polymer concentration of 0.1% was used.

Table 6.3: Polymer Dosage Required for Effective Dewatering with Different Polymer Dilutions (C 6237)

Polymer No.	Location No.	Polymer conc. wt/wt	Polymer dosage (mls/ 100 ml of sludge sample)	Gram of Polymer required/Gram of dry solid	Time to Filter (seconds to collect 50% of liquid)
C 6237	1	0.107%	20	0.005	8.42
		0.25%	14	0.0079	10.53
		0.5%	10	0.011	12.11
		1%	5	0.011	17.91

Table 6.4: Polymer Dosage Required for Effective Dewatering with Different Polymer Dilutions (C 6257)

Polymer No.	Location No.	Polymer conc. wt/wt	Polymer dosage (mls/ 100 ml of sludge sample)	Gram of Polymer required/Gram of Solid	Time to Filter (seconds to collect 50% of liquid)
C 6257	1	0.103%	16	0.003	7.78
		0.25%	11	0.006	11.69
		0.5%	9	0.01	13. 09
		1%	5	0.011	16.04

Table 6.5: Polymer Dosage Required for Effective Dewatering with Different Polymer Dilutions (C 6285)

Polymer No.	Location No.	Polymer conc. wt/wt	Polymer dosage (mls/ 100 ml of sludge sample)	Gram of Polymer required/Gram of dry solid	Time to Filter (seconds to collect 50% of liquid)
C 6285	1	0.099%	24	0.005	9.13
		0.25%	15	0.008	12.26
		0.5%	11	0.012	16. 88
		1%	6	0.013	19.31

Results obtained from all these tables proved that the 0.1% polymer concentration was the most effective to dewater sludge samples from location 1. Further C 6257 appeared to be more effective in dewatering location 1 sludge than C 6210, C 6237 and C 6285.

6.3 Determination of Most Effective Polymer (TTF Test)

The following part will discuss the most effective polymer out of the four (C 6210, C 6237, C 6257 and C 6285). For determining the most effective polymer, 72 Time to Filter (TTF) tests were performed. Tests were performed for all three locations. Six different dosages (gm of polymer/ gm of dry solids) were used for each polymer to determine the optimum dose. The polymer with the minimum dose required for equal TTF was determined as the most effective polymer based on cationic charge concentration. Solids concentration of 4.45~5.2% and polymer concentration of 0.099~0.108% were used. Figures 6.3, 6.4, 6.5 and 6.6 show the results of TTF Test for dewatering sludge from lagoon location 1.

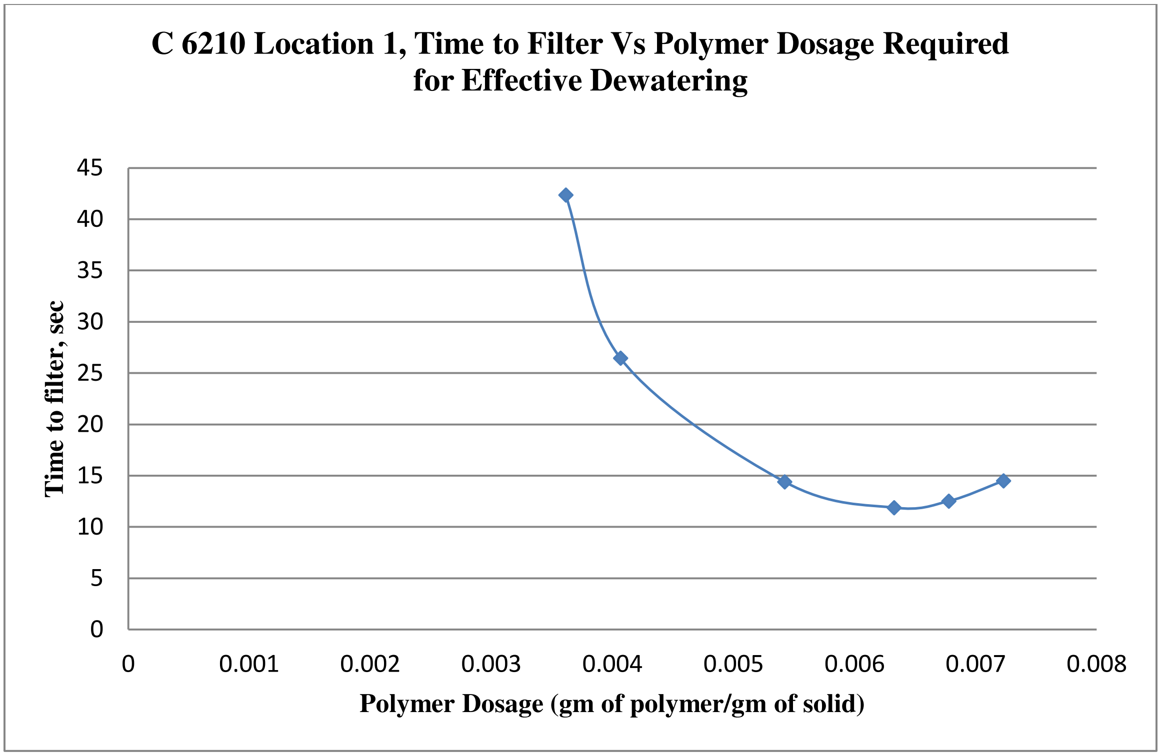

Figure 6.3: C 6210 Location 1, Time to Filter Vs Dosage

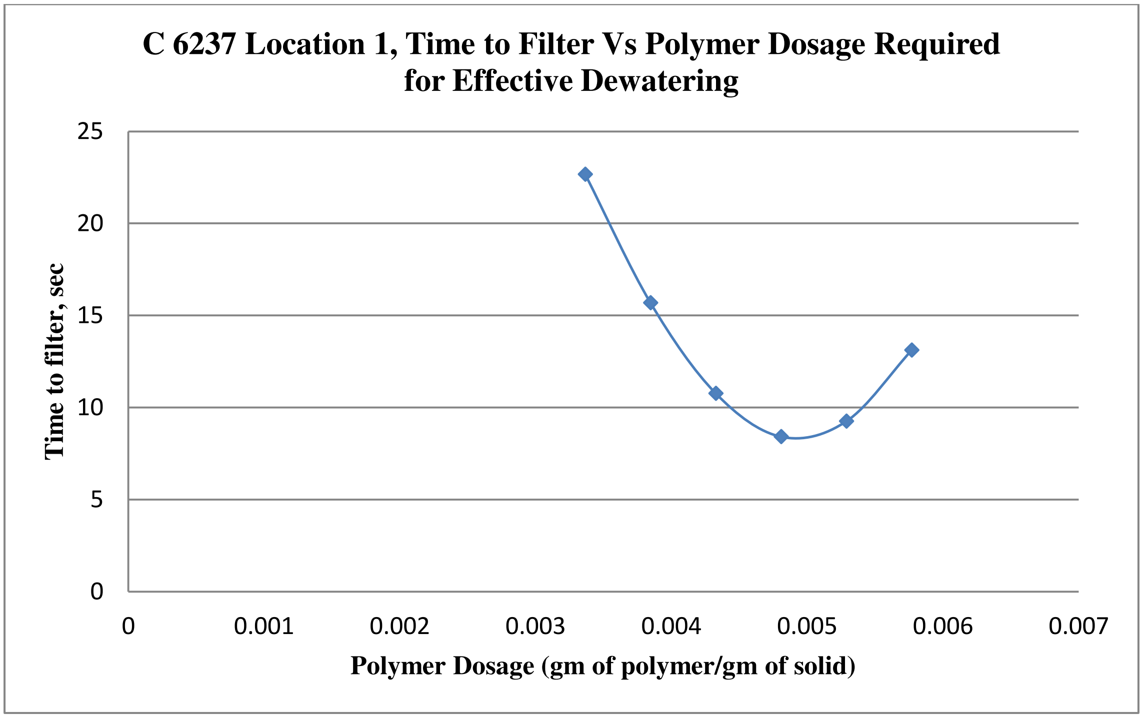

Figure 6.4: C 6237 Location 1, Time to Filter Vs Dosage

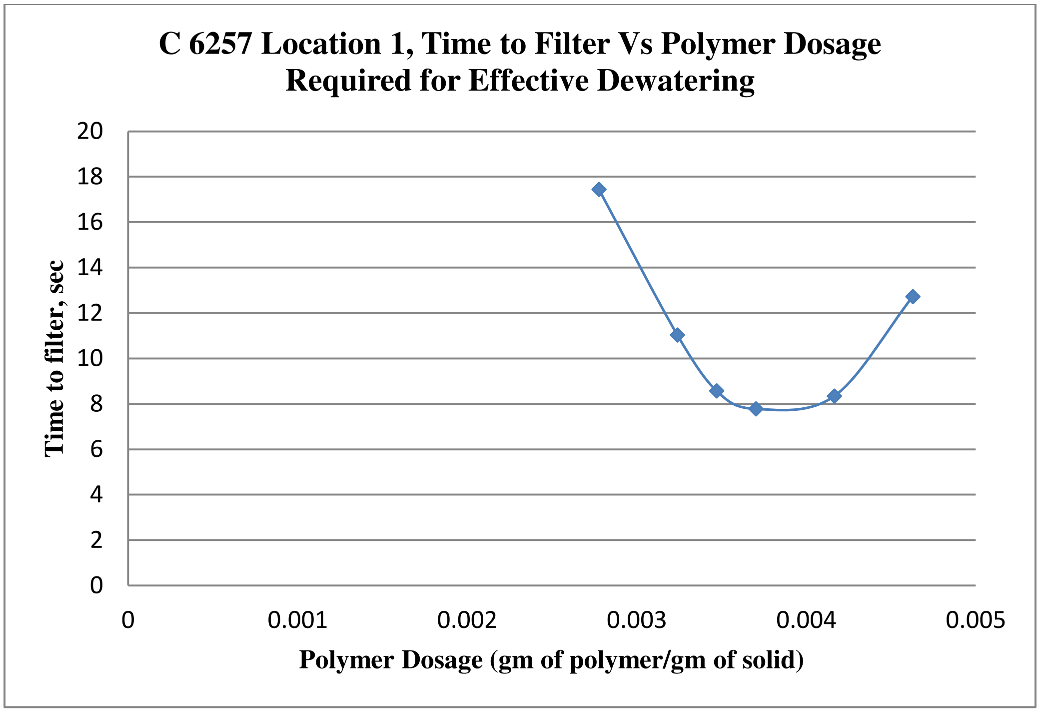

Figure 6.5: C 6257 Location 1, Time to Filter Vs Dosage

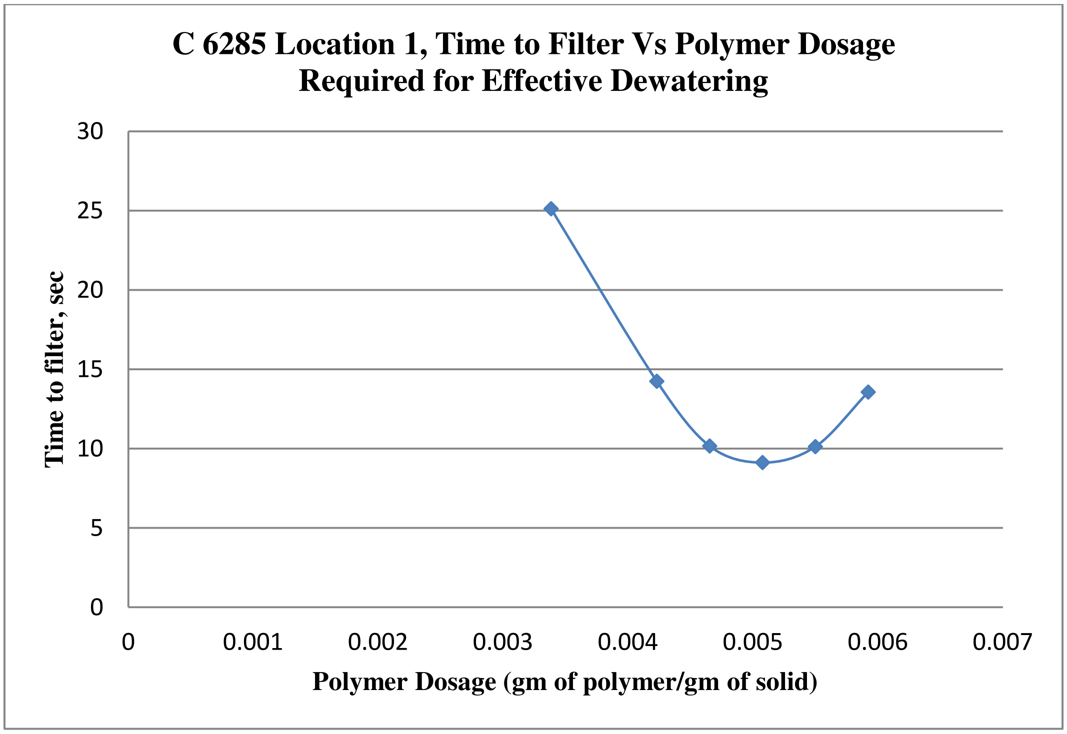

Figure 6.6: C 6285 Location 1, Time to Filter Vs Dosage

A comparison for effectiveness among all four polymers used for dewatering sludge from location 1 is shown in Figure 6.7

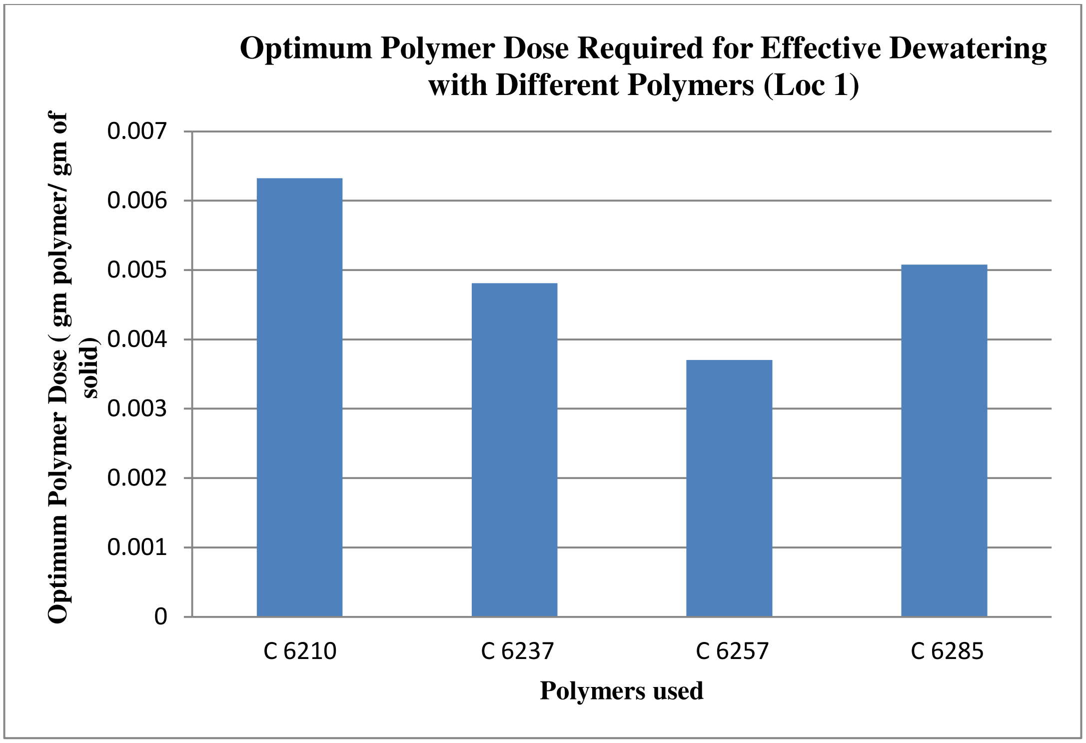

Figure 6.7: Comparison of Polymers for Effective Dewatering (Location 1)

Figure 6.7 gives a summary of test results for lagoon location 1 sludge dewatering. From this figure, it is understood that C 6257 requires the least amount of polymer to achieve effective dewatering. Furthermore, C 6257 polymer produced TTF less than 8 seconds for location 1 sludge dewatering at the optimal dosage of .0036 mg polymer/ mg of dry solids. Figure 6.8, 6.9, 6.10 and 6.11 shows the results of the TTF Test for dewatering sludge from lagoon location 2. A summary of these graphs is shown in Figure 6.12. Figure 6.12 will show the comparison for effectiveness among all four polymers used for dewatering sludge from location 2.

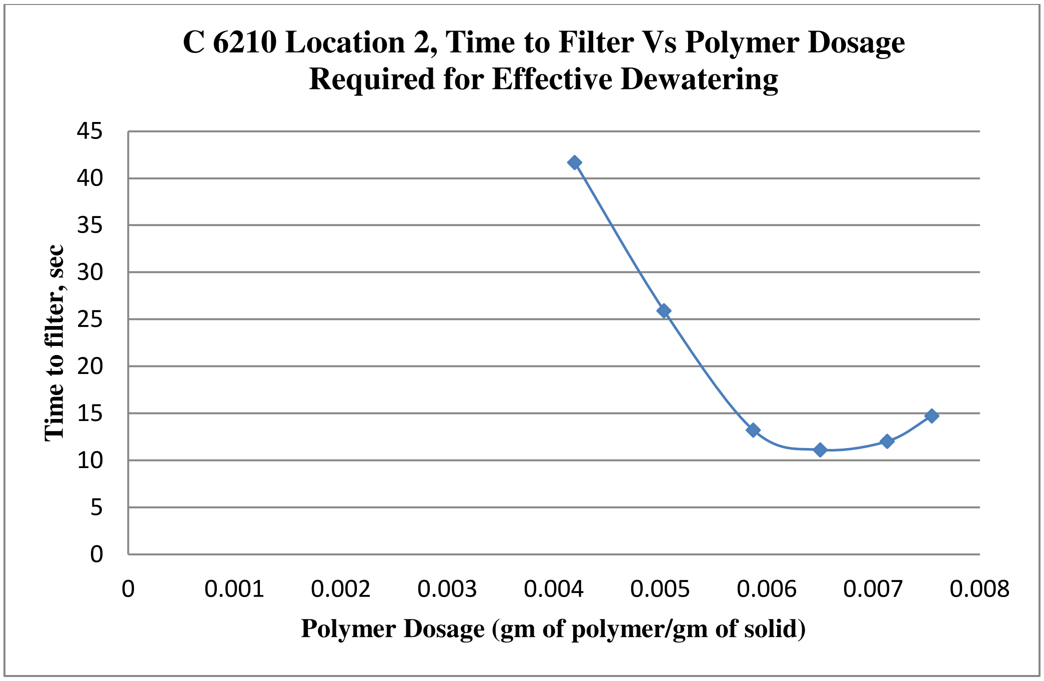

Figure 6.8: C 6210 Location 2, Time to Filter Vs Dosage

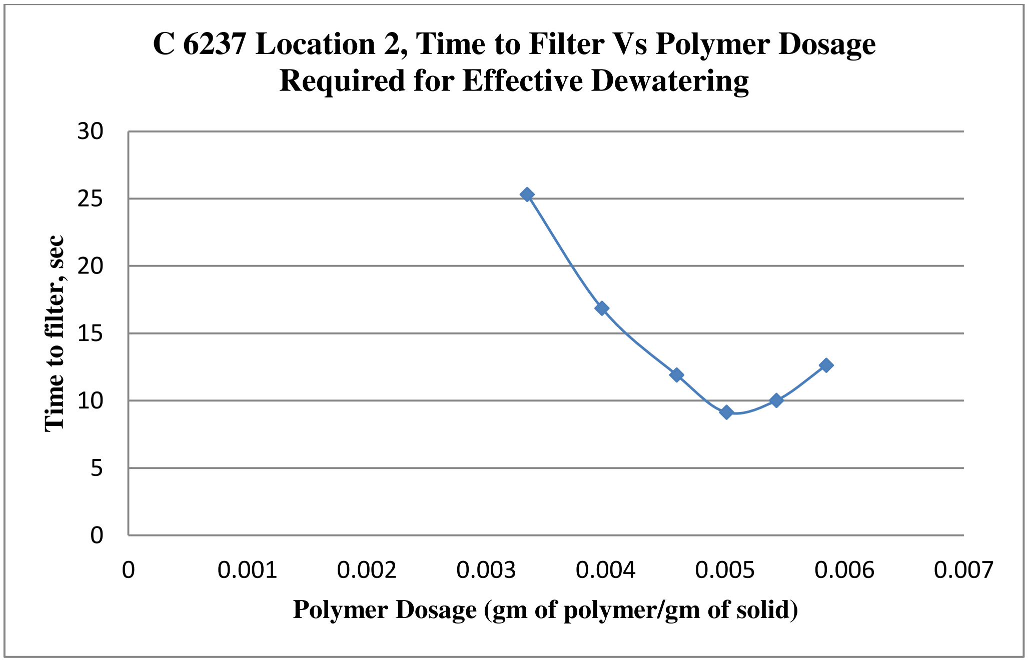

Figure 6.9: C 6237 Location 2, Time to Filter Vs Dosage

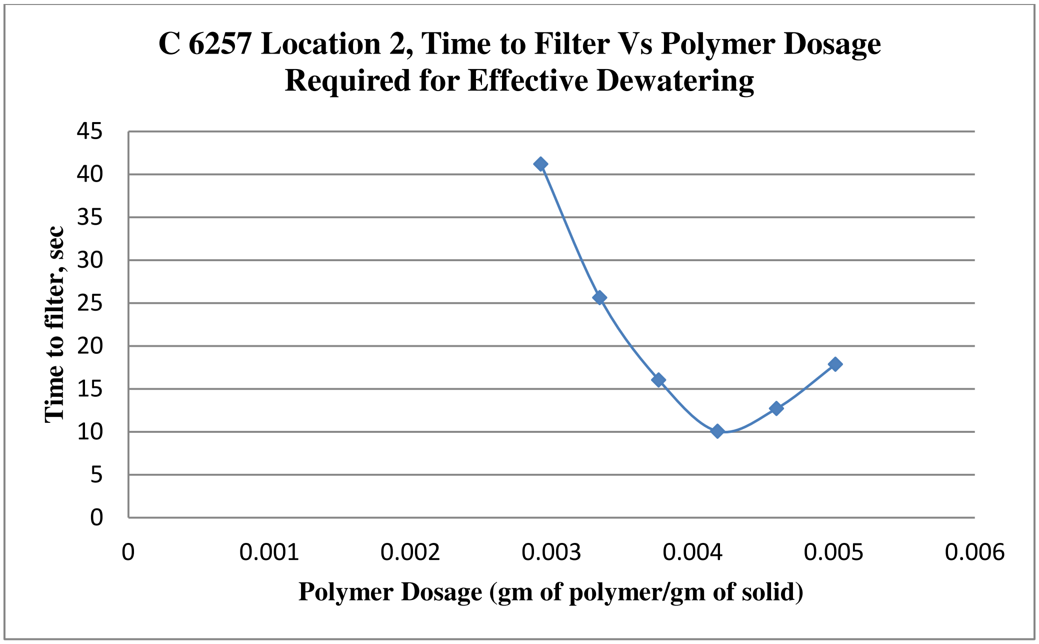

Figure 6.10: C 6257 Location 2, Time to Filter Vs Dosage

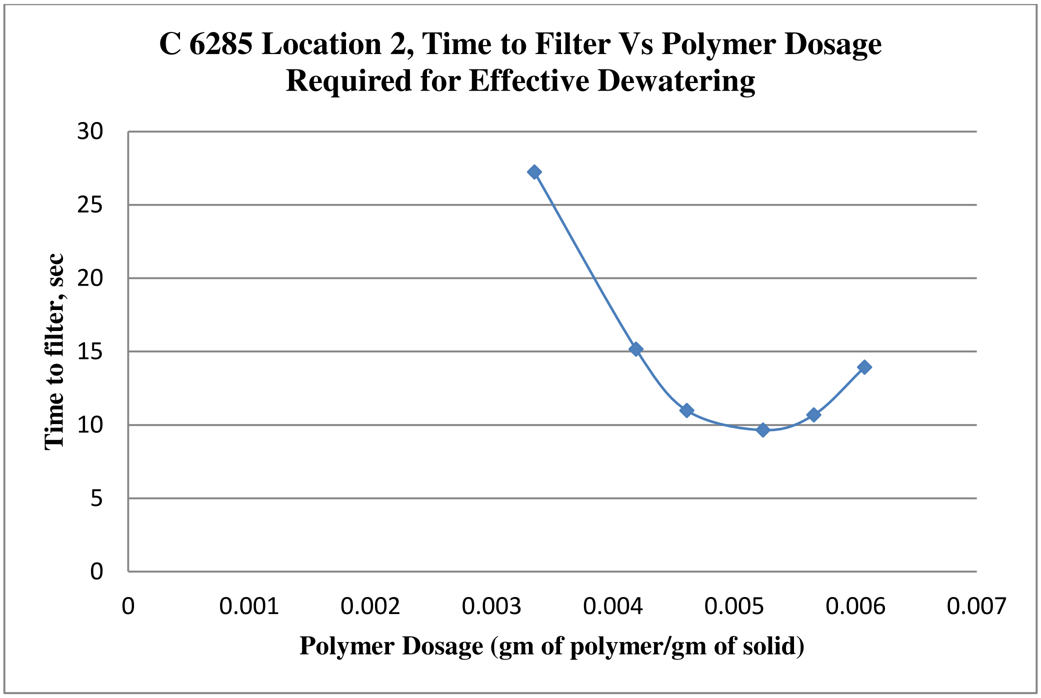

Figure 6.11: C 6285 Location 2, Time to Filter Vs Dosage

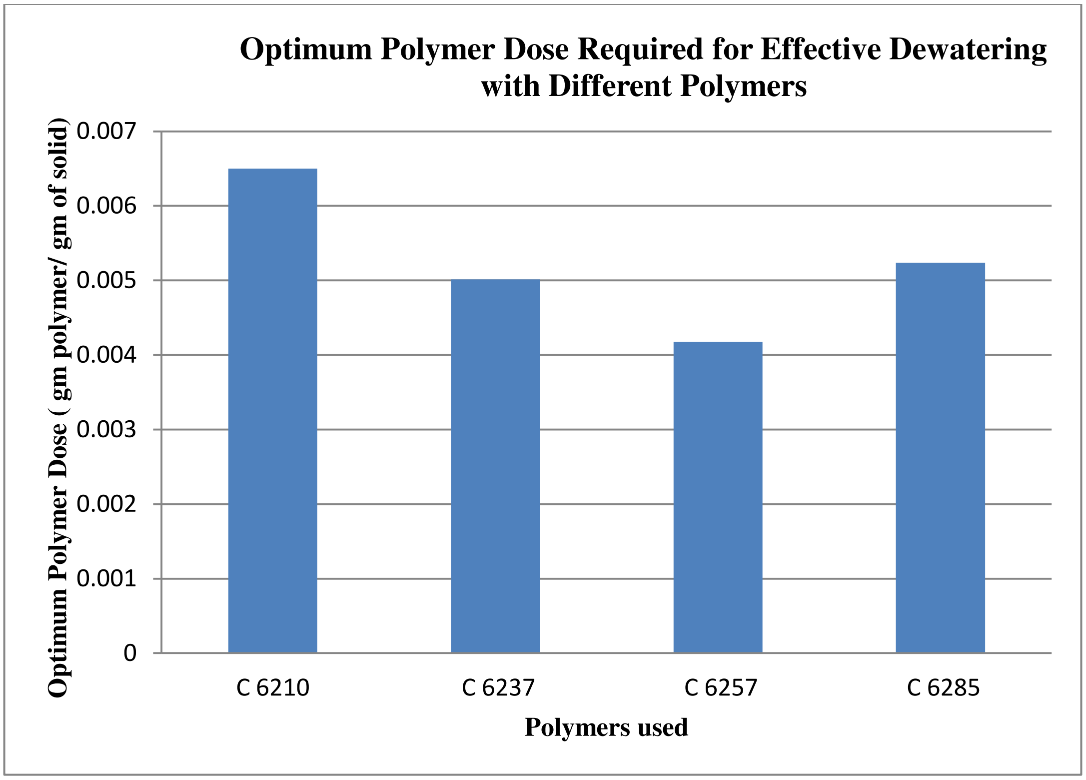

Figure 6.12: Comparison of Polymers for Effective Dewatering (Location 2)

Figure 6.12 is very similar to Figure 6.7. Figure 6.12 also demonstrates that the most effective polymer for dewatering location 2 sludge is C 6257. TTF was approximately 10 seconds.

The last set of TTF test results is shown in figure 6.13, 6.14, 6.15 and 6.16. All these figures will show results for sludge samples collected from lagoon location 3. These figures will also be followed by a summary graph which will be represented by Figure 6.17.

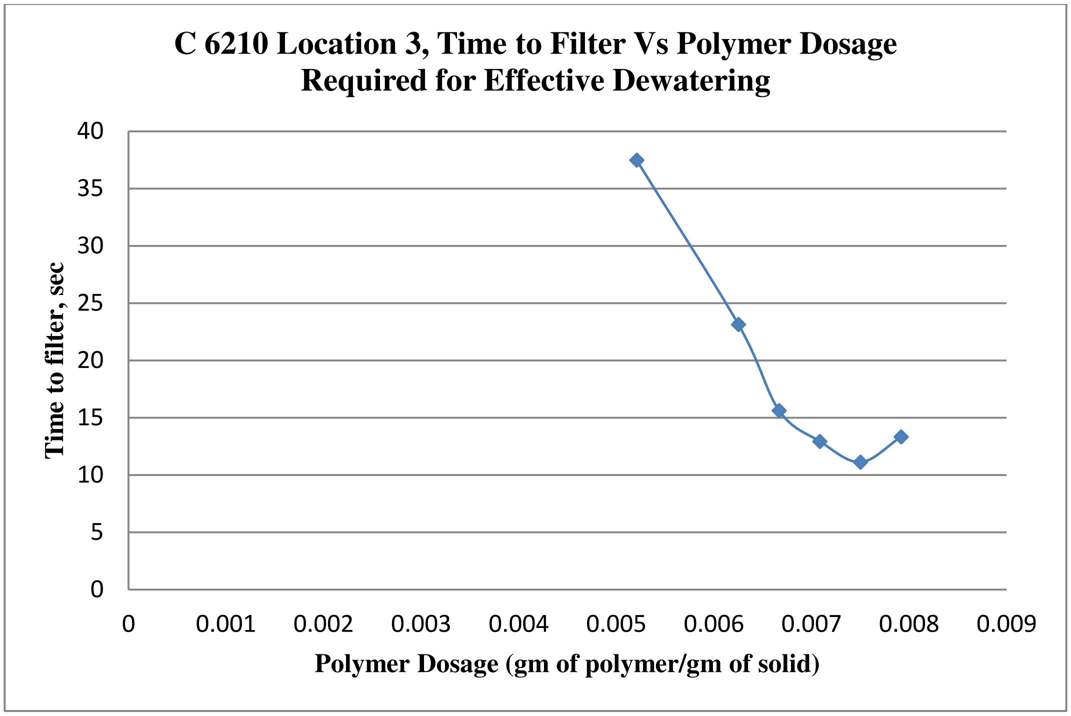

Figure 6.13: C 6210 Location 3, Time to Filter Vs Dosage

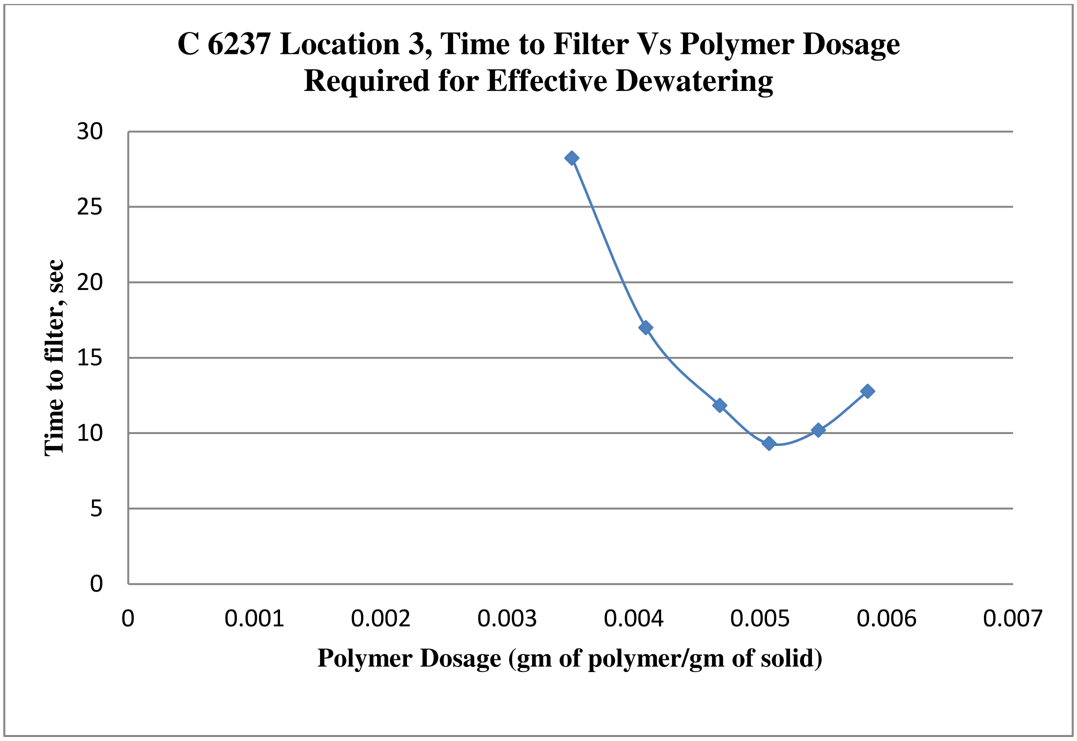

Figure 6.14: C 6237 Location 3, Time to Filter Vs Dosage

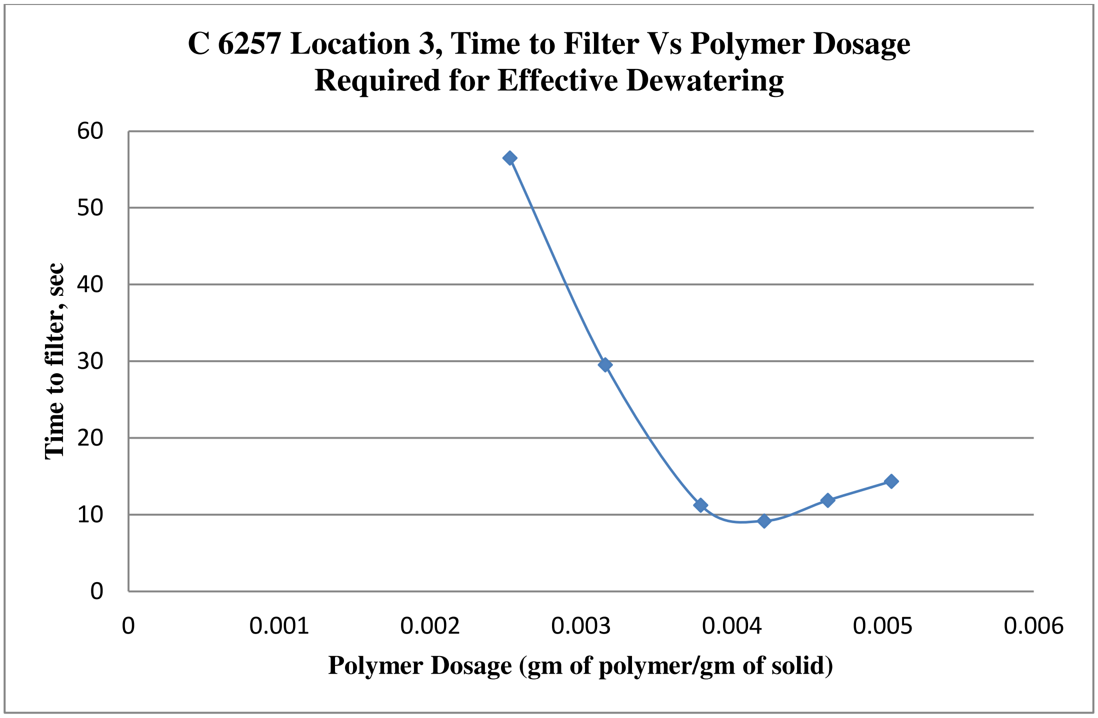

Figure 6.15: C 6257 Location 3, Time to Filter Vs Dosage

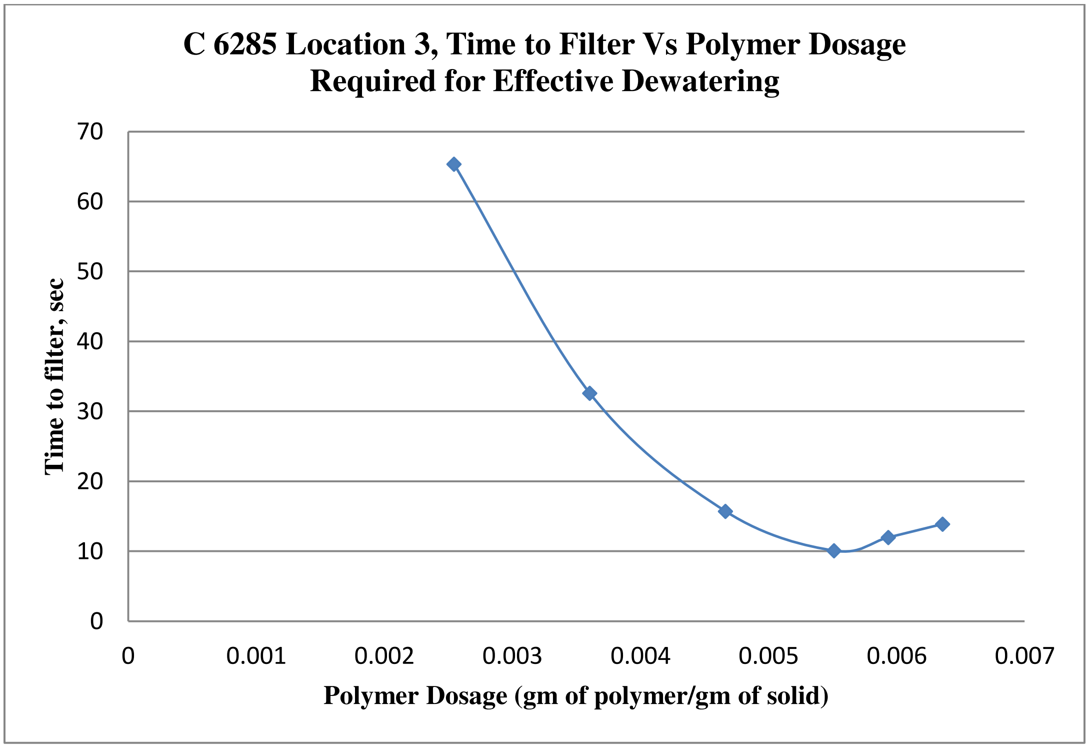

Figure 6.16: C 6285 Location 3, Time to Filter Vs Dosage

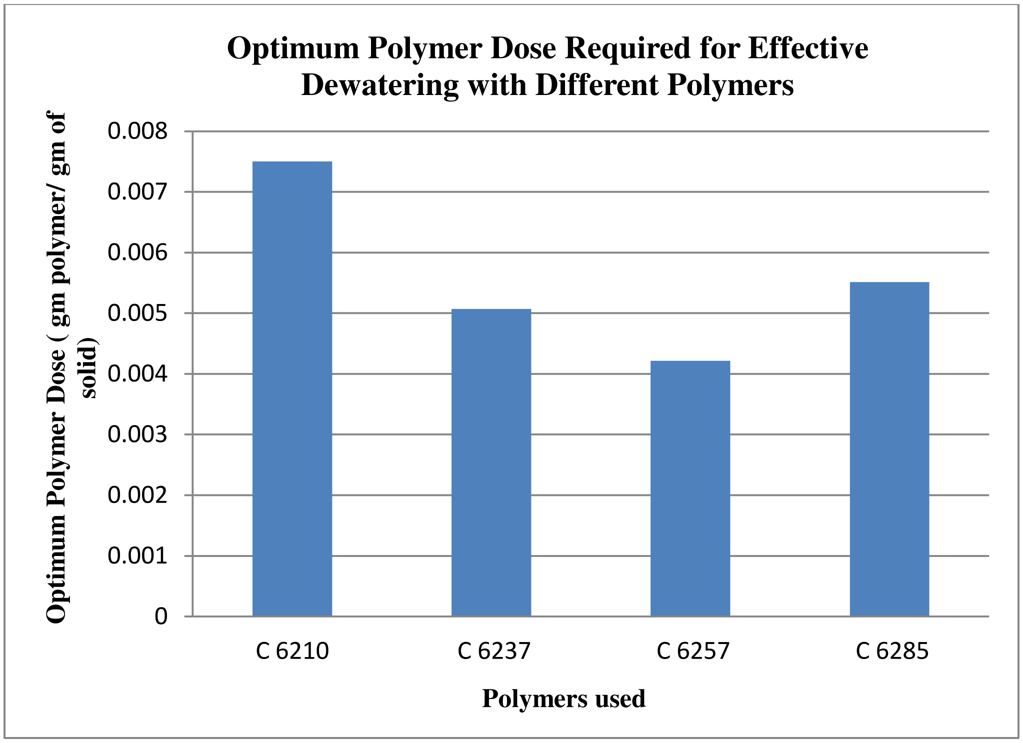

Figure 6.17: Comparison of Polymers for Effective Dewatering (Location 3)

From the above figures, it is quite clear that C 6257 with cationic charge concentration of 50% is the most effective polymer out of the four. C 6257 worked the best for all three lagoon location sludges. The least preferable polymer was C 6210 with a cationic charge density of 10%. Between C 6237 and C 6285, C 6237 had better results but the difference between those two were not very significant. A summary of these results is shown below in a tabular form.

Table 6.6: Summary of Results for the Most Effective Polymer (C 6257) from the TTF Test

Location No.	Most Effective Polymer	Polymer Conc.	Solids Conc.	Dosage (ml)	Time to Filter (seconds to collect 50% of liquid)	Sludge sample volume (ml)	Optimum polymer dose (kg/dry ton solids)
1	C 6257	0.103%	4.45%	16	7.78	100	3.34
2	C 6257	0.104%	4.98%	20	10.07	100	3.79
3	C 6257	0.106%	5.03%	20	9.17	100	3.81

6.4 Calculation for optimum polymer dose

A 0.103% polymer solution means 0.103 gm of polymer is added to a 100gm total mass of polymer solution assuming a specific gravity of 1 for the final polymer solution.

From Table 6.6, 16 ml of 0.103% polymer solution is required to dewater 100 ml sludge.

A 16 ml polymer solution has $\frac{0.103\ gm X 16ml}{100ml}$ or 0.0165 gram of polymer

Assuming a specific gravity of 1 for sludge at 4.45% solid concentration, the amount of polymer needed to dewater 1 ton of sludge solid is

$\frac{0.0165 gm X 1000 Kg X 1\ m\ ton}{4.45 gm X 1 m\ ton X 1.1023 ton}$ Or 3.34 Kg polymer/ Ton of sludge dry solid.

Taking the average of results from Table 6.6, it can be said that approximately 4 Kg of C 6257/Dry Ton of solids will be needed for dewatering the lagoon sludge. The following tables will show the amount of polymer needed for other polymer types.

Table 6.7: Summary of Results for C 6210 Polymer from the TTF Test

Location No.	Best Usable Polymer	Polymer Conc.	Solids Conc.	Dosage (ml)	Time to Filter (seconds to collect 50% of liquid)	Sludge sample volume (ml)	Optimum polymer dose (kg/dry ton solids)
1	C 6210	0.108%	4.78%	28	11.87	100	5.74
2	C 6210	0.108%	5.15%	31	11.12	100	5.9
3	C 6210	0.109%	5.23%	35	11.11	100	6.62

Table 6.8: Summary of Results for C 6237 Polymer from the TTF Test

Location No.	Best Usable Polymer	Polymer Conc.	Solids Conc.	Dosage (ml)	Time to Filter (seconds to collect 50% of liquid)	Sludge sample volume (ml)	Optimum polymer dose (kg/dry ton solids)
1	C 6237	0.107%	4.45%	20	8.42	100	4.36
2	C 6237	0.104%	4.98%	24	9.14	100	4.55
3	C 6237	0.102%	5.23%	26	9.31	100	4.6

Table 6.9: Summary of Results for C 6285 Polymer from the TTF Test

Location No.	Best Usable Polymer	Polymer Conc.	Solids Conc.	Dosage (ml)	Time to Filter (seconds to collect 50% of liquid)	Sludge sample volume (ml)	Optimum polymer dose (kg/dry ton solids)
1	C 6285	0.099%	4.68%	24	9.13	100	4.6
2	C 6285	0.102%	4.87%	25	9.65	100	4.75
3	C 6285	0.11%	5.19%	26	10.08	100	5.00

From these tables it can be concluded that, in terms dewatering of effectiveness, the four polymers can be arranged in this order- C 6257> C 6237> C 6285> C 6210.

Collected sludge samples from the lagoon were used for numerous tests. The sludge samples were stored in refrigeration but, these tests took almost 35 days to finish. So, there was a concern about the effect of freshly added sludge in the lagoon on these tests. To verify these test results with addition of fresh sludge, laboratory-stored sludge for location 3 was mixed thoroughly with fresh sludge collected from the return activated sludge (RAS) pump and was diluted with lagoon water. The following table will show the effect of fresh sludge and dilution with lagoon water.

Table 6.10: Results for TTF Test after Adding Fresh Sludge and Diluting with Lagoon Water

Polymer No.	Polymer Conc.	Solids Conc.	Dosage (ml)	Time to Filter (sec)	Sludge Sample volume (ml)	Optimum polymer dose (Kg/dry ton)
C 6257	0.103%	4.65%	18	22.02	100	
			20	10.00		4.02
			22	13.72		
C 6237	0.103%	4.65%	18	31.44	100	
			22	14.37		
			24	11. 61		4.82
			26	12. 29		
C 6285	0.102%	4.65%	18	24.11	100	
			20	12.35		
			21	11.47		4.22
			22	13.58		
C 6210	0.099%	4.65%	24	29.91	100	------------

Table 6.10 showed some interesting results. Although C 6257 was still the most effective polymer, C 6285 was slightly more effective than C 6237. C 6285 worked better than C 6237. So, for mixed sludge (waste activated and digested) cationic concentrations

of 50~80% worked the best. Optimum polymer dose for the mixed sludge was slightly higher than that previously demonstrated for refrigerated lagoon sludge.

6.5 Results from APF Test

APF tests were performed after all the TTF tests were done. These tests were performed to verify the results obtained from TTF test. For the APF test, the filtrate volume removed every 10 seconds was recorded and put in the spreadsheet. Figure 6.15 will show APF test filtrate removal patterns with time for sludge samples from lagoon location 1 for polymers C 6210, C 6237, C 6257 and C 6285. Polymer dosages of 20ml were used for all polymers.

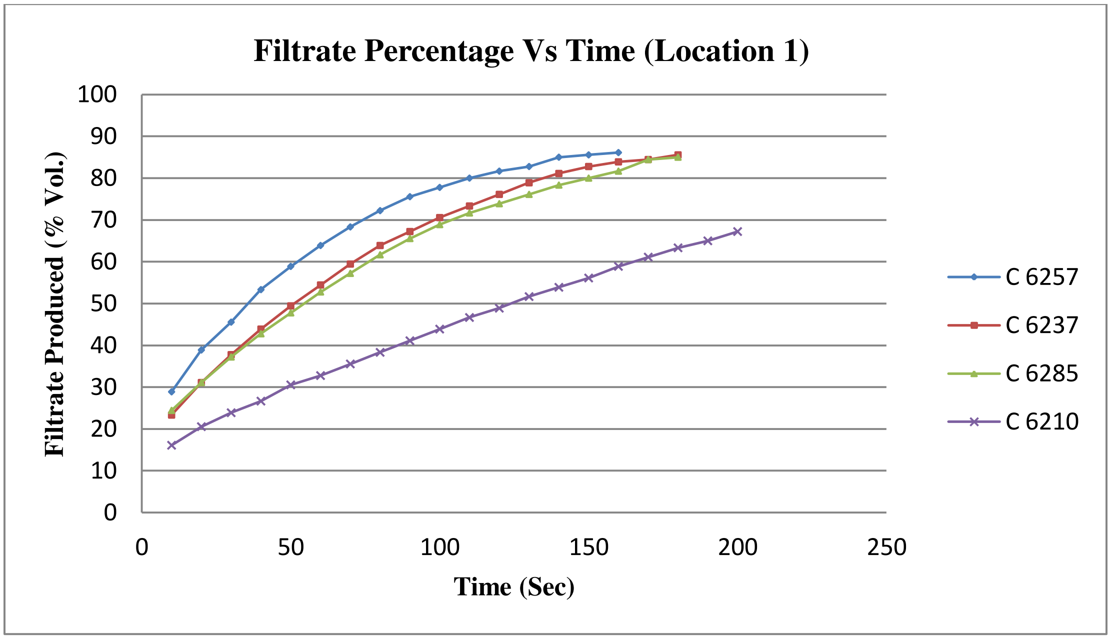

Figure 6.18: Filtrate Percentage Vs Time Graph for Sample from Location 1

From Figure 6.18, it was verified that C 6257 works best for dewatering. It was difficult to distinguish between the dewatering effectiveness of C 6237 and C 6285, but C 6237 worked a little better. The C 6210 worked poorly compared to the other three. Since

C 6210 removed 75% of water and required a longer period of time, it was omitted from tests on lagoon locations 2 and 3 sludge samples. Figures 6.19 and 6.20 demonstrate APF test filtrate removal patterns for lagoon locations 2 and 3 sludge samples respectively for polymers C 6257, C 6237 and C 6285.

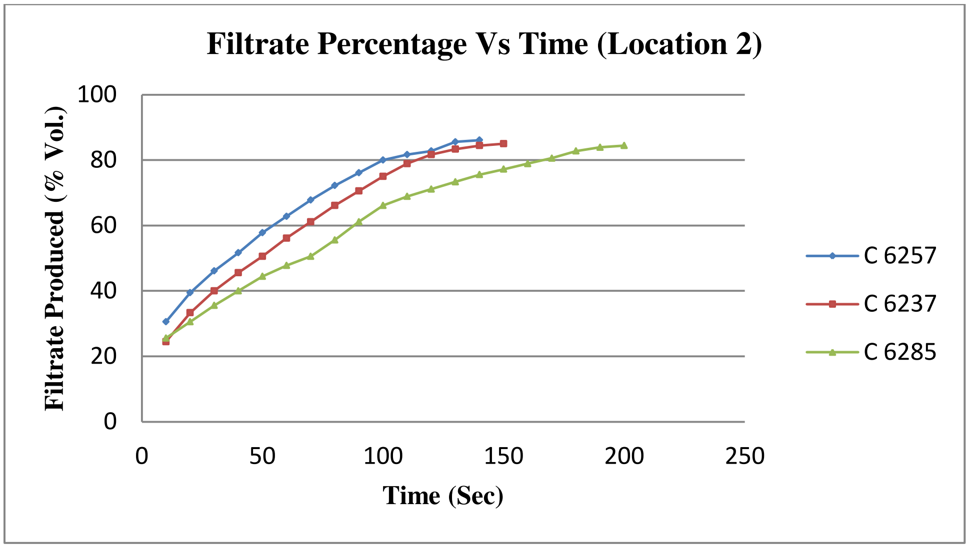

Figure 6.19: Filtrate Percentage Vs Time Graph for Sample from Location 2

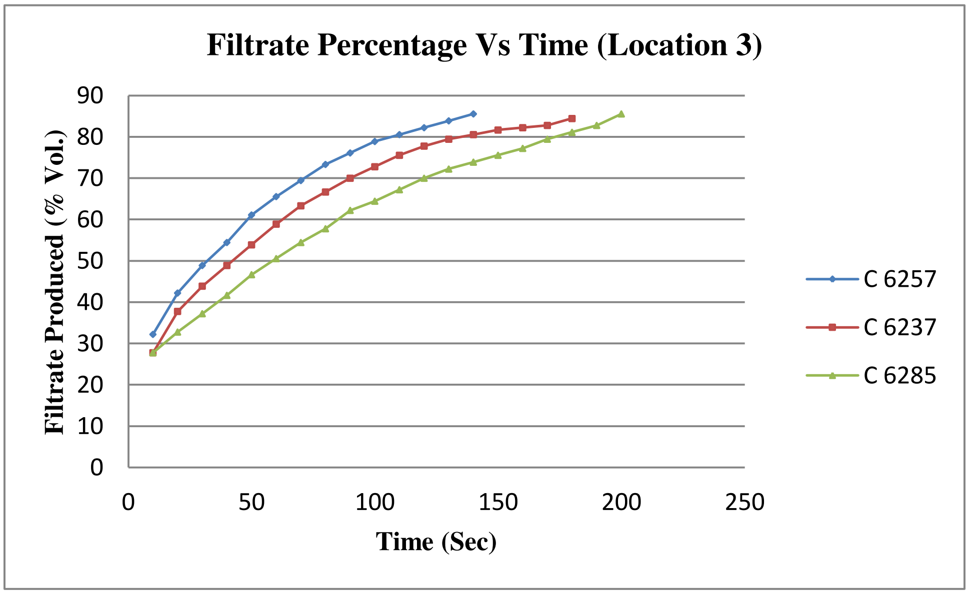

Figure 6.20: Filtrate Percentage Vs Time Graph for Sample from Location 3

A summary of APF test polymer C 6257 results are shown below in Table 6.11

Table 6.11 Summary of the APF Test Results for Polymer C 6257

Location No.	Most Effective polymer	Polymer concentration	Initial Solids Concentration	Filtrate Percentage	Time required (seconds to achieve maximum solids conc.)
1	C 6257	0.103	5.07%	85.56	140
2	C 6257	0.108	5.2%	86.11	140
3	C 6257	0.118	5.35%	86.11	160

Data obtained from APF tests were further analyzed to see the formation pattern of dry cake solids with time. Figure 6.18 demonstrates the comparison for cake formation with time for all the polymers for sludge samples from lagoon location 1. Polymer dosages of 20 ml per 100 ml sludge.

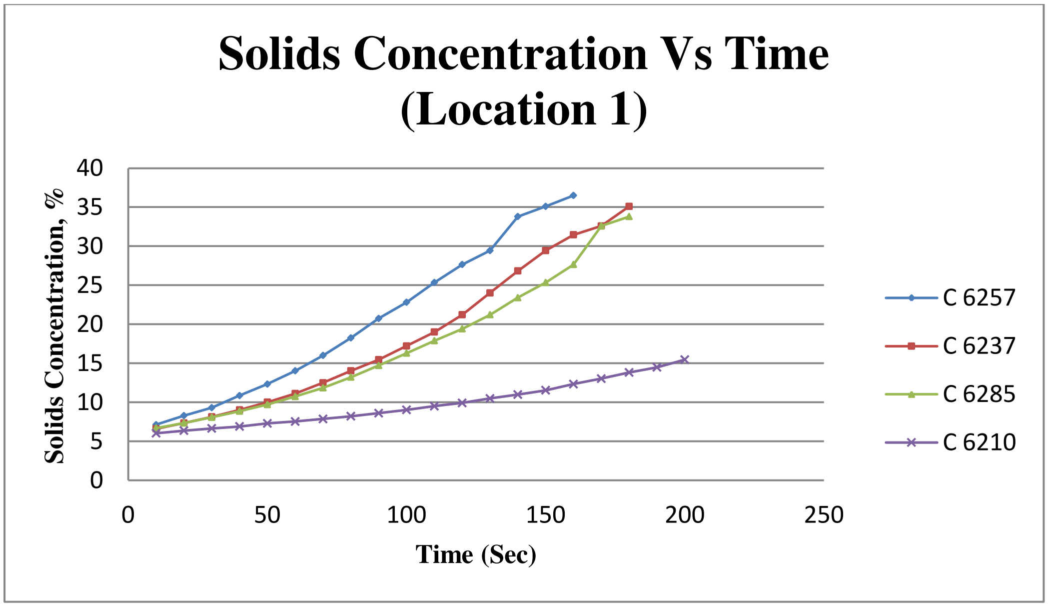

Figure 6.21: Solids Concentration Vs Time Graph for Sample from Location 1

Polymer C 6257 produces the highest solids concentration of 36% at the shortest time while polymer C 6210 produces a solid concentration of only 23%. Polymers C 6237 and C 6285 reached close to 35% solid concentrations but with longer periods of time than polymer C 6257. If our dewatered solids concentration goal is 20~23%, C 6257 gets to that point in 100 seconds.

Table 6.12 Summary of Results from Figure 6.21

Polymer No.	Polymer concentration	Initial solid concentration	Dewatered solid concentration	Time required (seconds estimated)
C 6210	0.101	5.07%	22%	260
C 6237	0.105	5.07%	22%	130
C 6257	0.103	5.07%	22%	100
C 6285	0.103	5.07%	22%	140

Cake formation analyses were done for lagoon locations 2 and 3 sludges as well. Figures 6.22 and 6.23 illustrate the test results.

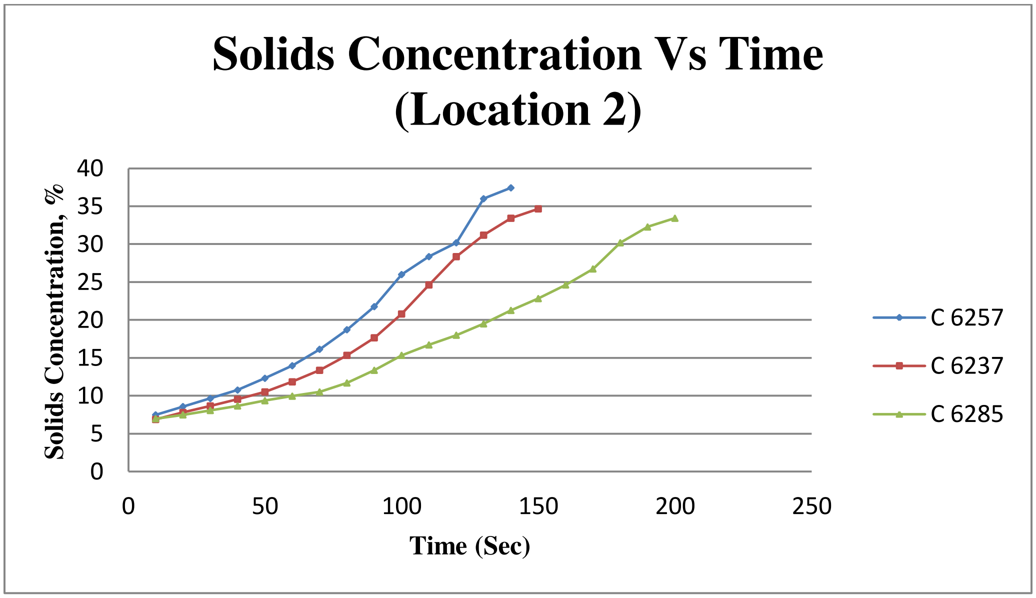

Figure 6.22: Solids Concentration Vs Time Graph for Sample from Location 2

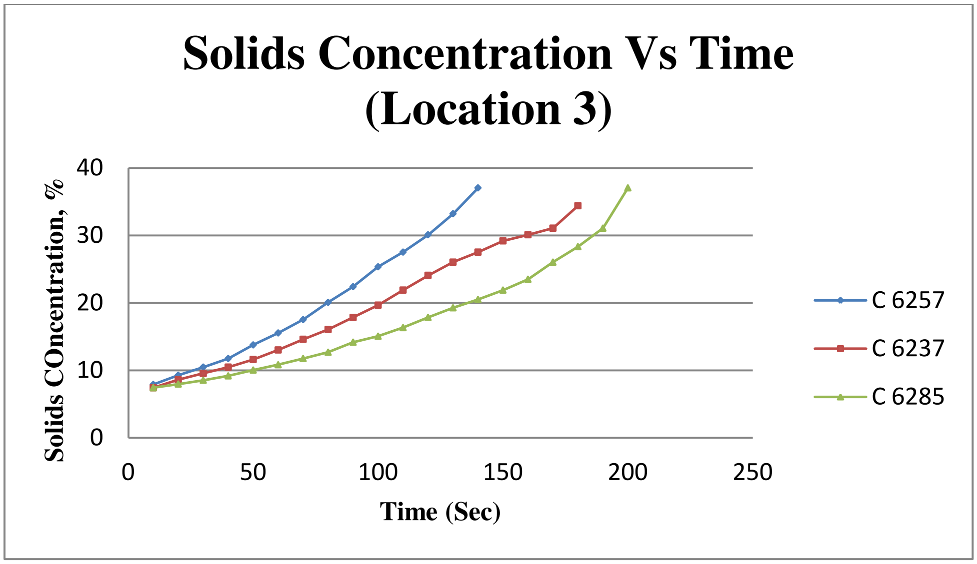

Figure 6.23: Solids Concentration Vs Time Graph for Sample from Location 3

Based on Figures 6.21, 6.22 and 6.23, polymer C 6257 was the most effective in dewatering the lagoon sludge. Therefore, further analysis was done for polymer C 6257 to see the cake formation pattern with lower dosage.

Figure 6.21 will illustrate the analysis for C 6257 for location 1.

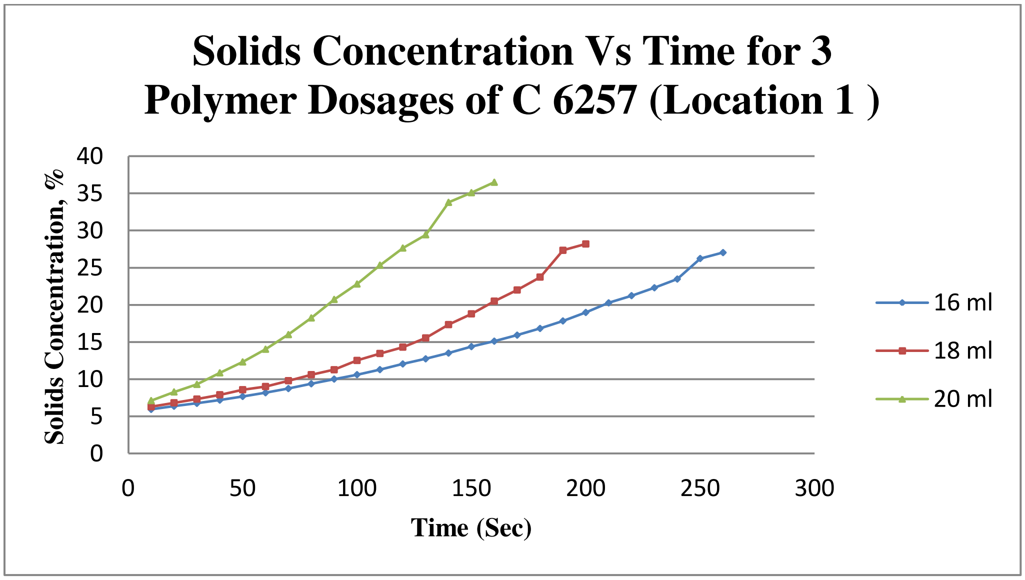

Figure 6.24: Solids Concentration Vs Time Graph for C 6257 (Location 1)

Figure 6.24 demonstrates attainment of 37% cake solids formation with a polymer dose of 20 ml per 160 ml initial sludge volume. With a polymer dose of 18 ml per 160 ml sludge, a solids concentration of 28% was achieved. With a 20 ml per 160 ml sludge polymer dose, a 27%, a solid concentration was achieved. So, all C6257 dosages were able to reach the desired solid concentration of 22% but with 20ml dosage it was achieved faster than the other two dosages. A summary of the Figure 6.24 is shown in Table 6.13.

Table 6.13: Summary of Results from Figure 6.24

Polymer No.	Location No.	Polymer concentration	Initial solid concentration	Dosage (ml/ 160 ml sludge)	Desired solid concentration	Time required (sec)
C 6257	1	0.103%	5.07%	16	22%	230
				18	22%	170
				20	22%	100

It is clear that all C 6257 polymer dosages tested can achieve a solid concentration of 22%. With higher reaction time, this 22% solids concentration can be achieved with the lower dose of 16 ml per 160 ml sludge. A polymer dose of 14 ml per 160 ml sludge was also tried, but the dewatering rate was low and the filtrate was turbid. So, a dose of 16 ml was assumed to be the lower limit for achieving desired solids concentration and acceptable filtrate quality. The same analyses were performed for C 6257 polymer dosages for lagoon locations 2 and 3 sludge samples and are illustrated in Figures 6.25 and 6.26. Both Figures 6.25 and 6.26 are followed by summary Tables 6.14 and 6.15 respectively. Results for lagoon location 2 and 3 sludge were consistent with lagoon location 1 observations.

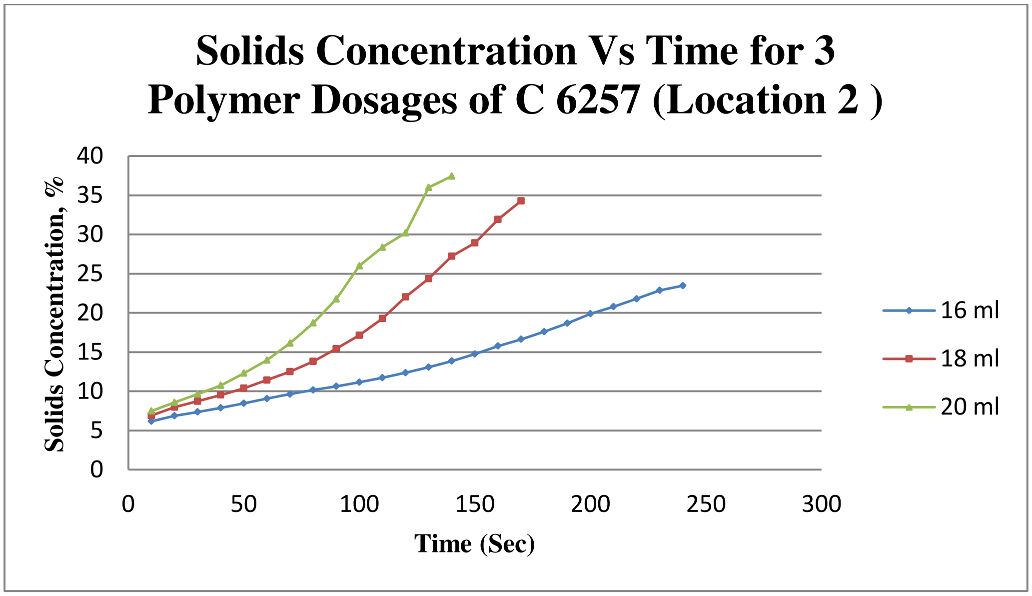

Figure 6.25: Solids Concentration Vs Time Graph for C 6257 (Location 2)

Table 6.14: Summary of Results from Figure 6.25

Polymer No.	Location No.	Polymer concentration	Initial solid concentration	Dosage (ml/ 160 ml sludge)	Desired solid concentration	Time required (sec)
C 6257	2	0.108%	5.2%	16	22%	230
				18	22%	120
				20	22%	90

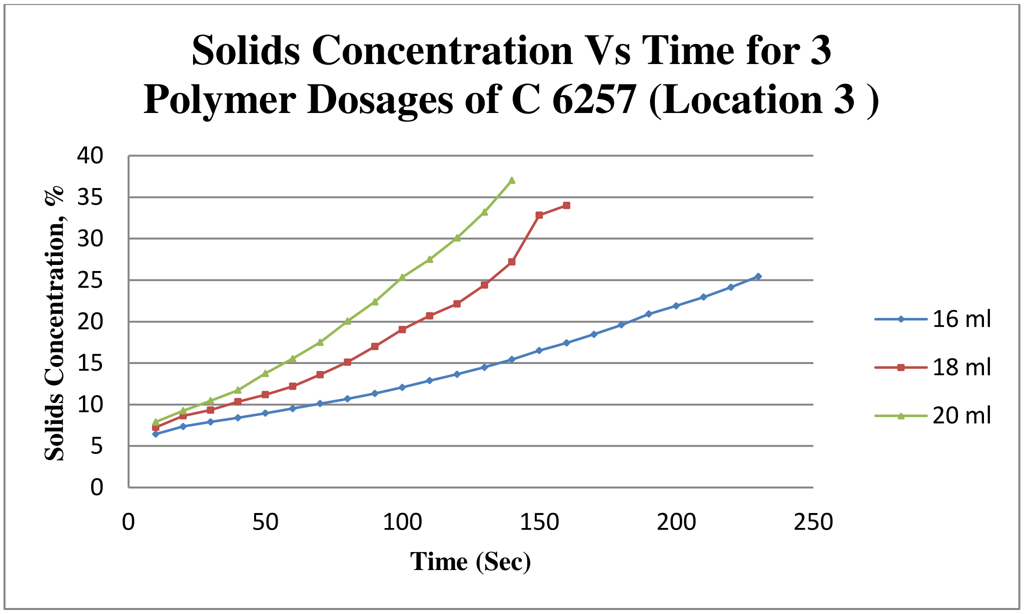

Figure 6.26: Solids Concentration Vs Time Graph for C 6257 (Location 3)

Table 6.15: Summary of Results from Figure 6.26

Polymer No.	Location No.	Polymer concentration	Initial solid concentration	Dosage (ml per 160 ml sludge)	Desired solid concentration	Time required (sec)
C 6257	3	0.118%	5.35%	16	22%	210
				18	22%	120
				20	22%	90

CHAPTER VII

COST ANALYSIS

At the time of decommissioning the lagoon, dredging and dewatering will be required for transport and disposal of sludge solid. A major cost will come from the polymers required for sludge dewatering. So, cost analysis in this chapter will be done to get an overview of how much polymer cost can be associated with decommissioning the lagoon. For analyzing cost, must first estimate how much sludge from the lagoon must be dewatered. Table 7.1 shows the lagoon area and the amount of sludge required for dewatering. This table is taken from the 'Technical Memorandum, 2009' submitted to the City of Grand Forks by Glenn Gustafson, PE from AE2S. It is based on the maximum biosolids accumulation by primary cell 2(PC2) by the end of its service life.

Table 7.1: Primary Cell 2 – Maximum Biosolids Accumulation

Total Acreage of PC2	201	Acres
Total Sludge Depth	4	Ft
Percent Solids in Sludge	9.4	%
Total Available Volume for Biosolids	262,001,377	Gallons
Estimated Quantity of Dry Biosolids	204,306,054	Lbs
	102,153	Tons

(Source: Gustafson, G., 2009)

The amount of C 6257 polymer needed for dewatering lagoon sludge has been found from the test results (see Table 6.6, 6.10 and 6.13-6.15). Amounts found from both tests are tabulated in Table 7.2. Costs are also estimated in this table. According to Mr. Steve Kuenneth, Technical Sales Representative of Polydyne, Inc, the costs of the polymers used in these tests are the same ($ 1.24 / lb).

Table 7.2: Cost of Polymer C6257 Based on TTF and APF Test Results

Tests	Location No.	Polymer Dosage (ml)	Polymer Conc.	Initial Solids Conc.	Polymer amount (lb/dry ton)	Cost* for polymers (USD)
TTF	1	16/100 ml sludge	.103%	4.45%	7.36	932,289
	2	20/100 ml sludge	.104%	4.98%	8.35	1,057,692
	3	20/100 ml sludge	.106%	5.03%	8.44	1,069,092
APF	1	16/160 ml sludge	.103%	5.07%	4.06	514,279
		18/160 ml sludge			4.57	578,880
		20/160 ml sludge			5.08	643,482
	2	16/160 ml sludge	.108%	5.2%	4.15	525,679
		18/160 ml sludge			4.67	591,547
		20/160 ml sludge			5.2	658,683
	3	16/160 ml sludge	.118%	5.35%	4.4	557,347
		18/160 ml sludge			4.96	628,282
		20/160 ml sludge			5.51	697,950

*Cost calculated for entire lagoon.

The highest polymer C 6257 cost calculated is nearly 1.1 million dollars and lowest cost calculated is nearly 515,000 dollars.

CHAPTER VIII

DISCUSSION

Both the TTF and APF bench top tests were done with polymer samples received from SNF-Polydyne. This company is the polymer provider for the GFWWTP. However, GFWWTP does not use any of the polymers which were used for the tests. They use Polydyne CE 985 for their DAF units. According to Mr. Steve Kuenneth, Technical Sales Representative of Polydyne, Inc, C 6257 and CE 985 polymers are very similar in specifications, except for the fact that CE 985 has a longer molecular chain.

The most effective polymer, as well as optimum dose, was determined from the TTF test. Many industries use the 'jar test' to find out the polymer dose required for dewatering. But with jar tests, there is always a possibility of overestimating polymer dosages required for dewatering. Sludge solids may get separated rapidly from the liquid with a higher polymer dosage but the TTF test results demonstrate that time to filter sludge samples increases with a higher polymer dose than the optimal dosage. So, this higher dosage may potentially cause wasting of polymer and affect the overall cost for sludge dewatering. The TTF test, on the other hand, determines the optimum polymer dosage required for dewatering. For these reasons, the TTF test was chosen over jar tests.

The TTF tests demonstrated that, polymer C 6257 was the most effective for dewatering the lagoon sludge. Figure 3.7, page 36, shows that, polymers of medium cationic concentration are the most effective for dewatering digested sludge. Polymer C 6257 has a cationic concentration of 50%. So, the result from the TTF test supported the figure.

The TTF test results were very consistent. Filtrate quality was acceptable as it had minimal turbidity. So, the solids capture rate was high for all the tests. The TTF tests demonstrated a lower polymer requirement for lagoon location 1. The most probable reason behind this was presence of lower solids concentration in the lagoon location 1 sludge sample following its dilution in the laboratory for testing. Also, TTF tests for lagoon location 1 sludge were started ahead of lagoon location 2 and 3 sludges. Lagoon location 2 and 3 sludges were refrigerated for a longer time than lagoon location 1 sludge prior to testing and may have been further digested. According to EPA- Sludge Dewatering Manual (2012), digested sludge requires a higher polymer dose to dewater. This statement explains the reason behind the lower polymer requirement for lagoon location 1 sludge dewatering. A contradictory result was found when waste activated sludge (WAS) was added with refrigerated sludge. Polymer requirement for dewatering this mixed sludge was higher than dewatering the refrigerated sludge.

Lagoon sludge with a solid concentration of 4.5~5.5% was tested for dewatering. This concentration was assumed to be the most probable consistency while dredging and decommissioning the lagoon. From the report of Gustafson, 2011, we know that sludge accumulated at the bottom of the lagoon has a solid concentration of 9.4%. So, dredging and its accompanying dilution is likely to result in a solids concentration of 4.5~5.5% or lower. The TTF test results demonstrated the requirement of lower polymer dosage for a lower solids concentration. So, if the dredged sludge has a solids concentration lower than 4.5~5.5%, polymer requirement will likely be lower, resulting in a lower cost for polymer use for dewatering.

For both the TTF and APF tests, a manual mixing blade was used. The mixing blade was operated at a higher speed at the beginning of the mixing procedure. After almost 30 seconds of rapid mixing, the speed was reduced to observe the formation of solid flocs. Once flocs started to form, the sludge sample was put on the funnel and pressure was applied to dewater the sample. Automated mixing tools may provide more repeatable mixing. Some dewatering test result discrepancies may exist for manual versus automated mixing of polymers with sludges. For determining sludge solid concentration, the same mixing blade was used. While storing the sludge samples in the incubator, some liquid got separated from the solids. With the help of the mixing blade, sludge solid and separated water were remixed before solid concentration measurement. Four sludge samples from each lagoon locations were tested simultaneously to check the consistency of the solids concentrations measured.

Sludge samples were diluted with distilled water to achieve desired solid concentrations (4.5~5.5%,) for all the tests. In order to observe the effect of waste activated sludge (WAS) addition to the refrigerated sludge, WAS collected from the GFWWTP was mixed with the refrigerated sludge. Polymer C 6257 was still the most effective for dewatering the mixed sludge. Polymer C 6285 worked better than polymer C 6237 for dewatering the mixed sludge. Referring again to Figure 3.7 (page 36), polymer with a higher cationic concentration works better for biological sludge dewatering. As fresh WAS is primarily biological, test results after addition of the fresh sludge were consistent with figure 3.7 expectations, as well.

The ‘Solids Handling Modification’ report, 2010 from North Dakota State University (NDSU), had some laboratory test reports on polymer use for sludge dewatering for GFWWTP. The NDSU team sent samples to the dewatering equipment suppliers and those companies ran their own pilot scale tests on polymers for sludge dewatering. Ashbrook Simon-Hartley (Belt Filter Press Supplier) ran their tests with Polydyne CE-985 (The same polymer used by GFWWTP) for belt filter press dewatering and they reported the requirement of polymer for sludge dewatering as 10-12 lbs/dry ton of solids. Based on the UND TTF test results reported in this thesis, the required polymer dosage is expected to be 7.5~8.5 lbs/dry ton of solids. So, the TTF test results matched well with pilot scale test results from the manufacturers.

The APF test was performed to verify test results from TTF tests, as well as to observe lagoon sludge dewatering patterns with different polymer dosages. Polymer C 6257 was the most effective APF test polymer as well, but there were additional interesting APF observations. The APF tests showed that with a longer dewatering residence time, desired solid concentration (22% solids concentration) in the dry solids cake can be achieved. The GFWWTP is considering the use of screw press systems for dewatering WAS. It is reasonable to expect that the dewatering system used for WAS may also be used for dewatering the lagoon sludge while decommissioning the lagoon. The APF test indicates that if the residence time of sludge in a screw press is long enough, then a lower, more cost effective polymer dose can be used. For example, polymer dosage can be lowered down to 4.1 lbs/ dry ton of solids from 5.6 lbs/dry ton of solids if the residence time can be raised to 240 seconds from 90 seconds. If this dosage can be used, cost for polymers can be cut down by a significant amount.

While performing a literature search on screw presses for municipal sludge dewatering, some interesting statistics on polymer use were found. Atherton et al. (2006) described some performance testing results for inclined screw press installed for dewatering municipal wastewater sludge in Old Town, Maine. As per the design criteria at the time of installation in 2004: the hydraulic loading rate for the inclined screw press was 70-80 gal/min, the solids loading rate was 700-900 lb/ hr, solids feed was 2~3%, and polymer use was expected to be less than 13lbs/ dry solids ton. After fine-tuned performance testing in June, 2005: the solids loading rate was increased to 1100 lbs/hr, solids feed concentration was 2.5 %, polymer use was 7 lbs/ dry solids ton, and concentration of dewatered solids was 21%. The screw press system does not have a filter media and also it does not exert continuous pressure on the sludge. The APF test is a filtration test and exerts a continuous pressure on sludge for the entire testing time. Although the APF test procedure does not match the design specifications of the screw press, the APF test estimation of polymer use for GFWWTP sludge dewatering appeared to agree closely with the fine –tuned performance testing results for the inclined screw press in Old Town.

Other interesting observations were found while searching for more testing on screw press performance. Huber technology installed their screw presses in Kennebunk, ME and York, ME. For the Kennebunk plant, the solids loading rate was 68-125 lb/hr, concentration of solids feed was 1.2~1.4% and polymer use was 18.5~38.4 lb/ dry solids ton. For the York plant, the screw press was used only for secondary sludge. The solids loading rate was 32~55 lb/hr, concentration of solids feed was 0.6~0.8% and polymer use was 20.5~28 lbs/ dry solids ton. (Huber Technology, 2011) These polymer requirements were much higher than those of the Old Town plant. Due to these kinds of differences in test results, it is strongly recommended that a pilot scale be test is performed prior to installation of an inclined screw press system at the GFWWTP.

CHAPTER IX

CONCLUSION

Time to Filter (TTF) test is a standardized test for determining polymer dose for sludge but the APF test is not. However, APF test is very useful to analyze sludge dewatering patterns, evaluating the effect of pressure, residence time, and much more. The TTF test worked very well in determining the most effective polymer and the optimum polymer dose. The APF test gave an overview of the possibility of the requirement of lower polymer dose in the screw press dewatering system. For both tests, polymer C 6257 worked the best and was recommended for dewatering lagoon sludge while decommissioning the lagoon. Based on the TTF test, polymer required for dewatering the lagoon sludge is 7.5~8.5 lb/ dry ton of sludge solid. Polymer cost estimated for decommissioning the entire lagoon (PC2) was approximately $ 1.1 million. It was observed in the APF tests that polymer dose can be much lower with a longer sludge residence time in the dewatering equipment. Based on the APF test, polymer required for dewatering the entire lagoon (PC2) may be as low as 4.1 lb/ dry ton of sludge solid and the polymer cost may be as low as $ 515,000. Screw press performance tests from different municipal wastewater plants showed variations in results for dewatering polymer use. It cannot be concluded that the polymer dosage obtained from the TTF and APF test results are adequate for viability confirmation or design of a screw press system for the GFWWTP. The TTF and APF test results gave an overview of appropriate polymer type and appropriate polymer dose required for lagoon sludge dewatering and the estimated cost of dewatering polymers. However, it recommended that pilot scale tests be performed for screw presses before selecting this technology as dewatering equipment for the GFWWTP WAS or lagoon sludge.

APPENDICES

APPENDIX A

POLYMER FACT SHEETS

APPENDIX A-1: CLARIFLOC® C-6210 POLYMER

PRINCIPAL USES

CLARIFLOC C-6210 is a low charge cationic polyacrylamide in emulsion form that is used as a flocculant in a wide variety of municipal and industrial wastewater treatment applications. It has been success- fully applied in all liquid/solids separation systems including clarification, thickening, and dewatering. Clarifloc C-6210 is approved by the **NSF** for use in potable water at dosages up to 1mg/L.

TYPICAL PROPERTIES

Physical Form	Clear to Milky White
Liquid Density	8.6 - 8.7 Lbs./Gal.
Cationicity	Low
Freezing Point	7° F (-14° C.) Flash Point> 200° F (>93° C.)

PREPARATION AND FEEDING

CLARIFLOC C-6210 is a single component emulsion polymer that must be prediluted in water before use. In most cases, this product should not be applied neat. One method for dilution is adding the neat polymer into the vortex of a mixed tank at a concentration between 0.25-1.0% polymer (0.5% is optimum) by weight. The polymer can also be injected through a number of commercially available systems that provide in-line mechanical mixing. The best feed systems use initial high energy mixing (>1000 rpm) for a short time (<30 sec) to achieve good dispersion followed by low energy mixing (<400 rpm) for a longer time (10-30 min). Polymer solutions should be aged for 15-60 minutes for best results. Solution shelf life is 8-16 hours.

MATERIALS OF CONSTRUCTION

Cross-linked polyethylene, fiberglass, stainless steel or lined steel are the preferred materials of construction for bulk tanks. Avoid natural rubber and Buna-N gaskets as these materials swell when placed in contact with neat polymer. Unlined mild steel, black iron, galvanized steel, copper or brass are not recommended in any part of the feed system. Stainless steel, Viton or Teflon are the best choices for pump heads. For feed lines, use PVC or reinforced Tygon tubing.

MANUFACTURING SPECIFICATIONS

Total Solids	39.5 - 46.5 %
Residual AcAm	< 500 ppm
Neat Viscosity	300 - 2000 cPs
Molecular Weight	High

HANDLING AND STORAGE

Suggested in-plant storage life is 6 months in unopened drums. For best results, store at 50-80 F. Bulk tanks should be mixed by periodically recirculating the contents bottom to top. Bulk tanks can also be fitted with an agitator type mixer that reaches the bottom 2 feet of the tank. Drums and bins should be mixed very well before first use and weekly after that. Do not allow emulsion polymers to freeze. Should freezing occur, allow the product to thaw thoroughly in a heated area and mix well before attempting to use it. For spills of CLARIFLOC C-6210, sprinkle vermiculite or equivalent absorbant over the spill area and sweep the material into approved chemical disposal containers. Do not spray water onto a spill because the resulting gel is very difficult to clean up.

SAFETY INFORMATION

CLARIFLOC C-6210 is a mildly acidic product that can irritate the skin and eyes and should be handled accordingly. Gloves, goggles and apron are highly recommended. Anyone responsible for the procurement, use or disposal of this product should familiarize themselves with the appropriate safety and handling precautions involved. Such information is outlined in the **POLYDYNE** Material Safety Data Sheet. In the event of an emergency with this product, contact Chemtrec anytime day or night at (800) 424-9300.

SHIPPING

CLARIFLOC C-6210 Polymer is shipped in 55 gallon, lined steel drums containing approximately 450 pounds net or in 275 gallon **nonreturnable** tote tanks. Bulk quantities are also available.

ADDITIONAL INFORMATION

To place an order or obtain technical information from anywhere in the continental United States, call toll free: (800) 848-7659

APPENDIX A-2: CLARIFLOC® C-6237 POLYMER

PRINCIPAL USES

CLARIFLOC C-6237 is a low charge cationic polyacrylamide in emulsion form that is used as a flocculant in a wide variety of municipal and industrial wastewater treatment applications. It has been success- fully applied in all liquid/solids separation systems including clarification, thickening, and dewatering.

TYPICAL PROPERTIES

Physical Form	Clear to Milky White Liquid
Cationicity	Low
Freezing Point	7° F (-14° C) Flash Point>200° F (>93° C)
Density	8.6 - 8.7

PREPARATION AND FEEDING

CLARIFLOC C-6237 is a single component emulsion polymer that must be prediluted in water before use. In most cases, this product should not be applied neat. One method for dilution is adding the neat polymer into the vortex of a mixed tank at a concentration between 0.25-1.0% polymer (0.5% is optimum) by weight. The polymer can also be injected through a number of commercially available systems that provide inline mechanical mixing. The best feed systems use initial high energy mixing (>1000 rpm) for a short time (<30 sec) to achieve good dispersion followed by low energy mixing (<400 rpm) for a longer time (10-30 min). Polymer solutions should be aged for 15-60 minutes for best results. Solution shelf life is 8-16 hours.

MATERIALS OF CONSTRUCTION

Cross-linked polyethylene, fiberglass, stainless steel or lined steel are the preferred materials of construction for bulk tanks. Avoid natural rubber and Buna-N gaskets as these materials swell when placed in contact with neat polymer. Unlined mild steel, black iron, galvanized steel, copper or brass are not recommended in any part of the feed system. Stainless steel, Viton or Teflon are the best choices for pump heads. For feed lines, use PVC or reinforced Tygon tubing.

MANUFACTURING SPECIFICATIONS

Total Solids	41 - 48 %
Residual AcAm	< 1000 ppm
Neat Viscosity	300 - 2000 cPs
Molecular Weight	High

HANDLING AND STORAGE

Suggested in-plant storage life is 6 months in unopened drums. For best results, store at 50-80 F. Bulk tanks should be mixed by periodically recirculating the contents bottom to top. Bulk tanks can also be fitted with an agitator type mixer that reaches the bottom 2 feet of the tank. Drums and bins should be mixed very well before first use and weekly after that. Do not allow emulsion polymers to freeze. Should freezing occur, allow the product to thaw thoroughly in a heated area and mix well before attempting to use it. For spills of CLARIFLOC C-6237, sprinkle vermiculite or equivalent absorbant over the spill area and sweep the material into approved chemical disposal containers. Do not spray water onto a spill because the resulting gel is very difficult to clean up.

SAFETY INFORMATION

CLARIFLOC C-6237 is a mildly acidic product that can irritate the skin and eyes and should be handled accordingly. Gloves, goggles and apron are highly recommended. Anyone responsible for the procurement, use or disposal of this product should familiarize themselves with the appropriate safety and handling precautions involved. Such information is outlined in the **POLYDYNE** Material Safety Data Sheet. In the event of an emergency with this product, contact Chemtrec anytime day or night at (800) 424-9300.

SHIPPING

CLARIFLOC C-6237 Polymer is shipped in 55 gallon, lined steel drums containing approximately 450 pounds net or in 275 gallon **nonreturnable** tote tanks. Bulk quantities are also available.

ADDITIONAL INFORMATION

To place an order or obtain technical information from anywhere in the continental United States, call toll free: (800) 848-7659

APPENDIX A-3: CLARIFLOC® C-6257 POLYMER

PRINCIPAL USES

CLARIFLOC C-6257 is a medium charge cationic polyacrylamide in emulsion form that is used as a flocculant in a wide variety of municipal and industrial wastewater treatment applications. It has been success- fully applied in all liquid/solids separation systems including clarification, thickening, and dewatering.

TYPICAL PROPERTIES

Physical Form	Clear to Milky White Liquid
Density	8.5 - 8.7 lbs/gal
Cationicity	Medium
Freezing Point	7° F (-14° C.)
Flash Point	> 200° F. (>93° C.)
Specific Gravity	1.032 - 1.044

PREPARATION AND FEEDING

CLARIFLOC C-6257 is a single component emulsion polymer that must be pre-diluted in water before use. In most cases, this product should not be applied neat. One method for dilution is adding the neat polymer into the vortex of a mixed tank at a concentration between 0.25-1.0% polymer (0.5% is optimum) by weight. The polymer can also be injected through a number of commercially available systems that provide in-line mechanical mixing. The best feed systems use initial high energy mixing (>1000 rpm) for a short time (<30 sec) to achieve good dispersion followed by low energy mixing (<400 rpm) for a longer time (10-30 min). Polymer solutions should be aged for 15-60 minutes for best results. Solution shelf life is 8-16 hours.

MATERIALS OF CONSTRUCTION

Cross-linked polyethylene, fiberglass, stainless steel or lined steel are the preferred materials of construction for bulk tanks. Avoid natural rubber and Buna-N gaskets as these materials swell when placed in contact with neat polymer. Unlined mild steel, black iron, galvanized steel, copper or brass are not recommended in any part of the feed system. Stainless steel, Viton or Teflon are the best choices for pump heads. For feed lines, use PVC or reinforced tygon tubing.

MANUFACTURING SPECIFICATIONS

Total Solids	43 - 50 %
Residual AcAm	< 1000 ppm
Neat Viscosity	300 - 2000 cPs
Molecular Weight	High

HANDLING AND STORAGE

Suggested in-plant storage life is 6 months in unopened drums. For best results, store at 50-80 F. Bulk tanks should be mixed by periodically recirculating the contents bottom to top. Bulk tanks can also be fitted with an agitator type mixer that reaches the bottom 2 feet of the tank. Drums and bins should be mixed very well before first use and weekly after that. Do not allow emulsion polymers to freeze. Should freezing occur, allow the product to thaw thoroughly in a heated area and mix well before attempting to use it. For spills of CLARIFLOC C-6257, sprinkle vermiculite or equivalent absorbant over the spill area and sweep the material into approved chemical disposal containers. Do not spray water onto a spill because the resulting gel is very difficult to clean up.

SAFETY INFORMATION

CLARIFLOC C-6257 is a mildly acidic product that can irritate the skin and eyes and should be handled accordingly. Gloves, goggles and apron are highly recommended. Anyone responsible for the procurement, use or disposal of this product should familiarize themselves with the appropriate safety and handling precautions involved. Such information is outlined in the **POLYDYNE** Material Safety Data Sheet. In the event of an emergency with this product, contact Chemtrec anytime day or night at (800) 424-9300.

SHIPPING

CLARIFLOC C-6257 Polymer is shipped in 55 gallon, lined steel drums containing approximately 450 pounds net or in 275 gallon **nonreturnable** tote tanks. Bulk quantities are also available.

ADDITIONAL INFORMATION

To place an order or obtain technical information from anywhere in the continental United States, call toll free: (800) 848-7659

APPENDIX A-4: CLARIFLOC® C-6285 POLYMER

PRINCIPAL USES

CLARIFLOC C-6285 is a very high charge cationic polyacrylamide in emulsion form that is used as a flocculant in a wide variety of municipal and industrial wastewater treatment applications. It has been success- fully applied in all liquid/solids separation systems including clarification, thickening, and dewatering.

TYPICAL PROPERTIES

Physical Form	Clear to Milky White Liquid
Cationicity	Very High
Freezing Point	7° F. (-14° C.)
Flash Point	> 200° F. (>93° C.)
Density	8.5 - 8.6 lbs/gal

PREPARATION AND FEEDING

CLARIFLOC C-6285 is a single component emulsion polymer that must be pre-diluted in water before use. In most cases, this product should not be applied neat. One method for dilution is adding the neat polymer into the vortex of a mixed tank at a concentration between 0.25-1.0% polymer (0.5% is optimum) by weight. The polymer can also be injected through a number of commercially available systems that provide in-line mechanical mixing. The best feed systems use initial high energy mixing (>1000 rpm) for a short time (<30 sec) to achieve good dispersion followed by low energy mixing (<400 rpm) for a longer time (10-30 min). Polymer solutions should be aged for 15-60 minutes for best results. Solution shelf life is 8-16 hours.

MATERIALS OF CONSTRUCTION

Cross-linked polyethylene, fiberglass, stainless steel or lined steel are the preferred materials of construction for bulk tanks. Avoid natural rubber and Buna-N gaskets as these materials swell when placed in contact with neat polymer. Unlined mild steel, black iron, galvanized steel, copper or brass are not recommended in any part of the feed system. Stainless steel, Viton or Teflon are the best choices for pump heads. For feed lines, use PVC or reinforced tygon tubing.

MANUFACTURING SPECIFICATIONS

Total Solids	Report
Residual AcAm	< 1000 ppm
Neat Viscosity	500 - 2000 cPs
Molecular Weight	Structured

HANDLING AND STORAGE

Suggested in-plant storage life is 6 months in unopened drums. For best results, store at 50-80 F. Bulk tanks should be mixed by periodically recirculating the contents bottom to top. Bulk tanks can also be fitted with an agitator type mixer that reaches the bottom 2 feet of the tank. Drums and bins should be mixed very well before first use and weekly after that. Do not allow emulsion polymers to freeze. Should freezing occur, allow the product to thaw thoroughly in a heated area and mix well before attempting to use it. For spills of CLARIFLOC C-6285, sprinkle vermiculite or equivalent absorbant over the spill area and sweep the material into approved chemical disposal containers. Do not spray water onto a spill because the resulting gel is very difficult to clean up.

SAFETY INFORMATION

CLARIFLOC C-6285 is a mildly acidic product that can irritate the skin and eyes and should be handled accordingly. Gloves, goggles and apron are highly recommended. Anyone responsible for the procurement, use or disposal of this product should familiarize themselves with the appropriate safety and handling precautions involved. Such information is outlined in the **POLYDYNE INC.** Material Safety Data Sheet. In the event of an emergency with this product, contact Chemtrec anytime day or night at (800) 424-9300.

SHIPPING

CLARIFLOC C-6285 Polymer is shipped in 55 gallon, lined steel drums containing approximately 450 pounds net or in 275 gallon **nonreturnable** tote tanks. Bulk quantities are also available.

ADDITIONAL INFORMATION

To place an order or obtain technical information from anywhere in the continental United States, call toll free: (800) 848-7659

APPENDIX B

TIME TO FILTER TEST DATA

APPENDIX B-1: TTF Test Data for Lagoon Location 1

Table B-1.1: TTF Test Data for C 6210 (Location 1)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.78%	0.108%	16	0.0036	42.35
2	4.78%	0.108%	18	0.004	26.45
3	4.78%	0.108%	24	0.0054	14.39
4	4.78%	0.108%	28	0.0063	11.87
5	4.78%	0.108%	30	0.0067	12.51
6	4.78%	0.108%	32	0.0072	14.49

Table B-1.2: TTF Test Data for C 6237 (Location 1)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.45%	0.107%	14	0.0033	22.67
2	4.45%	0.107%	16	0.0038	15.69
3	4.45%	0.107%	18	0.0043	10.77
4	4.45%	0.107%	20	0.0048	8.42
5	4.45%	0.107%	22	0.0052	9.26
6	4.45%	0.107%	24	0.0057	13.12

Table B-1.3: TTF Test Data for C 6257 (Location 1)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.45%	0.103%	12	0.0027	17.44
2	4.45%	0.103%	14	0.0032	11.03
3	4.45%	0.103%	15	0.0034	8.57
4	4.45%	0.103%	16	0.0037	7.78
5	4.45%	0.103%	18	0.0041	8.34
6	4.45%	0.103%	20	0.0046	12.72

Table B-1.4: TTF Test Data for C 6285 (Location 1)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.68%	0.099%	16	0.0033	25.12
2	4.68%	0.099%	20	0.0042	14.25
3	4.68%	0.099%	22	0.0046	10.17
4	4.68%	0.099%	24	0.005	9.13
5	4.68%	0.099%	26	0.0055	10.13
6	4.68%	0.099%	28	0.0059	13.57

APPENDIX B-2: TTF Test Data for Lagoon Location 2

Table B-2.1: TTF Test Data for C 6210 (Location 2)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	5.15%	0.108%	20	0.0041	41.67
2	5.15%	0.108%	24	0.005	25.91
3	5.15%	0.108%	28	0.0058	13.22
4	5.15%	0.108%	31	0.0065	11.12
5	5.15%	0.108%	34	0.0071	12.03
6	5.15%	0.108%	36	0.0075	14.73

Table B-2.2: TTF Test Data for C 6237 (Location 2)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.98%	0.104%	16	0.0033	25.31
2	4.98%	0.104%	19	0.0039	16.86
3	4.98%	0.104%	22	0.0045	11.91
4	4.98%	0.104%	24	0.005	9.14
5	4.98%	0.104%	26	0.0054	10.02
6	4.98%	0.104%	28	0.0058	12.63

Table B-2.3: TTF Test Data for C 6257 (Location 2)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.98%	0.104%	14	0.0029	41.19
2	4.98%	0.104%	16	0.0033	25.63
3	4.98%	0.104%	18	0.0037	16.04
4	4.98%	0.104%	20	0.0041	10.07
5	4.98%	0.104%	22	0.0045	12.72
6	4.98%	0.104%	24	0.005	17.87

Table B-2.4: TTF Test Data for C 6285 (Location 2)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	4.87%	0.102%	16	0.0033	27.23
2	4.87%	0.102%	20	0.0041	15.16
3	4.87%	0.102%	22	0.0046	10.98
4	4.87%	0.102%	25	0.0052	9.65
5	4.87%	0.102%	27	0.0056	10.68
6	4.87%	0.102%	29	0.0061	13.93

APPENDIX B-3: TTF Test Data for Lagoon Location 3

Table B-3.1: TTF Test Data for C 6210 (Location 3)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	5.23%	0.109%	25	0.0052	37.47
2	5.23%	0.109%	30	0.0062	23.13
3	5.23%	0.109%	32	0.0066	15.61
4	5.23%	0.109%	34	0.0071	12.92
5	5.23%	0.109%	36	0.0075	11.11
6	5.23%	0.109%	38	0.0079	13.32

Table B-3.2: TTF Test Data for C 6237 (Location 3)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	5.23%	0.102%	18	0.0035	28.23
2	5.23%	0.102%	21	0.0041	16.99
3	5.23%	0.102%	24	0.0047	11.83
4	5.23%	0.102%	26	0.0051	9.31
5	5.23%	0.102%	28	0.0055	10.19
6	5.23%	0.102%	30	0.0059	12.77

Table B-3.3: TTF Test Data for C 6257 (Location 3)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	5.03%	0.106%	12	0.0025	56.49
2	5.03%	0.106%	15	0.0031	29.53
3	5.03%	0.106%	18	0.0038	11.23
4	5.03%	0.106%	20	0.0042	9.17
5	5.03%	0.106%	22	0.0046	11.86
6	5.03%	0.106%	24	0.0051	14.34

Table B-3.4: TTF Test Data for C 6285 (Location 3)

Sample No.	Solids Conc.	Polymer conc.	Dosage (ml)	gm of polymer/gm of solids	Time to Filter (sec)
1	5.19%	0.110%	12	0.0025	65.34
2	5.19%	0.110%	17	0.0036	32.59
3	5.19%	0.110%	22	0.0047	15.71
4	5.19%	0.110%	26	0.0055	10.08
5	5.19%	0.110%	28	0.0059	11.97
6	5.19%	0.110%	30	0.0064	13.88

APPENDIX C

AIR PRESSURE FILTRATION TEST DATA

APPENDIX C-1: APF Test Data for Lagoon Location 1

Table C-1.1: APF Test Data for C 6210 (Location 1)

Polymer no.	Loc No.	Charge density	Initial Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C 6210	1	10%	5.07%	10			29
				20			37
				30			43
				40			48
				50			55
				60			59
				70			64
				80			69
				90			74
				100			79
				110			84
				120			88
				130			93
				140			97
				150			101
				160			106
				170			110
				180			114
				190			117
				200			121
				210			125
				220			128
				230			131
				240			133
				250			135
				260			139
				270			140

Table C-1.2: APF Test Data for C 6237 (Location 1)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6237	1	30%	5.07%	10			42
				20			56
				30			68
				40			79
				50			89
				60			98
				70			107
				80			115
				90			121
				100			127
				110			132
				120			137
				130			142
				140			146
				150			149
				160			151
				170			152
				180			154
				190			--
				200			--
				210			--
				220			--
				230			--
				240			--
				250			--
				260			--
				270			--

Table C-1.3: APF Test Data for C 6257 (Location 1)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6257	1	50%	5.07%	10	26	35	52
				20	36	46	70
				30	44	55	82
				40	52	64	96
				50	60	73	106
				60	67	78	115
				70	74	86	123
				80	81	93	130
				90	87	98	136
				100	92	106	140
				110	97	111	144
				120	102	115	147
				130	106	120	149
				140	110	126	153
				150	114	130	154
				160	117	134	155
				170	120	137	--
				180	123	140	--
				190	126	145	--
				200	129	146	--
				210	132	--	--
				220	134	--	--
				230	136	--	--
				240	138	--	--
				250	142	--	--
				260	143	--	--
				270	--	--	--

Table C-1.4: APF Test Data for C 6285 (Location 1)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6285	1	80%	5.07%	10			44
				20			56
				30			67
				40			77
				50			86
				60			95
				70			103
				80			111
				90			118
				100			124
				110			129
				120			133
				130			137
				140			141
				150			144
				160			147
				170			152
				180			153
				190			--
				200			--
				210			--
				220			--
				230			--
				240			--
				250			--
				260			--
				270			--

APPENDIX C-2: APF Test Data for Lagoon Location 2

Table C-2.1: APF Test Data for C 6237 (Location 2)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6237	2	30%	5.2%	10	20	36	44
				20	32	50	60
				30	43	61	72
				40	51	70	82
				50	58	79	91
				60	65	88	101
				70	72	96	110
				80	78	105	119
				90	83	112	127
				100	88	118	135
				110	93	123	142
				120	97	128	147
				130	101	132	150
				140	105	136	152
				150	109	140	153
				160	112	143	--
				170	115	146	--
				180	118	148	--
				190	121	149	--
				200	123	--	--
				210	125	--	--
				220	127	--	--
				230	130	--	--
				240	131	--	--

Table C-2.2: APF Test Data for C 6257 (Location 2)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6257	2	50%	5.2%	10	28	44	55
				20	43	62	71
				30	52	72	83
				40	60	81	93
				50	68	89	104
				60	75	97	113
				70	81	104	122
				80	86	111	130
				90	90	118	137
				100	94	124	144
				110	98	130	147
				120	102	136	149
				130	106	140	154
				140	110	144	155
				150	114	146	--
				160	118	149	--
				170	121	151	--
				180	124	--	--
				190	127	--	--
				200	130	--	--
				210	132	--	--
				220	134	--	--
				230	136	--	--
				240	137	--	--

Table C-2.3: APF Test Data for C 6285 (Location 2)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6285	2	80%	5.2%	10	20	26	46
				20	31	43	55
				30	40	53	64
				40	48	61	72
				50	54	68	80
				60	60	71	86
				70	65	77	91
				80	70	84	100
				90	75	88	110
				100	79	93	119
				110	83	98	124
				120	87	103	128
				130	91	107	132
				140	95	111	136
				150	99	115	139
				160	103	118	142
				170	106	121	145
				180	110	124	149
				190	113	127	151
				200	116	129	152
				210	118	132	--
				220	120	134	--
				230	123	136	--
				240	126	138	--
				250	129	143	--
				260	132	145	--
				270	135	147	--

APPENDIX C-3: APF Test Data for Lagoon Location 3

Table C-3.1: APF Test Data for C 6237 (Location 3)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6237	3	30%	5.35%	10	23	42	50
				20	37	59	68
				30	47	69	79
				40	54	77	88
				50	60	85	97
				60	66	94	106
				70	71	101	114
				80	76	108	120
				90	81	114	126
				100	85	120	131
				110	89	126	136
				120	93	131	140
				130	97	135	143
				140	101	138	145
				150	105	142	147
				160	109	147	148
				170	113	148	149
				180	116	--	152
				190	119	--	--
				200	122	--	--
				210	125	--	--
				220	128	--	--
				230	130	--	--
				240	132	--	--

Table C-3.2: APF Test Data for C 6257 (Location 3)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6257	3	50%	5.35%	10	30	47	58
				20	48	68	76
				30	57	76	88
				40	64	86	98
				50	71	93	110
				60	77	100	118
				70	83	108	125
				80	88	115	132
				90	93	122	137
				100	98	128	142
				110	103	132	145
				120	107	135	148
				130	111	139	151
				140	115	143	154
				150	119	149	--
				160	122	150	--
				170	125	--	--
				180	128	--	--
				190	131	--	--
				200	133	--	--
				210	135	--	--
				220	137	--	--
				230	139	--	--
				240	--	--	--

Table C-3.3: APF Test Data for C 6285 (Location 3)

Polymer no.	Loc No.	Charge density	Solids Conc.	Time (sec)	Volume filtered (ml)	Volume filtered (ml)	Volume filtered (ml)
					Polymer Dosage 16 ml	Polymer Dosage 18 ml	Polymer Dosage 20 ml
C6285	3	80%	5.35%	10	20	28	50
				20	38	44	59
				30	48	54	67
				40	56	62	75
				50	63	70	84
				60	69	78	91
				70	76	85	98
				80	83	91	104
				90	88	98	112
				100	93	104	116
				110	98	108	121
				120	102	112	126
				130	107	116	130
				140	111	120	133
				150	114	123	136
				160	117	127	139
				170	120	129	143
				180	123	132	146
				190	126	135	149
				200	128	137	154
				210	130	139	--
				220	132	142	--
				230	134	145	--
				240	137	147	--
				250	--	149	--
				260	--	150	--
				270	--	152	--

REFERENCES

Albert, J. (1977). DIFFICULT SLUDGE DEWATERING., 273-283.

Ashland. (2008). *Liquid/ solids seperation in wastewater treatment in wastewater treatment and biosolids dewatering.* Unpublished manuscript.

Atherton, P. C. (2012). Innovation in wastewater sludge dewatering. Retrieved 05/10, 2012, from http://www.wright-pierce.com/article-wastewater-sludge-dewatering.aspx

Australian Water Association. (2009). Australia and new zeland biosolids partnership. Retrieved 05/04, 2012, from http://www.biosolids.com.au/what-are-biosolids.php

Colin, F., & Gazbar, S. (1995). Distribution of water in sludges in relation to their machanical dewatering. *Water Research, 29*(8), 2000-2005.

Don W. Green (Ed.). (1997). *Perry's chemical engineering handbook* (7th ed.). North America: McGraw Hill.

Gumerman, R. C., & Burris, B. E. (1982). *Design manual - dewtering municipal wastewater sludges*. Cincinati, OH: U.S. Environmental Protection Agency.

Gustafson, G. (2009). *Technical memorendum- grand forks wastewater decommissioning study.* (). Grand Forks, ND: Advanced Engineering and Environmental Services, Inc.

Guyer, J. P. (2011). An introduction to sludge handling, treatment and disposal. Retrieved 05/11, 2012, from http://www.cedengineering.com/upload/An%20Intro%20to%20Sludge%20Hand%20Treat%20Disposal.pdf

Houghton, J., & Stephenson, T. (2002). Effect of influent organic content on digested sludge extracellular polymer content and dewaterability. *Water Research, 36*, 3620-3628.

Katsiris, N., & Kouzeli-Katsiri, A. (1987). Bound water content of biological sludges in relation to filtration and dewatering. *Water Research, 21*(11), 1319-1327.

Kistner, B. T. (2011). *Sludge digestion and management at the grand forks wastewater treatment plant.* (Unpublished Master of Science). University of North Dakota, Grand Forks, North Dakota.

Mikkelsen, L. H., & Keiding, K. (2001). Physico-chemical charactereistics of full scale sewage sludges with implications to dewatering. *Water Research, 36*, 2451-2462.

Novak, J., Sadler, M., & Murthy, S. (2003). Mechanisms of floc destruction during anaerobic and aerobic digestion and the effect on conditioning and dewatering of biosolids. *Water Research, 37*, 3136-3144.

PUB, Singapore's national water agency. (2011). History of NEwater. Retrieved 05/03, 2012, from http://www.pub.gov.sg/about/historyfuture/Pages/NEWater.aspx

Smollen, M. (1988). Moisture retention characteristics and volume reduction of municipal sludges. *Water SA, 14*(1), 25-28.

SNF FLOERGER.Sludge dewatering. Retrieved August, 2011, from http://www.snf-group.com/IMG/pdf/Water_Treatment_3_E.pdf

USEPA. (2012). A plain guide to the EPA part 503 biosolids rule. Retrieved 05/08, 2012, from http://water.epa.gov/scitech/wastetech/biosolids/503pe_index.cfm

USEPA. (2012). Water: Sewage sludge (biosolids). Retrieved 05/03, 2012, from http://water.epa.gov/polwaste/wastewater/treatment/biosolids/index.cfm

Varjavandi, J. J. (1990). Dewatering and disposal of sewage sludge. *CHEMECA '90, Australasian Chemical Engineering Conference,* , 1045-1052.

Wastewater Committee of the Great Lakes--Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. (2004). Recommended standards for wastewater facilities. Retrieved Aug,01, 2012, from http://10statesstandards.com/wastewaterstandards.html#93

Wilen, B., Jin, B., & Lant, P. (2002). The influence of key chemical constituents in activated sludge on surface and flocculating properties. *Water Research, 37*, 2127-2139. doi: 10.1016/S0043-1354(02)00629-2

Wu, C., Huang, C., & Lee, D. (1996). Effects of polymer dosage on alum sludge dewatering characteristics and physical properties. *Collfoids and Surfaces, 122*, 89-96.

Zhao, Y., & Bache, D. (2002). Integrated effects of applied pressure, time, and polymer doses on alum sludge dewatering behaviour. *Waste Management, 22*, 813-819.