# Technical Memorandum

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| Re: | South Plant Solids Thickening Technologies Evaluation |

## 1. Introduction

South Plant is one of three large regional treatment plants owned and operated by the Wastewater Treatment Division (WTD) of King County (the County). It is an activated sludge treatment facility currently permitted for 144 million gallons per day (mgd) maximum month flow (MMF). The liquid treatment process consists of screening, grit removal, primary sedimentation, activated sludge aeration tank, secondary clarification, chlorine disinfection and tertiary filtration (for producing a limited supply of reclaimed water). Plant effluent is discharged to Puget Sound. The solids process consists of Dissolved Air Flotation Thickening (DAFT) for primary sludge and Waste Activated Sludge (WAS) co-thickening, mesophilic anaerobic digestion, and centrifuge dewatering. DAFT also treats primary scum, centrate and overflow from the grit cyclone treating DAFT thickened bottom sludge. The dewatered Class B biosolids (Loop® biosolids) is beneficially used for land application in agriculture and forestry.

## 2. Goals and Objectives

The goal of this project is to summarize currently available sludge thickening technologies and evaluate them for feasibility at South Plant to inform future planning efforts or to scope more specific requests for project formulation.

The County is concurrently undertaking a project to rehabilitate and replace some major components of the existing DAFTs due to age and high levels of corrosion. The DAFT rehabilitation and replacement project will likely extend the existing DAFT lifetime by at least twenty years. Therefore, this evaluation considers a context of long-term planning and potential implications from the Puget Sound Nutrient General Permit.

The evaluation is accomplished through the following tasks:

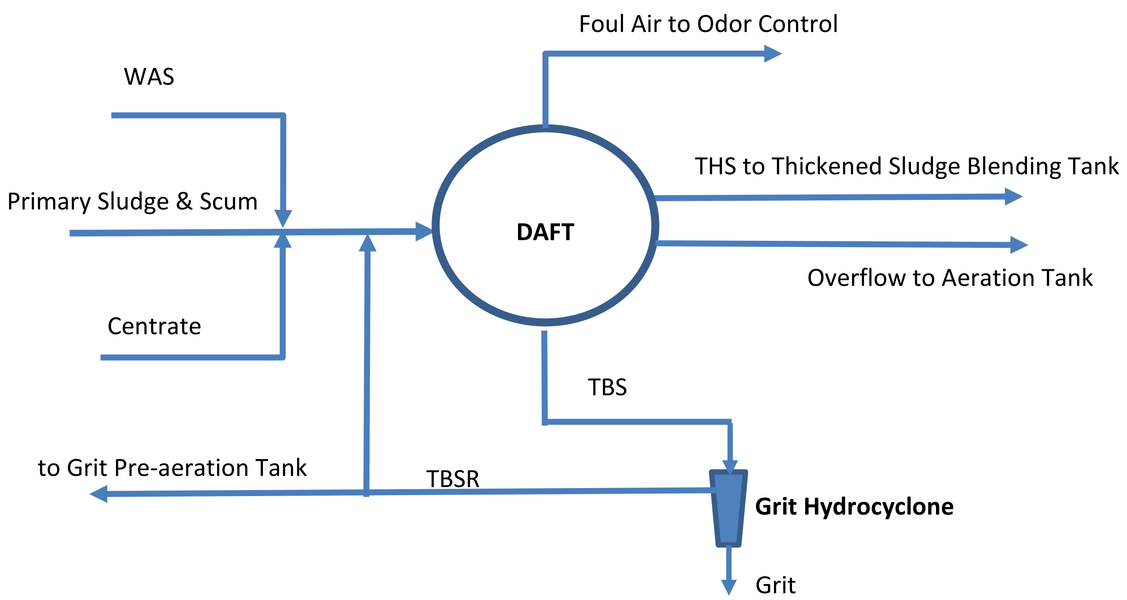
- Summarize available technologies and develop the description sheet of each
- Screen out technologies that are not applicable for South Plant
- Evaluate the remaining technologies based on the evaluation criteria developed specifically for South Plant

# 3. Current Thickening Operation

There are a total of six DAFTs at South Plant, with space reserved for two additional ones. Four of the DAFTs have a 55-foot diameter and were installed in mid-1980's. The other two have a 65-foot diameter and were installed in mid-1990's. DAFTs provide thickening as well as additional grit removal to the primary sludge and WAS.

As shown in the process flow diagram in Figure 1, primary scum, primary sludge, WAS, dewatering centrate and DAFT thickened bottom sludge return (TBSR) are pumped individually to a common line, then go through multiple bends and a grinder before getting fed into the DAFTs. Although there is no blending tank for this mixed sludge, it is believed the sludge is well mixed before entering the DAFTs. Thickened sludge (THS) is pumped to a small thickened sludge blending tank prior to being sent to the anaerobic digesters. DAFT overflow is conveyed to the liquids stream upstream of the aeration tanks. Thickened bottom sludge (TBS) is sent to hydrocyclones for degritting and separation of organic matter. Overflow from the hydrocyclones is conveyed back to the DAFTs or upstream of grit pre-aeration tanks as TBSR.

## Figure 1. Current South Plant DAFT Process Flow Diagram




The primary sludge pumps all operate continuously at a fixed flowrate, which could be adjusted manually by the operator to maintain a certain primary sludge solids content (around 0.4% to 0.7%). The WAS pumping is also continuous at varied flowrate setpoints throughout a day in order to maintain a relatively constant mixed sludge solids loading to the DAFTs. These flowrate setpoints could be adjusted to achieve a target aeration tank Sludge Retention Time (SRT).

# 4. Thickening Alternatives Screening

Seven technologies have been considered during the screening process. A general process description of each technology has been developed and included in Appendix A of this Technical Memorandum. Table 1 provides a summary of representative manufacturers and design basis of the seven technologies. The assumption for this screening is that the plant will continue co-thickening of primary sludge and WAS. If separate thickening is desired in the future, the thickening alternatives screening will need to be re-visited.

## Table 1. Summary of Available Thickening Technologies

| Technology | Manufacturer | Polymer Dosage (lb active/ton dry solids) | Solids Capture (%) | Thickened Sludge (%TS) |
|---|---|---|---|---|
| Centrifuge | Centrisys<br>Flottweg<br>Andritz<br>GEA | 0 – 10 | 90 - 97% | 2 – 10% |
| DAFT | WesTech<br>Eimco/FLSmidth | 0 -10 | 95% + | 5 – 8% |
| Disk Thickener | Huber | 6 - 10 | 97% + | 4 – 8% |
| Gravity Belt Thickener (GBT) | Eimco/FLSmidth<br>BDP<br>Andritz | 5 - 10 | 95% + | 4.5 – 7.5% |
| Gravity Thickener | WesTech<br>Eimco/FLSmidth | 0 – 12 | 80 - 90% | 3 – 6% |
| Membrane Thickener | Kubota Membrane | 0 | 99% + | 2 – 3% |
| Rotary Drum Thickener (RDT) | FKC<br>BDP<br>Huber<br>Parkson | 8 - 15 | 90 – 98% | 5 - 7% |

TS = Total solids

Upon review of these technologies, gravity thickening, disk thickening and membrane thickening are determined to not be well suited for further consideration due to the following reasons.

**Gravity thickener** is not well suited for co-thickening as it is intended for quickly settling sludges that help to minimize solids residence time within the tank. If used for co-thickening or thickening of WAS, lower hydraulic and solids loading rates, therefore larger footprint, will be required to achieve performance similar to thickening of primary sludge alone due to the poorer settleability characteristics of WAS.

**Disk thickener** is a relatively new technology that is only offered by a single manufacturer. At this time there are a limited number of capacity offerings for this technology, all of which are better suited for small to medium sized facilities. Due to the capacity limitation, a large number of units (thus a large footprint) would be required. For example, over 30 disk thickeners will be required to handle the amount of mixed sludge produced at South Plant in 2050. Additionally, the large number of units will result in an increased need for operation and maintenance (O&M).

**Membrane thickening** is also a relatively uncommon technology that is promoted by a single manufacturer to thicken WAS from the membrane bioreactor process. Membrane thickening is not well suited to co-thickening due to the presence of fats, oils and grease that will foul the membrane and increase the frequency of membrane flux maintenance. Additionally, membranes have low membrane flux rates and need large membrane surface areas to match the hydraulic loading rates of gravity thickeners and DAFTs. Lastly, membrane thickening systems rely on more mechanical equipment for their operation and have higher power requirements.

# 5. Thickening Alternatives In-depth Evaluation

This section provides an in-depth evaluation on the remaining four thickening technologies based on a list of evaluation criteria developed jointly by the County staff and the Consultant. Representative equipment vendors of these technologies were contacted to provide the proposals which became the basis of the conceptual design and evaluation.

## *5.1 Thickening System Design Criteria*

Each of the four thickening systems was sized and evaluated based on the 2050 projections from the 2019 King County Treatment Plant Flows and Loads Study prepared by Brown and Caldwell and current plant operation data provided by the County, as summarized in Table 2. These solids loads were developed assuming that South Plant would be operated under the current operation mode, without nitrogen removal. The total mixed sludge quantity and flow would be reduced if South Plant is operated to achieve Biological Nitrogen Removal (BNR). These design criteria also do not consider the potential for South Plant receiving additional solids from the other County's plants, i.e. West Point.

### Table 2. South Plant Thickening Design Criteria

| Parameter | 2050 Projections | |
|---|---|---|
| | Average Annual | Max Month |
| Raw Sewage Flow (mgd) | 94 | 151 |
| Primary Sludge TS (%) | 0.4[1] | 0.4[1] |
| Primary Sludge TS (lb/d) | 163,940 | 182,590 |
| Primary Sludge Flow (mgd) | 4.9 | 5.5 |
| WAS TSS (mg/L) | 6,180 | 8,530 |
| WAS TSS (lb/d) | 106,930 | 129,150 |
| WAS Flow (mgd) | 2.1 | 1.8 |
| Centrate TS (mg/L) | 400–1,500[2] | 400–1,500[2] |
| Centrate TS (lb/d) | 6,000 | 6,000 |
| Centrate Flow (mgd) | 0.5[3] | 0.5[3] |
| Total Mixed Sludge TS (lb/d) | 280,000 | 320,000 |
| Total Mixed Sludge Flow (mgd) | 7.5 | 7.8 |
| Target Thickened Sludge TS (%) | 5.5 to 6.2 | 5.5 to 6.2 |

Notes:

1. The Flows and Loadings Study predicts 0.7% primary sludge TS. Plant staff reported 0.4% TS as the current primary sludge TS. Assume the solids content of primary sludge in 2050 is the same as the solids content under current operating conditions for a conservative estimate of sludge flow.
2. Centrate TSS concentrations are based on plant staff's input. Use 1,500 mg/L for TS calculation.
3. The current centrate flow rate is 0.4 mgd. Assume it will increase to 0.5 mgd in 2050.

lb/d = pounds per day
mg/L = milligrams per liter

Other equipment design criteria include:

- The system shall be sized to handle the 2050 maximum month sludge quantities up to 24 hours/day and 7 days/week operation
- Total number of units shall be less than 10, with at least one redundant unit

## *5.2 Thickening Technologies Evaluation Criteria*

The high-level comparison was conducted using a qualitative rating and ranking system. The definition and explanation of the ratings are summarized in Table 3 below.

### Table 3. Qualitative Evaluation Criteria

| Evaluation Criteria | Consideration |
|---|---|
| Footprint | Land requirements for installation and operation |
| Energy Use | Energy consumption associated with operation |
| Carbon Emissions | Potential greenhouse gas emissions associated with operation |
| Impacts to Existing Treatment Processes | Impacts to, or compatibility with other existing treatment processes, i.e. grit and screenings removal and centrifuges |
| Impacts to Digestion | Impacts to digestion performance and capacity, related to sludge characteristics and quantity |
| Scum Handling | Capability of handling scum that is currently handled in DAFTs |
| Chemical Reliance | Polymer and other thickening chemicals required to achieve thickening and solids capture percentages |
| O&M Requirement | Level of effort to operate and maintain the system |
| O&M Cost | Operation and maintenance cost associated with the system |
| Capital Cost | Capital cost of constructing a new system |
| Impact to Nitrogen Removal | Impact to plant's capability of removing nitrogen due to nitrogen in the return stream |
| Impacts to Plant Long-term Planning Goal | Impacts to or compatibility with future potential plant upgrade, i.e. Class A biosolids, co-digestion, energy recovery |
| Reliability | Proven technology by multiple credible manufacturers, and sufficient successful installations at comparable sized facilities |
| Constructability | Site-specific construction considerations |
| Environmental Impact | Odor and noise impact to the neighborhood |
| Thickening Performance | Solids capture & thickened solids concentration |

Each alternative was compared against the DAFT baseline. A rating was given for each criterion in accordance with the following definition, as shown in Table 4.

## Table 4. Qualitative Rating Criteria

| Rating | Definition |
|---|---|
| + | Better - The alternative provides a more desirable/beneficial outcome |
| 0 | Same - The alternative displays similar performance |
| - | Lower - The alternative provides a less desirable/beneficial outcome |

## *5.3 Qualitative Comparison*

Table 5 summarizes the comparison of the three alternatives against the baseline DAFT, considering the ratings discussed in Table 4. Details for the high-level carbon emissions (i.e. greenhouse gas emissions) calculation and the order of magnitude (Class 10) capital and O&M cost estimates are included in Appendix C and Appendix D, respectively. The Class 10 cost estimate has an accuracy in the range of +300% to -50% for the purpose of supporting the County's near and long-term capital project identification and budgeting.

## Table 5. Comparison of Alternatives Against DAFT Baseline for In-depth Evaluation

| Category | GBT | RDT | Centrifuge | Notes |
|---|---|---|---|---|
| Footprint | + | + | + | Six DAFTs require about 44,000 square feet of footprint, the others require less than 14,000 square feet of footprint. |
| Energy Use | + | + | - | 2050 annual energy use is about 3.5 million kWh for DAFT, 2.1 million kWh for GBT, 2.7 million kWh for RDT and 8.5 million kWh for centrifuge. |
| Carbon Emissions | - | - | - | 2050 annual carbon emission, including carbon emission from polymer production, is about 1,800 metric tons (mt) of $CO_2e$ for DAFT, 5,300 mt of $CO_2e$ for GBT, 7,000 mt of $CO_2e$ for RDT and 3,700 mt of $CO_2e$ for centrifuge. |
| Impacts to Existing Treatment Processes | - | - | - | GBT, RDT and centrifuge thickeners will require rerouting of centrate, which may require additional screening due to the floatable debris. Influent grit removal improvements or a primary sludge grit removal system will be required to achieve grit removal similar to what the DAFTs currently provide. |
| Impacts to Digestion | + | + | + | GBT, RDT and centrifuge thickeners have the similar solids capture and produce the comparable solids content to the DAFT. By diverting centrate from thickening, the flowrate of thickened sludge fed to the digesters will be slightly reduced, therefore the digester hydraulic retention time will be increased. This positive impact from centrate diversion will likely be greater than the potential negative impact caused by diluted primary scum and additional grit entering the digesters. |
| Scum Handling | - | - | - | DAFT is good at removing scum, while the others will be susceptible to blinding and clogging. Thickening performance will be impacted, and maintenance will be increased if scum is thickened by GBT, RDT and centrifuge. Therefore, rerouting of scum is preferred for these three technologies. |
| Chemical Reliance | - | - | + | Polymer dose requirement is 0-10 lb/dry ton for DAFT, 5-10 lb/dry ton for GBT, 8-15 lb/dry ton for RDT and 0-4 lb/dry ton for centrifuge. |
| O&M Requirement | + | + | + | DAFT requires high O&M and confined space entry during maintenance. The others require less O&M and do not require confined space entry. |

| Category | GBT | RDT | Centrifuge | Notes |
|---|---|---|---|---|
| O&M Cost | - | - | - | Approximate annual O&M cost, including polymer cost, is $0.8 million for DAFT, $1.5 million for GBT, $2.0 million for RDT and $1.6 million for centrifuge. |
| Capital Cost | - | - | - | Approximate capital cost is $16 million for DAFT, $22 million for GBT, $24 million for RDT and $30 million for centrifuge. Costs for GBT, RDT and centrifuge include a new building. |
| Impact to Nitrogen Removal | 0 | 0 | 0 | None of the alternatives will alter the plant's capability of removing nitrogen since nitrogen in the return stream is not impacted. Although centrate returns to DAFT, the same ammonia-nitrogen loading eventually ends up being in the aeration tanks via the DAFT overflow since DAFTs do not remove any ammonia-nitrogen. This is the same as the situation where centrate bypasses GBT, RDT or Centrifuge and returns to the aeration tanks directly. |
| Impacts to Plant Long-term Planning Goal | + | + | + | Co-thickening using the GBT, RDT or centrifuge thickeners will be compatible with any long-term planning goals for digestion process upgrade, i.e. Class A biosolids, co-digestion, energy recovery. The thickened sludge solids concentration could be controlled in a wide range by adjusting the equipment and polymer dose, to better meet the requirement of any future upgrade if designed accordingly. If housed in the multi-story building as shown in Figure 4, they will also free up the space currently occupied by the DAFTs for other future use. |
| Reliability | + | + | - | DAFT is a reliable thickening technology that has been used in many wastewater plants for decades. However, the number of new installations in municipal wastewater treatment area has been declined. Both GBT and RDT technologies have many installations at large municipal wastewater plants and multiple manufacturers to allow reliable and competitive equipment supply. The centrifuge thickener has fewer installations. |
| Constructability | + | + | + | As shown in Figure 4, space is likely available for the new thickening building west of the existing DAFTs. Construction could be done without interrupting the existing thickening operation. |

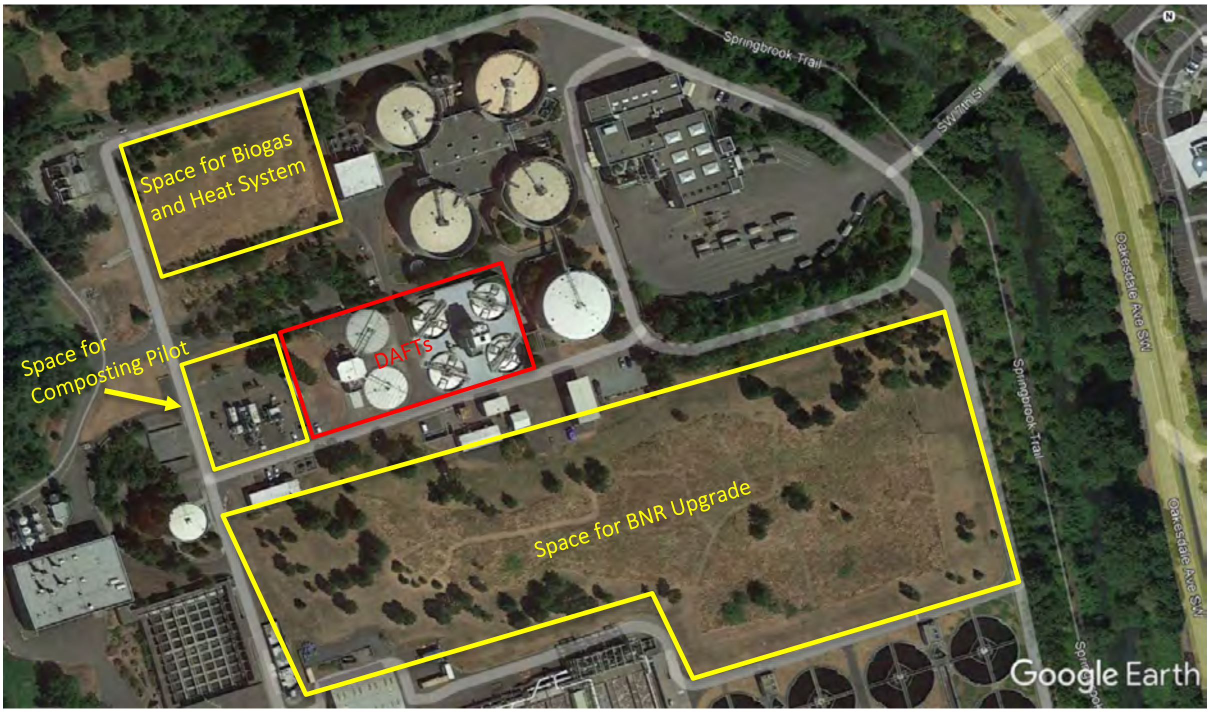
| Category | GBT | RDT | Centrifuge | Notes |
| --- | --- | --- | --- | --- |
| Environmental Impact | 0 | 0 | 0 | Existing DAFT operation has minimal odor and noise impact to the environment with odor control and ancillary equipment in the gallery. The others will also have minimal odor and noise impact to the environment with odor control and all the equipment enclosed in a building. |
| Thickening Performance | 0 | 0 | 0 | DAFT can achieve 95%+ solids capture and 5-8% solids. GBT can achieve 90%-98% solids capture and 4.5-7.5% solids. RDT can achieve 90%-98% solids capture and 5-7% solids. Centrifuge can achieve 95%+ solids capture and 5-10% solids. All thickening technologies have comparable performance. |
| **Total No. of "+"** | **7** | **7** | **6** | |
| **Total No. of "-"** | **6** | **6** | **7** | |

## 5.4 Baseline – Dissolved Air Flotation Thickening (DAFT)

### 5.4.1 Description

The existing DAFTs are located on the northern part of South Plant, as shown in Figure 2 below. They are south of the digester building and west of the digested sludge blending storage tank. The area allocated for the six existing DAFTs and two future DAFTs is approximately 55,000 square feet. The space currently occupied by the six existing DAFTs is approximately 45,000 square feet. According to various County planning documents, most of the space around the DAFTs has been identified for future use, for example, the area to the west of DAFTs will be used for the biosolids compost pilot test in the next few years; the area in the northwest corner of the plant has been proposed for the biogas and heat system improvements use; the large space south of the DAFTs is reserved for the secondary treatment process upgrade to accomplish BNR.

Figure 2. Site Plan of South Plant Showing DAFT and Spaces for Future Use




### 5.4.2 Major Equipment and Power Consumption

It has been determined in the King County Treatment Plant Flows and Loads Study provided by Brown and Caldwell that six DAFTs, at the existing dimensions and capacity, are sufficient to handle the 2050 sludge quantities. It is assumed the existing concrete DAFT Tanks will be in a fair condition in 2050 and could be reused at that time. WesTech provided a proposal for the DAFT equipment replacement according to the design criteria described above. Table 6 summarizes the major DAFT equipment and horsepower requirement based on 2050 sludge projection.

## Table 6. DAFT Equipment and Horsepower Requirement

| Parameter | 55-ft Dia. DAFT | 65-ft Dia. DAFT |
|---|---|---|
| No. of Unit | 4 | 2 |
| Drive Unit, hp each | 1 | 1 |
| Recycle Pump, hp each | 50 | 75 |
| Air Compressor, hp each | 15 | 15 |
| Other major components (one per unit): | | |
| Saturation Tank, volume each | 1,400 gal | 1,615 gal |
| Back Pressure Valve, size each | 8" Dia. | 10" Dia. |
| Air Control Panel | | |

### *5.4.3 Advantages/Disadvantages*

The technology description sheets in Appendix A list the general advantages and disadvantages of each technology. Additional advantages and disadvantages of the DAFTs specific to South Plant are summarized below, based on the plant staff feedback.

*Advantages:*

**Grit removal:** At South Plant DAFTs remove70 to 80 percent of grit fed to the DAFTs through recycling the TBS through the grit hydrocyclones. This grit otherwise will enter and likely accumulate in the anaerobic digesters and additionally will cause increased wear on downstream equipment.

**Flow equalization:** DAFT is good at handling flow and load variations when receiving multiple sludge sources, including primary scum, primary sludge, WAS, TBSR and dewatering centrate. The primary sludge total solids content is typically 0.4 to 0.7 percent. The WAS total solids content is typically 0.5 to 0.8 percent. The total solids content in TBSR is 5.5 to 6.5 percent. The mixed sludge total solids are in the 0.5 to 1.0 percent range. Dewatering centrate typically contains 400 to 1,500 mg/L TSS, which will further dilute the mixed sludge going to the DAFTs.

**Impact on scum and centrate:** South Plant's centrate contains lots of floatable fruit labels and rubber bands, which makes its direct return to the aeration tank undesirable. Returning centrate to the screening facility is also challenging because the existing centrate pumps do not have sufficient head at current flow and the centrate would come in upstream of influent sampler. Since South Plant DAFTs are not hydraulically limited and the DAFTs are good at removing floatable solids, routing centrate and primary scum to the DAFTs simplifies the process and operation.

*Disadvantages:*

**High maintenance:** DAFT maintenance is a labor-intensive activity. Maintenance of in-basin equipment and structure is an annual activity and includes draining the DAFT tank and confined space entry. Typically, it takes three days per DAFT tank. In addition, on a quarterly basis staff must clean the THS pumps due to build-up of Fat Oil and Grease (FOG) most of which is captured in the primary scum and then fed to the DAFTs.

**High potential of corrosion**: Although the headspace in the covered DAFTs is ventilated and air is treated at the odor control system, hydrogen sulfide is still present in the headspace to cause corrosion of the equipment and structure over time. The rehabilitation of structure and replacement of equipment is a huge undertaking for the County.

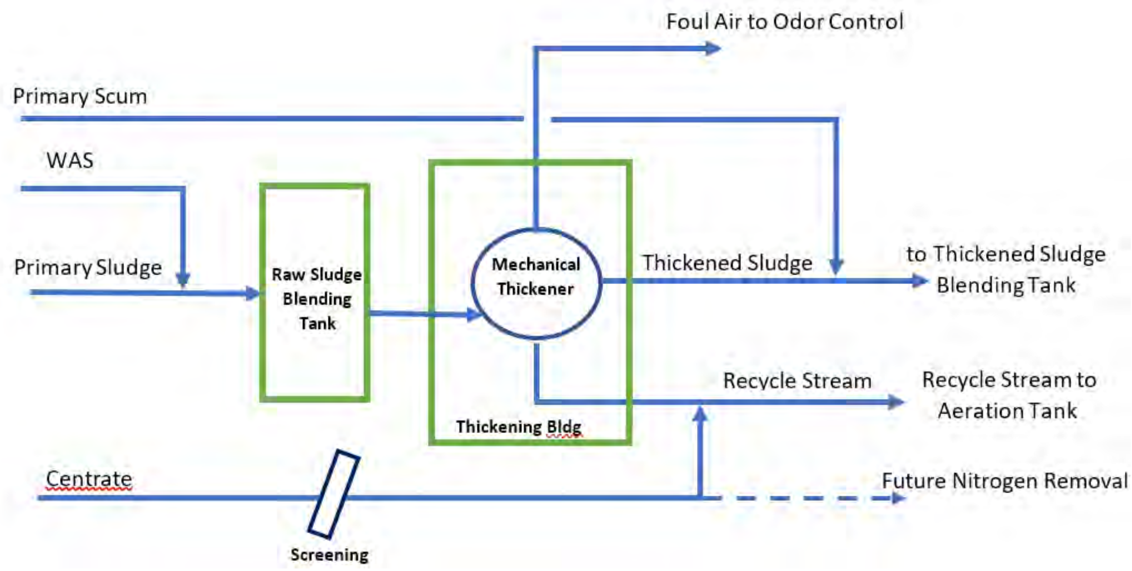
## 5.5 Alternative 1 – Gravity Belt Thickener (GBT)

### 5.5.1 Description

Gravity Belt Thickener (GBT) is a mechanical thickener that distributes feed sludge on a moving belt, solids concentrate on the belt and free liquid (filtrate) is allowed to drain from the sludge by gravity. GBT is different from a DAFT or gravity thickener, which are in-basin thickeners that utilize the gravity or buoyancy to achieve liquid and sludge separation. As with all the other mechanical thickeners, GBT requires proper blending and conditioning of the feed sludge (i.e., polymer or coagulant addition) and a building to house the thickeners and ancillary equipment. The unit capacity is often limited by the hydraulic loading rate; therefore, it is not economical to blend centrate with the feed sludge. In addition, the belt of a GBT is susceptible to blinding by FOG; therefore, primary scum should not be sent to the GBT. Figure 3 shows a process flow diagram for mechanical thickener options at South Plant. Several changes from the current thickening operation include:

- A new raw sludge blending tank
- A new thickening building
- Primary scum is diverted from thickening and routed to the thickened sludge blending tank or directly to the digesters
- Centrate is diverted from thickening and routed to the liquid treatment process. To remove excessive fruit labels and rubber bands that are currently present in centrate, additional finer screening unit dedicated for centrate may be required. Depending on the future nitrogen removal plans, centrate could be collected and treated separately in a side-stream treatment system before returning to the main plant.

## Figure 3. Mechanical Thickener Process Flow Diagram



A conceptual level sizing indicates a 2-story thickening building with a footprint of approximately 13,800 square feet (150 ft by 92 ft) will be sufficient to house the entire thickening system, including the raw sludge blending tank, thickened sludge tank, thickeners and sludge pumps, polymer system, and odor control system, as shown in Appendix B. Figure 4 shows the potential location of the new thickening building assuming the composting pilot test will be completed by the time this new thickening building is needed. It is assumed the existing DAFTs will remain operational during the construction so that the thickening is not interrupted.

## Figure 4. Site Plan of South Plant Showing Future Thickening Building


### 5.5.2 *Major Equipment and Power Consumption*

Andritz and BDP provided the GBT proposals according to the design criteria described in Table 2. Table 7 summarizes the GBT equipment and horsepower requirement based on 2050 sludge projection. Note that all the ancillary equipment, such as thickener feed pumps, thickened sludge pumps, raw sludge blending tank mixers, thickened sludge blending tank mixers, etc. are not included since they will be similar for all thickening technologies.

## Table 7. GBT Equipment and Horsepower Requirement

| Parameter | Value |
|---|---|
| No. of Unit | 7 (6 duty + 1 standby) |
| GBT Belt Width | 3-meter |
| Belt Drive, hp each | 5 |
| Hydraulic Power Unit, hp each | 1 |
| Wash Water Booster Pump, hp each | 7.5 |
| Other major components (one per unit): | |

| Parameter | Value |
|---|---|
| Control panel | |
| Polymer Mixing System | |
| Odor control hood | |
| GBT Enclosure Frame | |

### 5.5.3 Advantages/Disadvantages

Major advantages and disadvantages of GBT specific to South Plant are summarized below, based on the plant staff feedback.

*Advantages:*

**Proven and reliable technology:** The technology has been successfully used for over thirty years, at numerous facilities of the similar size to South Plant, including the County's Brightwater and West Point plants.

**Less maintenance:** Per County's staff, only three belts have been replaced for three GBTs in the last ten years at the Brightwater Plant. Other maintenance efforts include adjusting the belt tension and alignment and adjusting the side wipers to keep solids on the belt. All maintenance does not require confined space entry.

**Smaller footprint:** Building could be multi-story therefore would require a smaller footprint.

**Lower energy consumption**: The equipment typically has lower horsepower and requires lower energy consumption.

*Disadvantages:*

**Impact on centrate:** It is not economical to thicken dewatering centrate using GBT. Centrate will need to be re-routed to the plant liquid treatment process.

**Impact on scum:** It is not desirable to thicken scum using GBT. The negative impact of FOGs on GBT is greater than on RDT and centrifuge due to the tendency to clog up the belt.

**Impact on grit:** GBT does not provide additional grit removal of feed sludge unless additional grit cyclone is provided as for the existing DAFTs.

## 5.6 Alternative 2 – Rotary Drum Thickener (RDT)

### 5.6.1 Description

RDT is a mechanical thickener that thickens the sludge by gravity drainage and compaction while retaining the solids in a slowly rotating drum with a porous screen. A spray system is used to clean the drum and prevent the pores from becoming blocked by solids, scum, and FOGs.

Similar to GBT, RDT requires proper blending and conditioning of the feed sludge and a building to house the thickeners and ancillary equipment. The process flow diagram illustrated in Figure 3 also applies to RDT. A conceptual level sizing indicates a 2-story thickening building with a footprint of approximately 13,800 square feet (150 ft by 92 ft) will be sufficient to house the entire RDT system, including the raw sludge blending tank, thickened sludge tank, thickeners and sludge pumps, polymer system, and odor control system, as shown in Appendix B. The potential location of the new thickening building shown in Figure 4 also applies to this alternative.

### *5.6.2 Major Equipment and Power Consumption*

FKC and Huber provided RDT proposals according to the design criteria described in Table 2. Table 8 summarizes the RDT equipment and horsepower requirement based on 2050 sludge projection.

### Table 8. RDT Equipment and Horsepower Requirement

| Parameter | FKC | Huber |
|---|---|---|
| RDT Model | High-Capacity RST-HCW775x3600L | S-DRUM Size 4L |
| No. of Unit | 8 (7 duty + 1 standby) | 10 (9 duty + 1 standby) |
| Drum Drive Motor, hp each | 10 | 5 |
| Screw Drive Motor, hp each | 5 | n/a |
| Flocculation Tank Mixer, hp each | 2 | 0.25 |
| Spray Wash Motor, hp each | n/a | 0.25 |
| Other major components (one per unit): | | |
| Control Panel | | |
| Flocculation Tank, volume each | 540 gal | n/a |

### *5.6.3 Advantages/Disadvantages*

RDT has very similar advantages and disadvantages to the GBT except that the County staff is very familiar with the GBT but not with RDT.

## *5.7 Alternative 3 – Centrifuge*

### *5.7.1 Description*

Centrifugal thickening is a high-speed mechanical process that uses centrifugal force from rapid rotation of a cylindrical bowl to separate wastewater solids from liquid. It is more suitable for WAS or WAS and primary sludge blend thickening, but not suitable for primary sludge alone due to its high settleability and abrasive material. As with all the other mechanical thickening equipment, centrifuges are an enclosed system and requires a building to house equipment and ancillary systems. Most of the thickening centrifuges have very similar design as the dewatering centrifuges. They rely on adjusting the polymer dose to control the output solids quality. Centrisys is the only manufacturer who provides the patented hydro-pneumatic solids control that allows the operator to modify the output solids consistency by adjusting airflow injected into the thickened solids blanket. Centrisys' equipment does not have an external flocculation tank. Polymer is injected directly into the equipment.

The process flow diagram illustrated in Figure 3 applies to the centrifuge thickener as well. A conceptual level sizing indicates a 2-story thickening building with a footprint of approximately 13,000 square feet (142 ft by 92 ft) will be sufficient to house the entire centrifuge system, including the raw sludge blending tank, thickened sludge tank, thickeners and sludge pumps, polymer system, and odor control system, as shown in Appendix B. The potential location of the new thickening building shown in Figure 4 also applies to this alternative.

### 5.7.2 Major Equipment and Power Consumption

Centrisys provided its centrifuge thickener proposal according to the design criteria in Table 2. Table 9 summarizes the centrifuge equipment and horsepower requirement based on 2050 sludge projection.

## Table 9. Centrifuge Equipment and Horsepower Requirement

| Parameter | Value |
|---|---|
| No. of Unit | 7 (6 duty + 1 standby) |
| Centrifuge Model | THK 600 |
| Main Motor, hp each | 150 |
| Back Drive Motor, hp each | 25 |
| Other major components (one per unit): | |
| Control panel | |
| Internal Polymer Injection | |
| Automatic Air/Oil Lubrication System | |

### 5.7.3 Advantages/Disadvantages

Major advantages and disadvantages of the centrifuge specific to South Plant are summarized below.

*Advantages:*

**Less reliance on polymer:** The reported benefit is that centrifuge thickening uses 10 to 20 percent of the polymer dose required by other mechanical thickening technologies to achieve the equivalent solids capture and thickened sludge solids content.

**Smaller footprint:** Building could be multi-story therefore requires smaller footprint.

*Disadvantages:*

**Impact on centrate:** It is not economical to thicken dewatering centrate using the centrifuge.

**Impact on scum:** It is not desirable to thicken the scum using the centrifuge due to the increased maintenance caused by FOGs.

**Impact on grit:** Excessive grit in the feed sludge will increase the scroll and bowl wear and tear thus reduce interval required for servicing and refurbishment. And the centrifuge does not provide additional grit removal of feed sludge.

# 6. Conclusions and Recommendations

Based on the qualitative comparison of the alternatives, GBT and RDT have a slightly higher rating (seven "+" and six "-") than centrifuge (six "+" and seven "-"). They also have slightly more desirable benefits than the undesirable features comparing to the DAFT baseline. Because the difference is minor and each criterion may have a different weighting, the evaluation indicates all three remaining alternatives, GBT, RDT and centrifuge, deserve further consideration during future South Plant facility planning and/or when a thickening technology upgrade project enters formulation or capital project delivery.

In order to determine the most appropriate thickening alternative to meet the specific needs at South Plant, the following is recommended in the future:

1. Refine the evaluation criteria and assign weighting as the plant's priorities and long-term goals become better defined in future planning efforts.
2. Update the thickening design criteria as the plant operation strategy becomes better defined, i.e. co-thickening vs. separate thickening, BNR, side stream ammonia removal, and any additional sludge transported from other plants.
3. Consider thickening primary sludge to at least 1 percent TS within the primary clarifiers before co-thickening primary sludge and WAS using the mechanical thickeners. More concentrated primary sludge will greatly reduce hydraulic loading to the mechanical thickener, therefore reduce capital cost of the system.
4. Consider sending scum directly to the thickened sludge blending tank or digesters. With any thickening alternative, this will help reduce maintenance requirement on the pumps, pipes and equipment that would otherwise handle scum.
5. Evaluate grit handling needs to protect equipment and reduce grit accumulation in the digesters. This may include improving influent grit removal or providing grit removal to the primary sludge prior to thickening.
6. Identify the cause of excessive fruit labels, rubber bands and straws in the dewatering centrate. Evaluate the options to remove them from raw sewage, sludge or centrate. Options could include improving influent screening, screening sludge prior to thickening, screening centrate with additional screen or sending centrate to the improved influent screens.

# Appendices

Appendix A – Thickening Technology Description Sheets

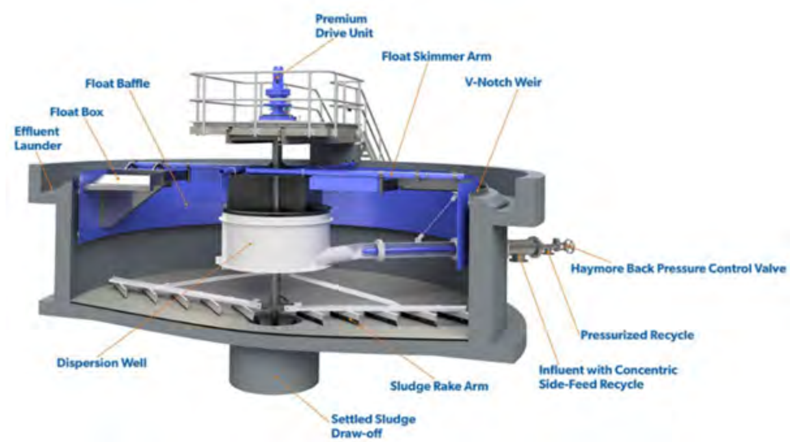
Appendix B – Conceptual Layout and Footprint

Appendix C – Carbon Emissions Calculation

Appendix D – Capital and O&M Costs Assessment

# APPENDIX A

# Dissolved Air Flotation Thickener (DAFT)



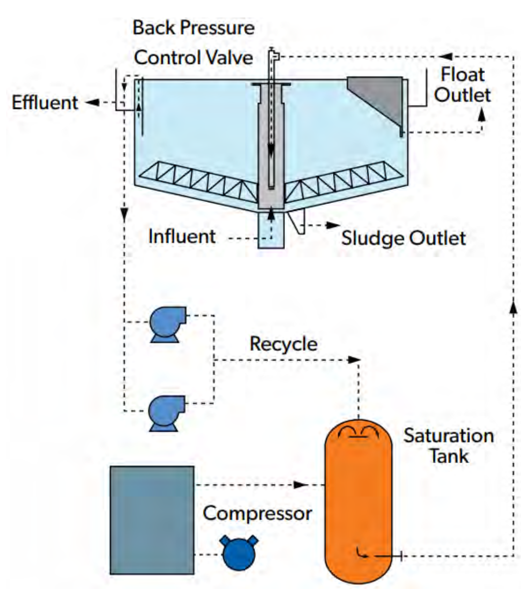

## Operating Principle

Dissolved air flotation thickening refers to the process of solids-liquid separation caused by the introduction of fine gas bubbles to the liquid phase. It best suited to solids that cannot be readily removed by settling, especially smaller and less dense particles. Long retention times, availability of nutrients and organic carbon sources can lead to putrefaction, generation of odors, release of phosphate, and biological conversion of nitrogen.

## Process Description

DAFT typically consists of an influent feed well, surface skimmer, thickened bottom solids collection mechanism, diffusers, overflow weir, and flotant collection trough that is installed within a tank (circular or rectangular). Ancillary systems consist of a polymer feed and mixing system, recycle water pumps, air compressor and a saturation tank. DAFTs are commonly installed outside with a cover.

Mixed sludge (i.e. primary, WAS and scum) enters DAFT through the influent feed well. To enhance particle aggregation and adherence of bubbles, polymer is commonly added to generate an enmeshment of larger flocs that have greater bonding strength and buoyancy once adhered with the air bubbles. Compressed air is injected into the pressurized air saturation tank along with a water source. Within the tank the air is dissolved producing a super saturated air-water solution. The air-saturated water flows under pressure to the diffusers where it mixes with the influent. As the water passes through the diffuser a pressure drop occurs, causing the gas to come out of solution and form micron-sized bubbles. As the bubbles are released a turbulent zone of mixing is formed where the bubbles adhere to the solids by entrapment or adsorption in the floc structure, reducing the specific gravity of the solids-gas matrix and creating a buoyant blanket that rises to the surface for removal by surface skimming. The size and density of a floc particle along with the amount of bubbles that adhere to it dictate how buoyant the matrix is as well as the velocity at which it rises to the surface and the shear forces exerted on the matrix as it rises through the water column. The bottom mechanism consists of rakes that help to break up water and gas pockets while conveying solids to the sludge outlet for removal of heavier solids such as grit that settle to the bottom of the tank.



## Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/hr/ft$^2$) | 2 |
| Hydraulic Loading Rate (gpm/ft$^2$) | 0.3 to 3 |
| Air-to-solids Ratio (lb/lb) | 0.015 to 0.05 |
| Polymer Dosage (lb polymer/ton dry solids) | 0 to 10 |
| Solids Capture (%) w/ polymer | 95%+ |
| Thickened Sludge (%TS) | 5 to 8 |

## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Proven and commonly used technology<br>• Familiar to King County operation staff<br>• Remove solids that tend to float as well as settle, i.e. primary sludge, WAS, scum and fats, oils and greases.<br>• Low polymer dosage<br>• In-basin thickener providing a degree of storage<br>• Additional benefit of removing grit<br>• High solids capture rate when using polymer<br>• Low to moderate shear environment under normal operation<br>• Recycling of clarified water for air saturation tank reduces water demand<br>• Unattended operation possible | • Large space requirements<br>• High energy consumption due to the use of air compressor and recycle pump, thus high carbon emissions<br>• Moderate operator attention due to more associated equipment<br>• High odor potential<br>• Require cover to contain odor and high odor control flowrate<br>• Potential sludge fermentation at long detention time<br>• Higher air-to-solids ratio required for higher solids loading rates<br>• Grit and other contaminants in recycle water can foul diffusers and cause biological growth and clogging in the air saturation tank |

## Representative Manufacturer

WesTech: https://www.westech-inc.com/solutions/municipal-wastewater/wastewater-thickening

# Gravity Belt Thickener (GBT)

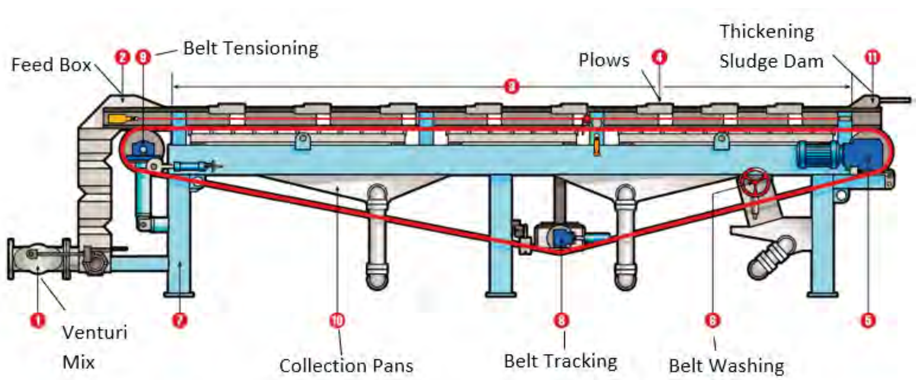
## Operating Principle

Gravity belt thickening increases the sludge solids concentration by allowing the filtrate to drain from the sludge under gravity through a moving belt on which the sludge is distributed. It typically applies to WAS and co-thickening of blended solids from wastewater treatment plants.

## Process Description

Gravity belt thickeners are machines that consist of a table-like structure fitted with rollers, a porous belt, belt tensioning system (hydraulic or pneumatic), belt guide system and plows. GBTs can be installed either with or without enclosures. Ancillary systems include a polymer feed and mixing system, flocculation tank, wash water system and odor control.

Polymer is injected to coagulate and flocculate the solids before they enter the GBT. Conditioned solids are conveyed from the flocculation tank and evenly distributed along the width of the belt. As the solids sit on the belt, they drain by gravity through it. As the belt travels towards the discharge hopper a series of plows windrow the solids to help release water (filtrate). The belt is continuously recirculated, as with a classical conveyor belt, and the thickened solids are allowed to fall off the end into a hopper. After the solids are discharged, the belt passes through a spray wash system to clean the belt prior to receiving conditioned solids on its next pass. The filtrate is collected in collection pans and recycled. Critical components and factors that impact the performance of the GBT are the belt material and size of pore opening, maintaining the proper tension on the belt, belt speed, proper conditioning of feed solids and cleaning of the belt. Before the equipment is shut down for extended duration, it is important to go through a cleaning cycle to remove remaining solids from the equipment to help minimize corrosion and odors. The enclosure can help minimize transmission of pathogens and reduce room humidity, although proper ventilation is required.



## Typical Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/hr/meter of belt width) | 1,000 |
| Hydraulic Loading Rate (gpm/meter of belt width) | 150 |
| Polymer Dosage (lb polymer/ton dry solids) | 5 to 10 |
| Solids Capture (%) | 90% to 98% |
| Thickened Sludge (%TS) w/ polymer | 4.5 to 7.5 |

## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Proven and commonly used technology<br>• Familiar to King County operation staff<br>• Suited for thickening of WAS and blended sludge<br>• Moderate capital costs<br>• Low space requirements<br>• Low power consumption, therefore low carbon emissions<br>• Enclosure controls odors and prevent high ventilation requirements<br>• Not susceptible to sludge settleability upset due to denitrification<br>• High solids capture rate<br>• Constructed of wear and corrosion resistant materials (i.e. stainless steel, nylon)<br>• Equipment not installed in basins and is easily accessible<br>• Equipment and ancillary devices are fully automated and easy for process control<br>• Use of nylon belts minimizes stretch and provide good performance in thickening sludges with moderate to low concentrations of FOGs | • May require a raw sludge blend tank prior to the thickening system<br>• Require additional thickener feed pumps<br>• Requires a building to house equipment<br>• Not economical to receive dewatering recycle stream since the equipment is limited by hydraulic loading<br>• High polymer usage<br>• More frequent washdown<br>• High wash water demand and associated impact on recycle stream<br>• Require proper conditioning of feed solids<br>• Grit and sharp solids will increase wear and tear of the belt therefore require more frequent O&M<br>• Need to maintain belts' tension to maintain thickening performance<br>• Susceptible to blinding of belt by scum, FOGs or sticky biosolids which must be removed with the spray wash system<br>• Relatively higher humidity may result in accelerated wear of building components<br>• Enclosure blocks operator view of flocculated solids on belt<br>• Operator exposure potential to wastewater solids without enclosure |

## Representative Manufacturers

BDP Industries: https://www.bdpindustries.com/products/gravity-belt-thickener/

Andritz: https://www.andritz.com/products-en/group/separation/screens-drains-presses/powerdrain-gravity-belt-thickener

# Rotary Drum Thickener (RDT)

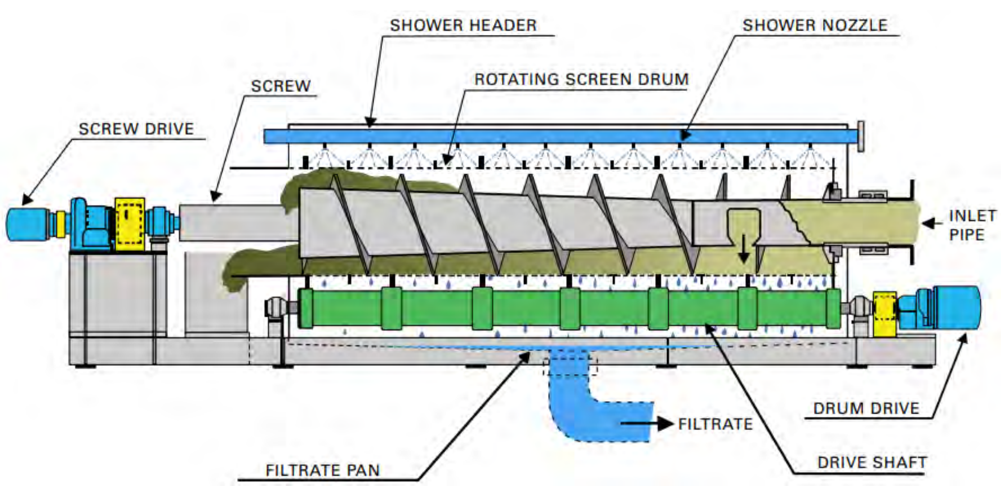
## Operating Principle

Rotary drum thickening thickens the sludge by gravity drainage and compaction while retaining the solids in a slowly rotating vessel with a porous screen. It typically applies to primary sludge, WAS and blended solids.

## Process Description

RDTs are machines that consist of an internally fed rotary drum that is covered with a porous screen and the feed solids enter through an integral internal screw. Ancillary systems consist of a grinder, polymer feed and mixing system, flocculation tank, wash water system and odor control.

Feed solids are chemically conditioned in a flocculation tank prior to entering the drum through the inlet pipe. Solids are feed continuously through an internal screw mechanism that rotates at a different speed from the bowl. As the drum rotates, free water (filtrate) drains through the moving porous media while flocculated solids are retained on the media. As the solids mat accumulates within the drum, the screw engages the material and provides a compressive force for further dewatering. Thickened solids are conveyed along the drum length by the internal screw and exit through a discharge opening. A spray system is used to clean the drum and prevent the pores from becoming blocked. Before the equipment is shut down for extended duration, it is important to go through a cleaning cycle to remove remaining solids from the equipment to help minimize corrosion and generation or odors. RDTs are commonly an enclosed system that helps minimize transmission of pathogens and reduce room humidity, although proper ventilation is required.



## Typical Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/hr) | 1,700 to 2,200 |
| Hydraulic Loading Rate (gpm) | 250 to 400 |
| Polymer Dosage (lb polymer/ton dry solids) | 8 to 15 |
| Solids Capture (%) | 90% to 98% |
| Thickened Sludge (%TS) w/ polymer | 5 to 7 |

## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Proven and commonly used technology<br>• Suited for thickening of primary sludge, WAS as well as blended sludge<br>• Moderate capital costs<br>• Low space requirements if hydraulic loading rate is higher<br>• Low power consumption, therefore low carbon emissions<br>• Enclosure controls odors<br>• Not susceptible to sludge settleability upset due to denitrification<br>• High solids capture rate<br>• Constructed of wear and corrosion resistant materials (i.e. stainless steel)<br>• Equipment not installed in basins and is easily accessible<br>• Equipment and ancillary devices are fully automated and easy for process control<br>• Low to no vibratory loads<br>• Moderate wear on equipment due to operation at lower speeds<br>• Unattended operation possible | • May require a raw sludge blend tank prior to the thickening system<br>• Require additional thickener feed pumps<br>• Requires a building to house equipment<br>• Not economical to receive dewatering recycle stream since the equipment is limited by hydraulic loading<br>• High polymer usage<br>• Wash water demand, although lower than GBT<br>• Require proper conditioning of feed solids<br>• Susceptible to blinding of filter screen by scum, fats, oils and grease or sticky biosolids which must be removed with the spray wash system |

## Representative Manufacturers

FKC: https://www.fkcscrewpress.com

BDP Industries: https://www.bdpindustries.com/products/rotary-drum-concentrator/

Parkson: https://www.parkson.com/products/hycor-thicktech

# Disk Thickener

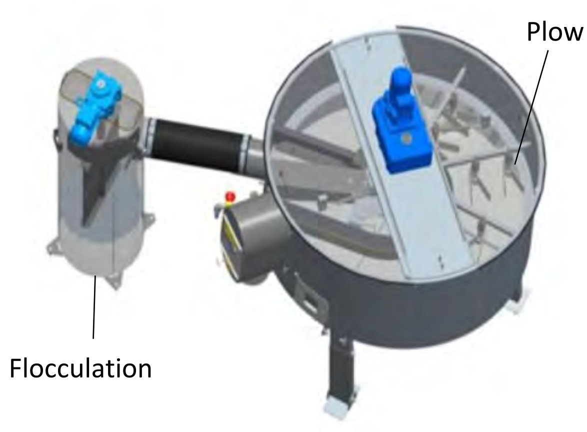
## Operating Principle

Disk thickeners thicken the sludge by gravity utilizing a slightly inclined and slowly rotating filter disc covered with a filter cloth to separate flocculated sludge from water (filtrate).

## Process Description

Disk thickeners are machines that consists of a perforated carrier disc that rotates within the machine housing. Ancillary systems include a polymer feed and mixing system, flocculation tank, wash water system and odor control.

Feed solids are chemically conditioned in a flocculation tank prior to entering into the disc thickener, a baffle plate distributes the feed evenly across the entire filter radius. As the disc rotates the sludge layer divided by chicanes so that water can easily drain through the filter cloth, thus enhancing the filtration effect. Thickened solids concentration is adjusted by the speed of the disk as well as its inclination. Filtrate collects on the bottom section of the filter disc so that a low hydrostatic pressure develops enhancing filtrate drain-off. At the sludge discharge outlet, a scraper pushes the thickened sludge from the disc to the outlet. Shear stress developed within the sludge is mainly attributable to the chicanes and scraper and is directly proportional to the speed of the disk as well as the viscosity of the dewatered solids. The filter cloth is cleaned by a spray bar so that the solids are washed back into the sludge to ensure the filtrate water is clear. Before the equipment is shut down for extended duration, it is important to go through a cleaning cycle to remove remaining solids from the equipment to help minimize corrosion and odors. Disk thickeners are an enclosed system that helps reduce odors and eliminates transmission of pathogens, although a proper ventilation design is required.



## Typical Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/hr) | Up to 880 [(1)] |
| Hydraulic Loading Rate (gpm) | Up to 180 [(1)] |
| Polymer Dosage (lb polymer/ton dry solids) | 6 to 10[(1)] |
| Solids Capture (%) | 97%+[(1)] |
| Thickened Sludge (%TS) w/ polymer | 4 to 8[(1)] |

Note:
(1) Based on Huber Technology's S-Disc series

## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Suited for thickening of primary sludge, WAS as well as blended sludge<br>• Low energy consumption, therefore low carbon emissions<br>• Low space requirements<br>• Enclosure controls odors<br>• Not susceptible to sludge settleability upset due to denitrification<br>• High thickened solids concentration<br>• High solids capture rate<br>• Constructed of wear and corrosion resistant materials (i.e. stainless steel)<br>• Equipment not installed in basins and is easily accessible<br>• Equipment and ancillary devices are fully automated and easy for process control | • May require a raw sludge blend tank prior to the thickening system<br>• Require additional thickener feed pumps<br>• Require a building to house equipment<br>• Not economical to receive dewatering recycle stream since the equipment is limited by hydraulic loading<br>• Limited manufacturers<br>• Limited operation experience<br>• Limited equipment size options. Only suitable for small to medium size plants<br>• High polymer demand<br>• Wash water demand<br>• Require proper conditioning of feed solids<br>• Susceptible to blinding of filter screen by scum, fats, oils, grease or sticky biosolids which must be removed with the spray wash system |

## Representative Manufacturer

Huber: https://www.huber-technology.com/products/sludge-treatment/sludge-thickening/huber-disc-thickener-s-disc.html

# Centrifuge Thickener

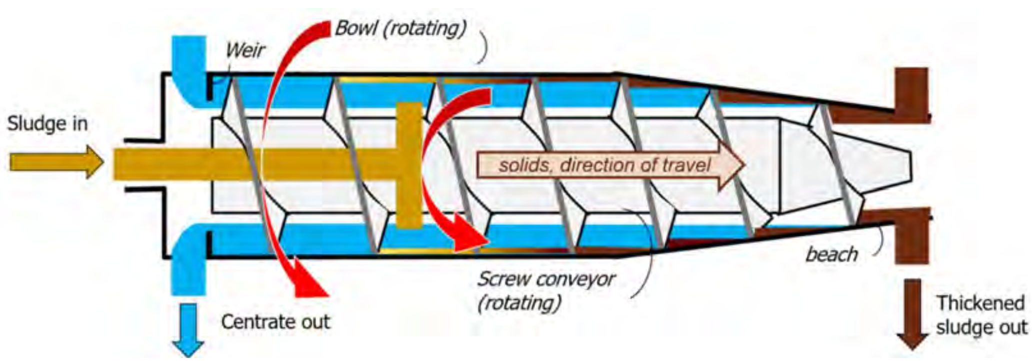

## Operating Principle

Centrifugal thickening is a high-speed process that uses centrifugal force from rapid rotation of a cylindrical bowl to separate wastewater solids from liquid. Centrifuges are more suitable for WAS or WAS and primary sludge blend thickening. Primary sludge alone is not well suited for centrifugal thickening because of its high settleability and abrasive material.

## Process Description

Centrifugal thickening consists of a horizontal, cylindrical solid bowl that is tapered at one end and is rotated at high speed. Ancillary systems consist of a motor actuated drain gate, polymer feed and mixing system, wash water system and odor control.

Feed solids are mixed with polymer and conditioned prior to the inlet of the centrifuge. Solids are conveyed continuously to the thickened sludge outlet by an internal screw mechanism that rotates at a different speed than the bowl. As solids are deposited within the centrifuge, the centrifugal force from the bowl distributes the solids on its periphery and thickening begins. Until a sufficient mat of solids material is obtained, centrate with high solids content is generated and is recycled back to upstream treatment processes. Once a solids mat is formed, the suspended solids content in the centrate decreases and the diversion gate is operated to begin producing thickened solids. As the solid layer continues to accumulate the internal screw moves the solids toward the tapered end for further thickening prior to discharge. At end of each thickening operation, it is important to go through a cleaning cycle to remove remaining solids from the equipment to help minimize corrosion and odors. Centrifuges are commonly an enclosed system that helps to reduce odors and eliminates transmission of pathogens, although proper ventilation is required.



## Typical Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/h) | 1,000 to 4,000, various modes [1] |
| Hydraulic Loading Rate (gpm) | 200 – 800, various modes; derate by 20-30% w/o polymer[1] |
| Polymer Dosage (lb polymer/ton dry solids) | 0 - 4[1] |
| Solids Capture (%) | 90 (w/o polymer); 97 (w/polymer)[1] |
| Thickened Sludge (%TS) | 2 to 6 (w/o polymer); 5 to 10 (w/polymer)[1] |

Note:
(1) Based on Centrisys CNP's THK series

## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Proven technology<br>• Similar equipment for dewatering is familiar to King County operation staff<br>• Low space requirements<br>• No to low polymer usage<br>• No floc tank is required. Polymer, if needed, is directly injected into sludge stream<br>• Enclosure controls odors<br>• Not susceptible to sludge settleability upset due to denitrification<br>• High thickened solids concentration<br>• High solids capture rate<br>• Constructed of wear and corrosion resistant materials (i.e. stainless steel)<br>• Equipment not installed in basins and is easily accessible<br>• Equipment and ancillary devices are fully automated and easy for process control<br>• Less susceptible to blinding by scum, fats, oils, grease or sticky biosolids<br>• Unattended operation possible | • Require a raw sludge blend tank prior to the thickening system<br>• Require additional thickener feed pumps<br>• Require a building to house equipment<br>• Not economical to receive dewatering recycle stream since the equipment is limited by hydraulic loading<br>• Limited manufacturers for thickening application<br>• Not suited for primary sludge only thickening<br>• High capital costs per unit<br>• High power consumption, thus high carbon emissions<br>• Fairly noisy<br>• Sensitive to abrasive material and debris<br>• High vibratory loads requiring more structural support for installation<br>• Requires effective wastewater grit removal and screening or grinding to mitigate potential machine damage or operational problems<br>• Requires scroll refurbishment every 2-5 years depending on service |

## Representative Manufacturer

Centrisys: https://www.centrisys-cnp.com/equipment/sewage-sludge-thickener

Flottweg: https://www.flottweg.com/product-lines/decanter/ose-decanter/

Andritz: https://www.andritz.com/separation-en/products/decanter-centrifuges

# Gravity Thickener (GT)

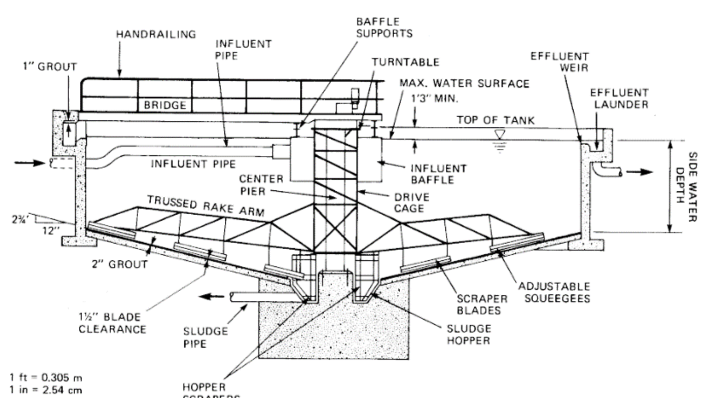
## Operating Principle

Gravity thickening uses gravitational forces and the natural tendency of higher-density solids to concentrate the solids. Gravity thickeners are usually applied to thicken primary sludge that typically settles quickly and achieve a high underflow concentration. Gravity thickening of WAS is not practical because WAS contains smaller and less dense colloidal particles that are less amenable to flocculate without conditioning. Gravity thickeners commonly exhibit anoxic and anerobic environments within the tank. Long retention times, availability of nutrients and organic carbon sources can lead to putrefaction, generation of odors, release of phosphorus and nitrogen.

## Process Description

Gravity thickeners typically consists of an influent feed well, surface skimmer, thickened bottom solids collection mechanism, overflow weir, and flotant collection trough that is installed within a tank (circular or rectangular). The floor slope of a gravity thickener is typically steeper than that of other sedimentation type tanks which promotes minimization of solids retention time and efficient removal of solids. Ancillary systems consist of a polymer feed and mixing system, recycle water pumps, odor control and ventilation for covered installations.

Solids are fed into the tank through a center feed well, which helps distribute the influent and releases the solids at a low velocity near its surface. The vertical depth of the thickener is comprised of three distinct zones with clarified effluent at the top, the sedimentation zone and then the thickening and solids storage zone. Three settling processes that are important to gravity thickeners are gravity settling, hindered settling, and compaction settling. As solids enter the tank, they initially undergo gravity settling until they reach the settling zone which is more viscous than the upper layer. When solids reach the settling zone less dense materials spread across the surface of the tank while some more dense particulate continue to settle by gravity to the compaction zone. Within the compaction zone scrapers slowly move through the settled solids allowing for release of interstitial water and gas pockets, helping with consolidation as well as conveying the thickened solids to a hopper at the bottom for removal. A v-notch weir located at the top of the tank allows the supernatant to return to other treatment process. In addition, a skimmer is used to collect and remove scum and other floatable material.



## Typical Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/d/ft$^2$) | 5 to 14 |
| Hydraulic Loading Rate (gpd/ft$^2$) | 400 to 800 |
| Polymer Dosage (lb polymer/ton dry solids) | 0 to 12 |
| Solids Capture (%) | 80 to 90 |
| Thickened Sludge (%TS) | 3 to 6 |

## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Proven and commonly used technology<br>• Low capital costs<br>• Low energy consumption, therefore low carbon emissions<br>• In-basin thickener providing a degree of storage<br>• Additional benefit of removing grit<br>• Effluent with lower turbidity<br>• Low O&M<br>• Low shear environment under normal operation | • Not suited for WAS thickening<br>• High space requirements<br>• Low solids capture<br>• High odor potential<br>• Require cover to contain odor and high odor control flowrate<br>• Higher corrosion potential<br>• Susceptible to sludge settleability upset due to denitrification<br>• Potential sludge fermentation at long detention time<br>• Polymer required to achieve higher solids loading rates<br>• Commonly installed in ground requiring consideration for buoyancy and can require dewatering for installation |

## Representative Manufacturer

WesTech: https://www.westech-inc.com/products/gravity-thickener-conventional

# Membrane Thickener

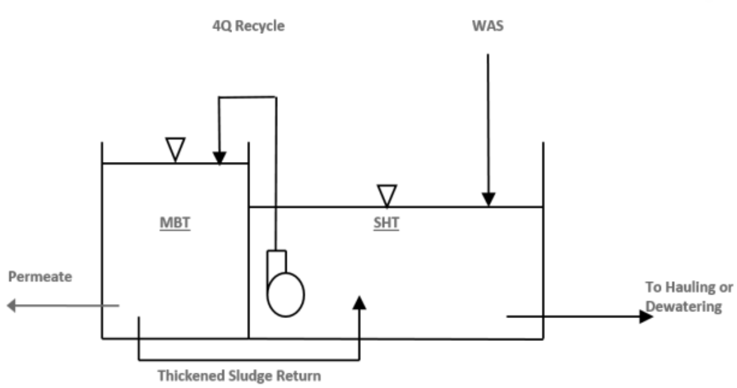
## Operating Principle

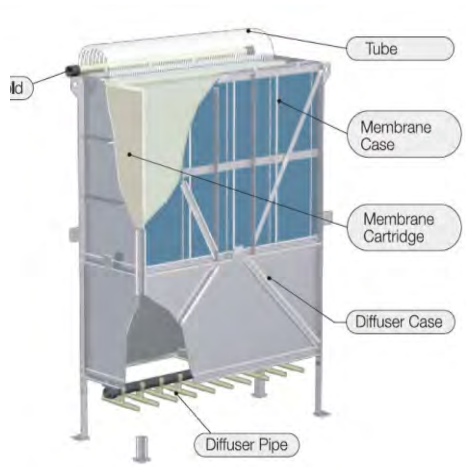
The membrane thickener thickens the sludge by creating a vacuum and pulling permeate through the membrane and leaving solids behind. It is better suited for thickening of WAS as part of membrane bioreactor system. If not sufficiently aerated and mixed, long retention times, availability of nutrients and organic carbon sources can lead to putrefaction, generation of odors, and release of phosphorus and nitrogen.

## Process Description

The membrane thickening system consists of a membrane thickener tank (MBT) fitted with cassettes of submerged porous membranes made from inert materials having a pore size range of 0.4 to 0.04 µm with an average pore size of 0.2 µm and an aerobic sludge holding tank (SHT). The membrane cassette houses multiple cartridges, while the diffuser case houses a coarse bubble diffuser. In the membrane cassette, the membrane sheet is welded on each side of the membrane panel. Permeates through the membrane sheets exit the cartridge through the nozzle. Ancillary systems consist of a blower, coarse bubble diffusers, permeate pumps, thickened sludge pumps and a clean in place system for membrane flux maintenance.

Solids feed are conveyed into the SHT which provides equalization volume and storage for thickened solids. Mixed solids are transferred into the MBT via a pump either on a continuous or batch basis. Sludge and water are separated by the membrane by the permeate pumps who create a vacuum within the hollow fiber membranes. The thickened sludge may be held in the MBT for thickening or transferred back into the SHT. In the SHT, the sludge is actively mixed and digested with the aid of coarse bubble diffusers. As mix solids concentration increases a decrease in the rate or permeate production can be expected. Higher viscosity of sludge and lower cross-flow velocity along membrane surfaces will result in membrane fouling. The presence of grit and larger particles will cause plugging problems decreasing the system efficiency.



## Typical Design Criteria for Mixed Primary Sludge and WAS

| Parameter | Value |
|---|---|
| Solids Loading Rate (lb/d/$ft^2$ of membrane) | 600 to 1,500 |
| Hydraulic Loading Rate (gpm/$ft^2$ of membrane) | 10 to 20 |
| Polymer Dosage (lb polymer/ton dry solids) | 0 |
| Solids Capture (%) | 99%+ |
| Thickened Sludge (%TS) | 2 to 4 |

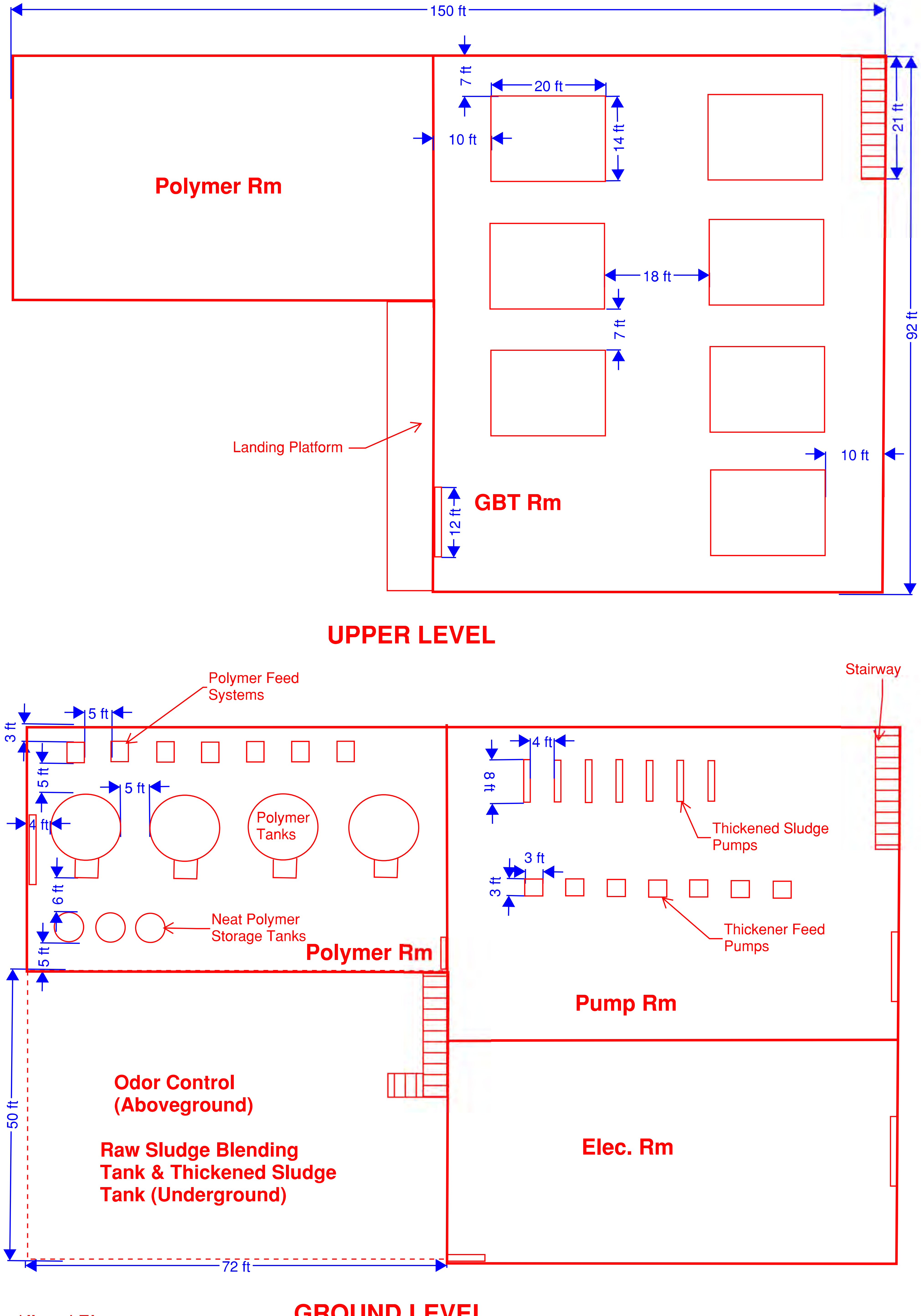
## Advantages and Disadvantages

| Advantages | Disadvantages |
|---|---|
| • Low space requirements<br>• No polymer required<br>• In-basin thickener providing a degree of storage<br>• High quality effluent (permeate)<br>• High solids capture<br>• Equipment and ancillary devices are fully automated and easy for process control<br>• Constructed of wear and corrosion resistant materials (i.e. stainless steel and plastics)<br>• Proper condition of feed solids is not critical to thickening performance | • Emerging technology, designed to thicken WAS from the membrane bioreactor system<br>• Unfamiliar operation<br>• Very limited manufacturers and installations<br>• High capital costs due to the membrane and ancillary system<br>• High energy consumption, therefore high carbon emissions<br>• High O&M requirements due to membrane scour and cleaning<br>• Low thickened sludge solids content<br>• Susceptible to membrane fouling due to solids particle size, fats, oils, grease or sticky biosolids |

## Representative Manufacturer

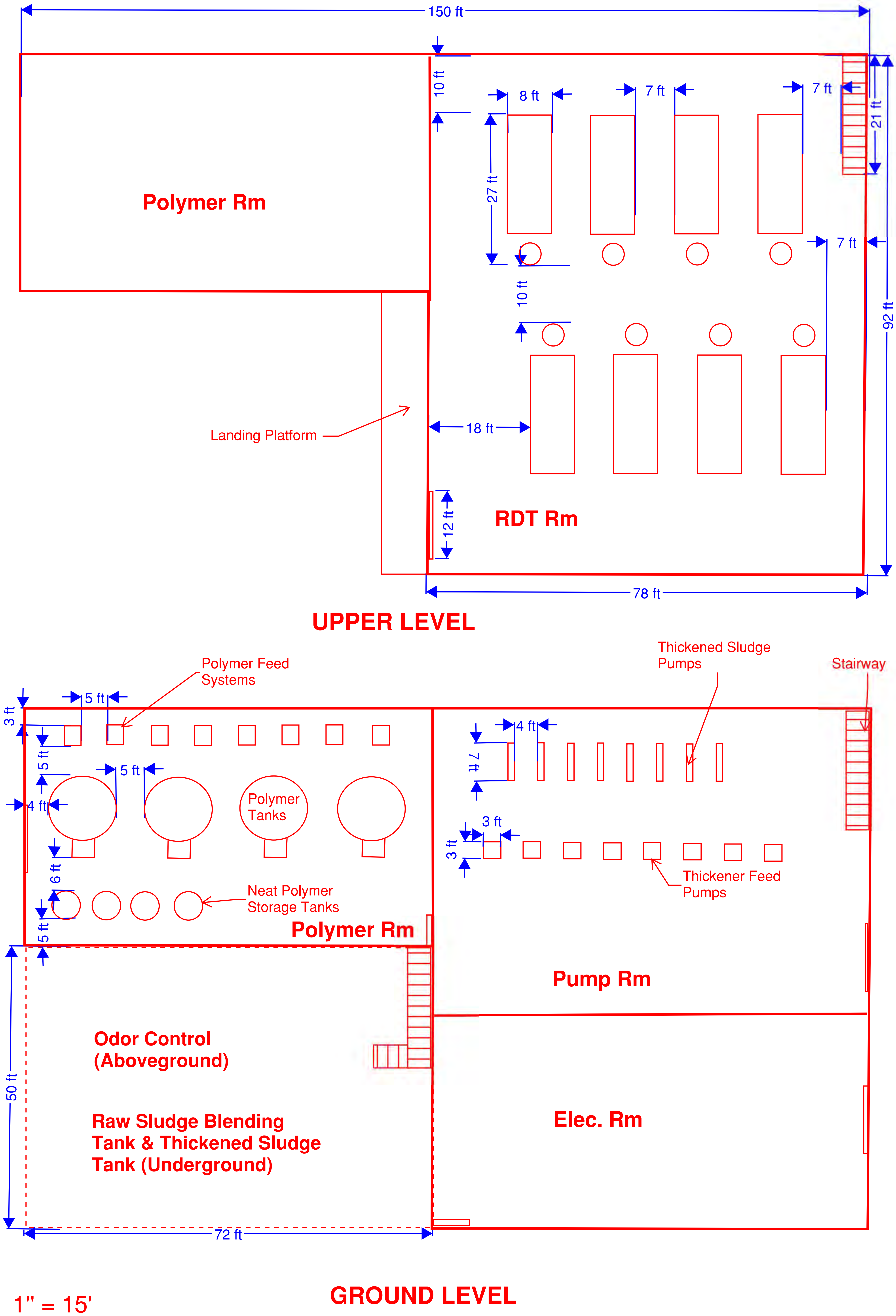
Kubota: https://kubota-membrane.com

# APPENDIX B

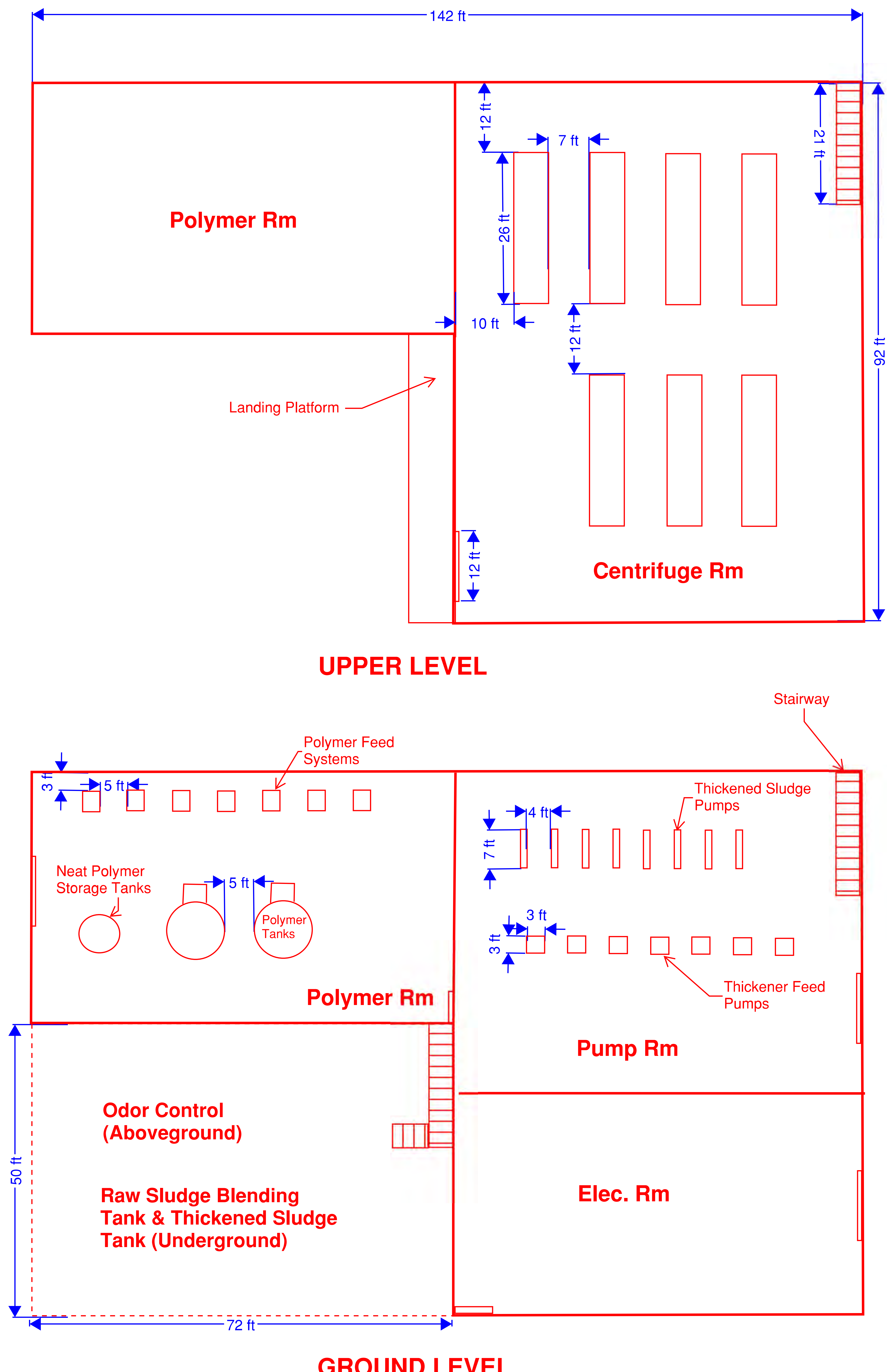



1" = 15'

## GBT ALTERNATIVE LAYOUT




# RDT ALTERNATIVE LAYOUT




1" = 15'

## CENTRIFUGE ALTERNATIVE LAYOUT

# APPENDIX C

## GHG Assumption

| Emissions Element | Value | Units | |
|---|---|---|---|
| ***Unit Conversions*** | | | |
| 1 Btu = | 0.0002928 | kWh | |
| 1 MMBtu = | 293 | kWh | |
| 1 kg = | 2.205 | lb | |
| 1 gal = | 3.785 | L | |
| 1 scf CH4 = | 0.042 | lb | |
| 1 gal = | 8.34 | lb | |
| ***Global Warming Potential*** | | | |
| CO2 | 1 | kg CO2e/kg CO2e | |
| CH4 | 28 | kg CO2e/kg CH4e | |
| N2O | 298 | kg CO2e/kg N2Oe | |
| HFCs | | | |
| Refrigerant Blends | | | |
| ***Chemicals*** | | | |
| Polymer | 9 | kg CO2e/kg Polymer | |
| ***Fugitive Emission Factor*** | | | |
| DAFT Thickening | 0 | g CH4/L Sludge | Low enough to be negligible |
| RDT Thickening | 0 | g CH4/L Sludge | Low enough to be negligible |
| GBT Thickening | 0 | g CH4/L Sludge | Low enough to be negligible |
| Centrifuge Thickening | 0 | g CH4/L Sludge | Low enough to be negligible |
| **Building** | | | |
| Heating | 45 | btu/ft2 | https://learnmetrics.com/heating-btu-calculator/?nowprocket=1 |
| NG | 53 | kg CO2e/MMBtu | |
| Lighting | 7 | kWh/ft2 | |
| **Electricity** | | | |
| South Plant | 6.5 | kg CO2e/MWh | Assume the same as Seattle City Light (91% Hydro, 4% Nuclear) |

## GHG Calculation

| | | | DAFT | RDT | GBT | Centrifuge |
|---|---|---|---|---|---|---|
| | | | WesTech | FKC | BDP | Centrisys |
| | | | DAFC5N | HCRST-775x3600L | GBT | THK600 |
| | | | 55' Diameter 65' Diameter | | | |
| **Scope 1 Emissions** | | | | | | |
| Fugitive Emissions (CH4) | Sludge Thickening | Emission, kg CO2e/yr | 0 | 0 | 0 | 0 |
| Thermal Demand | Building Heating | Thermal Energy Demand, mmbtu/yr | 1,183 | 8,042 | 8,042 | 7,461 |
| | | Thermal Energy Demand, kg CO2e/yr | 62,678 | 426209 | 426209 | 395455 |
| | | Subtotal, kg CO2e/yr | 63,000 | 426,000 | 426,000 | 395,000 |
| **Scope 2 Emissions** | | | | | | |
| Electrical Emissions | Thickening Equipment | Electricity Consumption, MWh/yr | 3,508 | 777 | 490 | 6,859 |
| | | Emission, kg CO2e/yr | 22,801 | 5,053 | 3,185 | 44,583 |
| | Polymer Feed System | Electricity Consumption, MWh/yr | 23 | 22.86 | 19.60 | 19.60 |
| | | Emission, kg CO2e/yr | 149 | 149 | 127 | 127 |
| | Thickener Feed Pump and Thickened Sludge Pu | Electricity Consumption, MWh/yr | 5,357 | 2,972 | 2,940 | 2,861 |
| | | Emission, kg CO2e/yr | 34,817 | 19,319 | 19,107 | 18,598 |
| | Odor Control System | Electricity Consumption, MWh/yr | 124 | 85 | 52 | 52 |
| | | Emission, kg CO2e/yr | 807 | 552 | 340 | 340 |
| | Building Lighting | Electricity Consumption, MWh/yr | 21 | 143 | 143 | 132 |
| | | Emission, kg CO2e/yr | 137 | 928 | 928 | 861 |
| | | Subtotal, kg CO2e/yr | 59,000 | 26,001 | 23,687 | 64,509 |
| **Scope 3 Emissions** | | | | | | |
| Polymer Consumption | Polymer Feed System | Polymer Use, kg/yr | 181,444 | 725,777 | 544,333 | 362,888 |
| | | Polymer Manufacturing, kg CO2e/yr | 1,632,998 | 6,531,992 | 4,898,994 | 3,265,996 |
| | | Subtotal, kg CO2e/yr | 1,633,000 | 6,532,000 | 4,899,000 | 3,266,000 |
| | | **Total, kgCO2e/yr** | **1,755,000** | **6,984,000** | **5,349,000** | **3,726,000** |
| | | **Total, mt CO2e/yr** | **1755** | **6984** | **5349** | **3726** |

murraysmith

# APPENDIX D

**South Plant Solids Thickening Technologies Evaluation**

**Class 10 Cost Estimate**

| | DAFT | GBT | RDT | Centrifuge |
|---|---|---|---|---|
| Construction Cost | $ 10,000,000 | $ 14,000,000 | $ 14,000,000 | $ 18,000,000 |
| Capital Cost | $ 16,000,000 | $ 22,000,000 | $ 24,000,000 | $ 30,000,000 |
| O&M Cost | $ 800,000 | $ 1,500,000 | $ 2,000,000 | $ 1,600,000 |
| | | | | |
| Energy Use, kwh/yr | 3,400,000 | 2,100,000 | 2,700,000 | 8,500,000 |

Project: South Plant Solids Thickening Technology Analysis
Client: King County

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Project No.: 20-2900 | | | | | | | |
| Date: | 6/16/2022 | | | | | | |
| **DAFT** | | | | | | | |
| **Item No.** | **Item** | **Unit** | **QTY** | **Materials** | **Installation** | **Total** |
| **Civil Site Prep/Earthwork** | | | | | | |
| | Demolition | LS | 0 | | $0.00 | $0 |
| | Excavation - General | CY | 0 | | $22.00 | $0 |
| | Backfill | CY | 0 | | $18.00 | $0 |
| | Subtotal | | | | | $0 |
| **Structural** | | | | | | |
| | RC - Slab on Grade | CY | 0 | $300.00 | $200.00 | $0.00 |
| | Covers | SF | 16140 | $50.00 | $15.00 | $1,049,096 |
| | Subtotal | | | | | $1,050,000 |
| **Mechanical** | | | | | | |
| | Demolition | LS | 1 | | $128,000 | $128,000 |
| | 55' DAFT Systems | LS | 1 | $2,065,600.00 | $619,680.00 | $2,685,280 |
| | 65' DAFT Systems | LS | 1 | $1,375,600.00 | $412,680.00 | $1,788,280 |
| | Polymer Feed System | LS | 1 | $20,000 | $6,000 | $26,000 |
| | Polymer Storage Tanks | EA | 2 | $5,000 | $1,500 | $13,000 |
| | Polymer Tanks | EA | 2 | $50,000 | $15,000 | $130,000 |
| | Thickened Sludge Pumps | EA | 6 | $30,000.00 | $9,000.00 | $234,000 |
| | Odor Control | LS | 1 | $569,000.00 | | $569,000.00 |
| | Subtotal | | | | | $5,600,000 |
| **Electrical, Instrumentation, and Controls** | | | | | | |
| | EI&C | LS | 1 | $1,120,000.00 | | $1,120,000 |
| | | LS | | | | |
| | Subtotal | | | | | $1,120,000.00 |
| Construction Material & Labor Subtotal: | | | | | | $ 7,770,000 |

| Markups | |
|---|---|
| Mobilization (8%) | $ 621,600 |
| General Conditions (8%) | $ 621,600 |
| Contractor O&P (12%) | $ 932,400 |
| **Subtotal** | $ 9,900,000 |
| Tax (10.1%) | $ 999,900 |
| Construction Contingency (30%) | $ 2,970,000 |
| Engineering, Legal, and Administration (25%) | $ 2,475,000 |
| **Total** | $ 16,000,000 |

**O&M Cost Estimate**

| **O&M No.** | **Operation and Maintenance** | **Quantity** | | | | **Total ($/yr)** |
|---|---|---|---|---|---|---|
| **Labor (Workload)** | | | Workload (hr/wk) | Workload (hr/yr) | Unit Cost ($/hr) | |
| 1 | Operation | 1 | 8 | | $78.66 | $32,723 |
| 2 | Maintenance | 1 | | 1104 | $78.66 | $86,841 |
| | Subtotal | | | | | $119,563 |
| **Power** | | Unit HP | Requirement (kW) | Annual Power (kWh) | Unit Cost ($/kWh) | |
| 3 | DAFT Drives | 6 / 1 | 4 | 39,194 | $0.08 | $3,268 |
| 4 | Air Compressors | 6 / 15 | 67 | 587,910 | $0.08 | $49,020 |
| 5 | Recycle Pumps for 55' | 4 / 50 | 149 | 1,306,466 | $0.08 | $108,933 |
| 6 | Recycle Pumps for 65' | 2 / 75 | 112 | 979,850 | $0.08 | $81,700 |
| 7 | Polymer Feed System | 6 / 0.5 | 2 | 19,597 | $0.08 | $1,634 |
| 8 | Thickened Sludge Pumps for 55' | 6 / 10 | 45 | 391,940 | $0.08 | $32,680 |
| 9 | Odor Control System | 1 / 19 | 14 | 124,114 | $0.08 | $10,349 |
| | Subtotal | 528 | | 3,449,071 | | $224,947 |
| **Material** | | | Amount (gal/wk) | Amount (gal/yr) | Unit Cost ($/gal) | |
| 10 | Polymer | 1 | 923 | 47996 | $9.15 | $439,019 |
| | Subtotal | | | | | $439,019 |
| **O&M Total:** | | | | | | $800,000 |

Project: South Plant Solids Thickening Technology Analysis
Client: King County

| | | | |
|---|---|---|---|
| Project No.: 20-2900 | | | |
| Date: | 6/16/2022 | | |
| | | | |
| **RDT-HCRST** | | | |

| Item No. | Item | Unit | QTY | Materials | Installation | Total |
|---|---|---|---|---|---|---|
| **Civil Site Prep/Earthwork** | | | | | | |
| | Demolition | LS | 1 | | $50,000.00 | $50,000 |
| | Site Clearing | SF | 13800 | | $1.00 | $13,800 |
| | Excavation | CY | 2424 | | $22.00 | $53,333 |
| | Backfill | CY | 364 | | $18.00 | $6,545 |
| | Subtotal | | | | | $100,000 |
| **Structural** | | | | | | |
| | Building | SF | 10300 | $400.00 | | $4,120,000 |
| | Concrete | CY | 2364 | 300 | 90 | $922,077 |
| | Subtotal | | | | | $5,000,000 |
| **Mechanical** | | | | | | |
| | Raw Sludge Blending Tank Mechanical Components | LS | 1 | $50,000 | $15,000 | $65,000 |
| | Polymer Feed System | LS | 1 | $20,000 | $6,000 | $26,000 |
| | Polymer Storage Tanks | EA | 4 | $5,000 | $1,500 | $26,000 |
| | Polymer Tanks | EA | 4 | $50,000 | $15,000 | $260,000 |
| | Thickener Feed Pump | EA | 8 | $100,000 | $30,000 | $1,040,000 |
| | RDTs-HCRST w/ Flocculation Tanks | LS | 1 | $2,217,600 | $665,280 | $2,882,880 |
| | Thickened Sludge Pumps | EA | 8 | $25,000 | $7,500 | $260,000 |
| | Odor Control | LS | 1 | $456,000 | | $456,000 |
| | Subtotal | | | | | $5,100,000 |
| **Electrical, Instrumentation, and Controls** | | | | | | |
| | EI&C | LS | 1 | $1,020,000.00 | | $1,020,000 |
| | Subtotal | | | | | $1,020,000 |
| | | | | | | |
| Construction Material & Labor Subtotal: | | | | | | $11,200,000 |

| Markups | | |
|---|---|---|
| Mobilization (8%) | $ | 896,000 |
| General Conditions (8%) | $ | 896,000 |
| Contractor O&P (12%) | $ | 1,344,000 |
| **Subtotal** | $ | 14,300,000 |
| Tax (10.1%) | $ | 1,444,300 |
| Construction Contingency (30%) | $ | 4,290,000 |
| Engineering, Legal, and Administration (25%) | $ | 3,575,000 |
| **Total** | $ | 24,000,000 |

**O&M Cost Estimate**

| O&M No. | Operation and Maintenance | Quantity | | | | | Total ($/yr) |
|---|---|---|---|---|---|---|---|
| **Labor (Workload)** | | | Workload (hr/wk) | | Workload (hr/yr) | Unit Cost ($/hr) | |
| 1 | Operation | 1 | 8 | | | $78.66 | $32,723 |
| 2 | Maintenance | 1 | | | 448 | $78.66 | $35,240 |
| | Subtotal | | | | | | $35,240 |
| | | | | | | | |
| **Power** | | | Unit HP | Requirement (kW) | Annual Power (kWh) | Unit Cost ($/kWh) | |
| 3 | RDT-HCRST Drum Drive Motor | 7 | 10 | 52 | 457263 | $0.08 | $36,581 |
| 4 | RDT-HCRST Screw Drive Motor | 7 | 5 | 26 | 228632 | $0.08 | $18,291 |
| 5 | Flocculation Tank | 7 | 2 | 10 | 91453 | $0.08 | $7,316 |
| 6 | Polymer Feed System | 7 | 0.5 | 2.6 | 22863 | $0.08 | $1,829 |
| 7 | Thickener Feed Pump | 7 | 30 | 157 | 1371790 | $0.08 | $109,743 |
| 8 | Thickened Sludge Pumps | 7 | 10 | 52 | 457263 | $0.08 | $36,581 |
| 9 | Odor Control System | 1 | 13 | 10 | 84920 | $0.08 | $6,794 |
| | Subtotal | | 415.5 | | 2714184 | | $217,135 |
| | | | | | | | |
| **Material** | | | Amount (gal/wk) | | Amount (gal/yr) | Unit Cost ($/gal) | |
| 10 | Polymer | 1 | 3690 | | 191880 | $9.15 | $1,755,702 |
| | Subtotal | | | | | | $1,755,702 |
| | | | | | | | |
| **O&M Total:** | | | | | | | $2,000,000 |

Project: South Plant Solids Thickening Technology Analysis
Client: King County

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Project No.: 20-2900 | | | | | | | |
| Date: | 6/16/2022 | | | | | | |
| | | | | | | | |
| **GBT** | | | | | | | |
| | | | | | | | |
| **Item No.** | **Item** | **Unit** | **QTY** | **Materials** | **Installation** | **Total** | |
| **Civil Site Prep/Earthwork** | | | | | | | |
| | Demolition | LS | 1 | | $50,000.00 | $50,000 | |
| | Site Clearing | SF | 13800 | | $1.00 | $13,800 | |
| | Excavation | CY | 2424 | | $22.00 | $53,333 | |
| | Backfill | CY | 364 | | $18.00 | $6,545 | |
| | Subtotal | | | | | $120,000 | |
| **Structural** | | | | | | | |
| | Building | SF | 10300 | $400.00 | | $4,120,000 | |
| | Concrete | CY | 2364 | 300 | 200 | $1,182,150 | |
| | Subtotal | | | | | $5,300,000 | |
| **Mechanical** | | | | | | | |
| | Raw Sludge Blending Tank Mechanical Components | LS | 1 | $50,000 | $15,000 | $65,000 | |
| | Polymer Feed System | LS | 1 | $20,000 | $6,000 | $26,000 | |
| | Polymer Storage Tanks | EA | 3 | $5,000 | $1,500 | $19,500 | |
| | Polymer Tanks | EA | 4 | $45,000 | $13,500 | $234,000 | |
| | Thickener Feed Pump | EA | 7 | $100,000 | $30,000 | $910,000 | |
| | GBTs | LS | 1 | $1,808,800 | $542,640 | $2,351,440 | |
| | Thickened Sludge Pumps | EA | 7 | $25,000 | $7,500 | $227,500 | |
| | Odor Control | LS | 1 | $421,000 | | $421,000 | |
| | Subtotal | | | | | $4,300,000 | |
| **Electrical, Instrumentation, and Controls** | | | | | | | |
| | EI&C | LS | 1 | $860,000.00 | | $860,000 | |
| | Subtotal | | | | | $860,000 | |
| | | | | | | | |
| Construction Material & Labor Subtotal: | | | | | | $10,600,000 | |

| Markups | | |
|---|---|---|
| Mobilization (8%) | $ | 848,000 |
| General Conditions (8%) | $ | 848,000 |
| Contractor O&P (12%) | $ | 1,272,000 |
| **Subtotal** | $ | 13,600,000 |
| Tax (10.1%) | $ | 1,373,600 |
| Construction Contingency (30%) | $ | 4,080,000 |
| Engineering, Legal, and Administration (25%) | $ | 3,400,000 |
| **Total** | $ | 22,000,000 |

| **O&M Cost Estimate** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **O&M No.** | **Operation and Maintenance** | **Quantity** | | | | | **Total ($/yr)** |
| **Labor (Workload)** | | | Workload (hr/wk) | | Workload (hr/yr) | Unit Cost ($/hr) | |
| 1 | Operation | 1 | 8 | | | $78.66 | $32,723 |
| 2 | Maintenance | 1 | | | 408 | $78.66 | $32,093 |
| | Subtotal | | | | | | $32,093.28 |
| | | | | | | | |
| **Power** | | | Unit HP | Requirement (kW) | Annual Power (kWh) | Unit Cost ($/kWh) | |
| 3 | GBT Belt Drives | 6 | 5 | 22 | 195970 | $0.08 | $15,678 |
| 4 | Wash Water Booster Pump | 6 | 7.5 | 34 | 293955 | $0.08 | $23,516 |
| 5 | Polymer Feed System | 6 | 0.5 | 2.2 | 19597 | $0.08 | $1,568 |
| 6 | Thickener Feed Pump | 6 | 30 | 134 | 1175820 | $0.08 | $94,066 |
| 7 | Thickened Sludge Pumps | 6 | 10 | 45 | 391940 | $0.08 | $31,355 |
| 8 | Odor Control System | 1 | 8 | 6 | 52259 | $0.08 | $4,181 |
| | Subtotal | | | 326 | 2129540 | | $170,363 |
| | | | | | | | |
| **Material** | | | Amount (gal/wk) | | Amount (gal/yr) | Unit Cost ($/gal) | |
| 9 | Polymer | 1 | 2768 | | 143936 | $9.15 | $1,317,014 |
| | Subtotal | | | | | | $1,317,014 |
| | | | | | | | |
| **O&M Subtotal:** | | | | | | | $1,500,000 |

Project: South Plant Solids Thickening Technology Analysis
Client: King County

| | | | |
|---|---|---|---|
| Project No.: 20-2900 | | | |
| Date: | 6/16/2022 | | |
| | | | |
| **Centrifuge** | | | |

| Item No. | Item | Unit | QTY | Materials | Installation | Total |
|---|---|---|---|---|---|---|
| **Civil Site Prep/Earthwork** | | | | | | |
| | Demolition | LS | 1 | | $50,000.00 | $50,000 |
| | Site Clearing | SF | 13064 | | $1.00 | $13,064 |
| | Excavation | CY | 2424 | | $22.00 | $53,333 |
| | Backfill | CY | 364 | | $18.00 | $6,545 |
| | Subtotal | | | | | $120,000 |
| **Structural** | | | | | | |
| | Building | SF | 9464 | $400.00 | | $3,785,600 |
| | Concrete | CY | 2323 | 300 | 200 | $1,161,726 |
| | Subtotal | | | | | $4,947,326 |
| **Mechanical** | | | | | | |
| | Raw Sludge Blending Tank Mechanical Components | LS | 1 | $50,000 | $15,000 | $65,000 |
| | Polymer Feed System | LS | 1 | $20,000 | $6,000 | $26,000 |
| | Polymer Storage Tanks | EA | 1 | $6,000 | $1,800 | $7,800 |
| | Polymer Tanks | EA | 2 | $40,000 | $12,000 | $104,000 |
| | Thickener Feed Pump | EA | 7 | $100,000 | $30,000 | $910,000 |
| | Centrifuges | LS | 1 | $4,620,910 | $1,386,273 | $6,007,183 |
| | Thickened Sludge Pumps | EA | 7 | $25,000 | $7,500 | $227,500 |
| | Odor Control | LS | 1 | $421,000 | | $421,000 |
| | Subtotal | | | | | $7,768,483 |
| **Electrical, Instrumentation, and Controls** | | | | | | |
| | EI&C | LS | 1 | $1,553,696.60 | | $1,553,697 |
| | Subtotal | | | | | $1,553,697 |
| | | | | | | |
| Construction Material & Labor Subtotal: | | | | | | $14,400,000 |

| Markups | | |
|---|---|---|
| Mobilization (8%) | $ | 1,152,000 |
| General Conditions (8%) | $ | 1,152,000 |
| Contractor O&P (12%) | $ | 1,728,000 |
| **Subtotal** | $ | 18,400,000 |
| Tax (10.1%) | $ | 1,858,400 |
| Construction Contingency (30%) | $ | 5,520,000 |
| Engineering, Legal, and Administration (25%) | $ | 4,600,000 |
| **Total** | $ | 30,000,000 |

**O&M Cost Estimate**

| O&M No. | Operation and Maintenance | Frequency (yr) | | | | | Total ($/yr) |
|---|---|---|---|---|---|---|---|
| **Labor (Workload)** | | | Workload (hr/wk) | | Workload (hr/yr) | Unit Cost ($/hr) | |
| 1 | Operation | 1 | 8 | | | $78.66 | $32,723 |
| 2 | Maintenance | 1 | | | 688 | $78.66 | $54,118 |
| | Subtotal | | | | | | $54,118 |
| | | | | | | | |
| **Power** | | | Unit HP | Requirement (kW) | Annual Power (kWh) | Unit Cost ($/kWh) | |
| 3 | Centrifuge Main Motor | 6 | 150 | 671 | 5879099 | $0.08 | $470,328 |
| 4 | Centrifuge Back Drive Motor | 6 | 25 | 112 | 979850 | $0.08 | $78,388 |
| 5 | Polymer Feed System | 6 | 0.5 | 2.2 | 19597 | $0.08 | $1,568 |
| 6 | Thickener Feed Pump | 6 | 30 | 134 | 1175820 | $0.08 | $94,066 |
| 7 | Thickened Sludge Pumps | 6 | 10 | 45 | 391940 | $0.08 | $31,355 |
| 8 | Odor Control System | 1 | 8 | 6 | 52259 | $0.08 | $4,181 |
| | Subtotal | | 1301 | | 8498564 | | $679,885 |
| | | | | | | | |
| **Material** | | | Amount (gal/wk) | | Amount (gal/yr) | Unit Cost ($/gal) | |
| 9 | Polymer | 1 | 1845 | | 95940 | $9.15 | $877,851 |
| | Subtotal | | | | | | $877,851 |
| | | | | | | | |
| **O&M Subtotal:** | | | | | | | $1,600,000 |