Farm Technology Group

MSc Internship Agricultural Biosystems Engineering

A System analysis on the dredge separation machine of Blauwe Bagger

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Abstract

Approximately 40.000.000 m^3 of dredge is dredged on a yearly basis in the Netherlands. Dredging is necessary to keep waterways clean, ports, rivers and canals accessible for ships, prevention of flooding, improvement of water quality and to protect infrastructure like bridges. River and canal dredge can be full of useful materials like sand, silt, clay and organic matter and could be applied to various industries. The composition of these materials in dredge however can differ a lot based on the origin of the material. In the west of the Netherlands for example you can find dredge with 70% clay while in the east maybe only 20%. Blauwe Bagger is a small company that believes in a sustainable and circular future for the Dutch dredge and building industry. They developed a (pilot) dredge separation system which separates dredge into coarse material, sand, clay, silt, organic matter and water using a drum filter, hydrocyclone and filter press. In this research a system analysis has been conducted on the processing capacity of the different unit operations of the machine as well as use of resources. The filter press is the biggest bottleneck in the system at this moment with a processing capacity of $0.057\ m^3/h$ of dredge compared to the hydrocyclone with a capacity of $0.66\ m^3/h$. However, the outcomes of this research highly depend on the composition of the dredge and the desired application of the output streams.

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1 Introduction

In the Netherlands approximately 40.000.000 m^3 of dredge is dredged on yearly basis (CBC, 2024). Dredging is an important process which involves removing debris, silt and sediments from the bottom of rivers, canals, ports and oceans (Manap & Voulvoulis, 2016). In the Netherlands dredging is necessary to keep waterways clean, ports, rivers and canals accessible for ships, prevention of flooding, improvement of water quality and to protect infrastructure like bridges (Delta, 2024; Rijkswaterstaat, 2024; Scheldestromen, 2024; Zuid-Holland, 2024). In the Netherlands dredging the waterways is the responsibility of the government where Rijkswaterstaat maintains most of the national waterways while the duty of dredging smaller regional waterways lies with local and regional governments and waterboards. The waterboards are the main players and have the biggest responsibility in ensuring the dredging happens, mainly by outsourcing to contractors (Waterschappen, 2024).

Every waterbody has to be dredged once every 7 to 15 years (Veluwe, 2024; Waternet, 2024). The dredged sediment is mostly treated as waste or as low value material. Moreover, the transportation and accurate handling of this waste stream is an enormous cost factor for the responsible organization (Elskens & Harmsen, 2007). At the same time, on global, European and national level multiple regulations are in place to enhance circularity in different sectors, also in the dredging industry (Castro et al., 2019; NederlandseOverheid, 2024). River and canal dredge can be full of useful materials like: sand, silt, clay and organic matter (Van der Meulen et al., 2007), and could be applied to various industries. The composition of these materials in dredge however can differ a lot based on the origin of the material. In the west of the Netherlands for example you can find dredge with 70% clay while in the east maybe only 20%. The same goes for the silt and sand ofcourse (CBC, 2024).

Clay is a material that is now largely retrieved from mines and often imported internationally. For instance, virgin clay used in the ceramics industry gets partially imported from Germany and Belgium. Sand is another component which is largely available in dredge and shows great potential in terms of market demand in the building sector. Local governments in the Netherlands are getting more reserved in granting permits for opening new sand mining pits (Huizen van, 2022). These pits usually serve a dual purpose. Often they are located next to major rivers in the floodplains and provide a good quality of sand that can be used in construction. After the pit is exhausted it is usually than filled with dredge which cannot be applied elsewhere. With lesser pits being opened both the mining of sand and place where dredge material can be stored will come under pressure, eventually this will also greatly affect the building industry which heavily relies on sand (Müller, 2022). Therefore, coupling these markets has a large potential in terms of sustainability for both the Dutch dredging and Dutch building sector. Besides the raw building materials dredge often also contains organic matter. This organic matter contains lots of nutrients and can be used as alternative and more sustainable fertilizer in for example agriculture (Sigua, 2009).

AMORAS is a dredge treatment plant owned by the government of Belgium which is tasked with processing all the dredge from the port of Antwerp. Each year they process more than 2.5 million m^3 of dredge. The separation is mainly focused on separation and dewatering of the dredge and the output streams are considered waste and stockpiled (Vandekeybus et al., 2010). Another plant that is processing dredge is the Metha Plant in Hamburg. Since 1993 at this facility dredged material is separated into several grain sizes and dewatered (Knüppel, 2012). The separated sand is largely uncontaminated and is used as earthwork material.

Blauwe Bagger is a small company that believes in a sustainable and circular future for the Dutch dredge and building industry. Upcycling Dutch dredge could play an important role in this transition. That is why they do everything with their team to investigate separation and cleaning of Dutch dredge into multiple raw material streams. Currently Blauwe Bagger has a (pilot) dredge separation system which is schematically presented in Figure 1 and can potentially separate 1 m^3/h.

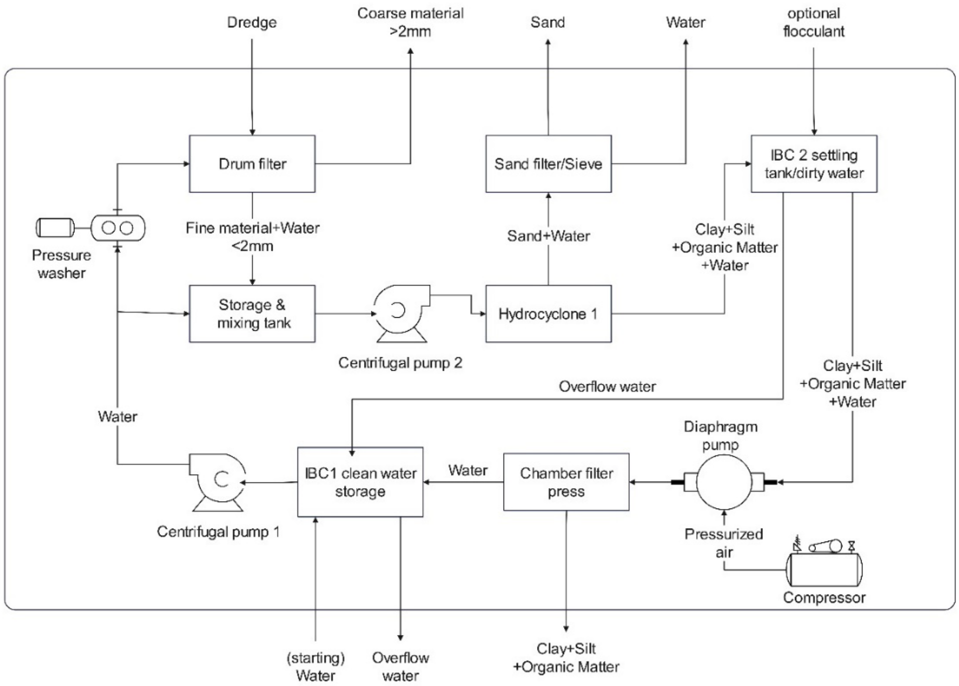

Figure 1 Dredge seperator Blauwe Bagger - System Overview

In the future Blauwe Bagger wishes to scale-up their system and produce sustainable and circular products with the outputs of their machine.

1.1 Current situation

Currently the different unit operations (UOs) of the system are connected to eachother, and the machine is operated step by step instead of continuously. I.e. first unit operation 1 runs than when it is finished UO2 starts etc.. The reason for this is because currently the system is still in a pilot phase (TRL 3-4) where all the UOs are researched and optimized individually on different topics and with different goals.

1.2 Desired situation

In the near future Blauwe Bagger would like to scale up and optimize their process. For scaling up and optimization it is required to know how the system functions as a whole and how the different UOs relate to each other. The key indicators for comparing the UOs are processing capacity and use of inputs.

1.3 Problem statement

At this moment there is no insight or knowledge on how and how well the system functions as whole. Besides this it is also unknown if all the UOs are scalable or if there are other UOs which are better suited for this purpose.

1.4 Research aim and Objectives

The aims of this research are to find out if and possibly how the different UOs relate to each other and if the current system can be upscaled to a certain size as determined by Blauwe Bagger. At the start of the internship the processing capacity for the scale up was set at $10m3/h$ of dredge. Due to certain events, collaborations with other parties and stakeholders and realistic chances for the company this scope has changed. The research will still analyse the current machine and identify bottlenecks in the current system. But instead of focusing on a scale up of a certain size, recommendations will be given for streamlining the entire process. Which eventually is also needed when Blauwe Bagger will scale up. In this research these objectives are studied from a technical perspective.

The objective of Blauwe Bagger is to know how they can upscale the dredge separation system as best as possible regarding technologic and economic performance. Blauwe bagger intends to do this with a Techno-economic assessment (TEA) of the technology. The aim of this study is to provide Blauwe Bagger with the technical insights that are necessary for the TEA.

A TEA is a method to evaluate the technological performance together with economic performance of a technology or technological system. It allows analyst to objectively weigh benefits against costs. The technical data that is needed for their TEA according to Blauwe Bagger is: energy usage, water usage and raw material usage. Therefore, these parameters will also be included in this research.

All of the above result in the following main research question:

What are the technological bottlenecks in Blauwe Baggers process in terms of processing capacity and resource use (use of energy, water and raw materials)?

From the main objective and research question above the following (sub)research questions arise:

1. What is the use of inputs of each UO
   1.1. Energy
   1.2. Water and slurry
   1.3. Main substrate/Dredge
   1.4. Other optional and relevant inputs (e.g. flocculant)
2. What is the processing capacity of each UO (m^3/h)
3. What is the relation between the different unit operations of the separation machine in terms of resource use and processing capacity?

1.5 Demarcation – Pollutants in dredge

River dredge can contain different kinds of pollutants like PFAS and heavy metals (Gerardu, 2021). This internship does not focus on removing these pollutants from the dredge, mainly due to time constraints and the current focus of the company. However, in the system analysis and recommendations for upscaling the possibility for removing these pollutants will be considered when selecting unit operations.

1.6 Outline

The theoretical framework chapter (2) discusses some of the background literature of the UOs of the the current separation machine of Blauwe Bagger. After this framework the material and methods for the system analysis are presented in chapter 3. This chapter gives more in-depth insight in how the machine is operated and how data regarding processing capacity and use of inputs is gathered. Chapter 4 will present the results of the experiments with graphs, tables and block flow diagrams. Discussion will be in chapter 5 and will go deeper into the results and how the results can be interpreted. Chapter 6 will conclude the research questions. In the last chapter recommendations for streamlining and possibly upscaling the current machine will be given.

2 Theoretical framework – Current Separation machine

In this chapter a more in-depth explanation about the current separation machine of Blauwe Bagger will be given using the Block Flow Diagram (BFD) as presented in Figure 2. As mentioned in the problem statement the machine is currently not run continuously but in three consecutive stages. In Figure 2 these stages or combination of unit operations (CUOs) are represented by three colors: red (Drum Filter), green (Hydrocyclone) and blue (Filter Press). The machine takes dredge as the raw material input and separates this in 4 main streams namely: coarse material, sand, clay, silt, small organic matter and water.

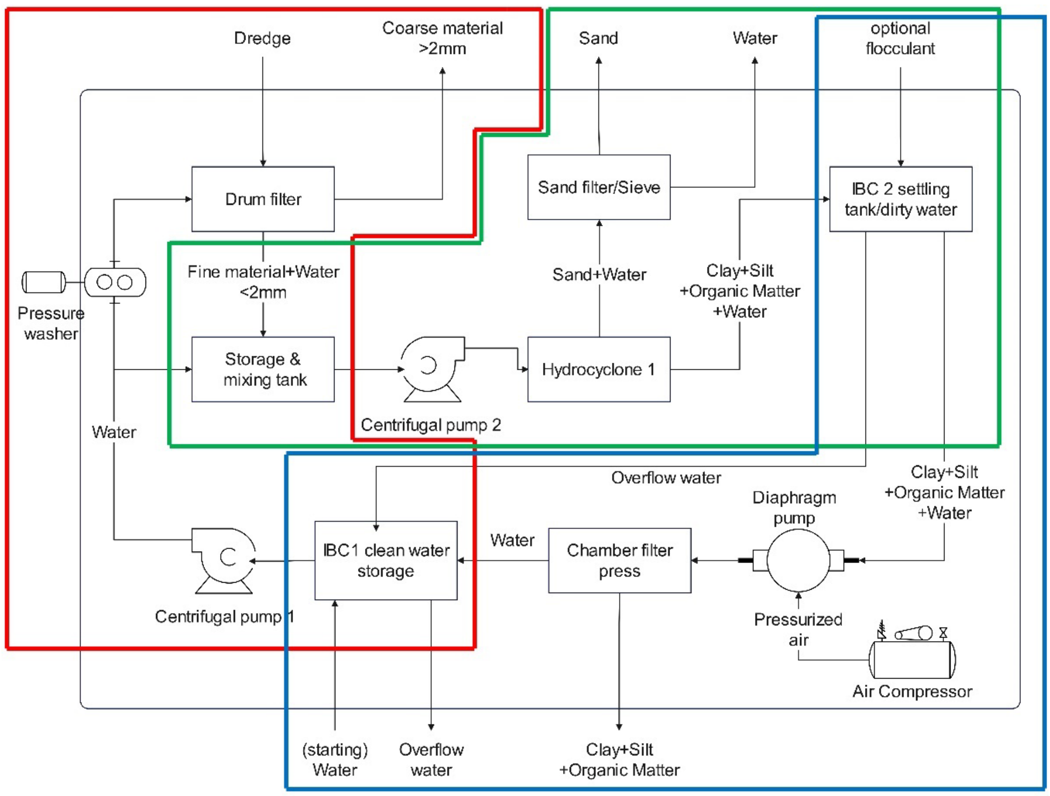

Figure 2 System Overview with Combination of Unit Operations marked

2.1 Drum Filter Stage 1 (Red)

The process starts by putting dredge into the drum filter, whereby spraying water from the international bulk container 1 (IBC1) with the pressure washer onto the dredge it is then sieved/filtered and falls into the mixing tank. The mesh size inside the drum filter is 2 mm so everything that is larger than that stays inside the drum filter. This material mainly consists of stones, soil foreign material and "large" organic matter like sticks, leaves, branches and other plant material. The pressure washer sprays water under pressure with nozzles inside the drum filter to dissolve the dredge and prevent clogging of the mesh screens. It uses "clean" water from IBC1 to do this. Initially this container is filled with fresh water to get the entire process started but as can be seen in Figure 2 the tank also gets filled by water that flows out of the chamber filter press. This means that water inside the system is being recirculated and after the system is operational no new water needs be added into the system. After a certain amount there will be an excess of water because the raw dredge input consists of at least 50% water.

Drum filters are very effective at eliminating suspended solids from water, because of this they are used extensively in many different sectors. Drum filters are used for instance in aquaculture to filter out fish waste and uneaten feed, maintaining the best possible water quality and providing a healthy habitat for aquatic life (Dolan et al., 2013; Dolan et al., 2011; Summerfelt & Penne, 2005). Also, in the treatment of municipal wastewater drum filters are used to eliminate impurities and improving the overall quality of the water before further processing (Alizadeh et al., 2023; Vaananen et al., 2016).

These filters are also widely used in the industrial water treatment industry to clean wastewater and process water (Ersahin et al., 2011; Stickland et al., 2018). Furthermore, drum filters are necessary in cooling tower systems because they stop scaling and fouling (Petrey Jr, 1974). The benefit of drum filters is that they are quite easily scalable and have a high processing capacity per m^2 compared to settling tanks (Asp et al., 2024). They can also handle highly varying sorts of inputs and large debris without getting clogged or having other issues (Dolan et al., 2013). These filters are therefore often applied as pre filtration step.

In the system of Blauwe Bagger the drum filter (Figure 3) is also used a pre/first filtration step. Dredge is poured into the drum and everything larger than 2mm stays inside the drum and can later be removed manually. The fine material(<2mm) goes into the mixing tank where together with the water it will be ready for the next stage.

Figure 3 Drum Filter Blauwe Bagger

2.2 Hydrocyclone Stage 2 (Green)

Now that the fine material is filtered from the large debris it is time for the next separation step using the hydrocyclone. The hydrocyclone (Figure 4) just as the drum filter functions based on particle size but it does not use a filter with a certain mesh size to separate the particles. Instead, the hydrocyclone utilizes centrifugal force to separate the particles that are present in a liquid suspension (Bergström & Vomhoff, 2007). The cyclone has a conical and a cylindrical section which together form the hydrocyclone. The slurry enters the cylindrical section tangentially through the inlet. Because of the centrifugal acceleration, the rapid slurry movement creates an intense whirlpool like motion that slings the solids to the outside of the cyclone. Then one part of the feed stream is released through the vortex finder at the top of the hydrocyclone. This stream, known as the overflow, is made up of the finer particles and is more liquid. The second stream, known as the underflow, exits the conical part at the bottom through a circular aperture known as the apex. Typically, the underflow is used to release heavier and/or bigger particles (Chen et al., 2000). The geometrical dimensions of the hydrocylone determine parameters like the separation efficiency, cut size and split ratio (De Greyt, 2013). For proper operation it is mandatory that the slurry is not too thick. If the slurry is too thick it will not be able to reach the required speed and there is not enough space for the particles to be properly separated (Kawatra et al., 1996).

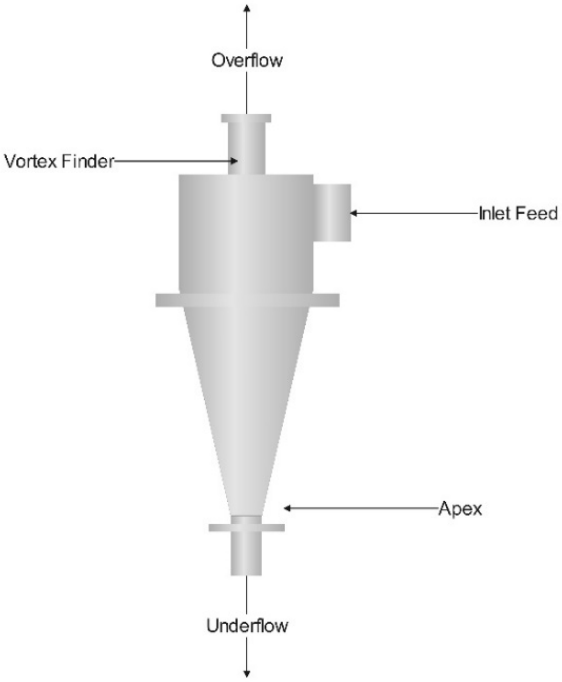

Figure 4 Hydrocyclone Schematic Overview

Because hydrocyclones are versatile and very effective at removing (small) particles from liquids they are used across various industries. In the mining industry, they are used for the classification and separation of ore particles for instance (Padhi et al., 2022). Hydrocylones are also being used in the oil and gas winning industry to remove sand and dewater. The sand and other solids that are removed from the process water and oil help to protect equipment from extensive wear and clogging which in turn reduces maintenance and operating costs (Zhang et al., 2023). In water treatment plants they are used to remove suspended solids like grit from the water. This results in cleaner water and reduces stress on filtration systems in the following stages of the water treatment (Khatri et al., 2020). They are also used in the food and beverage industry for things like starch refining and juice purification because of their scalability, high throughput and robustness (Ji et al., 2023).

The hydrocyclone used in the separator of Blauwe Bagger (Figure 5) is dimensioned to separate at 63 μm. This specific size is chosen because the grain size of sand is classified as being between 63 μm and 2 mm. And because in the drum filter a mesh size of 2 mm was chosen this means that the underflow of the hydrocyclone will output sand. The overflow logically will than output particles smaller than 63 μm. This fraction mainly consists of clay, silt, and small organic matter and will go into IBC2 settling tank ready to be dewatered by the filter press.

Figure 5 Hydrocyclone Blauwe Bagger

2.3 Filter Press Stage 3 (Blue)

The final stage is the chamber filter press in which the finest slurry consisting mainly of clay, silt and small organic matter is dewatered. Again, the separation principle is based on particle size and using a filter screen like in the drum filter. This filter is called a filter cloth and has a certain mesh size, as small as 0.5 micron, which "only" allows water to pass through in order to separate the solids from the liquid(s) (Morsch et al., 2020). The press (Figure 6) consists of filter plates with a filter cloth around each of them. The solid plates have hollow spaces on the inside which allows to be filled with slurry. Before filling the press it first should be closed, this is done by a hydraulic cylinder and ensures no fluid can escape the system. A feed pump then pumps slurry through the feed holes in the plates. At the same time fluids, in this case water, leave the filter press through the drain holes which are located at the bottom of each plate. Over time the feed pump will increase the pressure inside the chambers and a filter cake or simply cake will be formed. In the system of Blauwe Bagger the cake consists of clay, silt and organic matter as shown in Figure 2. With a buildup of cake, the amount of water that flows out of the drain holes decreases. A filtration is complete based on the goals of the operator for the DM of the cake. If the chambers are opened when a lot of water is still coming out of the drain holes the cake will be wetter than when almost no water comes out of the drain hole. After the filtration is complete the cake will be discharged by opening the press and separating the plates. This can either be done manually or automatically. Afterwards the press can either be cleaned or closed again for a next cycle. Figure 6 is a general representation of a filter press and for specific presses the layout and plates can be different but the principle in general is the same (Zhang et al., 2024).

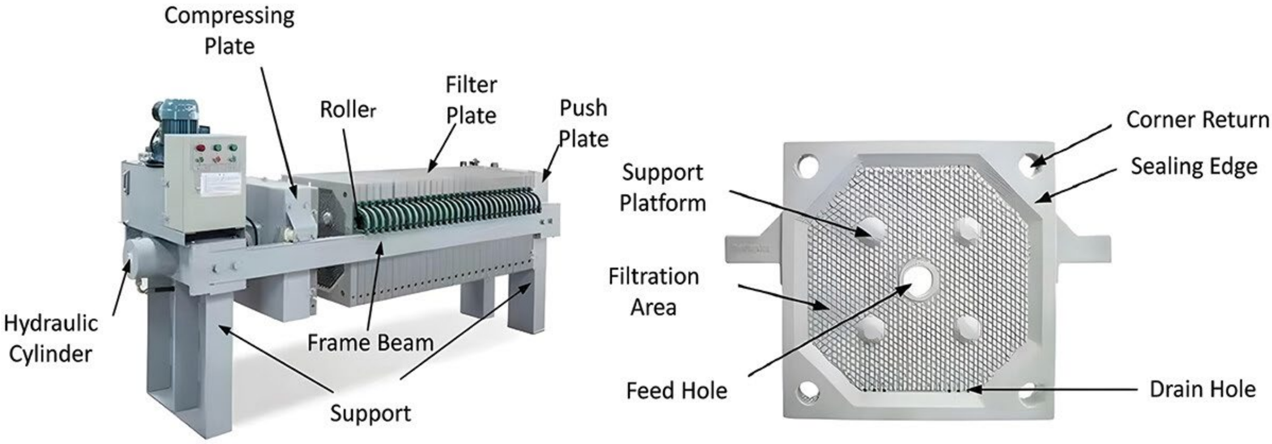

Figure 6 Chamber Filter Press - Schematic Overview (Zhang et al., 2024)

Chamber filter presses are used in many different industries similar to the hydrocyclone and drum filter. The mining and mineral industry for instance use filter presses to process tailings and dewater mineral concentrates to be able to later easier reclaim precious materials and easier disposal because volume and weight decrease (Furnell et al., 2022; Prat, 2012). In the food industry clarifying juices (De Paepe et al., 2015), beer (El-Shafey et al., 2004) and wine and removing impurities from edible is done by using filter presses (De Greyt, 2013).

The filter press of Blauwe Bagger Figure 7, pumps slurry out of IBC2 (settling tank) with a diaphragm pump, which is powered by an air compressor, into the filter press up to 6 bar. After a certain time, based on the type of input slurry and application that Blauwe Bagger has for the final product a filter cake gets formed and is removed by opening the filter press. Because the composition of dredge from different places can highly vary in clay/sand ratio and also the type of clay varies based on its origin the time it takes to get a filter cake with a certain DM contents can vary greatly (Al Jaber et al., 2021; Puderbach et al., 2021). This is also something Blauwe Bagger is continuously working on to better understand.

Figure 7 Chamber Filter Press Blauwe Bagger, summer 2023

3 Materials and Methods - System analysis of the current machine

This chapter focuses on the methodology for answering RQ 1,2 and 3. To summarize, these questions are about assessing the performance of the current separation machine. The results can then later be used as input for recommendations on streamlining the separator and possibly for a larger scale. Each UO will first be assessed individually on certain parameters and then as a whole. The results will give an overview of how streamlined the separator is and where the bottlenecks are. The first sub section of this chapter addresses some of the changes made to the separator before starting with the actual experiments and research. It also gives more in-depth information about the CUOs and relevant specifications of the machines. The second and third sub section handle the sensor selection process and implementation of hardware and software. Finally in the last section the experiments are explained.

3.1 Separation machine at the start of the experiments

At the start of the internship the separator was as in Figure 2. The project started with a literature study on the UOs to get a better understanding of the machine and the mechanics. And later some practical testing with the actual machine to predict if the ideas for the experiments of this research were reasonable and doable within the timeframe of the internship. The pressure washer had clogging issues because the recycled water was not 100% free of debris and regularly broke down because of that. Literature however did not show that the high pressure from the pressure washer was needed for the drum filter to function correctly. Therefore, the choice was made to replace the pressure washer from the system and use centrifugal pump 1 in combination with a large nozzle instead. This method was tested and proved to be more robust and therefore was also used for the research. The sand filter did also not completely work like it was supposed to so for the experiments was chosen to take the sand+water fraction from the underflow of the hydrocyclone as a final output of this stream without further separating. The "new" system overview is presented in Figure 8, note that in this figure sensor are not yet shown.

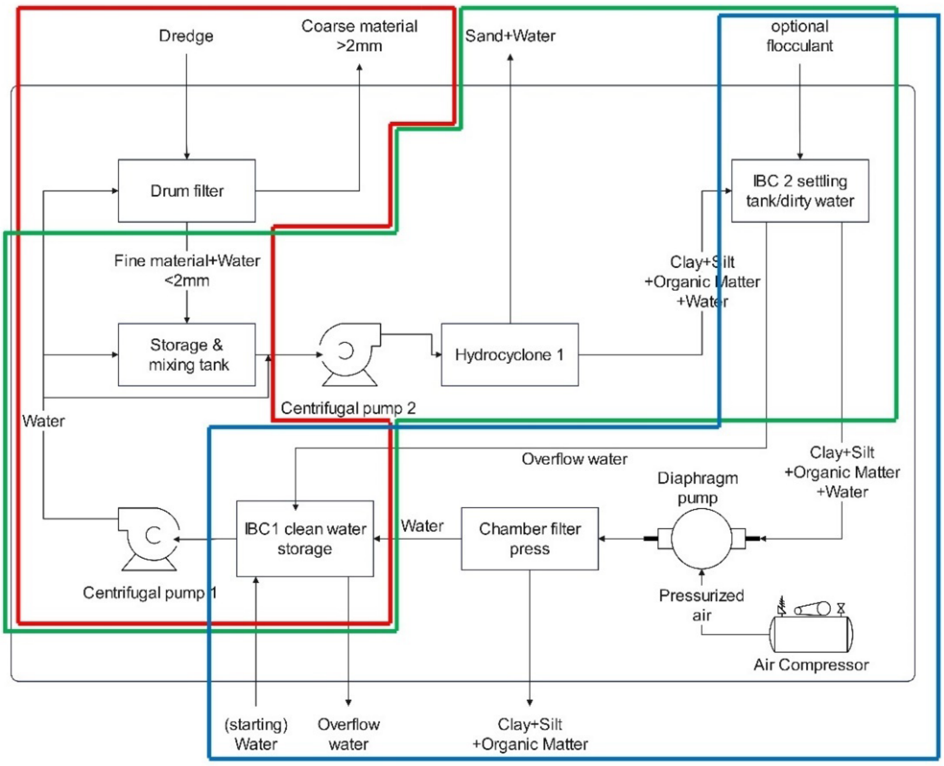

Figure 8 System Overview at start of experiments without sensors

3.1.1 Drum Filter (Red)

The first combination of UOs consists of the drum filter, mixing tank and inflow of clean water from IBC1 + Centrifugal pump 1. Table 1 shows per UO the energy consumption as well as some other relevant specifications. The energy consumptions values show the consumption when the load on the engine is at its maximum. The motor of the mixing tank for example will consume less power when the tank is half full compared to a full tank.

Table 1 Specifications of Combination of Unit Operations 1

Unit Operation	Energy Consumption	Other Specifications
Drum filter	0.36kW	2mm mesh size
Centrifugal Pump 1	1.25kW	$3m^3/h$
Mixing Tank	3kW	450L
IBC1 Clean Water Storage	-	1000L

3.1.2 Hydrocyclone (Green)

The second combination of UOs consists of the mixing tank, centrifugal pump 2, hydrocyclone, settling tank IBC2 and inflow of clean water from IBC1 + Centrifugal pump 1 for flushing the system on startup. The flushing is needed to prevent clogging of pump 2 when it is initially started, due to sediment buildup in the pipes. According to the specifications in Table 2 the hydrocyclone can reach an efficiency of 90%. This efficiency means that it can separate 90% of the solid particles of 75μ and larger. In other words, it can remove 90% of the sand in the slurry. However, to achieve this efficiency the minimal operating flow and pressure have to be met according to the manufacturer.

Table 2 Specifications of Combination of Unit Operations 2

Unit Operation	Energy Consumption	Other Specifications
Hydrocyclone	The cyclone itself does not use any energy but slurry is pumped through with centrifugal pump 2	90% efficiency, 75μ cut size, minimal operating flow of 1.8m^3/h and a pressure $\geq$ 2bar
Centrifugal Pump 1	1.25kW	$3m^3/h$
Centrifugal Pump 2	1.25kW	$3m^3/h$
Mixing Tank	3kW	450L
IBC1 Clean Water Storage	-	1000L
IBC2 Settling Tank	-	1000L

3.1.3 Filter Press (Blue)

The Last CUOs consists of the settling tank, diaphragm pump powered by the air compressor, chamber filter press and IBC1 for the outflow of clean water. Most of the components of this last CUOs are static in terms of energy consumption. The filter press consumes power when it opens and closes and for the rest of the time there are just some safety and control electronics that use minimal power. The diaphragm on itself also does not consume any power but needs pressurized air from the air compressor, this is also the UO that uses most of the energy in this CUOs.

Unit Operation	Energy Consumption	Other Specifications
Filter press	2.2kW (Hydraulic pump) Consumption of control electronics and valves is unknown	Hydraulic pump ~200 bar Volume between the plates is 180L
Diaphragm pump	-	Max 8 bar
Air compressor	4.6kW	8 bar, 720L/min net capacity
IBC1 Clean Water Storage	-	1000L
IBC2 Settling Tank	-	1000L

3.2 Sensor selection

There is a wide range of sensors that can be implemented to measure all kinds of parameters but not all will be implemented. The goal of implementing sensors into the separator of Blauwe Bagger is to gather data that can help answer the research questions. It is therefore necessary to determine which data specifically is needed and select a sensor or method that can deliver this data.

Table 3 presents an over overview of the possible sensors and/or methods that can measure the inputs as stated in RQ1. The use of energy is straightforward and can be measured using an energy monitor and the dredge input is most easily measured in weight with a scale. For measuring the input (and output) of fluids (water and slurry) however are multiple possibilities. For continuous measurement a flow meter is a very good choice but if just the total volume has to be known a simpler measurement of start and end level volume of for instance IBC1 is sufficient.

Table 3 Possible Sensors and methods for RQ1

Parameter	Possible "Sensor" or method
Energy	Energy monitor/meter
Water and slurry	Water or Flow meter, Level measurement in tank or IBC
Dredge input	Scale to weigh the input

The second research question will give the processing capacity of each UO and the third will compare the UOs with eachother. To be able to compare there must be some common metrics for each UO (or CUOs). For this research this will be the processing capacity, energy consumption and water consumption. The processing capacity is important because it will show how much each UO can handle per hour and thus bottlenecks can be identified. Energy consumption will give insight into the costs of operation as where the water consumption will show if the system consumes or produces water in total.

Due to time, financial constraints, issues that arised and to avoid unnecessary complexity the number of sensors was limited. A few proposals with sensors were made that met the requirements for the research goal and together with Blauwe Bagger a decision was made on the sensors that were eventually implemented. Figure 9 shows once again the system overview but this time with the sensors that are implemented into the system. It must be noted that however the number of sensors is limited the original RQs could still be answered.

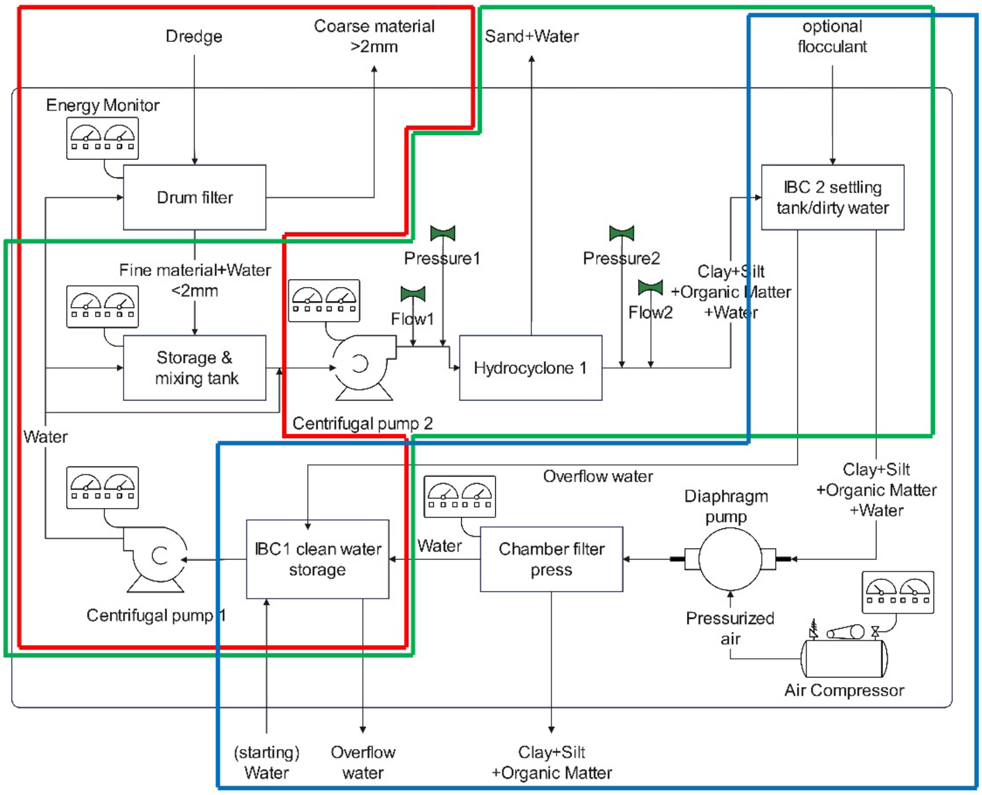

Figure 9 System Overview at start of experiments with sensors

Table 4 gives an overview of the sensor and measurement methods that are implemented into the separator together with their purpose. For the water and slurry consumption eventually the choice was made to manually measure the level of liquid inside the tanks. The reason for this was mainly because the available (digital) level sensors were neither accurate nor a good fit for the current machine.

Table 4 Sensor and measurement methods overview

Sensor or Method	UO	Purpose	Remarks
Energy monitor	Every powered UO	Measure Energy input/consumption	Digital energy monitor
Level measurement	Mixing tank, Under Flow of hydrocyclone, IBC1 and IBC2	Measure water and/or slurry input/consumption and output	Manual measuring with tape measure
Flow meter	Hydrocylone	Correct operation	Electromagnetic Flow meter
Pressure meter / Manometer	Hydrocyclone	Correct operation	Manometer

Scale	Drum filter and Filter press	Measure dredge input and filter cake output	Analog dial hanging scale

3.3 Hardware and Software Engineering

Besides the development of a system overview the different sensors also had to be physically implemented into the machine. Also, an electrical control box had to be designed and constructed that acts as the brain of the machine where all digital data is gathered and through which it is possible to control certain UOs with a remote. Emergency buttons were also installed in case of an accident or if something went wrong with the installation during operation. For the hydrocylone a web dashboard was programmed to real-time monitor the flows during operation. All sensors and modules were connected to a Raspberry Pi using different communication protocols. Figure 10 presents a schematic overview of the network and the communication protocols.

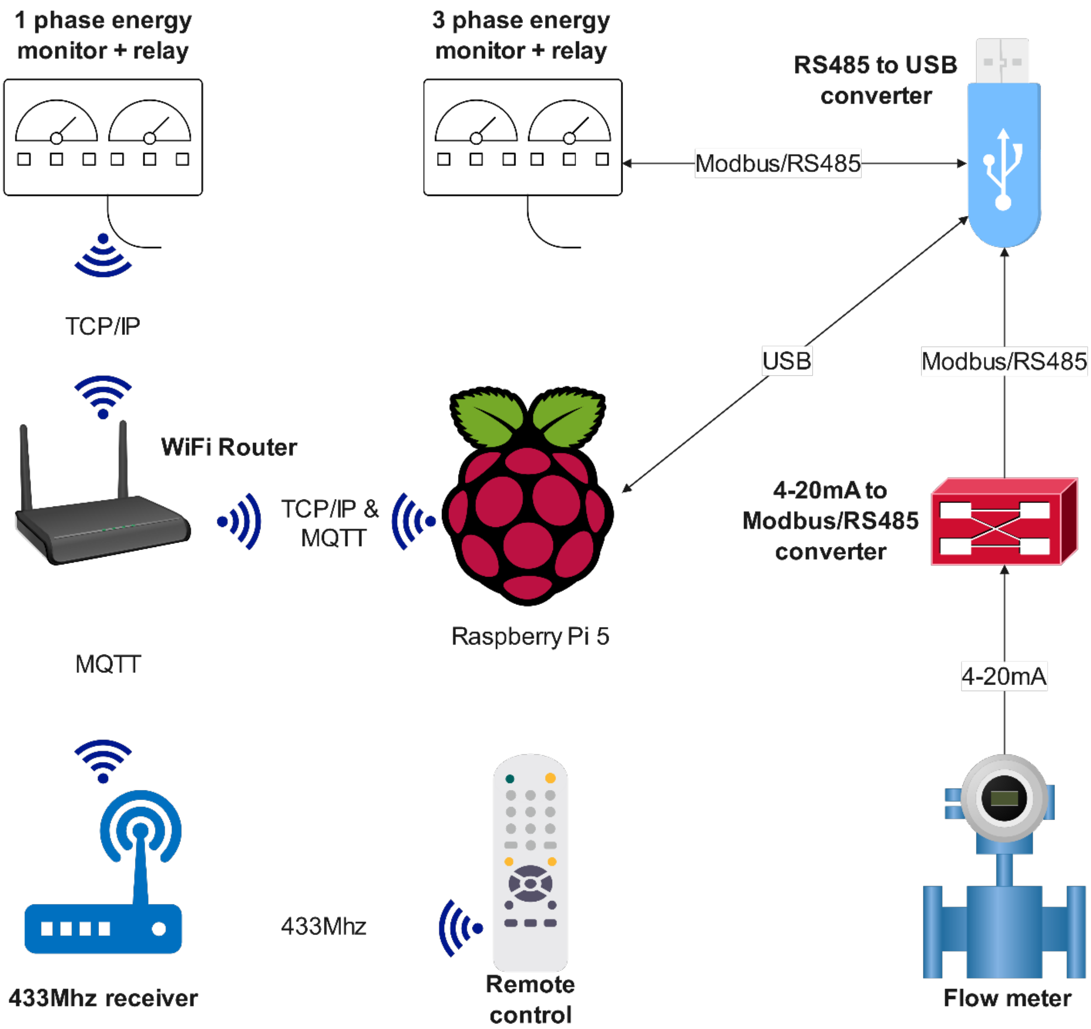

Figure 10 Communication Network Overview

The Raspberry Pi as heart and brains of the system was mainly programmed using Node-RED. Node-RED is flow-based, low code editing tool for visual programming and is built on Node.js (Javascript). The modbus devices were connected to the Raspberry Pi via a USB(serial) to RS485 converter and data was pulled through a python script. The 433Mhz receiver is an ESP based device and therefore was programmed using C++. As said before, all of this hardware was built into a control box Figure 11.

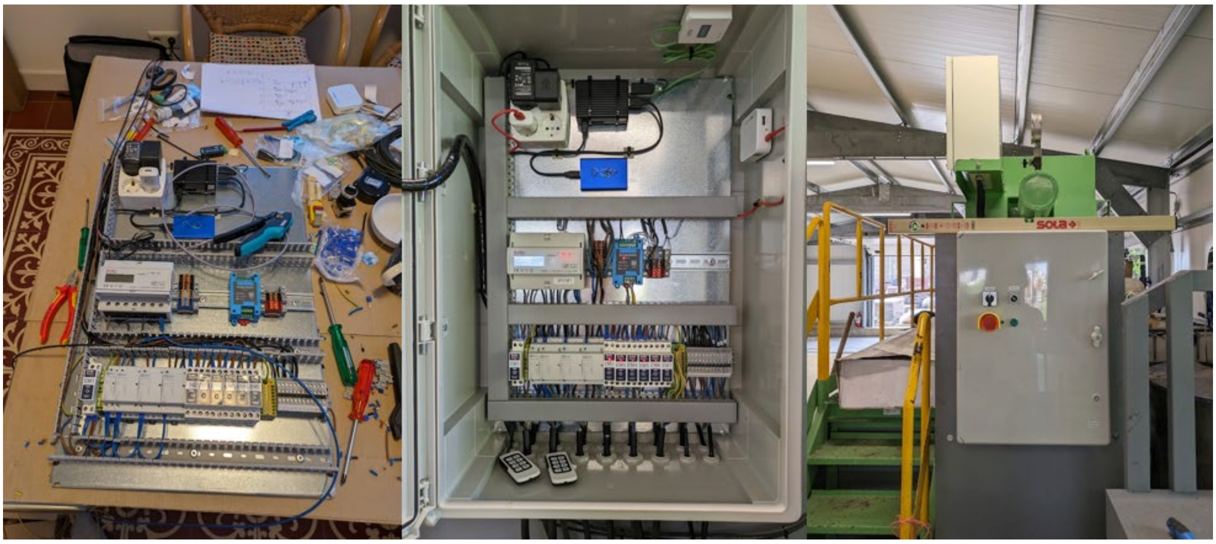

Figure 11 Control Box Dredge Seperator

3.4 Experiments dredge separator

As can be seen in Figure 9 and Figure 2 the separator is divided into three stages. Before (Figure 2) it was the choice of Blauwe Bagger but for the experiments this could have been different. The reason the stages are the same is out of practical considerations. The process starts with inserting dredge into the drum filter. To properly operate the drum filter water must be added to it. The filtered sludge then falls into the mixing tank. In this sense these three UOs are connected to eachother and thus the first CUOs is set. It would be possible to not run the mixing tank during operation of the drum filter. But from experiences in the past like settling of the sludge on the bottom of the tank and clogging of the pipes it was chosen not to do this and also run the mixing tank. The second CUOs starts by pumping sludge from the mixing tank through the hydrocyclone and separating into two streams, sand+water and clay+silt+small organic matter+water. Both streams go into a tank and this ends the second CUOs. The last CUOs is the filter press which uses the clay sludge from IBC2 to form filter cakes and the discharge water goes back into IBC1. Another way to explain or look at is that each CUOs boundary is set when a stream goes into a tank where it can stay static.

During the experiments each CUOs will be run separately, and inputs and outputs as determined in Table 4 as well as cycle time will be measured for each of them accordingly. One run of a CUOs is called a batch and the definition of a batch is different for each CUOs.

3.4.1 Drum Filter – Batch definition (Red)

The batch size for the Drum Filter was set at 6 buckets of 17L of dredge with a DM% of 44%. This amount of dredge was empirically determined by running a few tests. After 6 buckets there was too much debris in the drum filter and it had first to be emptied out before more dredge could be filtered. The filtered dredge/slurry that was in the mixing tank also proved to have enough water so that the hydrocyclone could function properly, so no extra water had to be added before going to the next stage.

3.4.2 Hydrocyclone – Batch definition (Green)

The hydrocyclone uses the slurry in the mixing from the first stage as an input material so this also determines the batch size => output of drum filter batch. Because the drum filter and cyclone are run sequentially energy consumption, use of water from IBC1 and cycle time can be directly compared.

3.4.3 Filter Press – Batch definition (Blue)

Determining the batch size of the filter press is a bit harder and some assumptions had to be made. Wet slurry is pumped into the press which dewaters the slurry until a filter cake with unknown DM% (the results of the experiments will show how dry the filter press can actually get the cake) is formed. If an assumption is made on the maximum DM% of the cake than together with the volume of the press it is possible to calculate how many batches of Stage 1 and 2 are needed to completely fill the filter press. This is important because if the filter press is not completely filled the cake will not be as dry as it potentially could be. An assumption of max 60% DM was taken. This percentage is based on the AMORAS plant in Antwerp which was visited on the 24th may with Blauwe Bagger, the municipality of Rotterdam, Waterweg and some other partners. AMORAS is a dredge treatment plant owned by the government of Belgium which is tasked with processing all the dredge from the port of Antwerp. Each year they process more than 2.5 million m^3. The system is very similar to that of Blauwe Bagger and also employs filter presses where they can get to a DM% of 60%. Following equation 3.3 the number of batches required to fill the press accordingly is 2.4 (240L) thus 3 batches (300L) of the drum filter and hydrocyclone will be run and stored in IBC2 before running the filter press. In this calculation the organic matter and sand that is removed in stage 1 and stage 2 is not taken into account. However based on the official inspection reports of the dredge (which cannot be fully disclosed due to confidentiality) these fraction are around 10% of the total volume which still results in $300L * 90\% = 270L$ slurry that can be processed into a filter cake.

$$X_{batches} * V_{dredge_{in}} * DM_{dredge_{in}} = V_{press} * DM_{press} \qquad [-] \qquad 3.1$$

$$X_{batches} = \frac{V_{press} * DM_{press}}{V_{dredge_{in}} * DM_{dredge_{in}}} \qquad [-] \qquad 3.2$$

$$X_{batches} = \frac{6 * 17L * 0.44}{180L * 0.60} = 2.4 \qquad [-] \qquad 3.3$$

In Table 5 a summary of the batch sizes is presented.

Table 5 CUOs batch sizes

CUOs	Batch Size
Drum Filter	~100L of dredge (6 buckets)
Hydrocyclone	Output of 1 batch of the Drum Filter
Filter Press	Output of 3 batches of the Hydrocyclone

For this research both the drum filter and hydrocyclone will run 9 batches and the filter press will run 3 batches.

Because there is no universal rule or method to determine when a filter press is done with pressing it was decided to visually observe the discharge water from the plates. After 3 hours almost no water came out of the plates and then it was decided to press each batch for the same length of time in order to gain a dry as possible cake. And also by keeping the cycle time constant it was easier to compare the batches and results would be more reliable in terms of volume and DM%.

3.4.4 Standard Operating Procedure – SOP

In Appendix I - SOP a detailed description of how the separator should be operated is written down in an SOP (standard operating procedure). The SOP describes every step an operator must take when operating the machine and also how and when data should be gathered. This SOP was also used to gather data for the research.

3.4.5 Dry matter content

To determine the DM% of the filter cake and input dredge the following protocol was followed:

1. Take 1 samples of 600g
2. Mix the sample until homogeneous
3. Divide into 3 samples of 200g each
4. Put samples in the oven for 6 hours on 60 degrees Celsius
5. Weigh the 3 samples
6. Calculate the dry matter content using equation 3.4

$$DM\% = \frac{Weight_{DryCake}}{Weight_{WetCake}} \quad [g] \qquad 3.4$$

4 Results - System analysis of the current machine

In this chapter the results of the research experiments are presented. For each of the three combination of unit operations (CUOs) there is a subsection. In these sections the average in and outputs are shown. Also, in each section there is a paragraph with observations made during operating the machine. These observations do not directly contribute towards answering the research questions but do consist of relevant (practical) information for the recommendations of upscaling. In the last section an overall mass balance is drawn and all UOs are compared to eachother.

4.1 Drum Filter

Figure 12 schematically presents the CUO with the 4 inputs and 2 outputs. For the energy the input has been split into 2 entities in the results. The first is for the motor of the drum filter and centrifugal pump 1 which feeds water into filter and mixing tank. The second is for the mixer in the mixing tank. Due to technical limitations it was not possible to measure the energy consumption of the drum filter and pump 1 separately. Figure 12 quantifies the inputs and outputs in their respective measurement unit. The dredge at input for instance was weighed using a scale and the slurry in the mix tank was measured in litres. Because the density of the slurry is not known it was not possible to calculate the weight at this stage. However at this level this information is not interesting.

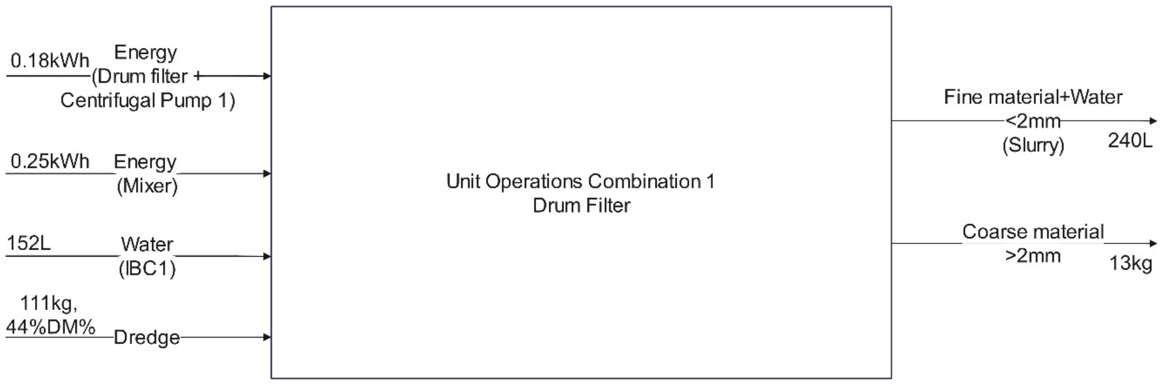

Figure 12 BFD of Combination of Unit Operations 1

Interesting to see from Figure 12 is that on average this dredge contains $\frac{13kg}{111kg}$ => 12% of Coarse material. On average 152L of water was added to every batch of dredge, the input dredge had an average DM% content of 44% so the slurry had a DM% of 18.6% (4.1).

$$\frac{m_{dredge} * DM\%}{\rho_{water} * V_{water} + m_{dredge}} = \frac{111 * 0.44}{0.997 * 152} = 18.6\% \qquad [\%] \qquad 4.1$$

As explained in section 3.4.1 the drum filter was full after 6 buckets and therefore it was decided that this was the batch. However after these 6 buckets the mixing tank was not yet full, the results in Figure 12 also confirms this because the average output of fine material was 240L whereas the tank itself has a capacity of 450L.

4.2 Hydrocyclone

CUO2 main unit operation is the hydrocylone and is presented by Figure 13. The fine material output from CUO1 feeds into here alongside water from IBC1 for flushing the system. In this CUO the energy input is also split into 2, pump1+2 and the mixer. The output of the hydrocyclone are sand+water which are separated in the sand filter and a slurry of clay and silt which go to the settling tank (IBC2).

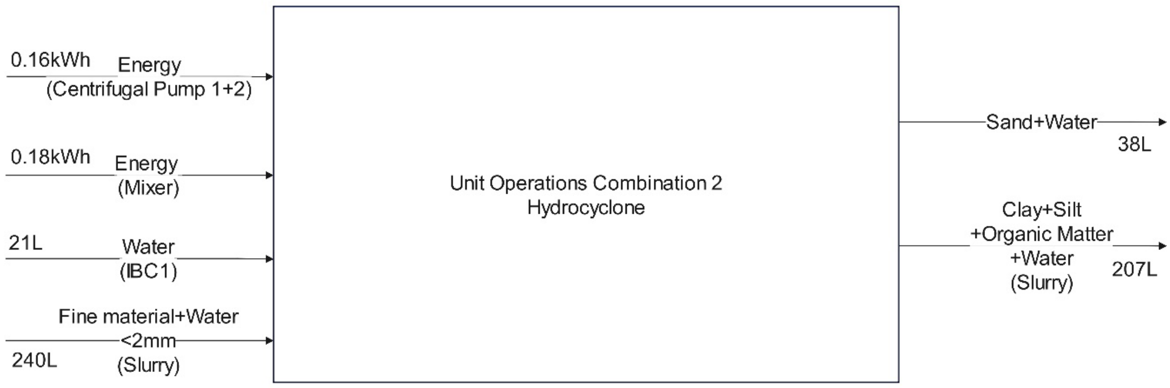

Figure 13 BFD of Combination of Unit Operations 2

Interesting to see is that average energy consumption, of the pumps compared to the mixer is almost equal. Pump 1 is switched off for more than 95% of the cycle time so concluding from this pump 2 uses almost the same amount of energy as the mixer. Even though their electrical specifications are different (3kW vs 1,25kW). There also is a discrepancy in the measured data between the inputs of $240 + 21 = 261L$ and the outputs of $38 + 207 = 245L$ on average.

Initially the Hydrocyclone was operated at 2 bar minimum as per the suppliers' specifications and a flow of 40/50 L/min. However during operation, the cyclone seemed to not function optimal and the pressure was increased to 2.5 bar and a flow of 30/38 L/min and the UO seemingly performed better. This hydrocyclone underflow had to be manually discharged with a ball valve. The cyclone had to be discharged every 10~20 seconds or the pressure and flow would drop because the cyclone would get clogged. When this valve was opened the pressure consistently dropped to 0 bar and took several seconds to return to 2.5 bar.

4.3 Filter Press

Instead of water from IBC1 as an input the filter press has water as an output as can be seen in Figure 14. This water can then be used again for the other UOs. The other output is the filter cake from which in the last section also the DM% is determined to complete the mass balance.

Figure 14 BFD of Combination of Unit Operations 3

The main consumption of energy is by the air compressor. This is because the compressor powers the diaphragm pump that pumps the slurry into the filter press. There also is a discrepancy between the volume of sludge pressed into a filter cake according to the measured data and the specifications of the press according to the manufacturer/seller: $464 - 315 = 149L$ and $180L$.

After every batch a small amount of slurry remained in IBC2. For practical reasons and because Blauwe Bagger was interested to know how much filter cake could be produced from this type of dredge the remains were left inside the tank. The experiments took place over several days so the remains inside the tank had time to settle on the bottom of IBC2. At the start of the experiments there even was a visible separation line of sediment and “clear” water. When this was observed the expectation was that this would have an impact on the DM% of the filter cake. However after the cycle time of 3 hours there was no significant difference in DM% => 40%-42.5%.

After the 3rd batch there were enough remains left from previous batches that another complete batch could be produced. This was done a week later and the slurry sedimented even more. However, it sedimented thus far that it remained on the bottom of the IBC2 and could not be pumped into the filter press anymore. Some water and light stirring had to be applied in order for the slurry to be pumped again.

4.4 Processing capacity

The processed is slurry is a shared parameter of all the CUOs and also a good parameter for indicating the processing capacity of each stage. Table 6 shows that the hydrocyclone has the highest capacity and the filter press by far the lowest.

Table 6 Processing capacity per CUOs on average

CUOs	Processing/batch	Cycle time	Processing Capacity
Drum Filter	111kg dredge or 240L of slurry	16min	900L/h Slurry
Hydrocyclone	240L slurry (fine material <2mm)	8min	1800L/h Slurry
Filter Press	464L slurry (clay/silt)	180min	155L/h Slurry

Using the available data it is also possible to calculate the amount of slurry $1m^3$ of dredge will yield. And with that number the processing capacity for each CUOs in m^3/h dredge can be determined but also the energy and water consumption per $m^3\ dredge$. Calculations for the processing capacity are presented in equation 4.2, 4.3 and 4.4, energy consumption in 4.5 and water consumption in 4.6.

$$V_{bucket_{avg}} = \frac{V_{SlurryDrumFilter_{out}} - V_{water\,in}}{\#BucketsDredge_{batch}} = \frac{240 - 152}{6} = 14.67 \qquad [L] \qquad 4.2$$

$$\frac{V_{Slurry}}{m^3_{Dredge}} = \frac{1000L}{V_{bucket_{avg}}} * \frac{V_{SlurryDrumFilter_{out}}}{\#BucketsDredge_{batch}} = \frac{1000}{14.67} * \frac{240}{6} = 2727 \qquad [L/m^3] \qquad 4.3$$

$$ProcessingCapacity_{DrumFilter} = \frac{\frac{V_{SlurryDrumFilter_{out}}}{h}}{\frac{V_{Slurry}}{m^3_{Dredge}}} = \frac{900}{2727} = 0.33 \quad [m^3/h] \qquad 4.4$$

$$\frac{EnergyConsumption_{DrumFilter}}{\frac{CycleTime}{60}} * ProcessingCapacity_{DrumFilter} \quad [kWh/m^3]$$
$$= \frac{0.18 + 0.25}{\frac{16}{60}} * 0.33 = 4.89 \qquad 4.5$$

$$\frac{WaterConsumption_{DrumFilter}}{\frac{CycleTime}{60}} * ProcessingCapacity_{DrumFilter} \quad [\mathrm{L}/m^3]$$
$$= \frac{152}{\frac{16}{60}} * 0.33 = 1727 \qquad 4.6$$

Table 7 presents the final and most important results. From this table can be seen that the hydrocyclone can process the most cubic metres of dredge per hour, this is coherent with the results from Table 6. In terms of energy consumption, the filter press uses the most energy per cubic metre of dredge. Both the drum filter and hydrocyclone have a positive consumption whereas the filter press is negative. This is because the filter press “produces” water by dewatering the sludge and therefore is negative.

Table 7 Processing capacity per Combination of Unit Operations and their energy and water consumption

CUOs	Processing Capacity	Energy consumption	Water consumption
Drum Filter	0.33 m^3/h Dredge	4.89 kWh/m^3 Dredge	1727 L/m^3 Dredge
Hydrocyclone	0.66 m^3/h Dredge	3.86 kWh/m^3 Dredge	239 L/m^3 Dredge
Filter Press	0.057 m^3/h Dredge	6.41 kWh/m^3 Dredge	-1851 L/m^3 Dredge

5 Discussion

5.1 Drum Filter

The results of the drum filter showed that the mixing tank was not completely filled with every batch. It also showed that the motor of the mixing tank was not mixing at full load. Also, only the total energy consumption per batch was measured instead of the continuous load. For the results of these experiments it does not matter and results and conclusions are correct. But if the mixing tank would be more full or the slurry in the tank would be thicker results could be different. A thicker slurry and fuller tank would put a higher load on the motor and thus increase the power consumption. Further research is needed to see how much these things will influence the power consumption and performance of the drum filter. As said in the results, due to technical reasons it was not possible to measure the energy consumption of the drum filter and centrifugal pump 1 separately. Therefore, it cannot be said with certainty which of the 2 uses the most energy.

5.2 Hydrocyclone

The hydrocyclone separates using a minimum flow and pressure to gain separation efficiency up to 90%. But following from the observations in the results the pressure drops to 0 when sand is discharged from the bottom of the cyclone every 10~20 seconds and it takes some time to get back to pressure. This means that, according to the literature but also from observations, the cyclone is not functioning optimally. This research did not focus on optimizing the UOs but this behaviour could influence other factors like cycle time and energy consumption. Following from the results there also was a discrepancy between the input slurry and two output streams. On average there is 16L slurry more going into the hydrocyclone than coming out. This of course is not possible because the system is closed. The presumption is that this has to do with the manual level measurements. These are measured using a tape measure inside the tank and a small error in taking these measurements can have a big impact. The IBC tanks for instance have a surface of $1\,m^2$, this means that if the measurement is 1 cm off there is an error of 10L. With batch sizes of 240L this means an error of 4%.

5.3 Filter Press

The level measurement errors that occur in the drum filter and hydrocyclone are also present in the filter press analysis. During the experiment the choice was made to run the filter press for 3 hours. This choice has a great influence on the processing capacity of the filter press and thus on the streamlining of the entire system. Because the filter press has no clear “finished state” the choice is made by the operator. For example, the press could also have been stopped after 1.5 hours, this would double the processing capacity. But would also lead to a wetter filter cake. The type of dredge also plays a crucial role in the processing capacity per cubic meter of dredge. The dredge used in the experiment had very little sand which means almost all slurry had to be dewatered by the filter press. If the dredge would have been sandier, less slurry would have needed to be pumped through the filter press and thus increasing the processing capacity per cubic meter of dredge.

5.4 Stage wise operating

In this research the system was run in three stages instead of continuous one of the reasons was that in this way it was easier to analyse the different CUOs and identify bottlenecks. Also because the process is not yet streamlined i.e. not all CUOs have the same processing capacity. A drawback however with this approach is that more energy is used than potentially possible. For instance, the mix tank is constantly mixing when operating the drum filter and then again when running the hydrocyclone. Ideally there would be overlap in these two stages. One of the benefits is the lower total energy consumption and another is a reduction in total cycle time.

5.5 Processing Capacity

When comparing the processing capacities from Table 7 it must be noted that these results rely heavily on the following specific circumstances: Composition of the dredge input material and the length of run time for the filter press as explained in 5.3. Thus stating that the filter press is the bottleneck in the system is technically correct but with the footnote that this is partially due to the other factors mentioned above. In theory it would be possible that with a different mixture of dredge and a very low run time for the filter press for instance this CUOs would be the fastest.

6 Conclusion

6.1 RQ1: What is the use of inputs of each UO?

The dredge separator of Blauwe Bagger basically has 3 types of inputs: energy, water and dredge. Ideally water should only have to be inserted into the system at the starting point. After that the water will be recirculated through the system. Water is an input for the drum filter and hydrocyclone but is an output of the filter press. In total 1966L of water per cubic meter dredge is consumed. The goal of the separator is to dewater the dredge so eventually there will be an excess of water. So even though water is an input for certain UOs it is not a real input because it supposedly does not leave the system, but rather accumulates. Energy on the other hand is a real input of the system. In total for separating 1 cubic meter of dredge 15.16 kWh is used.

6.2 RQ2: What is the processing capacity of each UO?

In the prototype separator of Blauwe Bagger the different UOs have not yet been dimensioned correctly in order to streamline the system. Therefore, the CUOs as researched during this internship have different processing capacities per hour. The choice was made to measure the processing capacity in slurry per hour because this was a parameter shared by all CUOs. The drum filter processes 111kg dredge into 240L slurry in 16 minutes thus having a capacity of producing 900L of slurry per hour. The hydrocyclone was twice as fast in the experiments and was able to process 1800L of slurry per hour. The filter press had the lowest processing capacity of 155L per hour.

6.3 RQ3: What is the relation between the different unit operations of the separation machine in terms of resource use and processing capacity?

For the final research question the processing capacity, energy consumption and water consumption were expressed in cubic meters dredge for a fair comparison. The hydrocyclone had the highest processing capacity of $0.66\ m^3/h$ of dredge and the filter press the lowest of $0.057\ m^3/h$. Interesting to see is that the hydrocyclone also has the lowest energy consumption of $3.86\ kWh/m^3$ dredge compared to the filter press which had the highest consumption of $6.41\ kWh/m^3$ dredge.

6.4 Main RQ: What are the technological bottlenecks in Blauwe Baggers process in terms of processing capacity and resource use (use of energy, water and raw materials)?

Following from the results of the experiments it can be concluded that the filter press is the biggest bottleneck of the system at this moment. It has the smallest capacity and consumes the most energy per cubic meter of dredge. Not only the low processing capacity poses an issue for the streamlining of the system but also the output of water. Because the filter press is the slow the amount of water that is outputted per hour is also low. This means that it is possible that there is not enough water available for the drum filter to operate properly. In order to overcome this the operator can wait till enough water comes available, which takes additional time, or add extra water into the system. Both options are not favourable. However it must be noted that these results and identified bottleneck highly depend on the composition of the dredge and the application Blauwe Bagger has for the output streams. If a wetter filter cake is acceptable or if there is more sand in the dredge the processing capacity would increase. To conclude: The research developed a method for analyzing the system and identifying bottlenecks, however the outcomes of this method highly depend on the composition of the dredge and the desired application of the outputs.

7 Recommendations

7.1 Streamlining and Scale-Up

Following the results of the research the drum filter and hydrocyclone showed no reason to replace this type of machine for another. They both successfully fulfil their function, are robust and easily scalable, without for instance needing a lot of extra space. The only recommendation here is, is that they should be dimensioned better to have a more equal processing capacity.

As explained in the discussion and conclusion the filter press is the bottleneck of the system. Depending on the goal of Blauwe Bagger for the filter cake a recommendation can be made. According to most literature and after conversations with experts it can be concluded that the filter press is the best choice for getting the highest DM% in the filter cake. A downside however is that this UO is slow. A belt filter press is a possible alternative for the filter press. Its function is also to dewater sludge but can do this much faster, but less dry than the filter press. So as said before, based on the preference and goal for the end products a decision can be made on either replacing the filter press for another type of dewatering machine or scaling it up. Besides being slow the filter press scales linearly, which means that to double the capacity it needs to get twice as big.

7.2 Hydrocyclone Bypass

For some applications and final products it will not always be necessary to completely separate the dredge in al the different streams and get is as dry as possible. At the time of writing this report Blauwe Bagger is doing experiments with a possible client which makes a soil improver. They are mainly interested in the organic matter because of the nutrients and in the clay particles for their water retention capacity. In the dredge used for these experiments is not a lot of sand present but still all slurry goes through the hydrocyclone, this costs both labour, energy, time and therefore money. During one of the conversations with the client it became clear that the presence of sand up until a certain degree (unknown at this moment how much) would not immediately be bad for the product. For Blauwe Bagger this is possibility to cut production cost and process faster. A recommendation for Blauwe Bagger therefore will be to make the entire system as modular as possible so that they can add and bypass UOs easily if the application needs it or if it is beneficial in any other way.

7.3 Sand Filter

At this moment the sand filter is not working properly and was therefore also left out of the research. The slurry discharged from the bottom of the hydrocyclone now goes into a settling tank and the sand is removed manually after it is settled on the bottom. This process is relatively slow and uses a lot of space, a solution to this could be forced mechanical filter like a vibrating sieve. This sieve can separate the sand into different particle size by using different mesh sizes. Using this type of machine, it is also possible to wash out any remaining clay and other (visible) pollutants from the sand like the organic matter which makes the sand smell and turn dark.

7.4 Flocculants

Flocculants play an important role in dewatering process in various industries such as mining, wastewater treatment, and food processing. They can be organic or inorganic agents that help agglomerate fine particles into larger clumps, or flocs, which can then be more easily separated from the water. For the system of Blauwe Bagger this means that potentially the filter press or another UO could dewater faster. This could be very interesting for optimizing and improving the system, however it may not be a possible solution. For instance, if the flocculant is a synthetic polymer this might not be acceptable for the final product and there cannot be used. Further research into flocculant is recommended if faster dewatering or a higher DM% is required.

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Appendix I - SOP

Document author: Thomas Visser

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Version: 2.0

SOP

“Separating dredge with pilot machine”

1 Introduction

- What is the purpose of this SOP?
  - The purpose of this SOP is to explain how to operate the dredge separator from Blauwe Bagger. This machine is still in pilot phase and adjustments are constantly made so regular updating and reviewing of this document is necessary.
- When should this SOP be implemented?
  - This SOP is specifically designed to accommodate the internship research of Thomas Visser. In this research all the UOs (unit operations) are compared to eachother based on some specific inputs, energy, water, raw materials and their processing capacity. However this SOP is also suitable for normal use and can be seen as an extended version with which the performance of the system can be measured.

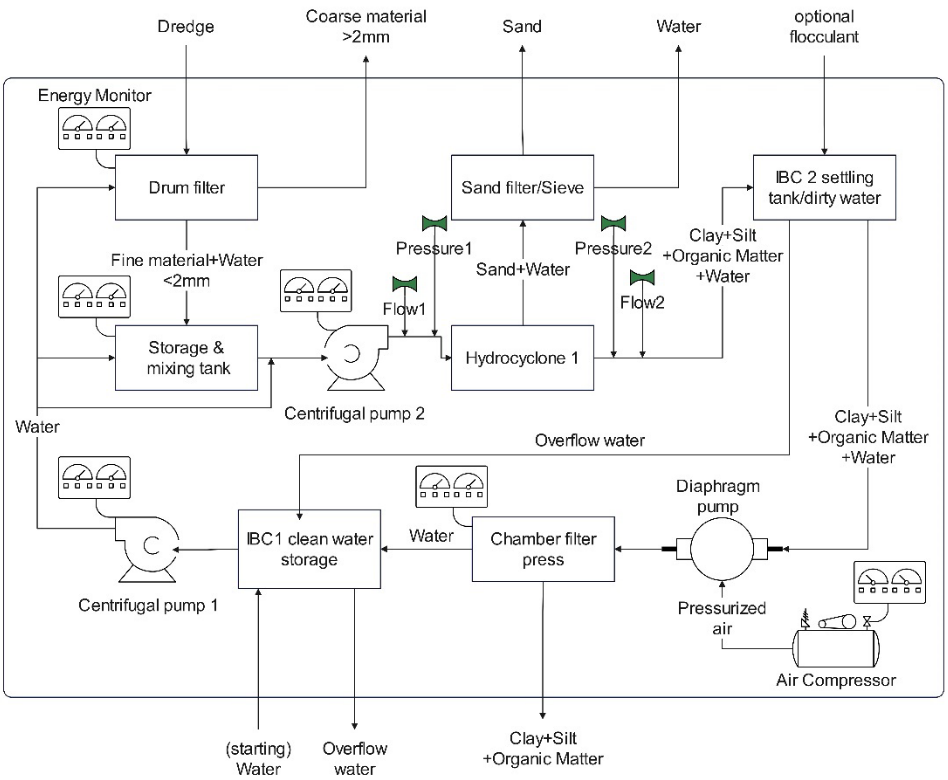
1.1 Theory

Formulas for calculating number of batches of drum filter for a full filter press

$$X_{batches} * V_{dredge_{in}} * DM_{dredge_{in}} = V_{press} * DM_{press} \quad [-] \qquad 1.1$$

$$X_{batches} = \frac{V_{press} * DM_{press}}{V_{dredge_{in}} * DM_{dredge_{in}}} \quad [-] \qquad 1.2$$

$$X_{batches} = \frac{6 * 17L * 0.44}{180L * 0.60} = 2.4 \quad [-] \qquad 1.3$$



1.2 Materials and methods

The table below gives an overview of the button layout for the remote

EnergyMeter / relay	Unit operation	Remote button
EM1	Raspberry Pi, Sensor readings, Router	-
EM2	Centrifugal pump 2 aka Felicia	2
EM3	FREE	3
EM4	Drum filter	4
EM5	Centrifugal pump 1 aka Destiny	5
EM6	FREE	6
EM7	Air compressor	7
3PEM1	Filter Press & Mixer	8
-	Switch EM2-7 & 3PEM1 OFF	1

2 Experimental procedure

2.1 Checklist (Safety)

Before any operations are performed the operator should always follow this (safety) checklist

1. All machine switches must be turned off
    a. Drum filter => on the left side of the drum filter
    b. Mixer of mixing tank => on top of mixing tank

c. Centrifugal pump 1 (under mixing tank) => on the main switch/control box
d. Centrifugal pump 2 (under filter press) => on the main switch/control box
e. Air compressor (under filter press) => on the compressor
f. Filter press => on the switch box of the filter press

2. Valves that must be **closed**
    a. Water supply to mixing tank/drum filter => black pp valve with red handle, above and to the right of the drum filter
    b. Mixing tank to centrifugal pump 1 => stainless steel valve under and in front of the mixing tank
    c. Water inlet valve on centrifugal pump 1 => on top of the pump
    d. Outlet valve of the hydrocyclone => on the bottom of the hydrocyclone
    e. The 2 compressed air ball valves of the membrane pump => next to the membrane pump
    f. The large orange venting valve of the filter press => between the membrane pump and inlet of the filter press
3. Valves that must be (partially) **opened**
    a. Water supply on centrifugal pump 2 => on the pump
    b. Bottom outlet on IBC 1 => bottom of IBC 1
    c. Bottom outlet on IBC 2 => bottom of IBC 2
    d. Hydrocyclone inlet => pvc valve with blue handle next to mixing tank
    e. Hydrocyclone outlet => pvc valve with blue handle above IBC 2, this valve should be partially (half) opened upon start and will later be adjusted when operating the hydrocyclone
    f. Filter press inlet => black butterfly valve between membrane pump and inlet of filter press

2.2 (Research) Preparation

2.2.1 Calculate the amount of dredge input needed to run 1 batch through the drum filter into the mixing tank. For calculations see 1.1

2.2.2 Calculate the amount of dredge needed to completely fill the filter press and produce a “cake” with a dry matter content of ~60%. For calculations see 1.1

2.2.3 Calculate how many batches the drum filter must run to fill the filter press +10%. For calculations see 1.1

2.2.4 Calculate how much water is needed. For calculations see 1.1

2.2.5 Mixing tank should be empty and clean

2.2.6 IBC 2 should be empty

2.2.7 Filter press should be empty and clean

2.2.8 Sand filter tanks (Hydrocyclone outflow) should be empty and clean

2.2.9 Check if the logs on the Raspberry Pi are logging data correctly

2.3 Drum filter

2.3.1 Prepare to run a batch by placing the correct amount of dredge next to the drum filter

2.3.2 Check if there is enough “clean water” in IBC 1 for this amount of dredge according to 2.2 and write down how much water is in IBC 1

2.3.3 Write down kWh meter reading of EM8
2.3.4 Have an empty bucket with the "push stick" next to the drum filter. This stick is needed to push/help the dredge through the inlet funnel
2.3.5 Turn on energy meter (relay) 2,4 and 8 inside the main switch box or with the remote. See table for remote layout in material and methods
2.3.6 Turn on Centrifugal pump 2 on the outside of the main switch box
2.3.7 Turn on the drum filter and write down the starting time (for research purposes)
2.3.8 Turn on the mixing tank
2.3.9 Open the black pp ball valve with red handle to start the washing water inside the drum filter
2.3.10 Take a bucket with dredge and pour it into the inlet funnel, if necessary use the push stick to push the dredge into the drum filter
2.3.11 Repeat previous step until
2.3.11.1 A full batch of dredge is poured into the drum filter. This is the preferred situation
2.3.11.2 The drum filter is filled with large debris and starts to overflow => stones, sticks, plastic etc. If this happens the drum filter needs to be emptied
2.3.11.3 The mixing tank is full. If this happens before all the dredge is poured into the drum filter calculations done in 2.2 for a full batch need to be revised
2.3.12 When all the dredge is poured into the drum filter let the drum filter run for 2 more min to make sure al the dredge is flushed through
2.3.13 Shutdown the drum filter
2.3.14 Close the ball valve to stop the washing water
2.3.15 Write down the end time
2.3.16 Write down kWh meter reading of EM8
2.3.17 Fill up the mixing tank until full, but prevent overflow. To do this switch the washing water hose with the filling hose of the mix tank and open the ball valve
2.3.18 Write down the starting time of filling up the mixing tank
2.3.19 When full close the ball valve
2.3.20 Write down the end time of filling the mixing tank
2.3.21 Switch off the mixer of the mixing tank for 1 minute. You should do this so it's also visible in the data from the energy meter that this Unit Operation task is finished
2.3.22 After 1 min switch on the mixing tank again to prevent settling
2.3.23 Write down how much water is left in IBC 1
2.3.24 Write down kWh meter reading of EM8

2.4 Hydrocyclone

2.4.1 Turn on Centrifugal pump 1 on the outside of the main switch box
2.4.2 Write down how much slurry is present in IBC 2, if it's the first batch the IBC should be empty
2.4.3 Write down kWh meter reading of EM8
2.4.4 Write down the starting time
2.4.5 Open the stainless steel valve under the mixing tank and **quickly proceed with the next 2 steps** in order to prevent clogging
2.4.6 Go to the hydrocyclone so that you can see the manometers and operate the bottom outlet valve of the hydroclone and ball valve with blue handle above IBC 2
2.4.7 Turn on the energy meter (relay) of centrifugal pump 1 with the remote (number 5) to start pumping the slurry through the hydrocyclone
2.4.8 Operate the blue valve in order to maintain a pressure of 2/2,5 bar at the inlet of the

hydrocyclone and a flow of 1,8m3/h == 30 l/min

2.4.9 Every 5~10 seconds or when pressure drops, depending on the composition (sand/clay) of the slurry the red bottom outlet valve of the cyclone should be opened for a brief period (~1s) to flush the “sand” particles out of the hydrocyclone

2.4.10 When the mixing tank is almost empty the flow will decrease. At this point shutdown the mixer by using the remote (button 8)

2.4.11 Turn off centrifugal pump 1 when mixing tank is empty

2.4.12 Write down the end time

2.4.13 Write down the slurry level in IBC 2

2.4.14 Write down kWh meter reading of EM8

2.5 Sand filter tanks

2.5.1 Measure the sand/water slurry volume in the filter tank

2.6 Settling tank

2.6.1 Check if enough slurry is present in the settling tank to completely fill the filter press according to calculations done in 2.2

2.6.2 If there is not enough slurry run additional batches with the Drum filter (2.3) and hydrocyclone (2.4) until there is enough slurry in the settling tank

2.7 Filter press

2.7.1 Write down kWh meter reading of EM9 and 3PEM1

2.7.2 Write down the water level in IBC 1

2.7.3 Write down the slurry level in IBC 2

2.7.4 Write down the starting time

2.7.5 Check if 3PEM1 is turned on

2.7.6 Turn on energy meter (relay) 7 inside the main switch box or with the remote. See table for remote layout

2.7.7 Turn on the filter press on the switch box located on top of the stairs of the filter press

2.7.8 Close the filter press completely and make sure there are no wrinkles in the filter cloth

2.7.9 Pressure of hydraulic press should be around 200 bar when fully closed

2.7.10 Set sludge pump to manual

2.7.11 Turn on the air compressor by pressing the green button on the machine

2.7.12 Open the 2 ball valves next to the membrane pump slowly

2.7.13 Filter press should be done when the amount of dredge/slurry as calculated in 2.2 is inside the filter press. Or after a pre-determined time. For the research this will be 3 hours

2.7.14 Write down the time between 2 thrusts of the membrane pump

2.7.15 Let the press run for 10 more minutes

2.7.16 Write down the time between 2 thrusts of the membrane pump

2.7.17 Close the 2 ball valves

2.7.18 Turn off the air compressor

2.7.19 Turn off the filter press

2.7.20 Write down the end time

2.7.21 Write down the level of slurry in IBC 2

2.7.22 Write down kWh meter reading of EM9 and 3PEM1

2.8 Shutdown procedure

2.8.1 Turn off all UOs inside the main switch box or with the remote (button 1)

2.8.2 Switch off all physical switches on the machines

2.9 Sampling (do this for every batch)

2.9.1 Take a sample of 1kg of input dredge

2.9.2 Sample cake from filter press of first, middle and last plate and mix together

2.9.3 Sample slurry of sand filter tank. First mix the contents of the tank manually

2.9.4 Weigh the coarse material inside the drum filter

2.10 Troubleshooting

2.10.1 After an emergency switch has been pressed it can take a while before some of the energy meter (relays) can be switched on/off again using the remote. Especially 3PEM1 can take some time. If after several minutes the remote still doesn't work you should restart the Raspberry Pi. This can be done in several ways but the easiest is to pres the button on the pi once. Wait 3 seconds and press it again. The light will now turn red. Wait 10 seconds and press it again. The Pi will now boot again. If after 3 minutes the remote still doesn't work, reboot again.

2.10.2 When there is not enough water in IBC 1 this should be refilled before continuing operations. This should also be written down in the log when taking measurements

2.10.3 When pressure on the inlet of the Hydrocylone drops and flushing the cyclone doesn't help probably the centrifugal pump is clogged. Shutdown the pump immediately to prevent damage to the pump. And follow these steps to resolve the issue