YRKESHÖGSKOLAN NOVIA

The influence of swell compensators on dredging non-cohesive soil

An analyiss of the relationship between fuel consumption and production rate

Trevor Yoak
Maxime Broer

Degree Thesis for Bachelor of Marine Technology

Degree Program of Maritime Management

Turku 2020

BACHELOR THESIS

Authors: Trevor Yoak and Maxime Broer

Degree Program: Maritime Management

Specialization: Marine Technology

Supervisors: Peter Björkroth, Ritva Lindell, Tony Karlsson, Wibbo Hofman, Pim Werner

Title: The influence of swell compensators on dredging non-cohesive soil

Date 1 April 2020 Number of pages 47 Appendices 1

Abstract

Dredging companies constantly need to assess their technical procedures to ensure the highest levels of efficiency resulting in happier customers, better profit margins and a healthier environment. The complicated nature of dredging with a Trailing Suction Hopper Dredger – influenced by environmental forces, soil mechanics, and onboard machinery functionality – tends to obfuscate points of optimization. This study eliminates many of those outside influences, via the use of a dredging simulator, in order to investigate the effect of the swell compensator on the relationship between fuel consumption and soil production.

Armed with mainly theoretical information on the swell compensator's effect, this research tested the theories through controlled experiments where the simulated dredging vessel conducted operations on different types of non-cohesive soil at 25 meters depth. The analysis found 20 bar of pressure in the swell compensator resulted in the lowest fuel consumption and highest soil production rate. The research also showed minimal deviation when altering soil granularity and water depth. Given the nature of controlled environments, this result can only be used as guidance for real vessels. However, it represents a starting point applicable to a wider range of ships that can go on to observe their own trends. Further research to improve the simulator is required to hone the results and make them more comparable to real life conditions.

Language: English

Keywords: dredging, non-cohesive soil, swell compensator, trailing suction hopper dredger

Table of Contents

1 Abbreviations

Abbreviation:	Meaning:
A	
Atm	Atmosphere.
B	
BFT	Beaufort.
E	
Etc	Etcetera.
F	
FWD	Forward.
H	
HAM	Hollandsche Aanneming Maatschapij.
I	
IHC	Industriele Handelscombinatie.
K	
Kts	Knots.
M	
MIWB	Maritime Institute Willem Barentsz.
MSTC	Maritime Simulation Training Centre.
N	
NB	Nota Bene.
P	
PMS	Power Management System.
PS	Portside.
R	
RPM	Revolutions per minute.
S	
SB	Starboard.
T	
TSHD	Trailing Suction Hopper Dredger.

2 List of symbols

2.1 Letters

Letter:	Description:	Unit:	Equation:
A			
A	= surface	[m^2]	R.2|R.3
B			
b	= draghead width	[m]	T.13|T.15
C			
C_D	= drag coefficient	[-]	T.18|T.17
C_L	= lift coefficient	[-]	T.18
C_t	= concentration transport	[-]	R.1|R.4
D			
D	= depth of the tillage	[m]	T.1
D	= diameter of pipe	[m]	T.8|T.17|T.18
d	= cutting depth	[m]	T.13|T.15
D	= diameter circle	[m]	R.2
E			
E_s	= specific energy	[J]	T.13|T.16
F			
F_{mom}	= momentum force	[N]	T.4
F_s	= cutting force	[N]	T.13|T.14
G			
g	= gravitational force	[N-m^2/kg^2]	T.2
g	= gravitational accelerations	[m/s^2]	T.8|T.10T.11
H			
Δh	= difference in height	[m]	T.12
H	= pressure head	[m]	T.2
$H_{minor,f}$	= head loss (friction of flow through fittings)	[Pa]	T.10
$H_{major,f}$	= head loss (friction in straight pipe)	[Pa]	T.8
$H_{major,m}$	= head loss (friction straight pipe,mixture)	[Pa]	T.9
H_{static}	= head loss (to overcome height)	[Pa]	T.12
I			
I_m	= hydraulic gradient in mixture flow	[-]	T.9
K			
K	= tillage transport coefficient k	[kg m^{-1}]	T.1
L			
L	= length of pipe	[m]	T.8|T.9|T.17|T.18
N			
n	= speed of the pump	[RPM]	T.6
N_s	= cutting power	[W]	T.14|T.16
P			
P	= production rate	[m^3/s]	R.4

P_{in}	= power required	[kW]	T.5
P_{pump}	= power pump	[kW]	T.3
P_s	= cutting production	[m^3/s]	T.15|T.16
ΔP	= pressure change	[kPa]	T.2|R.5
P_1	= pressure before the pump	[kPa]	R.5
P_2	= pressure after the pump	[kPa]	R.5
Q			
Q	= volumetric flow	[m^3/s]	T.3|T.4|R.3
R			
$R_{pipe\hookleftarrow}$	= drag force	[N]	T.17
$R_{pipe\rightarrow}$	= lift force	[N]	T.18
S			
S_m	= relative density of mixture	[-]	T.12
V			
V	= speed of the tillage	[m s^{-1}]	T.1
V_{trail}	= trailing speed	[m/s]	T.4|T.13|T.15
V_f	= Flow velocity	[m/s]	T.8|T.10|T.11|R.3
V	= relative water velocity to the ship	[m/s]	T.17|T.18

2.2 Symbols

Letter:	Description:	Unit:	Equation:
ρ_w	= density of the water	[kg m^{-3}]	R.1|T.17|T.11|T.18
ρ_k	= density of the grains	[kg m^{-3}]	R.1
ρ_m	= density of the mixture	[kg/m^3]	R.1|T.11|T.1|R.4|T.4
τ	= torque	[N*m]	T.5
ω	= angular velocity	[sec^{-1}]	T.5
λ_f	= flow friction coefficient	[-]	T.8
ξ	= minor loss coefficient	[-]	T.10|T.11
β	= pipe angle	[°]	T.17|T.18

3 Tables and Figures

3.1 Figures

3.2 Tables

4 Introduction

The basis for any competitive company – once the matters of safety and best practices are firmly in hand – is quality assurance. When Egyptian President al-Sisi announced the expansion of the Suez Canal in 2014, his incredible timeline of just nine months demanded extra attention to be paid to efficiency (Hazekamp et al, 2016). However, small dredging jobs require just as much attention to that detail because as the old adage goes “time is money”.

Much research has gone into optimizing the dredging process, specifically targeting the Trailing Suction Hopper Dredger (TSHD). But with so many variables to measure and balance, there is always room to add to the pool of knowledge. This research project investigates the function of one specific part – the swell compensator. Currently, there is a dearth of research conducted on the optimization of the swell compensator. Therefore, this research project puts forth as its main question: How is the relationship between the ratio of production and fuel consumption affected when the pressure in the swell compensator changes when dredging non-cohesive soils with the MSTC simulator? Figure 1 outlines the sub-questions required to execute the research fully and correctly. The overarching aim is to determine where the point of optimization is between the pressure exerted on the swell compensator and the increased fuel consumption due to drag. The hypothesis is that both dependent variables will react linearly to changes in the independent variable and reveal the aforementioned point of optimization.

To do this research, the simulator center at Maritime Institute Willem Barentsz is utilized. By isolating variables and running numerous tests, data is collected and analyzed. A conclusion and recommendations for operators is the overall goal. This study does not provide an irrefutable axiom but rather explores the stated relationship under certain simulated conditions. By conducting this research, hopefully, chief officers, chief engineers and pipe operators will be better informed about the possibilities and capabilities of the swell compensator settings and will aid their future dredging projects.

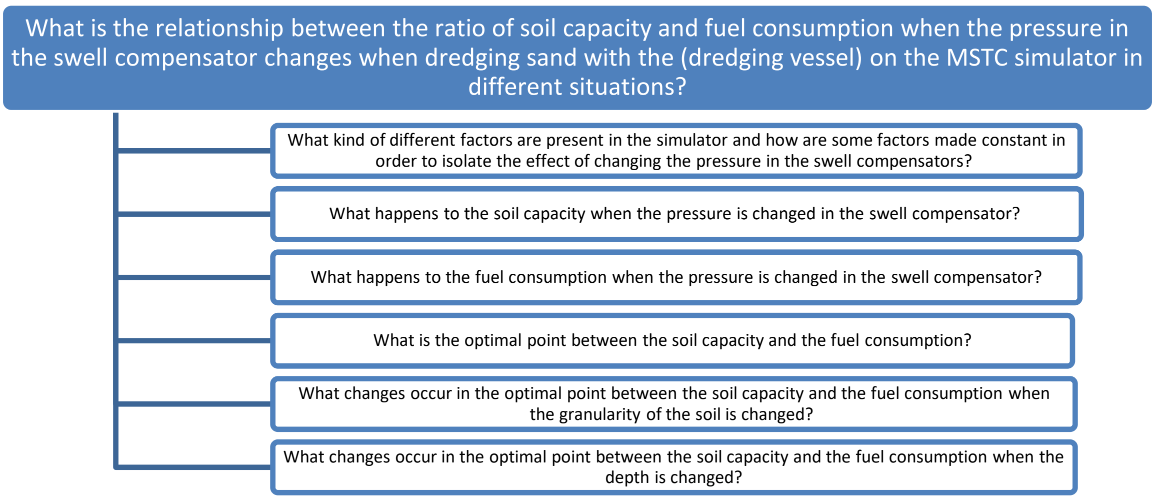

Figure 1: ***Research Questions***

5 Theoretical Framework

The theoretical framework provides background information and reviews prior research in order to define the scope of the research problem. All included elements facilitate the research by answering the sub-questions required to proceed with experimentation and analysis.

5.1 Kongsberg Maritime

Kongsberg Maritime is a company that develops maritime systems such as positioning, surveying, navigation and automatization systems. One of the products of Kongsberg Maritime is the K-sim and Polaris. Polaris is a bridge simulator system that enables the trainee to learn ship handling, maneuvering and navigation in a realistic setting. A dredging module was developed through a partnership of MIWB, Van Oord, and Kongsberg Maritime. The vessel used to design the TSHD model in the simulator was Van Oord's HAM 310 (www.kongsberg.com, 2019).

5.2 TSHD

A TSHD is a uniquely designed, self-contained, and self-propelled dredging vessel. It operates independently throughout all phases of the dredging cycle. The TSHD design includes one or two dredge pipes that hang below and to the aft of the ship. Through the draghead, the TSHD dredges soil with the help of large centrifugal pumps that move the product into the hopper – a sort of specialized cargo hold. The hopper capacity can vary from small (under 4000 m^3) to mega (over 30000 m^3) with the largest hoppers currently at 46000 m^3 (Rabobank International, 2013). The versatility in discharging the collected soil makes the TSHD a popular tool in the dredging community.

5.3 HAM 310

The HAM 310 is a part of the van Oord fleet. It was built in 1985 by IHC Holland. A layout of the vessel can be seen in the Appendix, Figure 20. The vessel underwent a major overhaul in 2000 by Singapore Technologies Marine when 30 meters were added to its length. The model of the vessel in the simulator is based on old version of the ship. The dimensions and general information about the vessel can be found in Table 3. Additionally, the HAM 310's pump characteristics diagram is located in the Appendices under Figure 21 (DEMAS, 2017).

5.4 Dredging process

Depending on the soil type, the draghead is outfitted with a teeth beam that consists of numerous chisels. The chisels are shaped to enhance the mechanical cutting of the seabed to increase the production rate. Via gantries, the dredge pipe is lowered into the water fixed at three points – the trunnion, the cardan, and the draghead. The pipe is in place once there

is an interface between the suction pipe and the inlet valve on the side of the ship.
The draghead is eased to the seafloor at a low ship speed (1-2kts) to reduce impact damage. If required, jet pumps are started; the high velocity water shoots out of nozzles located in the draghead. This facilitates increased efficiency in production via hydraulic cutting.

The powerful centrifugal pumps are started to create a suction pressure inside the dredge pipe. While the ship moves forward, the mechanical and hydraulic cutting loosen and lift the seabed sediment before it is sucked into the dredge pipe, through the centrifugal pump and into the hopper. Because materials such as sand and gravel do not naturally flow upward, the suction force is also pulling water into the pipe to create a slurry or mixture. The two main factors the chief officer is looking at during dredging operations are the density and velocity of the mixture. Too high of a density reduces the flow rate and decreases efficiency, likewise for too low density that increases the velocity (see Figure 19). Finally, because the water is of little use once in the hopper, an overflow system allows for it to run off leaving space for more product to be loaded. Loading is complete when either the load line is reached, the maximum load is reached (i.e. product starts to be lost to the overflow), or when the optimal load point is reached - dependent on sailing and discharge times (Vlasblom, 2007).

5.5 Swell compensators

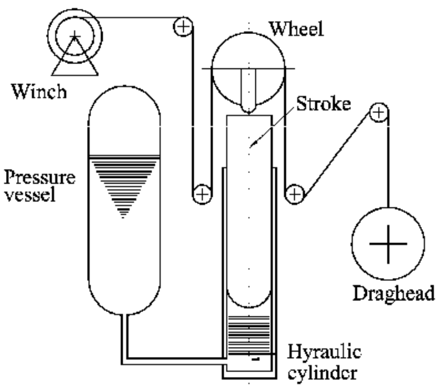

Figure 2: ***Swell Compensator***

A swell compensator is an accumulator that compensates the motion between the ship and seabed. This compensator regulates the contact with the seafloor and the draghead. Not only does it compensate for the swell but, also, when the seabed consists of irregularities. The swell compensator has three functions: preventing the wire from uncontrolled slacking, re-tensioning and providing constant pressure to the draghead on the seabed. The swell compensator is in the hoisting cable system of the draghead and located in the winch gantry of the draghead as can be seen in Figure 2. The compensator system consists of a hydraulic cylinder, a draghead, winch, one or two pulleys, pressure vessels (containing oil and air), oil pump, oil reservoir, an air compressor and pipeline system. The pulley system distributes the forces with which the swell compensator must overcome. In Figure 2, the pulleys halve that lifting force. When the draghead is not fully resting on the seabed, the force on the cable is increasing and the cylinder of the compensator will be pushed in. When the draghead is fully resting on the seabed the force on the cable is decreasing and the swell compensator will be pushed out. With this system a tensioned cable is always assured. When changing the pressure of the hydraulic fluid the force of the cylinder of the swell compensator is changed. This is done by changing the pressure in the oil-air vessel (Vlasblom, 2007).

5.6 Draghead

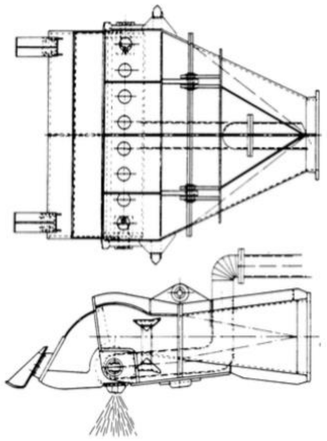

Figure 3: ***Dutch Draghead***

A draghead is the mouth on the suction pipe and is dragged over the seabed when dredging with a TSHD. The draghead breaks up the soil so it will become loose and enables it to be pumped into the hopper. The heads are designed to excavate the soil and mix it with water. This is done because otherwise the pump is not able to transport the soil to the hopper. An example of a draghead can be seen in Figure 3. The draghead consists of two parts: the fixed part on the suction pipe called the helmet, and adjustable part called the visor. The helmet can be adjusted to fully touch the seabed. The draghead excavates via hydraulic and mechanical cutting. Depending on the soil to be dredged, different chisels are mounted. Likewise, jet pumps are used to produce high velocity water in the draghead to churn up the seabed (Vlasblom, 2007).

During the dredging process the ship needs a certain speed in a certain direction. This speed is influenced by the resistance of the draghead on the seabed. The sand is entering the draghead by erosion from the sides and the back of the draghead. This creates a pressure difference. By multiplying the suction area by the pressure difference, the force of the draghead on the seabed is found. The pressure difference influences the erosion (see Section 5.8).

5.7 Soil information

With varying degrees of efficiency, a TSHD can handle most types of soil found on the seabed with the notable exception of large, hard rock. Because of the limited cutting capability and impeller size of the centrifugal pump, rock is better left to other types of dredgers. That said, the TSHD is still highly versatile and can tackle a number of jobs.

The TSHD is most efficient when dredging non-cohesive soil. Sand and gravel are sub-divided into fine, medium, and coarse indicating the average particle diameter. The soil subdivisions are categorized as follows (Miedema, 2019):

- Fine sand 0.100-0.200 [mm]
- Medium sand 0.200-0.600 [mm]
- Coarse sand 0.600-1.000 [mm]
- Fine gravel 2-6 [mm]
- Medium gravel 6-20 [mm]
- Coarse gravel 20-60 [mm]

5.8 Erosion around the draghead

The excavating process of the draghead is partially aided by erosive forces acting underneath and on the sides of the draghead. This is also called tillage erosion. Below the excavating profile of draghead equipped with a jet and without a jet is showed (Figures 5 and 6). Dredging jets can be used to make soil loose as to increase the effects of erosion and thus increase the production efficiency (Vlasblom, 2007).

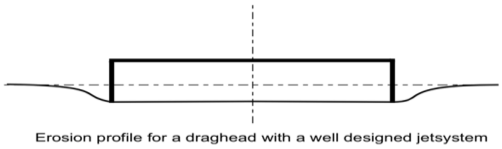

Figure 4: ***Draghead, erosion forces normal***

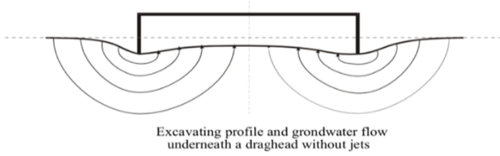

Figure 5: ***Draghead, erosion forces increased***

Section 5.8.1 and 5.8.2 discuss further factors influencing the erosive forces in dredging.

5.8.1 Compression of soil

Due to the water depth, the sea bottom is pressed because of the weight of the water column.
The rule of thumb is 1 atmosphere (atm) of pressure for every 10 meters depth. With a certain depth, it is understandable that the water is compressing the seabed underneath it. With the pressure on top of the seabed the permeability of the soil is decreased. This is also called the dredgability (see Table 4). The dredgability is a factor between 1 and 10, with one indicating a surface that cannot be dredged. The dredgability influences the erosion (Atkinson, 2000).

5.8.2 Amount of soil that moves down a slope

When dredging, the sand needs to be sucked underneath the rims of the draghead and a certain slope is created. This situation is also called tillage erosion. By tillage, soil is moving downslope. This is called tillage displacement and it depends on the depth, type of draghead, speed of the draghead and the angle of the soil. The amount of soil that is moving down can be described as tillage transport coefficient. Below the formula for the tillage transport coefficient can be found (Morgan, 2005).

$$K = -D * \rho_m * \mathrm{D}^{1,989} * V^{0,406} \quad \text{(T.1)}$$

5.9 Working of the pump

The following formula is used to see that when the manometric head changes the ΔP and the density also need to change.

$$H = \frac{\rho_m * g}{\Delta P} \quad \text{(T.2)}$$

In Figure 6, the increased flow rate of mixture/water results in changes in pump pressure requirements. As expected, the pressure required to move mixture is greater than for water. The resulting effect is a greater demand on power by the pump as characterized by the following equation:

$$P_{pump} = Q * \Delta P \qquad \text{(T.3)}$$

Q is inversely correlated to density. However, either an increase in Q or an increase in density will lead to a higher ΔP and therefore a higher requirement for power from the pump. The relationship between Q and density is not directly proportional; ΔP may decrease dramatically from a drop in density but not experience an equal rise again from the subsequent increase in flow. Again, Figure 6 reveals the different system requirements for dredging mixture versus water (Miedema, 2015).
As Q and ΔP decrease, for example, the required power of the pump also decreases. This results in a changing force of the pump. This is the force that is needed to accelerate the dredge mixture to the trail velocity of the ship (Vlasblom, 2007). The following formula is used to calculate the force needed for the acceleration:

$$F_{mom} = Q * \rho_m * V_{trail} \qquad \text{(T.4)}$$

Because the momentum force is changed the required torque delivered by the diesel engine is changed. The angular velocity is constant because the governor on the diesel engine is set on one specific speed. The following formula shows that the P_{in} required by the pump is increased.

$$P_{in} = \tau * \omega \qquad \text{(T.5)}$$

$$\omega = \frac{\pi * n}{30} \qquad \text{(T.6)}$$

5.10 Pump system working principle

The two components influence a pumping system:

- Pump characteristic
- Pipeline characteristic

A ΔP(H)-Q diagram (Figure 6) denotes the intersection of the two aforementioned components. This intersection is known as the working point of a system. The pump characteristic has a degree of dynamism when other factors are altered (e.g. density, pressure, power, etc.). The pipeline characteristic is more static; it is linked to a certain density. This type of diagram helps the operator tune variables in order to reach the working area, which enables the most efficient production rate. Additionally, an efficient pump leads to greater fuel efficiency (Talmon, 2016).

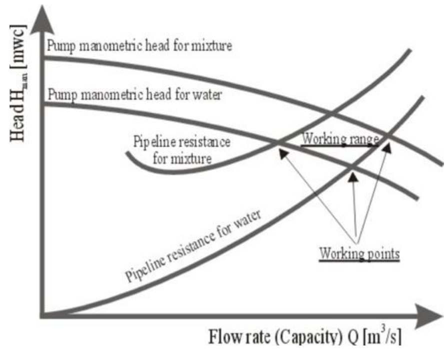

Figure 6: ***ΔP(H)-Q diagram***

5.10.1 Pump characteristic

Where Figure 21 gives the pump characteristics from the manufacturer's data, Figure 6 provides a relationship between pump and pipeline. In both cases, the most suitable RPM is chosen and remains constant. To translate the characteristic for different RPM the curve moves up or down. The manufacturer's graph is typically made for water, therefore calculations and tests are performed to achieve a suitable graphic representation of the point of efficiency as seen in Figure 6.

5.10.2 Pipeline characteristics

The second part of the pump system principles is the pipeline characteristic. This characteristic indicates the pressure required to reach certain flow rates in the pipe. The pipeline's resistance is the main obstacle to overcome, as seen in Figure 6. The pipeline-resistance curve is constant for a specific mixture density.

The resistance equates to head loss and can be divided into two component pieces: major head loss and minor head loss. The following equation represents the total head loss in simple terms:

$$Head_{totalloss} = Head_{major} + Head_{minor} \quad \text{(T.7)}$$

Major head loss is defined as the resistance in a straight pipeline, whereas minor head loss is the resistance found in valves, bends, joints, etc. Each is calculated differently for water and for mixture. For major head loss when pumping water, the equation is:

$$H_{major,f} = \frac{\lambda_f L}{D} * \frac{V_f^2}{2g} \quad \text{(T.8)}$$

Unfortunately, for pumping mixture, determining the pipe resistance becomes more complicated. A model must be developed in order to predict head loss in the pipeline. The equation, however, looks deceivingly simple:

$$H_{major,m} = I_m * L \quad \text{(T.9)}$$

In regard to minor head loss, all fittings have a loss coefficient assigned by the structural engineers. The equation to calculate the resistance when pumping water is:

$$H_{minor,f} = \xi * \frac{V_f^2}{2g} \quad \text{(T.10)}$$

Once more, the pumping of mixture complicates the process. It is generally assumed that the density is sufficiently representative of minor head loss in fittings caused by solids. The equation is as follows:

$$H_{minor,m} = \xi * \frac{V_f^2}{2g} * \frac{\rho_m}{\rho_w} \quad \text{(T.11)}$$

Finally, since the dredge pipe extends towards the seabed, the mixture must overcome the resistance caused by the height difference. This is known as the geodetic or static head:

$$H_{static} = s_m * \Delta h \quad \text{(T.12)}$$

Knowing how the pump system operates facilitates an understanding of the power requirements – and thus the changes in fuel consumption – when dredging different mixtures (Talmon, 2016).

5.11 Dredging at different depths

When dredging at different depths it costs more energy to move the soil from the seabed, as described in the static head (Equation T.12). Other factors also contribute to the higher rates of fuel consumption such as the specific energy and the pipe resistance.

5.11.1 Specific energy

In order to find out the cutting force of a draghead, the specific energy needs to be calculated. The specific energy is calculated as the energy required to cut one cubic meter. The cutting force is calculated by the following formula:

$$F_s = \frac{E_s * v_{trail} * d * b}{v_{trail}} \quad \text{(T.13)}$$

The cutting force is used to calculate the cutting power. The cutting power is calculated by the following formula.

$$N_s = v * F_s \quad \text{(T.14)}$$

The cutting power is used to calculate the cutting production. The cutting production is calculated by the following formula.

$$Ps = v_{trail} * d * b \quad \text{(T.15)}$$

The cutting production is used to calculate the specific energy that is needed to mechanically cut the soil. The specific energy is calculated by the following formula (Vlasblom, 2007).

$$E_s = \frac{N_s}{P_s} \quad \text{(T.16)}$$

5.11.2 Angle of the dredge pipe

When trailing, most of the resistance is created by the dredge pipes. The resistance of the pipes is caused because of the hydro-viscosity component and the propulsion force. The pipe is receiving resistance from the direction perpendicular of the pipe and direction parallel with the pipe. The resistance of the pipe in the direction perpendicular of the pipe is caused because the draghead is dragged on the seafloor. Below this resistance is calculated.

$$R_{pipe\hookleftarrow} = C_d * \frac{1}{2} * \rho_w * v * \sin\beta * (v * \sin\beta) * L * D \quad \text{(T.17)}$$

The resistance of the pipe in the direction parallel of the pipe is caused because the pipe is dragged through the water. Below this resistance is calculated.

$$R_{pipe\rightarrow} = C_d * \frac{1}{2} * \rho_w * v * \cos\beta * (v * \cos\beta) * L * D \quad \text{(T.18)}$$

From the calculations, it can be concluded that the angle is an important factor for the resistance of the ship in the water. An increase in resistance leads to a higher required propulsion force – thus more fuel (Vlasblom, 2007).

6 Research Design

Given the scope of the question pertaining to the relationship of the pressure in the swell compensator and the fuel consumption, a quantitative approach was adopted. To ascertain this relationship, several experiments were conducted at increments of 10 bar increases in the swell compensator's pressure. The resulting fuel consumption and production figures were recorded by hand as the simulator lacked logging capabilities for these particular variables. Each sub-category of non-cohesive soil was tested at 10-100 bar. Two further tests were conducted at 15m and 35m to verify the chosen water depth acted similarly to other depths and therefore was not an outlier or simulator anomaly.

6.1 Constants

There are two main families of variables within the simulator: Area and Own Ship. In order to best study the relationship between the variables in question, several others had to be isolated.

6.1.1 Area constants

Area variables include all information about the dredging location. The Table 1 outlines the variables made constant:

Table 1: ***Area Constants***

Area Constants	
Variable	Measurement
Bottom Density	1700.0 kg/m^3
Water Density	1.025 ton/m^3
Water Depth	15 m - 25m – 35 m

6.1.1.1 Weather constants

The purpose of eliminating wind and current is to reduce any forces that might act on the ship and thus change the fuel required to maintain speed and heading. The Table 2 outlines the variables made constant:

Table 2: ***Weather Constants***

Weather constants	
Variable	Measurement
Air Temperature	20°C
Barometer	1080 mbar
Current	0 °kts
Swell	0 m
Tide	0 m
Waves	0 m
Wind	0 bft
Sea Temperature	20°C

6.1.2 Own ship constants and configuration

Within this category, several of the elements are, in fact, particulars unique and unchangeable to the vessel (e.g. the dimensions). However, other choices are made in order to prevent changes to the vessel. For example, all dredged material was pumped overboard so that the hopper would remain empty ensuring a constant draft. The Table 3 outlines the ship's particulars:

Table 3: ***Own Ship Particulars and Constants***

Own Ship Particulars and Constants		
Variable	Measurement	Note
Model	Dredg06E	Version 5; Power Management System activated
Dimensions	138.5 x 23.0 x 7.8 m	
Displacement	16585 m^3	
Pump Configuration		Pumps located inside ship; not directly connected to main engine
Hopper Content	0.0 m^3	Pumping mixture overboard
Draft	3.5 m fwd / 5.5 m aft	
Speed	2.0 knots	
Course	000°	Auto-pilot on

6.1.2.1 Dredging equipment constants

Of the selectable dredging variables related to the research question, all but the swell compensator pressure is isolated in order to study that single variable. These variables are selected to produce an average dredging experience. That is to say, none of the figures are outstanding nor outliers. The Table 4 outlines the dredging constants with descriptions:

Table 4: ***Own Ship Dredging Constants***

Own Ship Dredging Constants			
Variable	Measurement	Description	Note
Visor Mode	Variable	Visor can be fixed or variable. Variable allows the draghead to adjust to the contour of the seabed.	
Pump revolutions	100 RPM	The speed of the pump can be changed.	
Knife Length	0.2 m	Chisels provide mechanical cutting to loosen up soil for better efficiency. Scale 0-1m.	
Draghead Friction Coefficient	3.00	Equates to the suction loss at the draghead. Normal values range from 2-4.	No unit
Dredgeability	0.5	Measures how easily the soil can be dredged. Range from 0.0-1.0 with 0 being un-dredgeable and 1 being maximum production rate for that area.	No unit

Bottom Resistance	0.3	Measures the resistance that the draghead must overcome to cut through the soil. Scale 0-1 with 1 providing the highest resistance.	No unit
Swell Compensator Height	1.5 m	Set to allow for give in the swell compensator. Scale 0-3 m.	

(NB! All measurements apply to both starboard and port dredging configurations).

6.1.3 Power management system

The PMS is in charge of controlling electrical systems. With a PMS on board of a vessel, the safety and efficiently is improved. The dredging ship in the dredging simulator is also equipped with a PMS system. It enables the user of the simulator to see the amount of power that is used by different consumers. It is also possible to connect/disconnect consumers from the switchboard. During experiments, the power consumers were recorded (see Appendix, Tables 14-16). No other consumers were allowed to use power so that the fuel consumed by the generators was only used for the dredging process. Figure 7 shows the one-line diagram of the PMS from the dredging simulator.

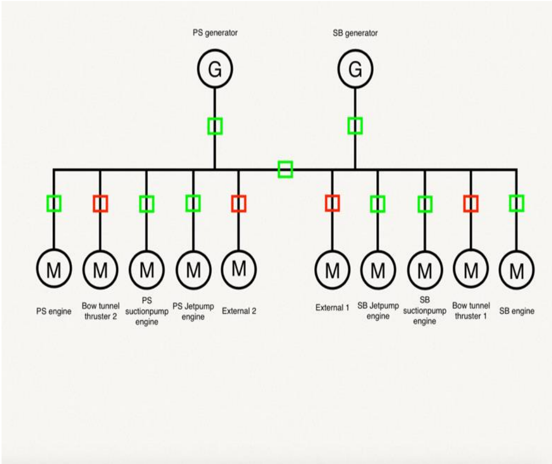

Figure 7: ***PMS One Line Diagram***

6.1.4 Location of the soil production

When dredging, normally the soil is pumped into the hopper. For the experiments, the soil was pumped overboard (see Figure 8). The justification is that the displacement of the vessel would have increased if the soil was pumped into the hopper. An increase in draft changes the profile of the ship and can increase both the resistance it faces and the ease at which the dredge pump can produce mixture (i.e. the distance between the draghead and pump decreases).

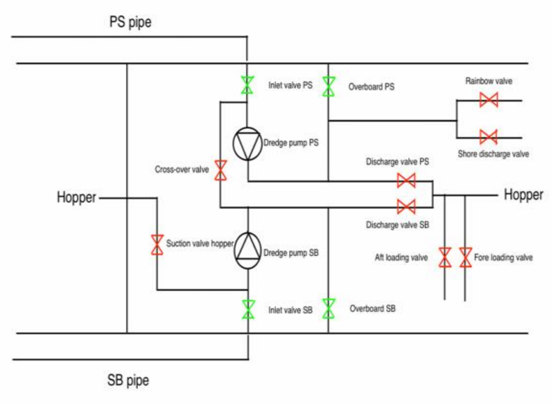

Figure 7: ***Process Flow Diagram***

6.2 Conduct of research

With all constants saved into a patch of open sea, each experiment session began with setting the vessel on its course and speed then manually lowering the dredge pipes and starting the pumps. Those two functions are hardware driven and therefore could not be saved in the simulation. When all equipment was functioning properly, the pressure was set in the swell compensators. The speed of the vessel was monitored to ensure a constant two knots was kept before noting the values of the dependent variables (i.e. fuel consumption and production rate).

After the data was collected at a certain pressure, the simulation was paused and the pressure was stepped up by 10 bar to the next level. After restarting, the speed was again monitored as an increase in pressure resulted in an increase in speed if no action was taken. These actions were undertaken for every 10 bar from 10 bar to 100 bar. An experiment was conducted at 25m on three gradients of sand and three gradients of gravel resulting in six experiments. Two further experiments – at 15m and 35m – were conducted to evaluate the role of water depth on the relationship between the dependent variables.

6.3 Data collection and method of analysis

Data was collected directly from outputs on the simulator. The figures were then transposed into an Excel spreadsheet. The initial data was raw and uncorrelated – swell compensator pressure, percentage in use of engine compensator, fuel consumption, flow velocity, and mixture density.

6.3.1 Method

Within Excel, a production rate was calculated based on the equations from section 6.3.2. The outputs result in the tables found in Appendix. The results were then put into a ratio against the fuel consumption. Graphical representations of the numerical figures were created to show correlational trends as seen in section 7.

6.3.2 Research data calculations

The following sections include equations used to evaluate the date collected from the simulator.

6.3.2.1 Density correction

For calculating the production rate, the flow velocity and density of the mixture is used. But the production is depending of the amount of sand that is dredged and not the amount of water. Because of this the concentration (*Ct*) is calculated (Talmon, 2016). With the *Ct* the production rate is calculated. The following formula calculates the *Ct*:

$$C_t = \frac{\rho_m * \rho_w}{\rho_k * \rho_w}$$

(R.1)

ρk is the density of the grains. 2650 [kg/m^3] is the density of quartz, the main component in most rocks. It is used as a dredging industry means to simplify density calculations of homogenous soil mixtures.

6.3.2.2 Flow rate

At the bridge the pipe operator is dredging with the help of the cross indicator. The cross indicator displays the production rate by showing the velocity of the soil and the density (see Figure 16). With this information the pipe operator checks if the soil is dredged efficiently. The higher the cross is located the higher the production rate. To solve for the production rate, the area of the dredge pipe must be calculated.

$$A = D^2 * \frac{\pi}{4} \tag{R.2}$$

The diameter of the suction pipe is 0.9m and the surface of the circle will then be 0,706858 m^2. During the simulation the production rate can then be calculated with the information given by the simulator and the information of the circle surface of the suction tube. With the help of the following formulas the production rate is calculated (de Bree, 1977):

$$Q = v_f * A \tag{R.3}$$

$$P = Q * \rho_m * c_t \tag{R.4}$$

6.3.2.3 Pressure difference of the pump

When dredging the pressure difference created by the pump is not indicated. But the system is indicating the pressure at the suction side of the pump and pressure side of the pump. With this information the pressure difference can be calculated (Chaurette, 2005). Knowing the changes in ΔP gives the operator an idea of changes in power demands.

$$\Delta P = P_2 - P_1 \tag{R.5}$$

7 Results

Prior to conducting the experiments, the non-quantitative hypothesis was that there should be a point of intersection where the ratio of the production rate and fuel consumption was best. The hypothesis among the researchers was that the dependent variables would act in a generally linear fashion.

The results that follow fall outside of the initial supposition[1]. Although both dependent variables act linearly, they do not share a proportional relationship with the independent variable – the swell compensator pressure. Several unforeseen factors – as described in the Theoretical Framework – contributed to the shape of the data in the graphs seen in section 7.1.

[1] See Appendix for tables of all data

7.1 Soil influence

The graphical representation of the collected data is based on the data tables found in Appendix. Further analysis is provided in section 7.2, however it is important to draw notice to the similar shape of the graphs in all six experiments (see graphs below).

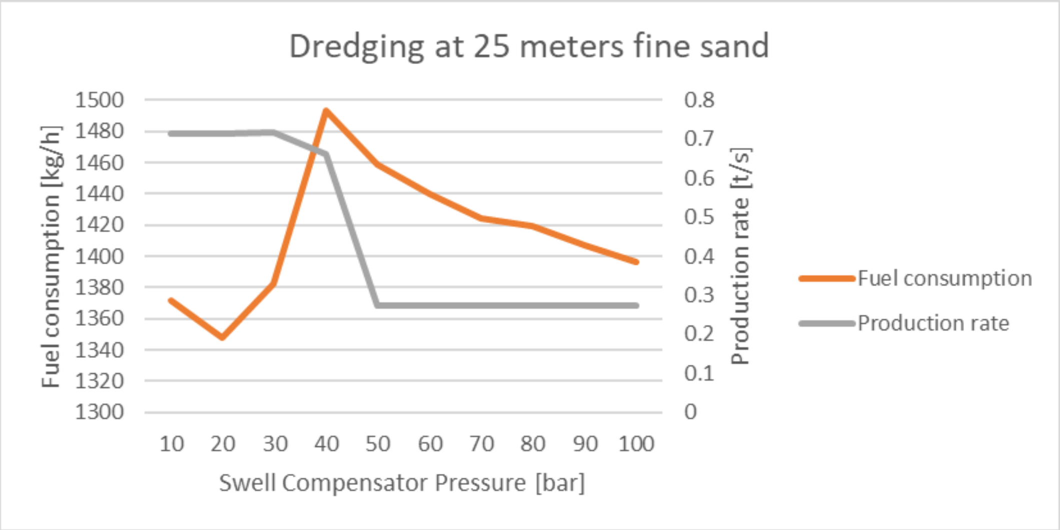

Figure 8: ***Fine Sand Graph***

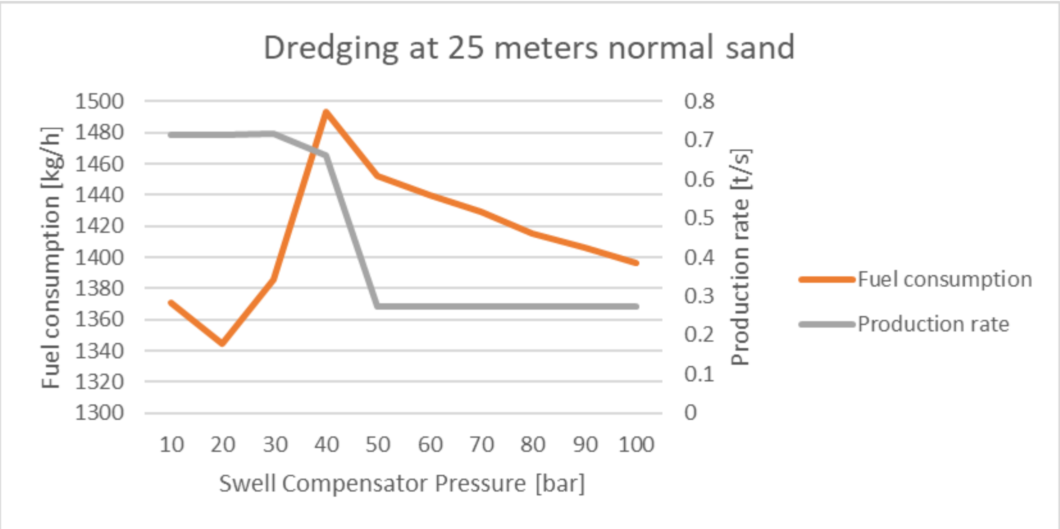

Figure 9: ***Normal Sand Graph***

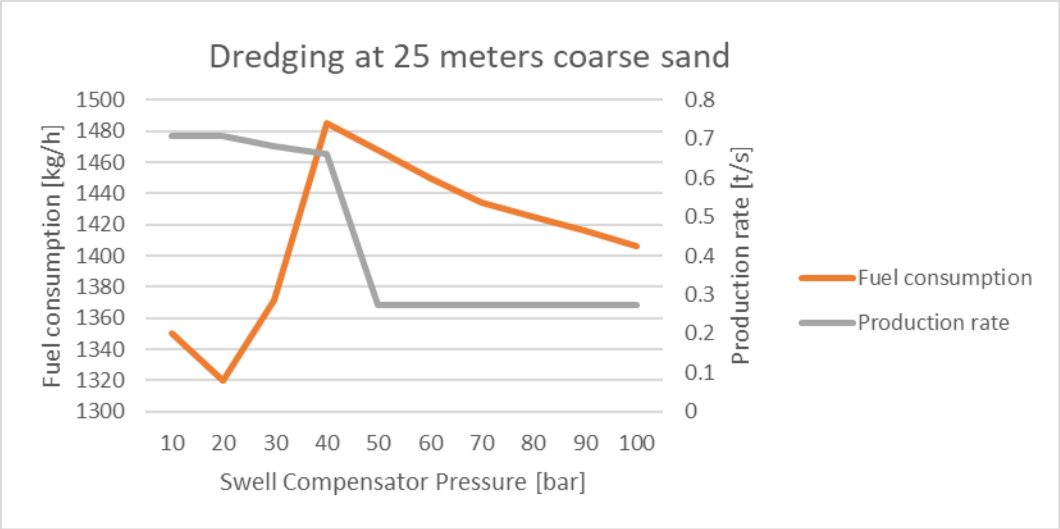

Figure 10: ***Coarse Sand Graph***

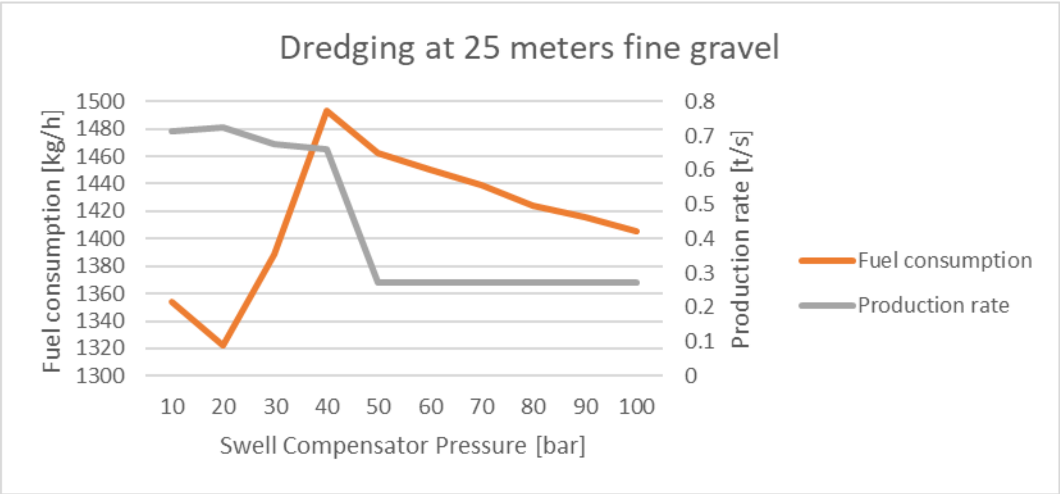

Figure 11: ***Fine Gravel Graph***

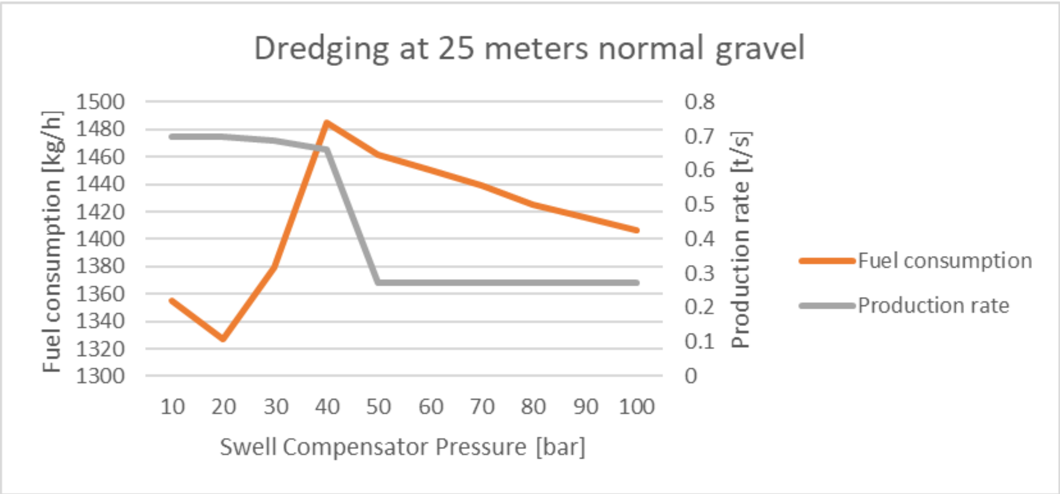

Figure 12: ***Normal Gravel Graph***

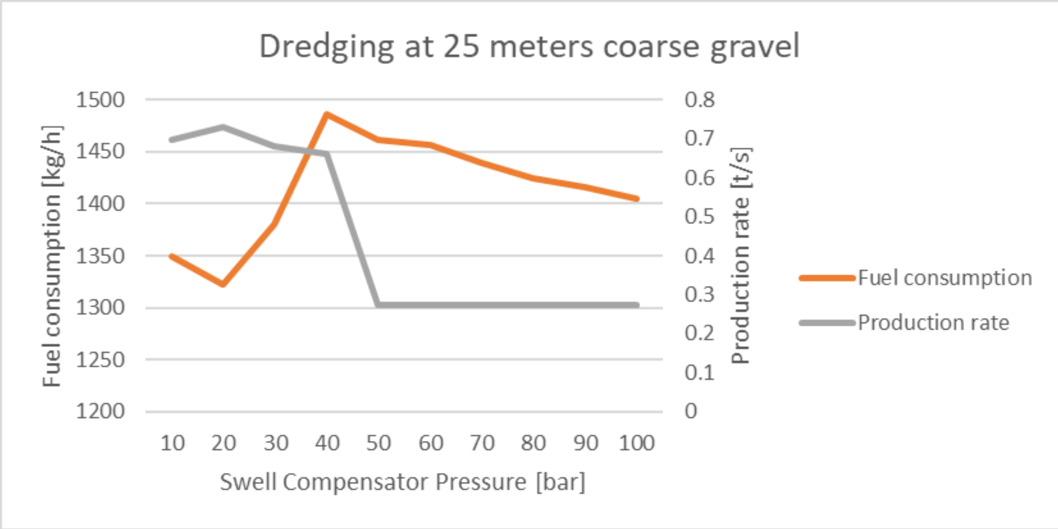

Figure 13: ***Coarse Gravel Graph***

7.2 Explanation graphs

This section interprets the graphical representations from the results section to facilitate easy understanding.

7.2.1 Explaining the fuel consumption

The graph, Figure 14, can be divided in 3 areas. Below the areas are explained.

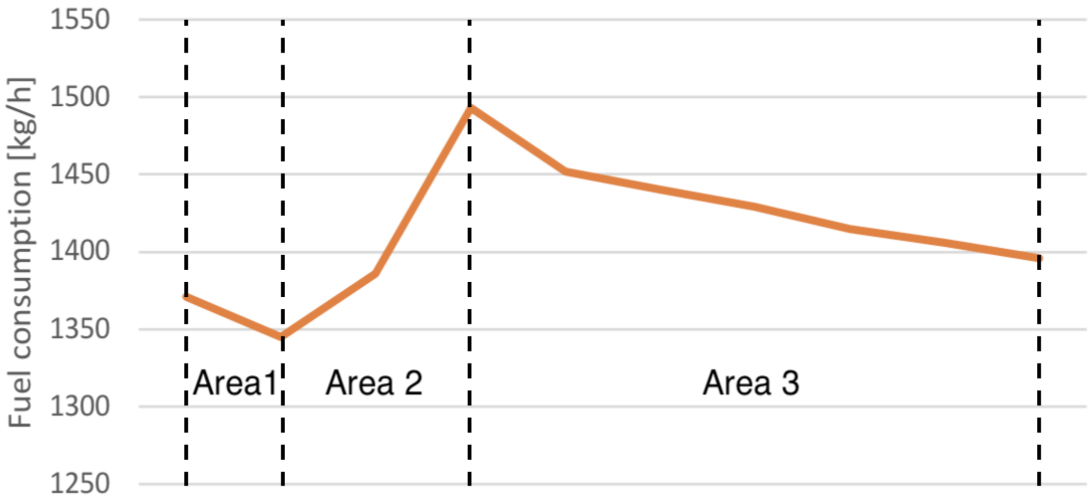

Figure 14: ***Fuel Consumption Trends Explanation Graph***

Area 1

The draghead force on the seabed is between 10 and 20 bar pressure of the swell compensator at a maximum point. At this point the volume flow is at its lowest and the density at its highest. The fuel consumption decreases at 20 bar because an increase of swell compensator pressure produces less friction on the dragheads on the seabed.

Area 2

After 20 bar the draghead force on the seabed is on a certain point that the volume flow is increasing. As described in Section 5.9, an increase in flow rate results in an increase in required pressure. Both of these facilitate a higher power requirement on the engines running the dredge pumps. This demand increase is illustrated in Figure 21. Furthermore, this demand increase outweighs the reduction in required power of the propulsion.

Area 3

At 40 bar, the power requirements of the dredge pumps plateaus and remains constant. The dragheads are no longer causing significant drag force on the seabed. From this point to 100 bar, the decrease in fuel consumption is precisely indicative of the decrease in required propulsion power in order to maintain the 2kts speed.

7.2.2 Explaining the production rate

The graph, Figure 15, can be divided in 3 areas. Below the areas are explained.

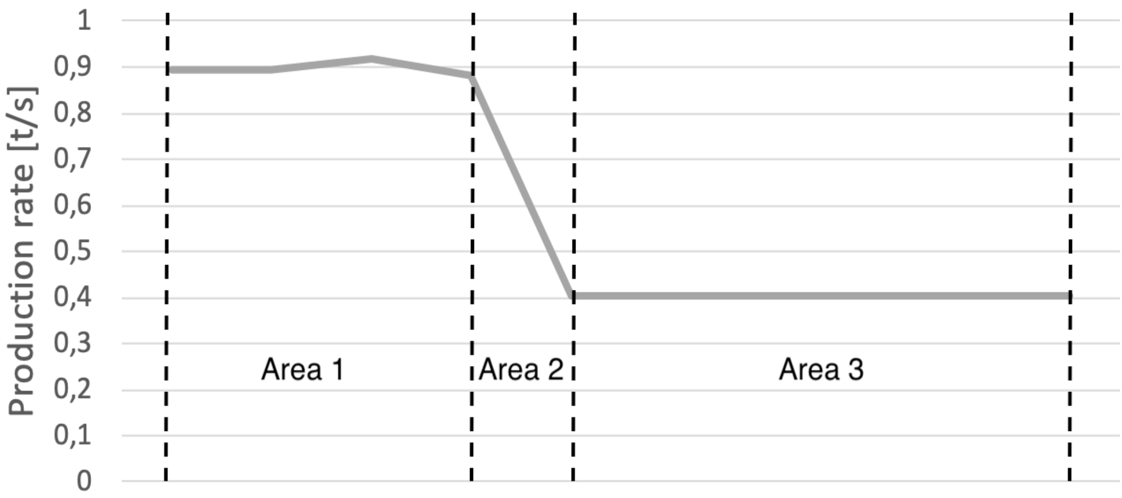

Figure 15: ***Production Rate Trends Explanation Graph***

Area 1
Between 10 and 40 bar, the volume flow is slowly increasing while the mixture density begins to decrease. The ratio between the two is generally still stable. This is because the force of the draghead is decreased due to the lift force of the swell compensator. At 20 bar, the erosion is presumed the largest, which explains how the compensator pressure can increase but incur no change to the soil density or velocity. In this area the production rate is the highest.

Area 2
Between 40 and 50 bar, the draghead lifts off the seabed. The only production is being caused by the jet nozzles that are churning up the surface of the seabed.

Area 3
Between 50 and 100 bar, the flow velocity reaches its maximum value and the density its lowest value. This produces the lowest rates, which remain constant because of the floating draghead.

7.3 Depth influence

The graphs in Section 7.1 indicate that when dredging at 25 meters the effect on the production rate and fuel consumption are almost the same when dredging any type of sand and gravel. The values of the production rate and fuel consumption may differ slightly in the graphs, but the shape of the graph is the same. Therefore, the depth tests were conducted only on normal sand as variants of non-cohesive soil had no significant impact on the 25 meter experiments. The following tests were done at 15 and 35 meters. The intention is to show what influence the depth has on the production rate and fuel consumption. A secondary purpose of the depth tests is to complete the feedback loop. That is to say, to ensure that 25 meters water depth is not an anomaly in this research.

7.3.1 Depth change graphs

As seen below, although the shapes of the graphs vary from those tests conducted at 25 meters, the general relationship remains relatively unchanged in the point of optimization. Additionally, the pressures at which the draghead begins to float right about the seabed is also the same for all three tested depths. However, there are some key differences worth noting.

7.3.2 Graph explanation, 15 meters

The point of optimization shifts to 30 bar. It appears that the dredge system is under a higher pressure at shallower depths, based on Table 12. This is further corroborated by the increased power consumption both by the dredge pumps and main engines for propulsion (see Table 15). Therefore, it is likely the ship is experiencing an increase in drag.

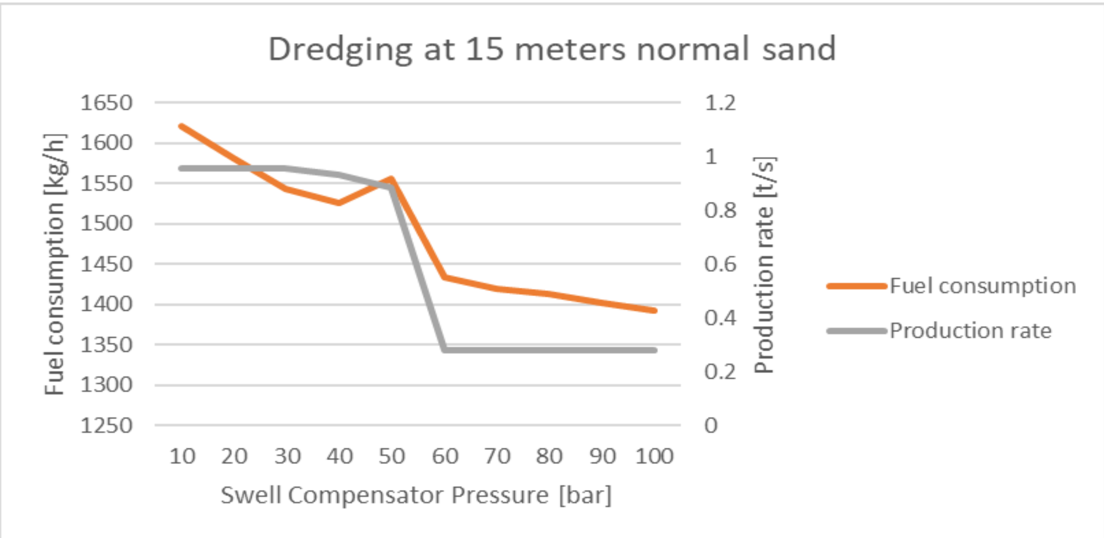

Figure 16: ***Normal sand, 15m***

7.3.3 Graph explanation, 35 meters

At a deeper depth, the point of optimization shifts the opposite direction towards 10 bar. The increased depth and decreased fuel requirements suggest that the draghead has a less-than-ideal interface with the surface. However, it is equally important to note, as per Table 12 that the flow velocity at 10 bar is unusually low. In practice, low flow velocity leads to deposit build-ups in the pipes. Therefore, in a real-life scenario, the useable optimal swell compensator pressure would return to the 20 bar point.

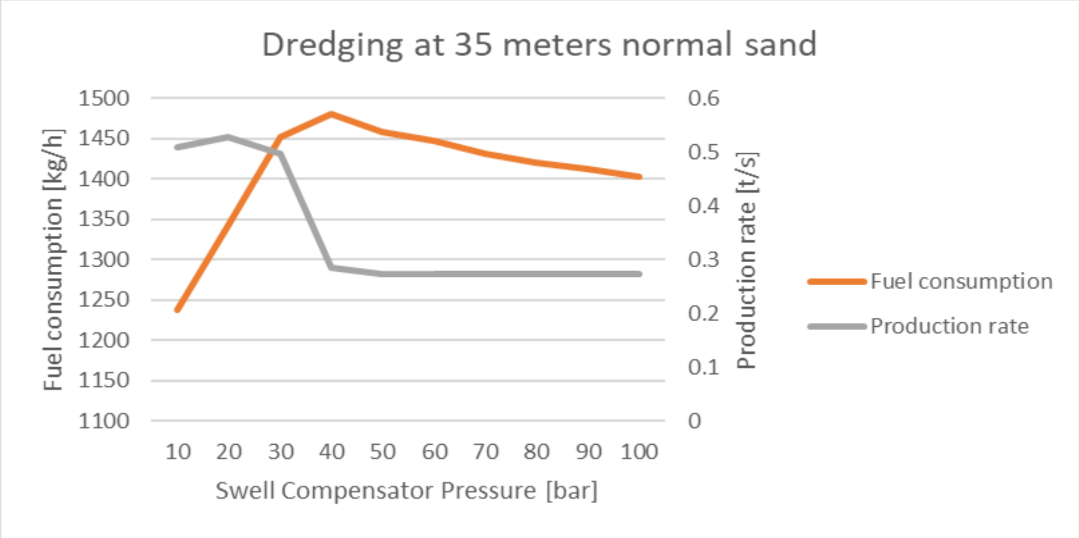

Figure 17*: Normal sand, 35m*

8 Conclusion

This research set out to determine how the swell compensator affects the relationship between the fuel consumption and soil production rate. Based on the similar trends in Figures 9-14, it is evident that the best ratio occurs at 20 bar of swell compensator pressure when dredging at 25m with the equipment of the simulator model based on the HAM 310. When dredging at different depths, the ratio of the fuel consumption and the soil production rate remain steady, although the swell compensator's optimal pressure point shifts. The dip in fuel consumption explained in 7.2.1 has no adverse effect on the production rate. The possible explanation for this phenomenon is that the production rate receives an increase in erosive dredging (see section 5.8) that mitigates losses seen at other pressures when the draghead is beginning to lift out of the seabed. Nor does the make-up of the non-cohesive soil have a significant effect; both gravel and sand - at all diameters - act similarly in terms of fuel consumption and their respective production rates.

The unexpected spike in fuel consumption at the 40 bar mark during every experiment indicates the point at which the suction pumps draw maximum required power (see Table 14 and Figure 21). The resulting decrease in production rate indicates the dragheads are floating above the surface of the seabed, effectively eliminating the mechanical forces of the dragheads and chisels. At those swell compensator pressures, 50 bar < p <100 bar, only the jet pumps are causing production as they stir up the surface of the seabed.

9 Discussion

Several remarks can be made about the results of the experiments executed on the simulator, in addition to data interpretation.

9.1 Cross Indicator

Of these discussion points, the most consequential lies in the interpretation of the sensor inputs on the simulator. As aforementioned, the values of mixture density and rate of flow are essential for calculating the production rate. Typically, TSHD vessels employ a graphical interface as seen in Figure 19[2]. The realism of this cross indicator is not in question. However, given the pixilation and large steps between hash marks, an exact interpretation of the values is left open to a degree of interpretation. Therefore, each individual researcher may read the outputs with slight variations. This is best described as "eye-balling" the values.

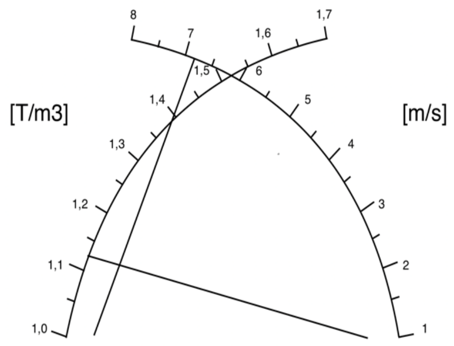

Figure 18: ***Simulator Cross Indicator***

There is a second graphical representation of the production rate. It is a bar that rises and falls according to rates. It suffers from the same drawbacks – pixilation and a scale that lacks minutiae. As a means of mitigating misinterpretations of the graphical displays, the researchers chose 10 bar steps in swell compensator pressures. Smaller adjustments in the independent variable would have resulted in insignificant changes – or uninterpretable changes – in the density and flow rate.

9.2 Simulator Realism

Unquestionably, the prevalent use of simulators in the maritime industry has improved safety and understanding of how a ship function. Manufacturers work hard to create as realistic of environments as possible. However, many simulators are not purpose-built for research. Without knowing exactly what the simulator module designers (MIWB, Van Oord, and Kongsberg) chose as models for the dredging inputs, it is impossible to guarantee the veracity of the data received as outputs when examined against real life figures.

Additionally, a simulator allows for a "scrubbed" environment; it is possible to isolate variables, as done in this research. Real life conditions are rarely so compliant. Therefore, the results gathered in the simulator possibly have a minimal effect on actual dredging operations. This point is especially salient given the enormous variations in different TSHDs and their equipment.

[2] See Figure 23 for a photograph of the cross indicator.

9.3 Human Element

Besides the aforementioned variation in cross indicator interpretation, the human element in this research is worth discussing. The research was conducted based on the knowledge from the theoretical framework. However, in the face of unexpected results, a justification had to be produced to explain inconsistencies. This reaction done after the fact is indicative of the level of understanding of the student researchers. Professionals in the field might draw contrary conclusions given their advanced expertise.

9.4 Outside Influences

The experiments were designed to limit as many variables as possible. To what degree these were eliminated is part of the discussion in Section 6.2. Some of these variables made constant are evident when disabled, such as wind, current, etc. Others are less overt, and it is unknown if they are even calculated for in the simulator. For instance, to eliminate changes in the draft, the research design called for the mixture to be pumped directly overboard (see Section 6.1.4). The resultant effect of pumping the mixture overboard remains unknown. Whether or not the simulator measures the influence of this action on the ship, let alone whether or not it actually influences the fuel consumption due to inertial forces, is unavailable information.

10 Recommendation

The following recommendations are based on the results of the experiments, the conclusions from data analysis, and the discussion points observed during the research.

10.1 Recommendations for Dredging

This research cannot present an optimal swell compensator pressure for maximizing the production rate to fuel consumption ratio to the greater dredging community. The conclusion of 20 bar (as presented in Section 7) is specific to the simulator TSHD model and the sterile environment designed to conduct the experiments. Although the simulator model is based on the HAM 310, certain modifications have taken place on the real vessel. Therefore, the crew of the HAM 310 can only use the results of this research as a guideline for their own operations. Similarly, for other TSHD vessels, if no standard operating procedures for dredging non-cohesive soils exist, then this conclusion could, also, be a good starting point for them. Chief officers and pipe operators can try to hone the efficiency of their own vessels by comparing their data to the data collected in this research project.

10.2 Recommendations for the Simulator

To benefit future dredging students and trainees, the dredging module for the MTSC simulator should be adjusted to improve user experience and understanding of outputs.

Specifically, a numerical output for the production rate and its component inputs is recommended. The graphical interface is sufficient for observing anecdotal trends. A numerical output would provide empirical data that could be used in future research.

Additionally, the development of a paper manual or software-based menu explaining what data is recorded and how it is recorded within the dredging module would aid future students' research. Without knowing how the simulator models its outputs or from where the inputs are derived, there is no proof that collected data corresponds to reality. Moreover, having this information available would allow students to mathematically prove if the simulator is accurate or catch incidents when there are errors.

11 References

Atkinson, J. (2000). Vertical Stress in the Ground. Retrieved from http://environment.uwe.ac.uk/geocal/SoilMech/stresses/stresses.htm.

Chaurette, J. (2005). Tutorial Centrifugal Pump Systems. Retrieved from www.fluidedesign.com

de Bree, S. E. M. (1977). Centrifugal Dredge Pumps. *IHC Ports and Dredging*. Retrieved from http://www.dredgingengineering.com/

DEMAS. (2017, November). HAM 310. Retrieved from https://www.dredgepoint.org/dredging-database/equipment/ham-310-0.

Hazekamp, N., Kate, G., & Wiertsema, W. (2016). *Dredging in the Dark*. Retrieved from https://www.bothends.org.

Kongsberg Maritime Products. (2019, November 12). Retrieved from http://www.kongsberg.com/.

Miedema, S. A. (2015). *Introduction Dredging Engineering*. Delft: TU Delft.

Miedema, S. A. (2019). *The Delft sand, clay & rock cutting model* (3rd ed.). Amsterdam: IOS Press.

Morgan, R. P. C. (2005). *Soil erosion and conservation* (3rd ed.). Malden, MA: Blackwell Science.

Rabobank International (2013). *Dredging: Profit margins expected to remain fairly healthy until 2018*. Retrieved from https://dredging.org.

Talmon, A. (2014, October 13). Dredge Pumps and Slurry Transport. Retrieved from https://ocw.tudelft.nl/.

Vlasblom, W. (2007). *Designing Dredging Equipment.* Retrieved from https://dredging.org.

Appendix

HAM 310 Drawing

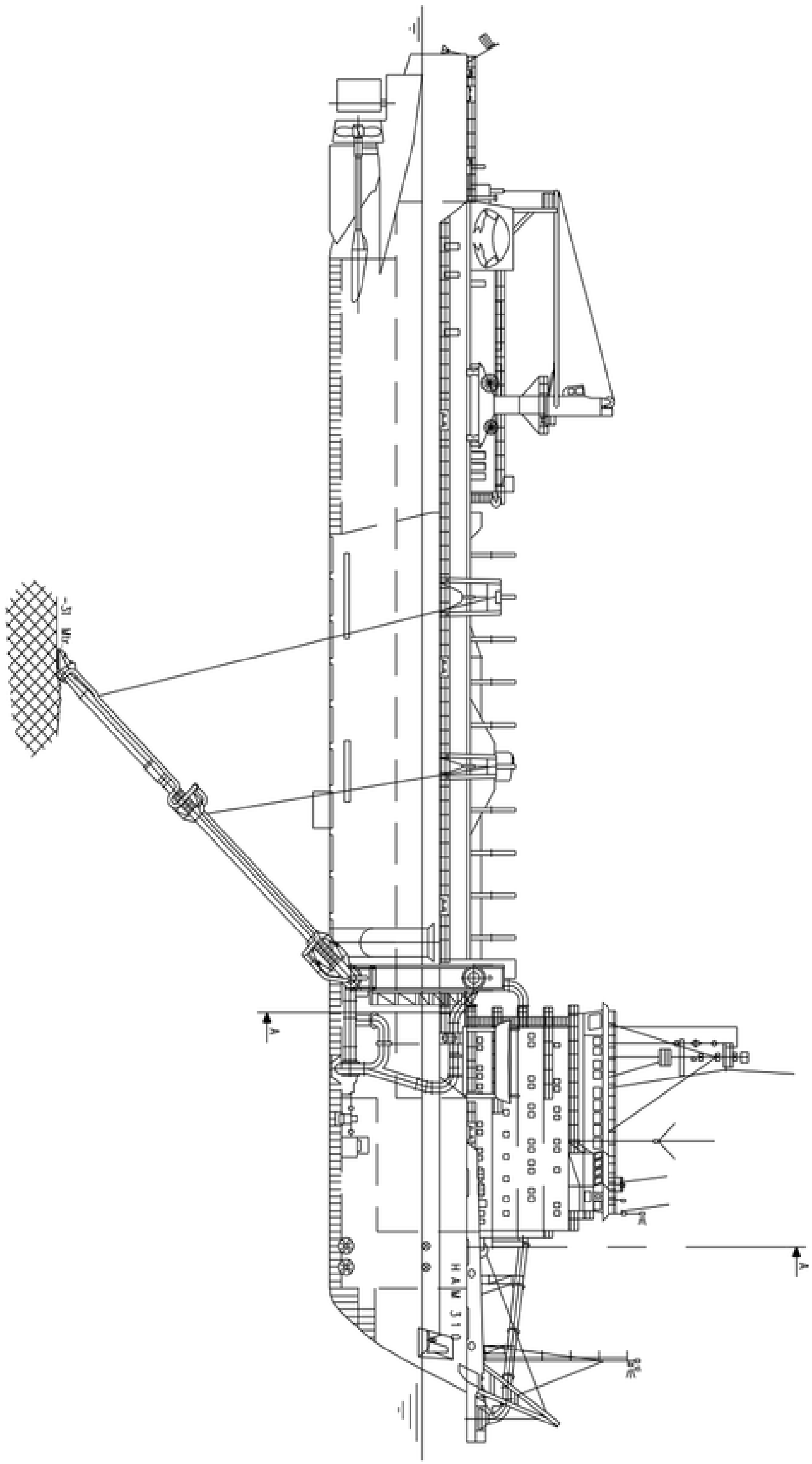

Figure 19: ***HAM 310 Profile Drawing***

Data Collection Tables

Table 5: ***Normal sand***

Normal Sand at 25 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	41	1371	4.6	3.25155	1.3	0.2197	0.7143652
2	20	39	1345	4.6	3.25155	1.3	0.2197	0.7143652
3	30	36	1386	5.3	3.74635	1.27	0.191	0.7155527
4	40	32	1493	6.4	4.52389	1.22	0.1464	0.662298
5	50	24	1452	7.6	5.37212	1.1	0.051	0.2739783
6	60	22	1440	7.6	5.37212	1.1	0.051	0.2739783
7	70	20	1429	7.6	5.37212	1.1	0.051	0.2739783
8	80	17	1415	7.6	5.37212	1.1	0.051	0.2739783
9	90	15	1406	7.6	5.37212	1.1	0.051	0.2739783
10	100	12	1396	7.6	5.37212	1.1	0.051	0.2739783

Table 6: ***Fine sand***

Fine sand at 25 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumptio n	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	41	1371.5	4.6	3.2515	1.3	0.2197	0.714365183
2	20	39	1348	4.6	3.2515	1.3	0.2197	0.714365183
3	30	35	1382	5.3	3.7463	1.27	0.191	0.715552705
4	40	32	1493	6.4	4.5239	1.22	0.1464	0.662297997
5	50	25	1459	7.6	5.3721	1.1	0.051	0.273978295
6	60	22	1440	7.6	5.3721	1.1	0.051	0.273978295
7	70	19	1424	7.6	5.3721	1.1	0.051	0.273978295
8	80	18	1419	7.6	5.3721	1.1	0.051	0.273978295
9	90	15	1407	7.6	5.3721	1.1	0.051	0.273978295
10	100	12	1396	7.6	5.3721	1.1	0.051	0.273978295

Table 7: ***Coarse sand***

Coarse sand at 25 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	41	1350	4.55	3.216205	1.3	0.2197	0.7066
2	20	39	1320	4.45	3.14552	1.305	0.2249	0.707427
3	30	36	1372	5.3	3.746349	1.26	0.1822	0.682585
4	40	33	1485	6.4	4.523893	1.22	0.1464	0.662298
5	50	25	1468	7.6	5.372123	1.1	0.051	0.273978
6	60	22	1450	7.6	5.372123	1.1	0.051	0.273978
7	70	19	1434	7.6	5.372123	1.1	0.051	0.273978
8	80	17	1425	7.6	5.372123	1.1	0.051	0.273978
9	90	15	1416	7.6	5.372123	1.1	0.051	0.273978
10	100	12	1406	7.6	5.372123	1.1	0.051	0.273978

Table 8: ***Normal gravel***

Normal Gravel at 25 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	41	1355	4.5	3.18086	1.3	0.2197	0.6988355
2	20	39	1327	4.5	3.18086	1.3	0.2197	0.6988355
3	30	36	1379	5.35	3.78169	1.26	0.1822	0.6890243
4	40	32	1485	6.4	4.52389	1.22	0.1464	0.662298
5	50	24	1462	7.6	5.37212	1.1	0.051	0.2739783
6	60	22	1450	7.6	5.37212	1.1	0.051	0.2739783
7	70	20	1439	7.6	5.37212	1.1	0.051	0.2739783
8	80	17	1425	7.6	5.37212	1.1	0.051	0.2739783
9	90	15	1416	7.6	5.37212	1.1	0.051	0.2739783
10	100	12	1406	7.6	5.37212	1.1	0.051	0.2739783

Table 9: ***Fine gravel***

Fine Gravel at 25 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Flow Velocity	Mixture Density	Mixture sand	Production Rate
		[%]	[kg/h]	[m/s]	[m/s]	[t/m3]	[t/m3]	[t/s]
1	10	41	1354	4.4	3.1102	1.31	0.2298	0.714718612
2	20	39	1322	4.45	3.1455	1.31	0.2298	0.722840414
3	30	37	1389	5.25	3.711	1.26	0.1822	0.676145352
4	40	33	1493	6.4	4.5239	1.22	0.1464	0.662297997
5	50	24	1462	7.6	5.3721	1.10	0.051	0.273978295
6	60	22	1450	7.6	5.3721	1.10	0.051	0.273978295
7	70	20	1439	7.6	5.3721	1.10	0.051	0.273978295
8	80	17	1424	7.6	5.3721	1.10	0.051	0.273978295
9	90	15	1416	7.6	5.3721	1.10	0.051	0.273978295
10	100	12	1405	7.6	5.3721	1.10	0.051	0.273978295

Table 10: ***Coarse gravel***

Coarse Gravel at 25 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	41	1350	4.5	3.180863	1.30	0.2197	0.698836
2	20	39	1322	4.5	3.180863	1.31	0.2298	0.730962
3	30	36	1380	5.3	3.746349	1.26	0.1822	0.682585
4	40	32	1486	6.4	4.523893	1.22	0.1464	0.662298
5	50	24	1462	7.6	5.372123	1.10	0.051	0.273978
6	60	23	1456	7.6	5.372123	1.10	0.051	0.273978
7	70	20	1439	7.6	5.372123	1.10	0.051	0.273978
8	80	17	1424	7.6	5.372123	1.10	0.051	0.273978
9	90	15	1416	7.6	5.372123	1.10	0.051	0.273978
10	100	12	1405	7.6	5.372123	1.10	0.051	0.273978

Table 11: ***Normal Sand, 15m***

Normal Sand at 15 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	46	1621	6	4.24115	1.305	0.2249	0.9538347
2	20	43	1582	6	4.24115	1.305	0.2249	0.9538347
3	30	40	1544	6	4.24115	1.305	0.2249	0.9538347
4	40	38	1526	6	4.24115	1.3	0.2197	0.9317807
5	50	34	1556	6.55	4.62992	1.27	0.191	0.8843151
6	60	21	1433	7.7	5.44281	1.1	0.051	0.2775833
7	70	18	1419	7.7	5.44281	1.1	0.051	0.2775833
8	80	17	1413	7.7	5.44281	1.1	0.051	0.2775833
9	90	14	1402	7.7	5.44281	1.1	0.051	0.2775833
10	100	11	1392	7.7	5.44281	1.1	0.051	0.2775833

Table 12: ***Normal Sand, 35m***

Normal Sand at 35 meters								
	Swell Compensator Pressure	Engine Combinator	Fuel Consumption	Flow Velocity	Volume flow	Mixture Density	Mixture sand	Production Rate
	[bar]	[%]	[kg/h]	[m/s]	[m3/s]	[t/m3]	[t/m3]	[t/s]
1	10	37	1238	3.95	2.7920905	1.26	0.1822	0.508718884
2	20	34	1343	5.1	3.6049776	1.22	0.1464	0.527768716
3	30	32	1452	6.25	4.4178647	1.18	0.1126	0.497451562
4	40	28	1481	7.4	5.2307518	1.105	0.0544	0.284552896
5	50	25	1459	7.55	5.3367805	1.1	0.051	0.272175807
6	60	23	1447	7.55	5.3367805	1.1	0.051	0.272175807
7	70	20	1431	7.55	5.3367805	1.1	0.051	0.272175807
8	80	18	1421	7.55	5.3367805	1.1	0.051	0.272175807
9	90	16	1412	7.55	5.3367805	1.1	0.051	0.272175807
10	100	14	1403	7.55	5.3367805	1.1	0.051	0.272175807

Table 13: ***Pressure Differences, different depths***

Pressure Difference (15m, 25m, 35m, normal sand)						
	15m		25m		35m	
Swell Compensator Pressure (bar)	ΔP (bar)	Vacuum (bar)	ΔP (bar)	Vacuum (bar)	ΔP (bar)	Vacuum (bar)
10	98	81	87	83	65	83
20	98	81	87	81	87	83
30	98	81	92	81	97	83
40	98	81	96	80	109	68
50	100	81	113	54	112	59
60	114	47	113	54	110	59
70	114	47	113	54	110	59
80	114	47	113	54	110	59
90	114	47	113	54	110	59
100	114	47	113	54	110	59

Power consumers PMS

Table 14: ***Power consumption, 25m***

PMS Outputs (tested at 25m, normal sand)										
	Swell compensator pressure	Engine combinator	PS generator	SB generator	PS engine	SB engine	PS suction pump	SB suction pump	PS jetpump engine	SB jetpump engine
	[bar]	[%]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
1	10	41	4530	4530	1708	1708	2446	2446	375	375
2	20	39	4450	4450	1641	1641	2434	2434	375	375
3	30	36	4580	4580	1550	1550	2655	2655	375	375
4	40	32	4909	4909	1463	1463	3070	3070	375	375
5	50	24	4769	4769	1257	1257	3136	3136	375	375
6	60	22	4733	4733	1222	1222	3136	3136	375	375
7	70	20	4700	4699	1188	1188	3136	3136	375	375
8	80	17	4657	4657	1146	1146	3136	3136	375	375
9	90	15	4632	4632	1121	1121	3136	3136	375	375
10	100	12	4601	4601	1090	1090	3136	3136	375	375

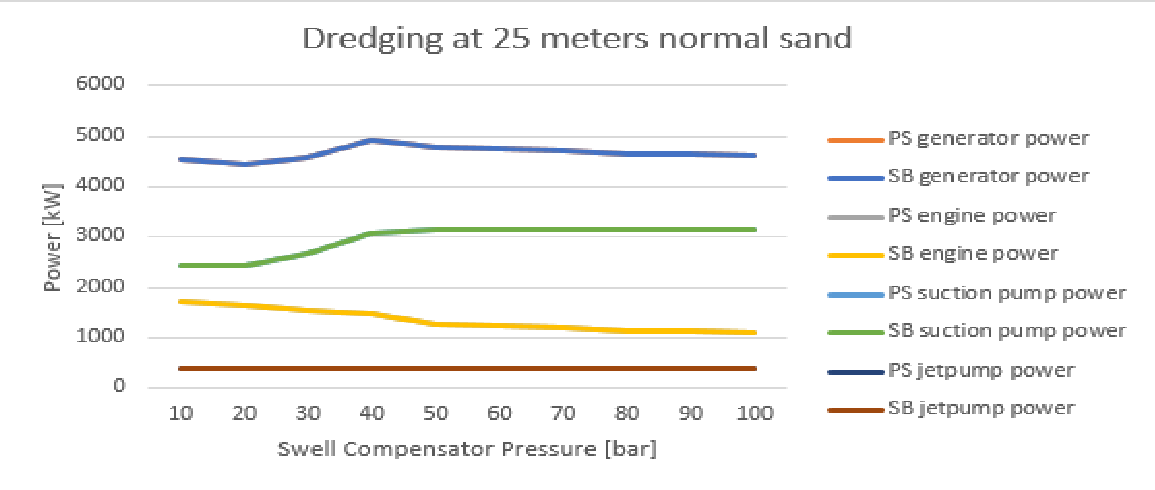

Figure 20: ***Power Consumption versus Swell Compensator Pressure***

Table 15: ***Power consumption, 15m***

PMS Outputs (tested at 15m, normal sand)										
	Swell compensator pressure	Engine combinator	PS generator	SB generator	PS engine	SB engine	PS suction pump	SB suction pump	PS jetpump engine	SB jetpump engine
	[bar]	[%]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
1	10	46	5253	5253	1884	1884	2989	2989	375	375
2	20	43	5147	5147	1776	1776	2996	2996	375	375
3	30	40	5045	5045	1675	1675	2999	2999	375	375
4	40	38	4983	4983	1611	1611	2999	2999	375	375
5	50	34	5070	5070	1491	1491	3207	3207	375	375
6	60	21	4713	4713	1205	1205	3133	3133	375	375
7	70	18	4669	4669	1161	1161	3133	3133	375	375
8	80	17	4652	4652	1144	1144	3133	3133	375	375
9	90	14	4618	4618	1109	1109	3133	3133	375	375
10	100	11	4588	4588	1080	1080	3133	3133	375	375

Table 16: ***Power consumption, 35m***

PMS Outputs (tested at 35m, normal sand)										
	Swell compensator pressure	Engine combinator	PS generator	SB generator	PS engine	SB engine	PS suction pump	SB suction pump	PS jetpump engine	SB jetpump engine
	[bar]	[%]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]
1	10	37	4111	4111	1578	1578	2156	2156	375	375
2	20	34	4423	4423	1494	1494	2557	2557	375	375
3	30	32	4770	4770	1438	1438	2952	2952	375	375
4	40	28	4853	4853	1338	1338	3139	3139	375	375
5	50	25	4789	4789	1274	1274	3140	3140	375	375
6	60	23	4752	4752	1237	1237	3140	3140	375	375
7	70	20	4704	4704	1190	1190	3140	3140	375	375
8	80	18	4675	4675	1161	1161	3140	3140	375	375
9	90	16	4648	4648	1134	1134	3140	3140	375	375
10	100	14	4624	4624	1109	1109	3140	3140	375	375

Pump Diagram

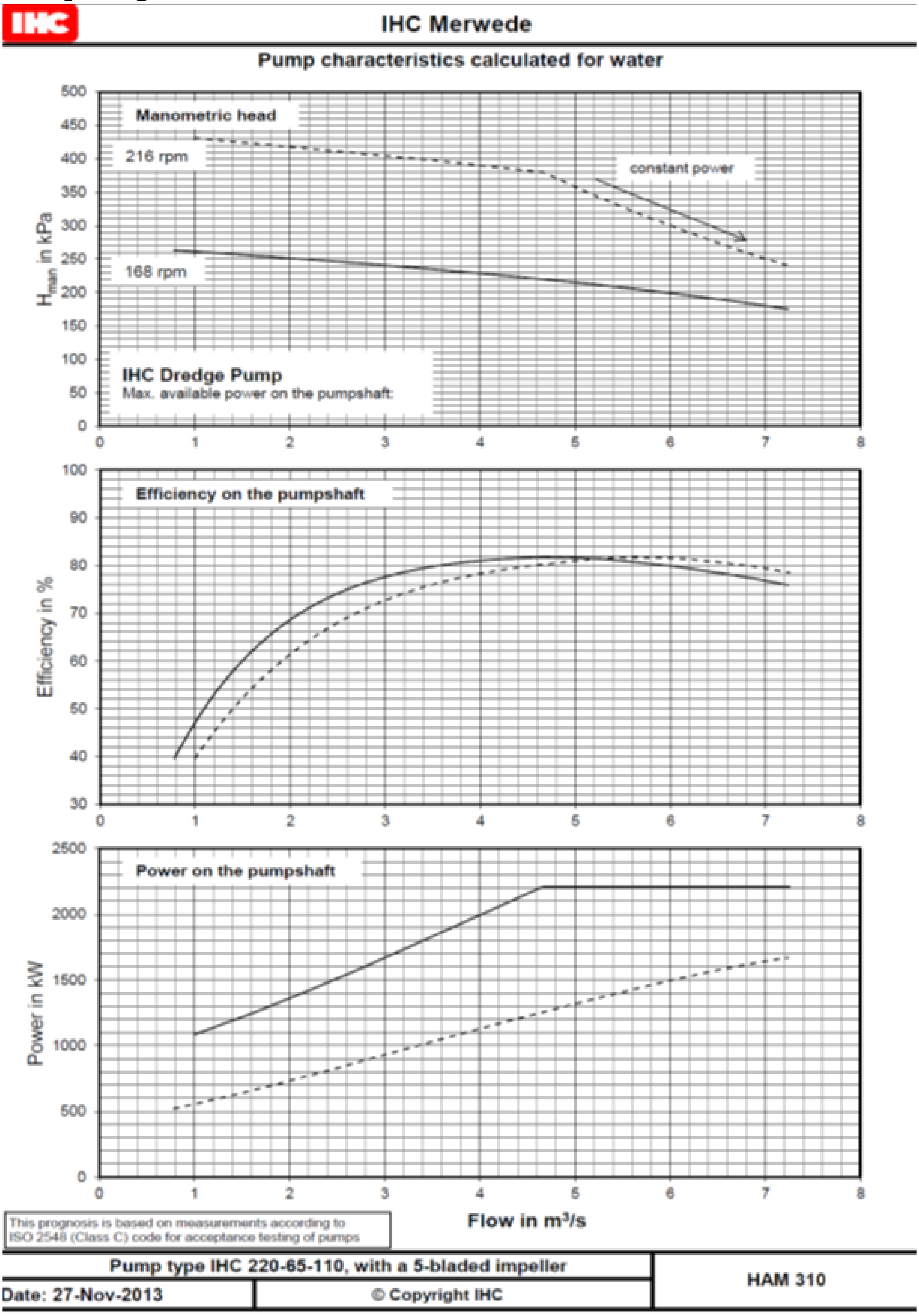

Figure 21: *HAM 310 Pump Characteristic Diagram*

Cross indicator

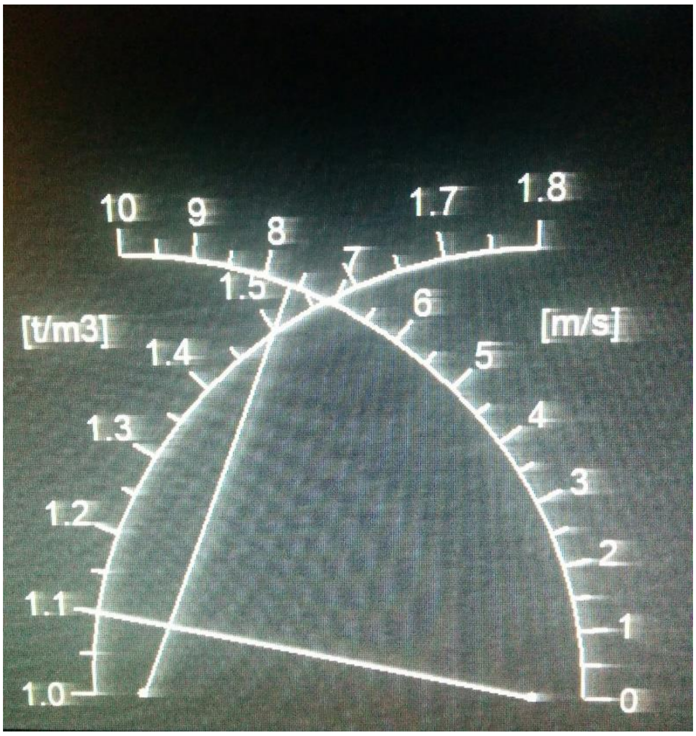

Figure 22: ***Photograph of Simulator Cross Indicator***

Peer review

Student A	Trevor Yoak
Student B	Maxime Broer
Date/Version of Research Plan	
Date/Version of Research Report	
Date/Version of Presentation	
Date of Review	12/12/2019
Reviewers	Corné Hilbrands & Stephan van Bemmel

Report 2/3*	Presentation (1/3)
7.7	1.0

* Provisional figure based on the indicators assessed so far, only final if all indicators have assessed at least a '2' score and all performance criteria.

Assessing research indicators based on performance criteria	
1. Reporting	
2. The preparation of the research plan is appropriate to the research question and feasible to execute in the	4.5
3. The research objective and question are relevant to a practical problem of sufficient level for the study program.	4.0
4. There is an effective use of sufficiently revelant and good quality sources.	3.7
5. The appropriate research methods are chosen and applied correctly.	3.0
6. Data is collected responsibly.	3.3
7. Shows development of appropriate (if not innovative) solutions for the practical problem.	4.0
8. Work displays an inquisitive and reflective attitude, and being evironmentally aware, curious, creative, respectful, honest, careful, and transparent.	3.5
Total points 1-5	26.0

Figure 23: ***Peer Review***

Process report

Maxime Broer

Process report PRTH

Name: Maxime Broer

Assessment of the cooperation process[1]

The collaboration process is assessed using the checklist of Goldfinch. This checklist assesses each student both themselves (self-assessment) and the other group (peer-assessment) process on issues within the partnership. The allocation of points is related to the contribution of itself with respect to other group members/the other group member/himself on the aspect concerned.

Points on the criteria have the following meanings:
3 : Better when comparing himself with other members of the group.
2 : Roughly the same as the other group members.
1 : Not as good as the others.
0 : No useful contribution.
-1 : Disturbing for the group.

Table 17: ***Goldfinch Checklist 1***

Write the names of the group members besides yourself and give each a point	**Yourself: Maxime**	**Group member: Trevor**
1. Enthusiasm / participation	2	2
2. Come up with ideas	2	2
3. Understanding of what required is.	2	2
4. Contribution to function as a team	2	2
5. Organizing / monitoring the group	2	2
6. Preform tasks efficiently	2	2
Total amount of points:	12	12

[1]This form of assessment has been taken from testing higher education (2014).

Feedback/feedforward to team members

You have just assessed your fellow group member and yourself. Give your group member in what way and / or when he / she was most valuable. This can be a specific action, but it can also be someone's character trait or talent. Also indicate what you liked very much and would therefore like to see (even more) from this person. Do this by completing the following sentences:

Name team member: Trevor Yoak

You helped us a lot when you:
Kept pressure on the speed of researching and because of this there was enough time left for the deadline. This resulted in a study of a high quality.

What I found very good and therefore would like to see more of you:
Is that preform good in a team. You are not only listening to yourself but also to someone else and because of this it is nice to work with you.

Personal process report

This was your second ''real'' research. If you look at what you knew about research at the start of PRTH and what you know now. What are the three most important things you learned about research during this period?
1)
To make a good research plan and that if you make the right research questions the research becomes easy to study the subject.
2)
What the requirements are of a thesis and how a thesis is build up.
3)
None.

During your second internship you will do research again. Name three things that you are going to do differently than in your PRTH study and also explain why.
1)
I will choose a subject that has value for the people on board or from the company. The idea that the research outcome is useful to someone else make you work harder on the quality of the thesis.
2)
When choosing a subject where values are part of the thesis look at how accurate the values are and what the quality is of the values. This due to the fact that the values are influencing the conclusion of the research.
3)
None.

Trevor Yoak

Process report PRTH

Name: Trevor Yoak

Assessment of the cooperation process[1]

The collaboration process is assessed using the checklist of Goldfinch. This checklist assesses each student both themselves (self-assessment) and the other group (peer-assessment) process on issues within the partnership. The allocation of points is related to the contribution of itself with respect to other group members/the other group member/himself on the aspect concerned.

Points on the criteria have the following meanings:
3 : Better when comparing himself with other members of the group.
2 : Roughly the same as the other group members.
1 : Not as good as the others.
0 : No useful contribution.
-1 : Disturbing for the group.

Table 18: ***Goldfinch Checklist 2***

Write the names of the group members besides yourself and give each a point	**Yourself:**	**Group member:**
1. Enthusiasm / participation	2	3
2. Come up with ideas	2	3
3. Understanding of what required is.	2	2
4. Contribution to function as a team	2	2
5. Organizing / monitoring the group	2	2
6. Preform tasks efficiently	2	2
Total amount of points:	12	14

[1]This form of assessment has been taken from testing higher eductation (2014).

Feedback/feedforward to team members

You have just assessed your fellow group member and yourself. Give your group member in what way and / or when he / she was most valuable. This can be a specific action, but it can also be someone's character trait or talent. Also indicate what you liked very much and would therefore like to see (even more) from this person. Do this by completing the following sentences:

Name team member: Maxime Broer

You helped us a lot when you:

Your knowledge of the technical side of the research has been invaluable. Additionally, it has been nice to have a partner who doesn't mind trying ideas even if they don't work. That level of commitment is useful and necessary for completing good research.

What i found very good and therefore would like to see more of you:

The continuous open communication has been really helpful. No deadlines were missed, no research forgotten because you communicated proficiently.

Personal process report

This was your second ''real'' research. If you look at what you knew about research at the start of PRTH and what you know now. What are the three most important things you learned about research during this period?

1) Good research needs to be focused and specific. That being said, it's ok to try out tangent ideas (time permitting) because maybe it will lead to an epiphany or somehow contribute to the main research goal.

2) Preparing the legwork thoroughly from the beginning helps keep organization and management of the project as it continues and evolves.

3) If there is a strict deadline in place, don't rely on outside assistance or other factors out of personal control.

During your second internship you will do research again. Name three things that you are going to do differently than in your PRTH study and also explain why.

1) Try to gain more theoretical knowledge first and build up a "reading list" of resources that can be drawn upon when writing the research paper. It eases the writing process and helps with a broader understanding of the topic.

2) Try to pick a topic where the impact is more visible so that motivation for the project remains high and purposeful. It is always easier to do research when one can answer the question "why bother?" for oneself.

3) Produce an outline of events for the research. The research plan was good for ideas but not as helpful for tracking how the the project should unfold.