IMPROVING COST EFFECTIVITY OF A PURIFIER INSTALLATION

Research Rapport

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Research rapport

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Improving cost effectivity of a purifier installation

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Abstract

This research is performed to give an advice for the current problem of Canada Feeder Lines regarding the purifier installation. This research has given an answer to the following main question:

''What is the best way to improve the cost-effectivity of the purifier installation on board of a 10.000 DWT ship of CFL?''

On each of the six ships of the Sole series from Canada Feeder Lines containing the Momentum Scan, Marvel Scan, Motion Scan, Industrial Maya, Industrial More and Industrial Merchant, is a main engine installed which is lubricated by oil. The oil that is used for direct lubrication is stored in the sump tank below the main engine. There is also a cleaning system connected in parallel to the lubrication line one the sump tank. This cleaning system contains a purifier who is only able to clean the lubrication oil properly if the oil temperature is 95°C or higher. In the sump tank, the oil temperature is normally about 60°C. A heat exchanger is placed in the circuit between the purifier and the sump tank to heat the oil before the cleaning process. Unfortunately the capacity of this heat exchanger is not enough to heat the oil out of the sump tank to the minimum required inlet temperature of 95°C with the current water temperatures of the heating system when the main engine is not running and the oil temperature in the sump tank drops too far.

Continuing the purifying of the lubrication oil while the main engine is not running will have cleaner lubrication oil as result because the main engine will not foul the oil while the cleaning process continuous. Cleaner lubrication oil will reduce the wear of the main engine (H.Wytzes, 1998).

To solve this problem, three solutions have been found and investigated:

1. Replacing the current heat exchanger by a heat exchanger with more capacity or expanding the capacity of the current heat exchanger
2. Heat recovery by using the returning lubrication oil temperature
3. Reduction of the oil flow

To determine which method is the most cost-effective, measurements have been done. After the measurements calculations are made. The outcome of the research results in three available options with heat recovery by using the returning lubrication oil temperature as the most suitable. The answer to the main research question is that all three options will increase the availability of the purifier installation but only the option based on using the returning oil for heat recovery will increase also the efficiency of the purifier installation on board of the 10.000 DWT ships of Canada Feeder Lines. Therefore this option appeared to be the best cost-effective solution.

Preface

This research report '' Improving cost effectivity of a purifier installation'' is written with the purpose of graduating for the bachelor maritime officer at the HZ University Of Applied Sciences. The research for this report is done from December till July 2016.

This project is done in order to give an advice to Canada Feeder Lines about the current purifier installation.

I want to thank my two supervisors Flip Wubben and Arie de Groot for the effective advice and support. I also want to thank Hille Faber and Vitalii Migas for the information and help during the research.

I hope you will enjoy reading this report.

Dirk Vermorken

Canada, June 17th 2016

Glossary

Adhesion	The non-chemical binding force between unequal molecules
Bilge water	Leakage water located in the lowest part of the engine room
Centripetal pump	Same as a centrifugal pump, only the house is moving instead of the rotor
Clarifier	A purifier who is only able to remove solid particles
Cohesion	The chemical binding force between equal molecules
Density	The specific weight of a liquid
Disk Stack	The package of discs inside a purifier
Displacement pump	A pump with the working based on displacement, this pump can provide higher pressures than a centrifugal/centripetal pump
DWT	Dead Weight Tonnage
Emulsion	A mixture of oil and water
EP	Extreme Pressure
Gravity ring	A ring inside a purifier the determine the position of the interface between oil and water
Heat exchanger	A device able to exchange the heat of two liquids or gasses flowing through it
HFO	Heavy Fuel Oil
Hydrodynamic	In lubrication this means that the two surfaces are not touching each other because there is an oil film between them
LO	Lubrication Oil
Oxidation	Aging
PH value	The value of the acidity, 0-7 is acid 7-14 is base
Purifier	A device able to separate the water and solid particles of the oil
RPM	Rotations per minute
Separation line	The interface between water and oil
Sludge	All the waste out of the fuel and oil
Sump tank	The tank below the main engine who contains the oil which is used during normal operation
TBN	Total Base Number

Trunk piston	This is inside an engine where the only connection between the piston and the crankshaft is a connection rod
VI	Viscosity Index
Viscosity	The thickness of a liquid, a high viscosity means a thick liquid
Water lock	This is inside a purifier and locks the water exit for oil going out

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1. Introduction

This chapter contains information about the company, the problem statement and the research questions.

1.1 Company introduction

Canada Feeder Lines is a Dutch company sailing with general cargo ships since 2006. At the moment there are 12 ships in the fleet, all the ships are built in Kampen (Holland) and the ships are sailing under the Dutch flag. Six of these ships have an equal design. These ships are called the Sole series of CFL. They have a deadweight tonnage of 10.000 ton, a length of 116 metres, a beam of 17,8 metres and a draft of 7,9 metres. The Sole series includes the following ships:

- Momentum Scan 2010
- Marvel Scan 2011
- Motion Scan 2011
- Industrial Maya 2012
- Industrial More 2013
- Industrial Merchant 2013

The actual research is done on board of the Industrial Maya but the results can also be used for the other five ships of the Sole series.

1.2 Problem statement

The purifier on board of the Industrial Maya and her sister-ships, is not able to clean the lubrication oil properly under any condition. The result is an increased wear and tear of moving pars what might increase the maintenance costs of the main engine. On top of that the effective usage time of the expensive lubrication oil might be reduced.

1.3 Problem analysis

Based on practical experiences it is only possible to clean the lubrication oil properly if the ingoing oil temperature is 95°C or higher. If the ingoing temperature is lower, the viscosity of the oil will be too high during the separation process. A too high viscosity will prevent the purifier form removing all the solid particles from the oil. A heat exchanger is installed to heat this oil to the preferred temperature before it enters the purifier. Unfortunately the current combination of the heating water flow, heating water temperature and heat exchanger is not able to heat the oil to the minimum required temperature of 95°C.

Another purpose of the heat exchanger in the purifier installation is pre-heating, this means that the heat exchanger must also be able to keep the sump tank temperature at 60°C when the main engine is not adding heat to the oil because it is not running.

1.4 Research objective

The research objective is to acquire knowledge what is helping to solve the problem-statement.

Therefore if the purifying process might be continued under the optimal conditions, the lubrication oil in the sump tank of the main engine will be cleaner which leads to reducing the wear of the main engine and expanding the lifetime of the oil.

1.5 Research questions

To make the installation able to always continue this process, the problem of the low ingoing oil temperature needs to be solved. This leads to the following main research question:

''What is the best way to improve the cost-effectivity of the purifier installation on board of a 10.000 DWT ship of CFL?''

To answer the main question the, sub questions need to be answered first. According Verschuren en Doorewaard the questions can be divided in theoretical, empirical and analytical questions (Verschuren, 2015). The main research question is to be regarded as an analytical question.

The theoretical sub questions are:

1. Which contamination can the lubrication oil contain?
2. What are the effects of using not proper cleaned lubrication oil?
3. What is the background of the temperature requirements for proper cleaning?

The empirical sub questions are:

4. What is the amount of energy needed to heat the oil during normal operation conditions of the purifier?
5. For which amount of time needs the cleaning process to continue to clean the oil when the main engine is not running?

The analytical sub question is:

6. What is the best solution to solve the problem?

2. Theoretical framework

In the theoretical framework, the involved components will be discussed. The theoretical framework will provide the knowledge to understand the research.

The subjects in the theoretical framework will be:

1. Oil cleaning with the use of purifiers
2. Lubrication to reduce friction and wear
3. Heat exchangers, the design, working principle and installation options
4. Warm water system for the heating of the components on board of the ship
5. Lubrication of the main engine

2.1 Purifier/separator

The purifier is used in the cleaning process of the lubrication oil. In the following chapters will become clear how a purifier works and which kind of purifiers are existing. Also the specifications of the lubrication oil purifier on board of the industrial Maya will be mentioned.

2.1.1 Definition of purifier/separator

Purifiers can separate liquids and solid particles if there is a difference in density. Purifiers are used on board of ships to clean big amounts of liquids like fuel, lubrication oil and sometimes also bilge water. In dairies they are used to separate the cream from the milk. Just like centrifugal pumps the working principle of purifiers is based on centrifugal force. Liquids who will dissolve in each other cannot be separated by a purifier. Purifiers can be self-cleaning if the bowl is able to open and close during the process. (Smit & Wytzes, 2007)

2.1.2 Separating methods

As described in 2.1.1 liquids can be separated if they have a difference in density and are not able to dissolve in each other. On this principle two separation methods are based.

- Separating by gravity
- Separating by centrifugal force

Separating by gravity

Different liquids in a same tank will slowly separate by gravity as visible in Figure 10 settling by gravity (Appendix 1 Illustrations to clarify the theoretical framework). The liquid with the highest density will sink to the bottom of the tank while the liquids with the lowest density will float on top. An advantage of this separation method is that it doesn't need any energy input. A disadvantage is that it's a relatively slow process and a moving ship will mix the liquids again. The height of the tank will influence the speed of the separation process, also the difference in density. If there are also solid parts in the mixed liquid three layers will occur. On the bottom the solid parts (contamination), above the solid parts the liquid with the highest density (water) and on top the liquid with the lowest density (oil).

Separating by centrifugal force

In a rotating bowl, like the bowl of a purifier, the gravity is replaced by centrifugal force. This force depends on the diameter of the bowl and the rotating speed of it and can be 13000 times bigger than the force of gravity. This bigger force makes it possible to separate different liquids and solid parts much faster than by gravity. In Figure 1 Settling by centrifugal force the separation layers visible. The only difference is now that they occur by centrifugal force and they are vertical.

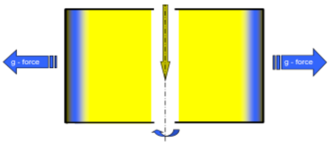


Figure 1 Settling by centrifugal force

2.1.3 The law of Stokes

It is possible to use the law of stokes to calculate the speed of the separation process. This formula will show the importance of a low viscosity. The viscosity is located under the slash and has a big influence on the separation speed. The lower the viscosity, the faster the cleaning process.

The basic formula of stokes is:

$$v = \frac{d^2(\rho 2 - \rho 1)}{18\eta} g$$

v	separation speed of the solid part
d	diameter of the solid part
$\rho 2$	density of the liquid
$\rho 1$	density of the solid part
η	viscosity of the liquid
g	Acceleration due to the gravity, this is approximately ten

The law of stokes can also be used for calculating the speed of the separation of the solid parts inside a purifier. In this case the acceleration due to the gravity will be replaced by the acceleration due to the centrifugal force.

The formula for this force is:

$$r\omega^2$$

Below an example of the law of Stokes for the separation of water and oil:

$$Vc = \frac{d^2(\rho w - \rho o)}{18\eta} r\omega^2$$

Figure 11 Explanation of the law of stokes (Appendix 1 Illustrations to clarify the theoretical framework) will explain the different values of the formula.

Three important factors for the separation speed can be explained by this formula. The size of the droplet is also a influence but this depends on the viscosity.

1. The centrifugal force $r\omega^2$
2. The difference in density of the two liquids $\rho w - \rho_o$
3. De viscosity of the contaminated liquid η

2.1.4 Factors who will affect the separation

In 2.1.3, different factors are indicated by the law of Stokes. Further explanation about these factors will follow in this chapter.

Temperature

For some types of liquids, for example mineral oil, a higher temperature will improve the separation process. The high temperature will lower the viscosity and the density which will cause a better separation. During the separation process a constant viscosity is required, this makes it possible to fine tune the purifier for an optimal process.

Figure 12 The density of oil and water (Appendix 1 Illustrations to clarify the theoretical framework) shows the density difference between oil and water, this difference will get bigger when the temperature of the mixture increases. The higher the temperature, the better these liquids can be separated. It is important to keep the temperature below 100°C to prevent boiling of the control water of the purifier. It is not always necessary to heat the mixture too just below 100°C, lower temperatures can be used sometimes to save energy.

Viscosity

When a liquid has a lower viscosity, the separation process will go faster. The viscosity of a liquid can be effected by changing its temperature. A higher temperature will result in a lower viscosity.

Density

The bigger the difference between two liquids, the better the separation process will go. The density can also be affected by changing the temperature.

Disk stack

In every bowl of a purifier is a package with disks installed. A complete package of these disks is called a disc stack. The more discs this stack contains, the more surface there is to separate the mixture and this will increase the speed of the separation process.

2.1.5 How does a purifier works?

The separation of liquids and solid parts is described in the previous chapters. Just like the factors and what has influence on these factors. In this chapter the working principal of the purifier will be explained.

Not self-cleaning, self-cleaning, purifier and clarifier

Before explaining the working principal, the different types of purifiers will be shown. These types are the not self-cleaning in Figure 13 Not self-cleaning purifier (Appendix 1 Illustrations to clarify the theoretical framework), and the self-cleaning type in Figure 14 Self-cleaning purifier (Appendix 1 Illustrations to clarify the theoretical framework).

Not self-cleaning purifier

The not self-cleaning purifier has to be cleaned by hand if the bowl contains too much sludge. The solid parts will stick to the bowl. If this layer becomes too thick it can block the exit of water from the purifier and get too close to the disc stack.

This type of purifier will only be used on small ships, because this type is only useful for diesel oil because this contains low amounts of sludge. If this purifier would be used for cleaning HFO it would foul with very short intervals.

Most of the not self-cleaning purifiers are equipped with a loose chamber inside the bowl. If the bowl is fouled this chamber can be removed for cleaning.

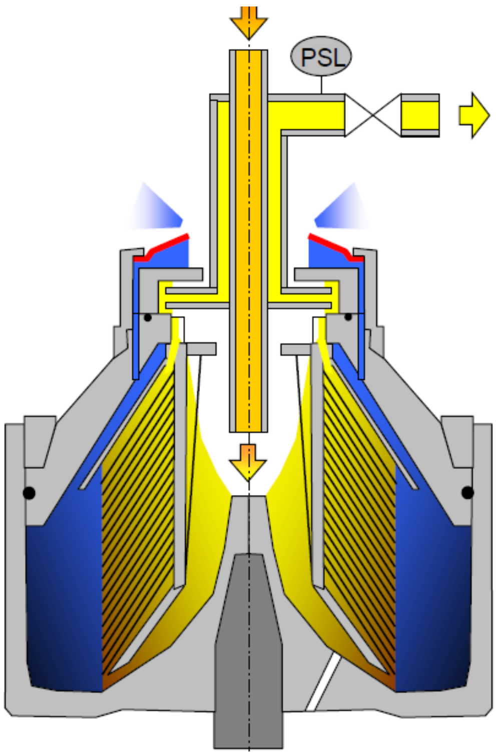


Figure 2 Working of a not self-cleaning purifier

Self-cleaning purifier

The self-cleaning purifier has a bowl who can open and close during the cleaning process. This purifier is shown in Figure 3 Working of a self-cleaning purifier. The opening of the bowl during the process will remove the layer of sludge and water. Every time after shooting, the bowl needs to be filled up with water again before the oil can enter. This type of purifier is equipped with several sensors to prevent the loss of oil and make sure there is no water coming with the clean oil. To open and close this bowl water pressure will be used.

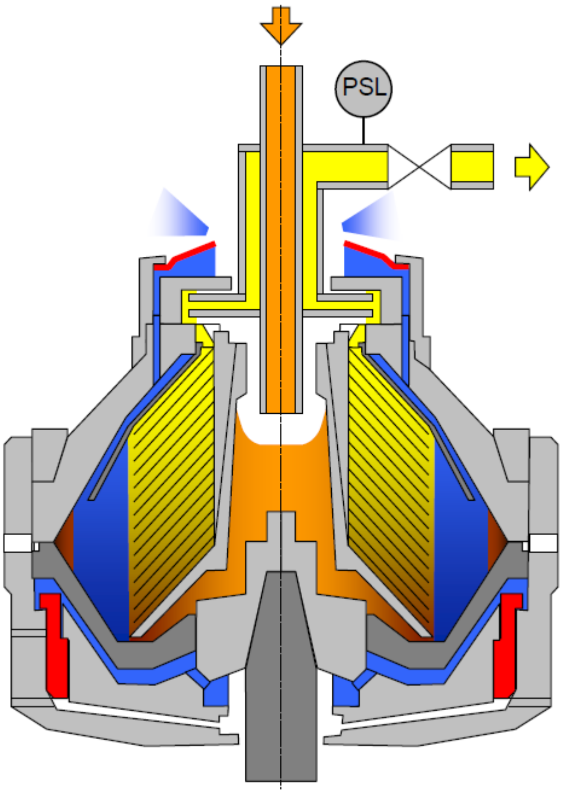


Figure 3 Working of a self-cleaning purifier

The working principle of the two types of purifiers are the same. Only the self-cleaning purifier will require longer cleaning intervals.

Purifier and clarifier

Beside the use of a purifier sometimes also clarifiers will be used. The difference between these machines is the separation method. A purifier separates water, oil and solid particles. A clarifier is only able to separate solid particles from a liquid.

The process inside a purifier

Figure 4 Route of the oil through purifier will be used to explain the route of oil through a purifier.

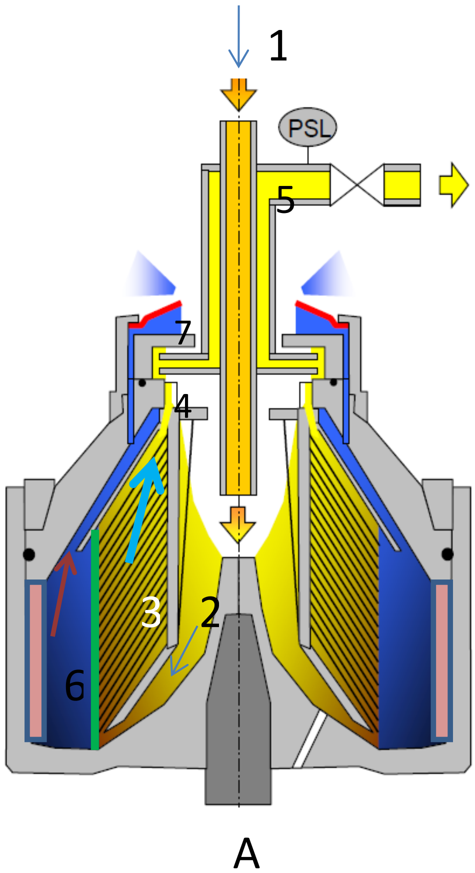


Figure 4 Route of the oil through purifier

The fouled oil needs to be filtered before it enters the purifier. Solid particles who are too big can get stuck between the disk stack. After filtering the big parts out of the oil, the smaller parts and the water remain in the oil. The oil enters through the inlet (1), the inlet flow is provided by a displacement pump. The entering oil falls on top of the rotating centre shaft (2). This shaft rotates with a speed of 8000 up to 13000 rpm depending of the type and size of the purifier. After entering the oil will go to the outside of the bowl by centrifugal force.

The inlet pipe is made of a small pipe inside a bigger pipe. The entering oil flows inside the smallest pipe while the bigger pipe leads the outgoing oil. The flow of the outgoing pipe is provided by a centripetal pump. Different layers of liquids and solids will occur in the bowl.

Thanks to the feeding pressure and the pressure of the water, the oil will be pressed through the disk stack in the direction of the arrow. The centripetal pump will increase the outlet pressure of the oil. The layer of water is located between the layer of separated solid parts and the clean oil.

The oil contains solid parts when is enters the purifier (2), to prevent the solid parts will of coming with the clean oil through the outlet, the disk stack is installed. The distance between the discs is equal and they increase the length of the route of the oil. This will help the centrifugal force to move the solid parts to the side of the bowl. The route of the solid parts is visible in Figure 16 The route of solid particles between the discs (Appendix 1 Illustrations to clarify the theoretical framework), and the forces on the solid parts in Figure 15 Forces on solid particles (Appendix 1 Illustrations to clarify the theoretical framework).

If the oil mixture contains water, it will go into the layer of water. If there is too much water inside the layer it will automatically drain from the bowl.

Centripetal pump

A centripetal pump Figure 17 Centripetal pump (Appendix 1 Illustrations to clarify the theoretical framework), is based on the same working principle as a centrifugal pump. The difference is that on a centrifugal pump the impeller rotates and the case doesn't move while on a centripetal pump the impeller doesn't moves while the case (the bowl) rotates.

The pressure on the outgoing side of the centripetal pump can reach up to two bar.

Disk stack

As described the disk stack is designed to improve the separation of the solid parts. A complete disk stack can contain 80 up to 120 disks. Spacers are on the disks visible in Figure 18 Disk from a purifier (Appendix 1 Illustrations to clarify the theoretical framework) to make sure the preferred distance between the disks is equal.

The disks inside the disk stack are very smooth to prevent the sticking of contamination against their surface.

Water lock, separation line and gravity ring

The water lock, separation line and the gravity ring correlate with each other. They are important for a proper separation process. The next chapters will give more explanation about these subjects.

Water lock

The water lock inside purifiers is a layer of water in between the solid parts and the oil. Every time the purifier starts the water lock needs to be made before the oil can enter. If the water lock would not resist the oil could exit through the water discharge.

Separation line and gravity ring

The separation line is the border between the oil and the water. To make the purifier as efficient as possible and the outgoing oil as clean as possible, this line should be very close to the disk stack. The position of the separation line depends on the density of the oil and the gravity ring. This is visible in Figure 5 Explanation gravity disk by settling tanks.

The gravity ring is located on top of the overflow. This will affect the thickness of the layer of water and the location of the border. It is the inside diameter of the ring who matters. Two common rules for the gravity ring are:

1. Oil with a high density needs a gravity ring with a small inside diameter
2. Oil with a low density needs a gravity ring with a big inside diameter

If the diameter is too small, the location of the separation line will be in between the disk stack. If the diameter is too big, there is a chance the oil will exit trough the water outlet.

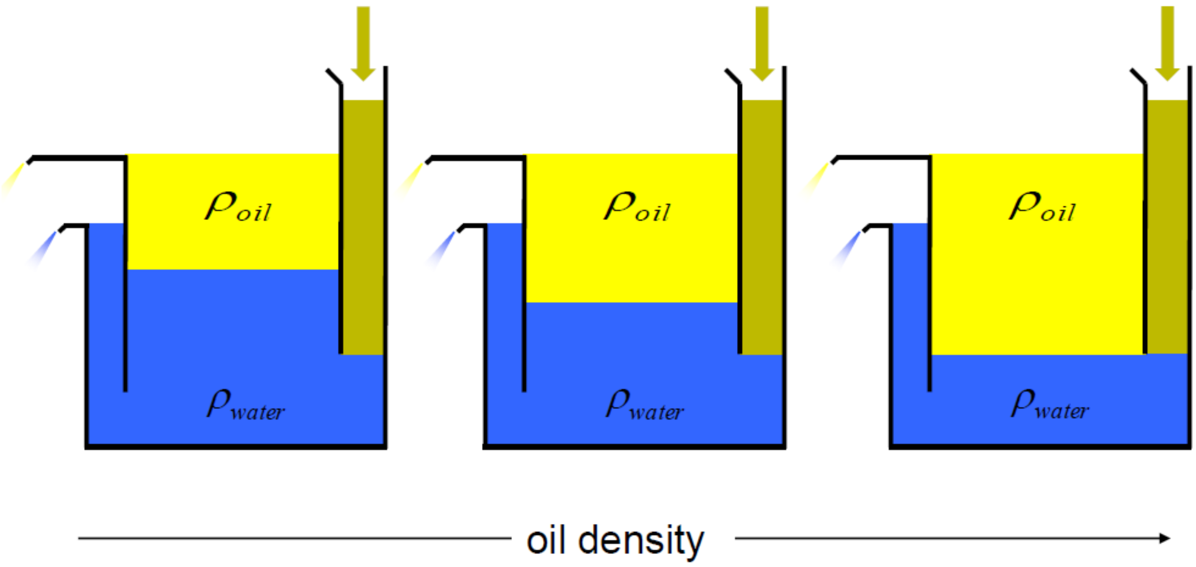


Figure 5 Explanation gravity disk by settling tanks

How to choose the wright gravity ring

There is a diagram designed to find the wright diameter visible in Figure 19 Diagram for determining gravity ring (Appendix 1 Illustrations to clarify the theoretical framework). The density and temperature of the oil are the guidelines to read the diagram. (Aertselaer, 2011-2012)

2.1.6 The concerning purifier

The purifier to clean the lubrication oil on board of the Industrial Maya is a Westfalia OSD6-0196-067/5. This is a self-cleaning purifier. (www.supercentrifugas.com, 2015)

2.2 Lubrication

This thesis is made to improve the purifier installation which will result in better lubrication of the main engine. This chapter will explain the importance of clean lubrication oil. Also several additives, kinds of lubrication, SEA notification and the decreasing quality of oil will be explained.

2.2.1 Lubrication oil

Lubrication oil is made out of petroleum. Before petroleum was found, natural oil and grease were used to lubricate wagon wheels, squeezing doors, steam machines, instruments and tools. These natural oils are made out of plants and animals and can provide a very good lubrication.

If a metal comes in tact with for example ricinusoil, this oil can only be removed for 100% by grinding it off. A disadvantage of almost every natural oil is that acidification occurs very easily. They can erode metal, become very thick ore very thin. Anyway, the natural oils are not suitable for proper lubrication. It took a long time before the mineral oils took over the natural oils. For some very special applications, natural oils are still used. They are more expensive than mineral oils and with mineral oils acidification will occur much slower. The disadvantage of mineral oils is that the lubrication is not as good as natural oils, unless additives will be added to the mineral oil.

By adding additives to the mineral oil, almost every characteristic can be provided. An additive is a substance, who will affect the lubricating qualities of the oil without having lubrication qualities by itself.

2.2.2 Additives

Characteristics of the oil can be improved by adding additives to the lubrication oil. It is also possible to add some new characteristics to the oil. For each kind of oil, different characteristics are important.

- Turbine oil has to be very resistant against aging.
- Motor oil has to be resistant against acid fuel and needs to have a good cleaning ability.
- Gearbox oil needs to have a good film strength and has to be very resistant against foaming.

Oil without additives can be used for some applications, but the quality will decrease relatively fast. Oil with additives will last much longer if it is used for the same purpose. The most common additives are:

- anti-oxidation additives
- anti-corrosion additives
- detergents
- anti-foam additives
- oiliness additives
- viscosity index improvers
- E.P. additives

Anti-oxidation

Mineral oils will oxidize slowly under the influence of oxygen. This is also called the aging of the oil. The oxidized oil can react acid to metals. Almost every oxidized oil will have an increased viscosity, darker colour and sticky solids parts will occur. The speed of oxidizing will be influenced by temperature. If the oil temperature is kept below 70°C, the oxidizing is minimal. For example: if the outlet temperature of a main engine is exactly 70°C, there is a big possibility that at some places inside the engine the oil still becomes hotter than the outlet temperature. The anti-oxidation dopes have in common that they reduce or prevent the oxidation of the oil influenced by oxygen.

Anti-corrosion

Corrosion inside a lubrication oil system can occur by the presence of acid products. These acid products can come from oxidized oil or sulphur acid out of heavy fuel oil. The additives who can neutralize these acids are called bases.

Corrosion can also be caused by water, the most anti-corrosion additives mix themselves with water to prevent corrosion by water. The only disadvantage of this characteristic is that when a purifier separates the water from the lubrication oil, a part of this additive will go with the water to the sludge tank.

Detergents

During the operation of diesel engines, small solid carbon parts can enter the oil inside the sump. Especially four stroke engines have this problem. The solid carbon parts will gather at places where the oil flow is relatively low. They also will increase the deposit of oil against hot surfaces.

The carbon parts will stick to each other, this can cause serious clogging of pipe lines and filters. The detergents can keep the carbon particles floating in the oil without sticking together. This will result in much smaller particles who will need much more time to gather inside the engine. If the sump will be drained, almost all the solid particles will go with the oil.

Anti-foam additives

Lubrication oil goes through a lot of movement during operation in much cases. This can cause air bubbles, foam will occur if the air bubbles stay intact for a too long time. This foam can enter the lubrication oil pump and will disturb the oil pressure. This will decrease the lubrication at engines and other mechanical machines. Foam can also disturb the proper working of hydraulic systems, this is possible because the working principle is based on oil pressure who cannot be compressed because it is a liquid. In all these cases, anti-foam additives will be added. This additive will break down the foam before any damage can occur.

Oiliness additives

The better the oil will stick to the surface, the better the lubrication will be. The oiliness is important when the oil film starts to disappear. The oiliness is influenced by the adhesion between the metal and oil, also by the cohesion between the oil molecules. The lubrication characteristics of natural oil are better than the characteristics of mineral oil, they also age faster than mineral oil and will cause more oxidation.

Another disadvantage of natural oil is that it will form an emulsion with water. The viscosity can become higher than the normal viscosity of the oil. In some cases, this emulsion will become like a kind of soap and the oiliness stays intact. Unfortunately this emulsion is incapable for proper lubrication of bearings under pressure. The relatively bad oiliness of the mineral oil can be improved by 5 till 20% by mixing it with natural oil. This mixture is called compound oil and is only use full if aging and the forming of an emulsion is not a big problem. For example the cylinders and pistons of compressors are lubricated by compound oil because the water on the cylinder liners will be absorbed by the lubrication oil.

Viscosity index improvers

The viscosity of lubrication oil changes when the oil temperature rises or drops. The change of viscosity is important for machinery that is designed to operate at big temperature differences. For example, a car engine has to operate in a hot summer and a cold winter without changing the oil. Also the lifeboat engine and the steering gear need to be available in every continent without changing the oil. The steering gear oil has to have a viscosity index of at least 140.

The viscosity index (V.I.) is an indication for the amount of change in viscosity by a change in temperature.

At a high viscosity index (V.I.) there will be a small change of viscosity when the temperature changes. If there is a low viscosity index the change of viscosity is relatively big when the temperature changes.

The viscosity index went from 0 to 100 in the past, nowadays the viscosity index can reach up to 160. This is possible because the existence of additives that are called V.I. improvers.

When the oil needs to have a very high lubrication performance under every possible circumstance, synthetic oil will be used. Synthetic oils have a very high resistance against aging and can resist very high and low temperatures. The only disadvantage of synthetic oil is the relatively high price.

E.P. additives

In cases where the oil film disappears by the cause of a high load, metal to metal contact will take place. Under normal circumstances, this is the beginning of wear. After a while the surfaces will get rougher what will increase the wear. An extreme pressure (E.P.) additive is the solution for this problem because this additive will create a smooth layer between the metal to metal contact. This layer reduce the wear when the film disappears.

2.2.3 Different kinds of lubrication

The purpose of lubrication is to reduce friction and wear between two touching surfaces by using medium in between the surfaces. This medium can be a solid, mouldable, liquid or gas. For example, graphite, grease, oil and air.

Even a polished surface looks rough under a microscope, little mountains are visible. If two materials slide against each other, these mountaintops will touch each other. The heat that is caused by friction, will attach the materials a little bit to each other by some kind of welding, after attaching they will break loose form each other during the friction. The surfaces will become rougher and the friction and wear increases.

The lubrication is between the surfaces to prevent the tops to touch each other. There can be full lubrication or boundary lubrication.

Full lubrication means that the oil film is thick enough to make sure the mountain tops don’t touch each other. This is also called wet or hydrodynamic lubrication. Is this case, there is almost no wear and friction. The friction of the oil itself is caused by a difference in speed of the oil layers. This kind of lubrication is often used for turbine bearings, crankshaft bearings and other bearings for rotating shafts.

Boundary lubrication occurs when the oil film is not able to separate the moving surfaces completely. Without taking special measurements, friction and wear will occur. That is why the oiliness additive will be added to prevent wear when boundary lubrication occurs. This will keep the oil film intact. If the oiliness additives are not enough to maintain the oil film, E.P. additives need to be added to make sure there won’t be any excessive wear.

Ball and roller bearings will always require a special kind of lubrication called hydro elastic lubrication. By the fast rising pressure on the surfaces, the oil/grease becomes like rubber and stays between the surfaces instead of being removed by the pressure. When there is a too heavy load, not enough rotation speed or no rotation speed wear can occur easily.

2.2.4 SEA notification

The SAE (Society of Automotive Engineers) is a American club of technician. The SEA made a lot of standard notifications.

For proper operation of a trunk piston engine, viscosity of the oil inside the sump is very important. This is because the oil also has to lubricate the cylinders and pistons. On the other side, a too high viscosity will cause unnecessary friction loss in the bearings. The SEA notification is an indication for the viscosity. The referential temperature for the notification is 210°F (100°C) visible in Table 1 Explanation SEA notification.

The SAE notification is only an indication for the viscosity at 100 °C. For example, in the winter where a car battery only has 60% of its normal capacity, the oil cannot be too thick. For this reason, SAE has also winter notifications indicated by the letter W. The temperature for the W indication is 0°F (18°C).

By the use of V.I. improvers, multi grade oils are designed. The SAE indication is for example 15W/40. 15 is the viscosity at 18°C and 40 at 100°C. For a car this will make sure it starts well in the winter an provide proper lubrication when the temperature rises. For lifeboats, only SAE 10W/30 is allowed to use. This is visible on a metal plate beside the engine.

In the name of several brands of oil the SAE notification is visible. For example Shell shows the SAE notification after the name of the oil: Melina 30, Turbo 20. Mobil uses the first number to indicate the SAE

Table 1 Explanation SEA notification

SAE-getal	minimale viscositeit in mm^2/s bij 100 °C	maximale viscositeit in mm^2/s bij 100 °C
20	5,6	9,3
30	9,3	12,5
40	12,5	16,3
50	16,3	21,9

SAE-getal	maximale viscositeit in mP.s bij -18 °C	minimale viscositeit in mm^2/s bij 100 °C
5 W	1250	3,8
10 W	2500	4,1
15 W	5000	4,7
20 W	10000	5,6

2.2.5 The changing quality of lubrication oil during the use

In cooperation with the engine manufactures, oil companies will test the lifetime of their oils during the operation of the engine without decreasing of the quality. In the manual of an engine, the lifetime of several brands of oil can be found. In a lot of cases, the lifetime of the oil is longer than the manual indicates because it is tested under the maximum load. But without proper checking the oil quality during the operation, it is a risk to expand the lifetime of the oil.

The use is a very important factor on the changes of the oil quality. A diesel engine operating under heavy load will have hot bearings, this will negatively influence the aging of the oil. The aging of the oil is even more when it is used for piston cooling/lubrication.

Oil inside an engine who operates in cold conditions without heating up properly will have condense inside. This will add water and acid fuel products to the oil, carbon can enter the oil during operation, fuel can enter the oil by a leakage, inside steam turbines the steam can leak and enter the oil, in a gearbox small metal parts can float inside the oil. The point is that the oil can be fouled in every machinery which will lead to aging.

Solid particles can be removed by filtering ore purifying the oil. The thickness of an proper oil film is approximately 10 micron. All the particles of this size ore bigger need to be removed to maintain the proper oil film. Also the smaller particles can cause damage. By sending an oil sample to the laboratory, the quality can be determined.

Nowadays, there is so much anti-corrosion additive inside that the oil almost never gets acid anymore. The TBN (total base number) is an indication of the amount of anti-corrosion additive inside the oil.

The lubrication oil can absorb the carbon because the presence of detergent. The absorption of carbon will influence the viscosity of the oil. It is common that the oil inside diesel engines is rejected for further use because of a too high viscosity. By purifying, a lot of carbon can be removed from the oil. If the purifier continuous cleaning inside the port, the quality of the lubrication oil will rise significant because the fouling of the engine is stopped temporary.

The flashpoint of the lubrication oil can be influenced by fuel leakage. A too low flashpoint can be the cause of an explosion who will occur when there is a small electric spark ore a flame passing by a leaking piston. Unfortunately, fuel cannot be removed from the lubrication oil. The lubrication quality will decrease because of the mixing with fuel. Especially diesel and gasoil can ruin the lubrication oil quality very fast.

When the oil if a steering gear is filtrated properly, it can take years before the oil needs to be changed. Also the oil inside a turbine installation can have a long lifetime. When only visual checks of the oil are done by looking at the colour, the quality cannot be determined. Also in these cases samples need to be send to laboratories to determine the oil quality. Sometimes there are also special kits on board to check the oil quality. (H.Wytzes, 1998)

2.2.6 The lubrication oil on board of the Industrial Maya

The lubrication oil of the main engine on board of the Industrial Maya is Mobilgard M440. The SAE notification is 40. This lubrication oil is specially designed for medium speed trunk piston engines.

2.3 Heat exchangers

Heat exchangers Figure 20 A plate heat exchanger (Appendix 1 Illustrations to clarify the theoretical framework) are devices which will provide an exchange of heat between two mediums. Some applications of heat exchangers are lubrication oil coolers, LT coolers, HT coolers, cooling condensers, steam condensers, fuel pre-heaters, feeding water pre-heaters and radiators of a cars. The heat exchange can go through metal plates or pipes. Also mixing is an option if this is not a problem for the two mediums, but it will not be discussed in this chapter.

2.3.1 Pipe heat exchangers

The oldest heat exchanger is a pipe heat exchanger. One medium flows through the pipes while the other medium is surrounding the pipes as visible in Figure 6 A pipe heat exchanger. Because of the fouling that can occur, sea water flows through the pipes instead of around the pipes. This results in much easier cleaning when the layer of fouling becomes too thick.

The medium around the pipes is forced to move sideways along the pipes by walls inside the cooler, they follow the route of the arrows. This will result in an better exchange of heat. The combination of the seawater and the bronze parts will cause erosion of the iron parts. To reduce or even prevent this corrosion of the metal, rubber paint is used inside and zinc anodes are placed.

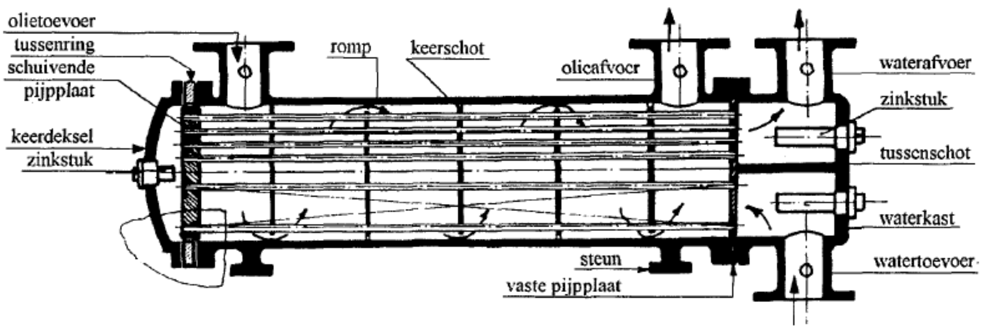


Figure 6 A pipe heat exchanger

Construction of a pipe heat exchanger

When the pipe heat exchanger is operating, the pipes are cooled by the seawater inside . The house is not cooled because the hot medium is flowing inside. This will cause a difference in expanding lengths. The pipes are attached to the plates in the front and aft of the heat exchanger. To prevent stress inside the heat exchanger caused by expanding, the plate in the aft can move inside the house. Two rubber O-rings will prevent the moving plate from leaking. Between the O-rings there is a hole inside the house. This hole makes it easy to detect leakages when one of the O-rings breaks.

If no fouling can occur inside the pipes they don't have to be straight for cleaning purposes. In this case they can be bended which results in more cooling surface as shown in Figure 21 Pipe heat exchanger with bended pipes (Appendix 1 Illustrations to clarify the theoretical framework). Another advantage is that there is no need for the moving plate.

In a heat exchanger with straight pipes, there are also plates installed in the middle of the house. They are installed for stabilizing the pipes and maintain the correct distance between them. In some cases there are also scrapers installed to clean the outside of the pipes. They can be moved by a spindle outside the heat exchanger. The scrapers that are visible in Figure 7 Pipe heat exchanger with scrapers, are often used when the heat exchanger is designed for heating fuel.

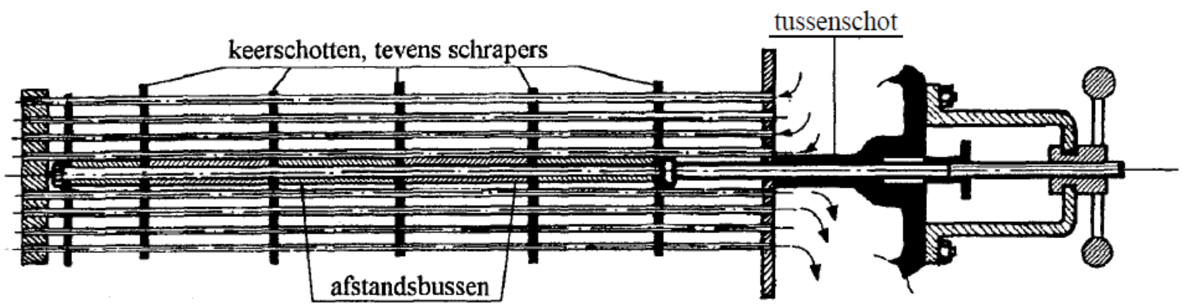


Figure 7 Pipe heat exchanger with scrapers

2.3.2 Plate heat exchanger

A pipe heat exchanger needs to be very big compared to a plate heat exchanger for the same amount of heat to exchange. When a pipe heat exchanger is installed there is also the need for extra space when it needs to be disassembled, the long pipes need to slide out of the house so when the pipe heat exchanger is disassembled the length will be almost twice the normal size of the exchanger.

If the pipes are replaced by plates, the same heat transferring surface can be realized in a much smaller space. A plate heat exchanger Figure 22 Working principle and exploded view plate heat exchanger (Appendix 1 Illustrations to clarify the theoretical framework) will use gaskets to keep the mediums inside and prevent leakages. If the gaskets are placed properly they will guide the mediums to flow next to each other.

There are special grooves inside the plates to keep the gasket in position. Most of the times the gasket will also be glued to the plates. The wave pattern of the plates will increase the guiding surface, this will increase the heat transferring capacity and the stiffness of the plates and will make sure that the flow between the plates always can be maintained when there is a pressure difference between the mediums.

2.3.3 Heat transfer

The flow of the heat between two liquids can be calculated by the following formula:

$$Q = k * A * \Delta Taverage$$

In this formula is:	Q	The flow of the heat in Watt
	A	Heated surface in m2
	ΔT average	The average temperature difference between the liquid in °C
	K	Heat transmission coefficient in Watt/m2/°C

This formula shows the influence of K, a heat exchanger can be very small if the heat transmission coefficient is very big. Another formula for the heat exchange is:

$$q = \frac{Q}{A} = k * \Delta Taverage$$

In this formula, q is the conduction in Watt/m2. This formula can be used for calculating the minimal surface of the plates if the amount of heating energy to exchange is already determined.

Heat transmission coefficient

The heat transmission coefficient (k) is an indication for the conduction of the separation material between the two liquids. There are several factors who have their influence on K:

- The thickness of the material
- Conduction of the material
- Fouling of the material
- Speed of the liquid flowing against the material

Especially the speed of the liquid against the material is an important factor for the heat transmission coefficient. A big flow will reduce the thickness of the layer sticking to the material compared to a small flow. In Table 3 K-value at different circumstances and coolers (Appendix 1 Illustrations to clarify the theoretical framework) are indications shown for heat transmission coefficients in several circumstances.

ΔT average

In the formulas from chapter 2.3.3, ΔT average is used. This value needs to be calculated. The calculation is based on the temperature changes during the heat exchange. The following values are used in the calculation:

- In (T1max) and outgoing (T1min) temperature of the cooled liquid.
- In (T2min) and outgoing (T2max) temperature of the heated liquid.
- The flow of the mediums (against each other or in the same direction).

The formula of ΔT average for mediums flowing in the same direction is:

$$\Delta Taverage = \frac{(T1max - T2\min) + (T1min - T2\max)}{2}$$

The formula of ΔT average for mediums flowing against each other is:

$$\Delta Taverage = \frac{(T1max - T2\max) + (T1min - T2\min)}{2}$$

The change of the temperatures is not linear in reality, the formula shown in this chapter will give a good indication but there will be a difference with ΔT average in reality. The difference for the liquids flowing against each other is small compared to the difference for the liquids flowing in the same direction Figure 8 Delta T average. (Smit & Wytzes, 2007)

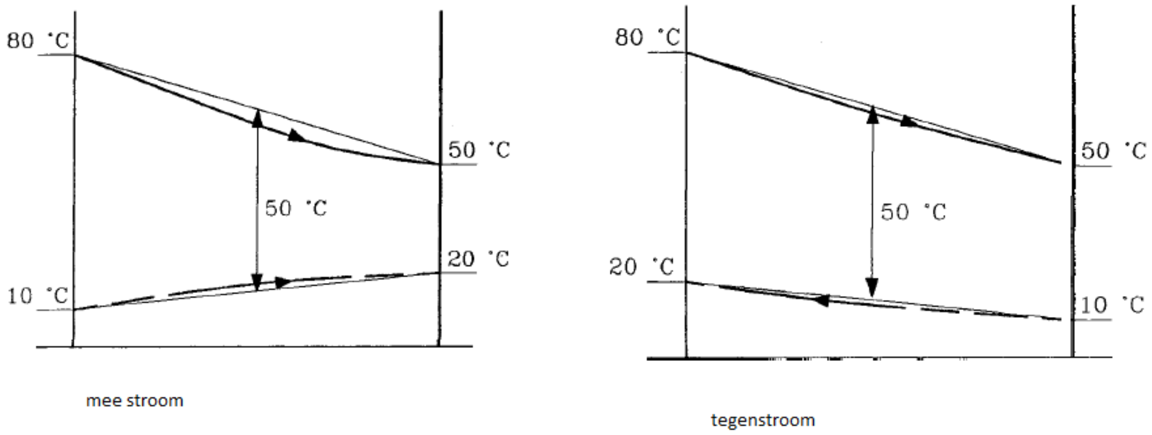


Figure 8 Delta T average

If the function Ln is added to the formula, the calculation of ΔT average will be more accurate.

The formula for ΔT average with Ln added for liquids flowing in the same direction is:

$$\Delta Taverage = \frac{(T1max - T2\min) - (T1min - T2max)}{Ln * (\frac{T1max - T2min}{T1min - T2max})}$$

The formula for ΔT average with Ln added for liquids flowing against each other is:

$$\Delta \mathrm{T\ average} = \frac{(T1max - T2\max) - (T1min - T2\min)}{Ln * (\frac{T1max - T2max}{T1min - T2min})}$$

(Martech opleidingen, sd)

Flow in the same direction or against each other

The two different types of flow have an influence on the amount of heat that can be exchanged. There is a difference in the capacity of the heat exchanger when the two types of flow are used. The capacity will be higher when flow against each other Figure 24 Flow against each other (Appendix 1 Illustrations to clarify the theoretical framework) is chosen than when to the flow in the same direction is used Figure 23 Flow in the same direction (Appendix 1 Illustrations to clarify the theoretical framework).

2.3.4 The pinch point

There will be a difference between the temperatures of the two liquids, even when flow against each other is used. This difference is called the pinch point. The higher the capacity of the heat exchanger is, the smaller the pinch point will be.(Ganapathy, 1996)

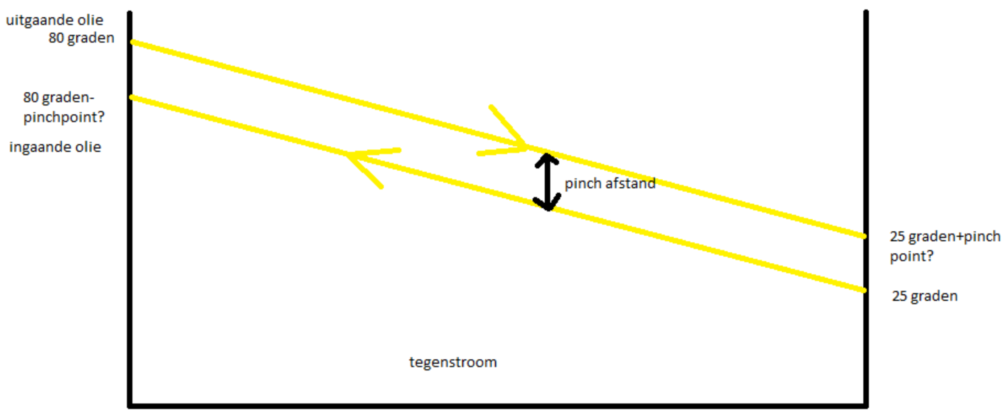


Figure 9 Pinch point

2.3.5 Exergy thanks to driving forces

At any process of devices during operation, the quality of energy becomes less. A part of this quality loss cannot be prevented, the other part can be prevented and will make the process more efficient.

Temperature-, pressure-, concentration-, difference in height.

The quality loss of energy is caused by driving forces, but what are these driving forces? An example of a driving force is the difference in air pressure between the inside of a rubber boat and the atmosphere. Or the difference between the temperature on the inside of a fridge and the temperature of the room where the fridge is located.

Another example of driving forces is the difference in concentration between pure oxygen and oxygen in the air of the atmosphere. All these driving forces will erase the difference if they get the chance. Compressed air will escape the rubber boat, hot air from the room will enter the fridge and the pure oxygen will mix with the air of the atmosphere.

Driving forces can also create a chemical reaction, for example when air and fuel ignite.

The bigger the driving force is, the faster the process will happen and the more quality loss of energy occurs. A disadvantage of reducing the driving forces is that the process speed also will be reduced. To compensate this reduced speed, bigger machines are necessary.

Example of a heat exchanger

A water flow of one litre per second has to be heated from 40°C to 50°C. There is a choice between two water temperatures for the heating.

- A hot water flow of 95°C and one litre per second
- A hot water flow of 70°C and one litre per second

There is adopted that all the heat will be transferred to the flow who needs to be heated and the heat exchanger is located in a room whit a temperature of 25°C. Which hot water flow is the best option?

Answer:

The smaller the driving force, the smaller the amount energy loss will be. The driving force is the temperature difference between the room and the water flow. This difference is the smallest when the flow of 70°C is chosen. A simple calculation will confirm that when the 70°C flow is chosen, the energy loss is smaller compared to the flow of 95°C. (Italsma, 2016)

The following formula will be used to calculate the exergy loss:

$$Exergy\ loss\ = To * (m1 * \left(\frac{c1}{1000}\right) * Ln\left(\frac{T1min + 273}{T1max + 273}\right) + m2 * \left(\frac{c2}{1000}\right) * Ln\left(\frac{T2max + 273}{T2min + 273}\right))$$

Exergy loss	Exergy loss during the heat exchange in KW
To	Environment temperature in Kelvin
m1	Flow in kg/second of the heating water
m2	Flow in kg/second of the water that needs to be heated
c1	Specific heat of the heating water J/Kg/Kelvin
c2	Specific heat of the water that needs to be heated in J/Kg/Kelvin
T1 and T2	Temperatures in °C

2.4 Hot water system

In systems where water is used to transport heat energy, the water pressure needs to be high enough to prevent the occur of steam. (Smit & Wytzes, 2007)

The system on board of the ship has a temperature of 102 degrees. The water is preheated by the HT cooling water system of the main engine. The water will be heated further by electric elements at sea or an oil fired boiler in port (CFL, 2015).

Only the capacity of the hot water system important for this research to calculate the possibility of the modifications. This capacity will be determined on board. The capacity needs to be big enough for the extra heating purposes.

2.5 Main engine

The main engine on board of the Industrial Maya is a MAK 8M32. The maximum power of this engine is 4000 KW. (CFL, 2015) This is a trunk piston eight cylinder four stroke engine with a nominal rpm of 600 what makes the engine a medium speed engine. (Kuiken, 2008)

The lubrication oil of the main engine is designed with a dry sump system. All parts of the main engine are lubricated by the same oil. The oil reduces the friction but also fulfils other tasks like:

1. Cooling of the parts
2. Sound damping during the operation of the engine
3. Cleaning because the fouling will be flushed by the oil
4. Sealing, for example between the piston and the cylinder liner
5. Lubrication
6. Conservation, because the acid fuel can damage the steel parts

The next parts of the four stroke engine require lubrication and cooling by lubrication oil:

- Crankshaft and bearings
- Pistons
- Connection rods
- Camshaft and bearings
- Cams, rollers who make contact with the cams, push rods, rocker arms, valve springs and valves
- Lowest part of the fuel pumps
- Cylinder liners
- The gears between crankshaft and the camshaft

Because the lubrication oil also absorbs a part of the heat created by the main engine, it needs to be cooled after leaving the engine. The oil is cooled by a heat exchanger who will exchange the heat of the LT cooling water system with the lubrication oil. The basics of the lubrication oil system are shown in Figure 25 Oil system of the main engine (Appendix 1 Illustrations to clarify the theoretical framework). There are two circuits parallel on the sump tank. (Kuiken, 2008)

As mentioned before in chapter 2.2, the lubrication oil can become acid and contain carbon parts. This fouling occurs because of the use of HFO. The fouling will pass the pistons to the sump of the main engine. The current types of lubrication oil have such high PH values that they will not become acid. The carbon parts become a threat for the lubrication of they are bigger than the clearance of the bearings. Also the viscosity will rise too high because of the contamination by carbon parts.

Beside carbon, small metal parts can also foul the oil. Detergents will make sure that also the metal particles will go with the oil flow instead of sticking inside the engine. This makes it possible to separate them from the oil by a filter ore purifier. Purifying when the engine is not running is very effective because the fouling is stopped during the cleaning process. (H.Wytzes, 1998)

3. Research method

This research is based on improving an existing purifier installation and is a practical research, so called case study. This thesis is a qualitative research combined with field research.

A case study is only concerning one unit and there is only one way to describe the problem of the case which gives problems for making the research generalizable. In a case study, it is possible to prove the validity and reliability of the research and systematic analysing is used. The results of a case study can be very useful to the concerning organisation (Verhoeven, 2011).

The current conditions of the purifier installation on board of the Sole series of Canada Feeder Lines are not optimal to clean the lubrication oil. The required oil temperature before the purifier of 95 °C cannot be reached with the current set point of 102 °C of the heating water system. Because Canada Feeder Lines will remain the set point of the heating water system for economic reasons, the heating gear at the purifier installation needs to be modified or redesigned to make it able to reach the required oil temperature of 95°C.

Different types of research are used to find the answer for each sub question. Below are the types of research mentioned which are used to find the answers for the sub questions.

Sub questions	Type of research
1. Which contamination can the lubrication oil contain?	Literature research
2. What are the effects of using not proper cleaned lubrication oil?	Literature research
3. What is the background of the temperature requirements for proper cleaning?	Literature research
4. What is the amount of energy needed to heat the oil during normal operation conditions of the purifier?	Measuring
5. For which amount of time needs the cleaning process to continue to clean the oil when the main engine is not running?	Literature and semi structured interview
6. What is the best solution to solve the problem?	Calculating and comparing

First the literature research is done to gather background information and to acquire the knowledge to continue the research. Observation on board has supplied the remaining information to finish the research and to draw a conclusion. This research contains three options to improve the conditions of the purifier installations on board of the Sole series.

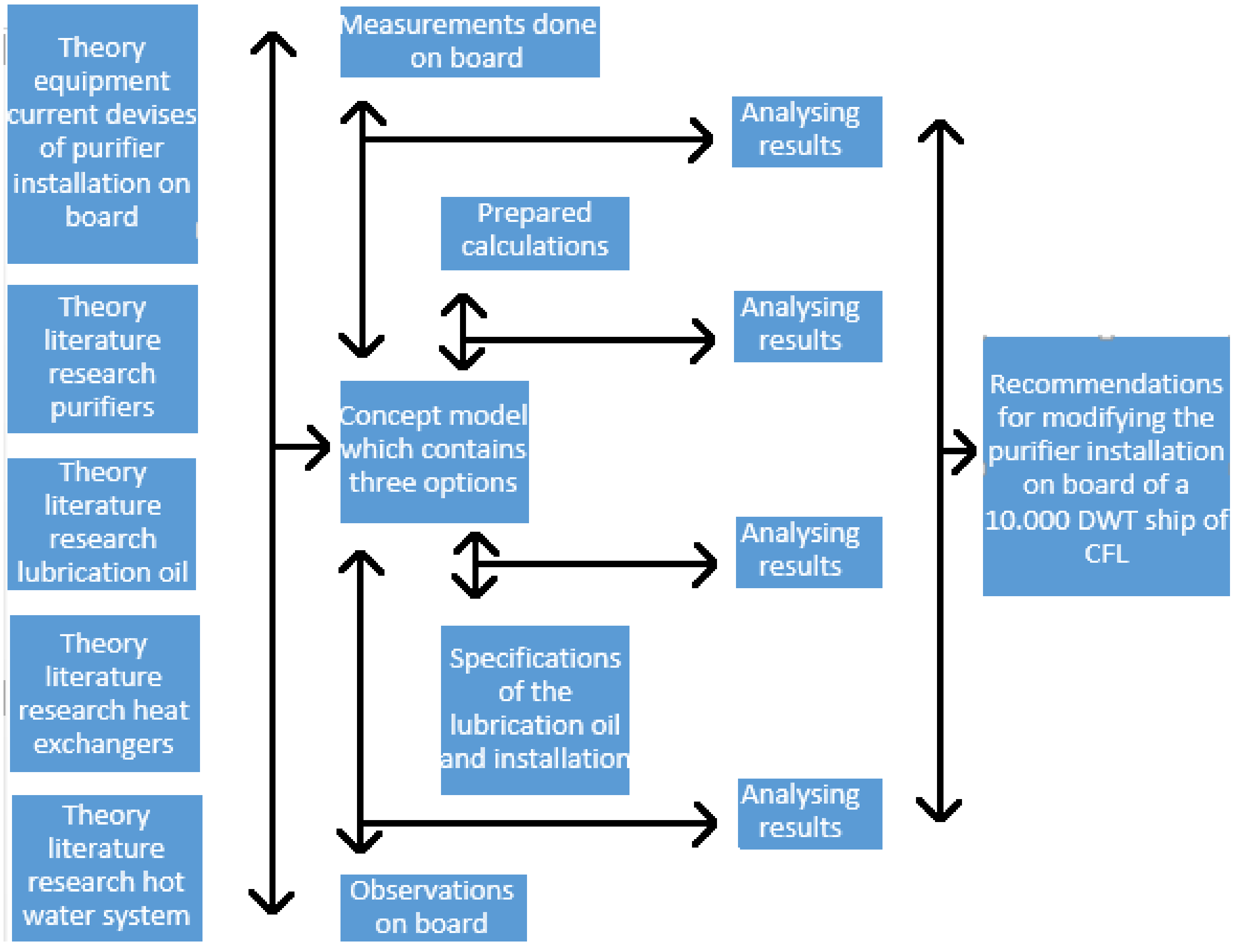
In the first place the feasibility is determined of each option. There is more than one option applicable for the installation and the most energy efficient option is determined. The calculations are prepared in the research proposal. To make the calculations as accurate as possible, the use of information which is gathered on board is necessary. The gathering of information is done by measurements when the installation was running in port, observation of the design of the installation and searching for information from manuals and test rapports.

For determining the most suitable option, a V-model is used. V-model means ''Verification and Validation model''. The V-shaped life cycle is a sequential path of execution of processes. Each phase must be completed before the next phase begins. Testing of the product is planned in parallel with a corresponding phase of development in V-model (ISTQB exam certification, 2016).

The advantages of a V-model are:

- Simple and easy to use.
- Testing activities like planning test designs happens well. This saves a lot of time.
- Proactive defect tracking – that is defects are found at early stage.
- Avoids the downward flow of the defects.
- Works well for small projects where requirements are easily understood.

A research model will provide a schematic view of the research goal and the global steps which need to be taken to reach this goal (Verschuren, 2015).



4. Results

This chapter contains the results of the research. The research is done to find the most suitable solution out of three options:

1. Replacing the current heat exchanger by a heat exchanger with more capacity or expanding the capacity of the current heat exchanger
2. Heat recovery by using the returning lubrication oil temperature
3. Reduction of the oil flow

The goal of option one is to increase the plate surface of the heat exchanger. A increased surface will provide the heat exchange between the heating water and the lubrication oil which leads to a smaller difference between the ingoing heating water temperature and the outgoing lubrication oil temperature. Because the ingoing heating water temperature remains the same, the outing lubrication oil temperature will rise. The smallest possible difference between these temperatures is called the ‘’pinch point’’.

Instead of changing/replacing the current heat exchanger, a heat exchanger will be added to the installation for option two. The additional heat exchanger will use the hot outgoing oil from the purifier to heat the oil that is transported from the sump tank by the feed pump of the purifier (Appendix 8 Pipe schedules of option two and three). This heat recovery will cause a higher ingoing temperature for the current heat exchanger. Less energy needs to be added by the current heat exchanger.

In option three the oil flow will be reduced (Appendix 8 Pipe schedules of option two and three). A lower flow will need a smaller amount of energy to heat it. The flow can be reduced till the capacity of the heat exchanger is enough to reach the preferred temperature of 95°C.

4.1 Information gathered on board by measurements and observations

This chapter contains information that is gathered on board of the ship.

4.1.1 Set point of the heating water system

The set point of the high temperature heating water which is used to heat the lubrication oil is reduced to 102 °C on board of the Industrial Maya. The purpose of the reduced set point is to save energy, the only disadvantage of the current set point is that the purifier installation is not able to operate under optimal conditions anymore. Because the oil fired boiler and the electric heaters are designed for higher temperatures up to 110 °C and the capacity of the circulations pumps remains the same, the capacity of the complete heating system is big enough to handle a bigger heat exchanger without dropping the heating water temperature.

4.1.2 Feeding pipe diameter

Because the feeding pipes of the heating water system have a limited diameter and the electrical valve which controls the heating water flow through the heat exchanger is normally fully opened during the process, the maximum heating water flow cannot be increased by only changing the heat exchanger. Increasing the water pressure can be possible by replacing the circulation pumps but this will increase the pressure on all the components of the system which will cost energy and is not necessary.

4.1.3 Measuring the temperatures during operation

A digital thermometer is used for measuring the temperatures (Appendix 2 Pipe schedule oil cleaning installation). The used thermometer is a ''Dallas 18 B 20''. This thermometer measures with 0,5 °C accuracy (Maxim Integrated Products, 2015). The measured oil temperatures are:

- The temperature of the lubrication oil before the heat exchanger 57,4 °C
- The temperature of the lubrication oil after the heat exchanger 87,3 °C
- The temperature of the lubrication oil after the purifier 91,0 °C

The measured water temperatures are:

- The temperature before the heat exchanger 98,7 °C
- The temperature after the heat exchanger 93,9 °C

4.1.4 Measuring of the heating water flow through the heat exchanger

Unfortunately it is not possible to monitor the heating water flow through the heat exchanger during normal operation without making changes on the installation. Because the flow of the heating water is a necessary value for further calculations during the research, the installation was temporary modified to make the measurements.

There are two thermometers installed, one after the inlet valve and before the outlet valve. These thermometers were replaced by manometers (Appendix 3 Pipe schedules pressure and flow measurement). During operation of the LO purifier the inlet and outlet pressures of the heating water system were measured on the installed manometers (Appendix 3 Pipe schedules pressure and flow measurement) ,the HFO purifier was switched off and the HFO heat exchanger was isolated from the heating water system during the measurements of the pressures.

After the measurements the return pipe of the hot water from the HFO heat exchanger was removed and the return valve of the heating water back to the pumps remained closed. By opening the return valve of the HFO heat exchanger, the outlet pressure dropped till the same pressure occurred as during the measurements.

By filling up a bucket with the water flow coming out of the return valve of the HFO heat exchanger which regulates the water pressure, it is possible to measure the exact amount of water and filling time of the bucket. With these two values the heating water flow in litres per hour through the current heat exchanger can be calculated:

$$\frac{3600}{fillingtime\ in\ seconds} \times volume\ of\ water\ inside\ the\ bucket\ in\ litres$$

Some extra actions were taken to improve the accuracy of the measurement:

- The chief engineer was located at the expansion drum of the heating water system to keep the pressure on a constant of 2,0 bar because the pressure drops slowly if a small amount of water from the system is drained.
- The measurement was done for ten times to determine an average flow.
- The automatic regulation valve is always fully opened during normal operation of the current system, during the measurements was checked if this was also the case.
- Checked if there was no difference in the pressures when the HFO heater is also working.

The average flow of the heating water is 1774,6 litre per hour.

4.1.5 Oil cleaning installation

The cleaning installation of the lubrication oil is equipped with a feed pump from which the suction is located in the lowest part of the sump tank and the returning pipe (with clean oil after the purifier) is located in the highest part of the sump tank, this will result in no mixture of the clean and dirty oil inside the sump tank (Migas, 2016). Before the feed pump is a suction filter and between the feed pump and the purifier is the heater installed. There is a bypass between the inlet of the heat exchanger and the returning oil which is fully closed during normal operation (Appendix 2 Pipe schedule oil cleaning installation).

4.1.6 The pinch point

The pinch point is discussed in the theoretical framework in chapter 2.3.4. The pinch point is determined during the measurements with a reduced oil flow. The pinch point for further calculation is 3,3 °C.

4.1.7 The density of the lubrication oil

The chief engineer requested the laboratory for the density of the lubrication oil at 95 °C and 60 °C. There is a relatively small difference in the density of the lubrication oil at 95 °C and 60 °C (Migas, 2016).

60 °C	909,1 gram/litre
95 °C	908,9 gram/litre

Because of the relatively small difference, the density of 95 °C will be used for further calculations.

4.1.8 The specific heat and density of the heating water

The water inside the heating water system is fresh water produced by the evaporator. The specific heat and density depend on the temperature of the water (Appendix 4 The water density). During the calculations a density and specific heat of 95 °C will be used because this is the average temperature in the heat exchanger during the measurements (The engineering toolbox, 2016).

Specific heat water	4213 J/kg/K
Density water	0,962 Kg/L

4.1.9 The coldest oil temperature inside the sup tank

The coldest sump tank temperature measured on board of the Industrial Maya is 56 °C (Migas, 2016).

4.1.10 The K-value

The K-value stands for the heat transmission coefficient. This is the amount of energy that is conducted through the separation layer between the heating water and lubrication oil. The unit of the K-value is Watt / square meter / Kelvin. The factors which have an influence on the K-value are:

- The thickness of the separation material
- Conduction of the separation material
- Fouling of the separation material
- Speed of the liquid flowing against the separation material

The K-value will vary during the heating process and also depends on the temperature differences between the two liquids. To make sure the results of the calculations are as close to the reality as possible with the current information that is gathered, an K-value is used which is based on the average of heat exchangers where the temperature of lubrication oil and water is exchanged. The K-value for further calculations is 2000 W/m2/K (Smit & Wytzes, 2007).

4.1.11 Sub conclusion information gathered on board by measurements and observations

A clear view of the current purifier installation is created with the information gathered on board by measurements and observations. The important values are measured which will be the input of the calculations. The research will be based on this gathered information.

The highest oil temperature that can be reached by modifying the purifier installation while maintaining the current heating water set point of 102 °C, is the inlet water temperature of the heater minus the pinch point. This is 98,7 °C – 3,3 °C = 95,4 °C and is above the required minimum inlet temperature of the purifier. Reaching an oil temperature of at least 95 °C is possible.

4.2 Results of the calculations

The calculations (Appendix 5 Calculations) are based on the gathered information from chapter 4.1 and the results are discussed in this chapter.

4.2.1 Minimal required surface of the heat exchanger to reach 95°C under all possible conditions

The biggest possible amount of energy that needs to be exchanged to heat the lubrication oil to 95 °C is when the oil inside the sump tank has reached the coldest measured temperature (56 °C) (Migas, 2016). This amount of energy is 12569 KW. If 12569 KW is taken out of the heating water with the current flow, the difference between the ingoing and outgoing heating water temperature will be 6,3 °C.

ΔT average in the bigger heat exchanger will be 14,3 °C during this circumstance. The minimal required surface of the bigger heat exchanger to make this heat transfer possible is 0,44 m2.

4.2.2 Minimal required surface of the additional heat exchanger to use heat recovery

The current heat exchanger and the additional heat exchanger (Appendix 8 Pipe schedules of option two and three) have to be able together to add at least 12569 KW to the lubrication oil before it enters the purifier. Because the current heat exchanger is able to add 9630 KW, the remaining 2939 KW has to be added by the additional heat exchanger.

This energy for the additional heat exchanger will be taken out of the cleaned oil after the purifier that is returning to the sump tank. On both sides of this heat exchanger is the difference between the ingoing and outgoing oil temperature 9,1 °C. ΔT average inside the additional heat exchanger is 33,6 °C. This results in a minimal required surface of 0,044 m2 for the additional heat exchanger.

4.2.3 Maximal lubrication oil flow that can be heated to 95 °C under the current conditions

The bypass can be opened to reduce the oil flow through the current heat exchanger (Appendix 8 Pipe schedules of option two and three). Same as for the other two options, the maximum ΔT for the lubrication oil before the purifier that can occur is 39 °C. To increase the lubrication oil temperature to 95 °C during the coldest circumstances, the oil flow has to be reduced to 429 litres per hour.

4.2.4 Sub conclusion results of the calculations

Table 2 Specifications of the options, shows the calculated values of the three modifications when they would be operational. As visible, only option number two (heat recovery by an extra heat exchanger) is able to reach the preferred oil temperature without increasing the heating energy consumption ore reducing the oil flow. This option is the best modification, it will increase the availability but also the efficiency.

Table 2 Specifications of the options

Option	Oil flow litre/hour	Watt	Oil temperature before purifier
1	560	12569	95,4 °C
2	560	9630	95,4 °C
3	429	9630	95,4 °C
Current	560	9630	87,3 °C

4.3.1 Possibility of replacing the current heat exchanger by a heat exchanger with more capacity or expanding the capacity of the current heat exchanger

Because the measured pinch point (which is the difference between the heating liquid and the liquid which needs to be heated) is 3,3 °C, the lubrication oil to the purifier can only be heated to a maximum temperature of 95,4 °C if the current set point of the heating water remains 102 °C. This lubrication oil temperature is high enough for proper purifying. There is enough space inside the purifier room to install the bigger heat exchanger and the capacity of the heating water system is able to deliver the bigger amount of energy to the purifier installation. Although a bigger heat exchanger will increase the availability of the purifier installation, it will not increase the efficiency of the purifier installation.

4.3.2 Possibility of heat recovery by using the returning lubrication oil temperature

An additional heat exchanger where heat recovery will be used will not require more energy from the heating water system than the current heat exchanger already does, the extra heating energy will be taken from the returning oil. The purifier itself also adds some heat to the lubrication oil, this added heat is caused by mechanical losses inside the heat exchanger. During the measurements, the temperature of the oil coming out of the purifier was almost 4°C higher than the ingoing oil. If the size of the additional heat exchanger will be increased to a bigger surface than the minimal required surface, the heating installation for the lubrication oil will be even more energy efficient. The cleaned oil after the purifier will have a lower temperature before it reaches the sump tank, this will result in less cooling of the oil during the voyage.

Unfortunately the current heat exchanger is also designed for pre heating the lubrication oil in the sump tank in the port. If the additional heat exchanger recovers too much heat of the returning oil, the temperature of the oil inside the sump tank will drop too far in port. Heat recovery is a suitable option which will increase the efficiency and availability of the purifier installation. It is important to keep the size of the additional heat exchanger limited to prevent the oil temperature of the sump tank of dropping below 56 °C during the stay in the port.

4.3.3 Possibility of reduction of the oil flow

Reducing the oil flow is the cheapest option, only the by-pass needs to be opened for this option (Appendix 8 Pipe schedules of option two and three). The oil flow with a fully opened by-pass can be heated till 95,4 °C. Off course the disadvantage is that the lower oil flow through the purifier will result in a longer cleaning time of the complete sump tank. Another disadvantage is that a part of the ''dirty'' oil will go back to the sump through the same pipe as the clean oil, this will result in a mixture of the two oils which will causes an even longer time to clean the oil in the sump tank. The third disadvantage of the reduced flow is that the K-value will be influenced negatively (Smit & Wytzes, 2007). After a discussion with the chief engineer about the reduced oil flow plates were installed which prohibited reducing the oil flow because increased fouling of the heat exchanger can occur (Appendix 6 Information plate reducing the oil flow). Because the fouling of the heat exchanger and the longer cleaning times, reduction of the oil flow is not a suitable option.

5.Discussion

This chapter will contain a critical back-view on the thesis.

5.1 The losses of the heat exchangers

The losses of the heat exchangers are neglected during this research. Because the surface of the complete plate package of heat exchanger is not available on board of the Industrial Maya. An article confirmed that the losses of a heat exchanger are relatively small compared to the amount of energy that is exchanged.

‘’Heat losses or gains of a whole heat exchanger with the environment can be neglected in comparison with the heat flow between both fluid flows; i.e. a heat exchanger can be assumed globally adiabatic. Thermal inertia of a heat exchanger is often negligible too’’ (Martinez, 2015)

The losses will also be minimalized because the heat exchanger is installed in the hot purifier room where the temperature is about 35 °C and the heat exchanger is packed with a thick layer of isolation.

5.2 The pinch point

The value of the pinch point that is used for the calculations is determined during the measurements with the reduced oil flow. In reality when a bigger heat exchanger is used there is a change the pinch point is even smaller than the measured value. This will positively affect the possibility of the three options because the oil temperature before the purifier can be higher.

6. conclusion and recommendations

6.1 Direct answers to the main research question

The complete thesis was based on the main question:

''What is the best way to improve the cost-effectivity of the purifier installation on board of a 10.000 DWT ship of CFL?''

Whit all the three option it is possible to improve the availability of the purifier installation because the temperature of 95 °C can be reached with relatively lower sump tank temperatures according to the calculations and measurements, unfortunately is option number three ''reduction of the oil flow'' not suitable because it will increase the cleaning time of the complete sump tank and foul the current heat exchanger (Migas, 2016). Only the additional heat exchanger which will use heat recovery is able to increase the cost-effectivity of the purifier installation. This option is the best way to improve the cost-effectivity of the purifier installation on board of a 10.000 DWT ship of CFL.

6.2 Direct answers to the sub questions

To answer the main question, the sub questions need to be answered first. According Verschuren en Doorewaard, the questions can be divided in theoretical, empirical and analytical questions (Verschuren, 2015). The main research question is to be regarded as an analytical question.

The theoretical sub questions are:

1. Which contamination can the lubrication oil contain?
2. What are the effects of using not proper cleaned lubrication oil?
3. What is the background of the temperature requirements for proper cleaning?

The empirical sub questions are:

4. What is the amount of energy needed to heat the oil during normal operation conditions of the purifier?
5. For which amount of time needs the cleaning process to continue to clean the oil when the main engine is not running?

The analytical sub question is:

6. What is the best solution to solve the problem?

6.2.1 Which contamination can the lubrication oil contain?

In the theoretical framework (chapter 2.2) is described which contaminations the lubrication oil can contain and which effect they have. A summary of these contaminations is:

1. Acid from sulphur that comes out of the high sulphur HFO
2. Water
3. Carbon, especially 4-stroke engines
4. Solid particles that occur because of wear

The amount of acid that will be added by the high sulphur HFO is no problem because the basic additives will keep the PH-value of the lubrication oil above the limit (chapter 2.2.2). Water, carbon and solid particles can be separated from the lubrication oil by purifier. Anti-corrosion additives will absorb the water while detergent additives keep the particles floating in the lubrication oil without sticking together (chapter 2.2.2.). The higher the oil temperature, the better the purifying process will go because of the lower density of the lubrication oil (chapter 2.1.4).

6.2.2 What are the effects of using not proper cleaned lubrication oil?

The four contaminations that will occur when the lubrication oil is not proper cleaned are mentioned in chapter 6.2.1.

1. The acid can cause corrosion to the metal parts of the main engine, the acid cannot be purified from the lubrication oil. The PH value of the lubrication oil is high enough to neutralize the acid during the lifetime of the lubrication oil (chapter 2.2.2 Anti-corrosion). Wear because of the acid sulphur out of the HFO is not a problem.
2. The water will cause corrosion to the lubricated parts of the main engine and can change the specifications of the lubrication oil. The anti-corrosion additive can absorb an amount of water to prevent it from corroding the main engine (chapter 2.2.2 Anti-corrosion). The only possibility to separate all the water from the lubrication oil and prevent it from corroding the main engine is by purifying it under the wright conditions.
3. Carbon can clock oil pipes and filters (chapter 2.2.2 Detergents), it has a negative influence on the viscosity of the lubrication oil. To prevent carbon of clocking the lubrication oil circuit, it can be removed from the lubrication oil by purifying it under the wright conditions.
4. The solid particles will reduce the lubrication of the main engine which results in more wear (chapter 2.2.5). They can clock the filters and can be removed from the lubrication oil by purifying it under the wright conditions.

6.2.3 What is the background of the temperature requirements for proper cleaning?

Because the lubrication oil has a certain flow through the purifier (560 litre per minute), the separation speed needs to be high enough to separate the oil and the fouling from each other before the oil exits the purifier.

It is possible to use the law of Stokes to calculate the separation speed (chapter 2.1.3). As visible in the formula of the law of stokes, a low viscosity of the liquid and a big difference in density will increase the speed of the purifying process. Both can be realized by increasing the temperature of the ''dirty'' lubrication oil before it enters the purifier.

6.2.4 What is the amount of energy needed to heat the oil during normal operation conditions of the purifier?

The amount of energy that is necessary to heat the lubrication oil before it enters the purifier depends on the difference in temperature (ΔT) and the flow of the lubrication oil. The preferred oil temperature before the purifier is 95 °C and the flow is 560 litre per minute, the minimum sump tank temperature that is measured is 56 °C (Migas, 2016).

The maximum amount of energy that needs to be added to the lubrication oil to reach 95 °C is 12569 KW (Appendix 5 Calculations).

6.2.5 For which amount of time needs the cleaning process to continue to clean the oil when the main engine is not running?

The suction of the relatively cold and dirty oil from the sump tank is on the bottom. After the lubrication oil is heated and cleaned is will enter the sump tank from the top. Because the difference in temperature, there will almost be no mixture between the dirty and purified oil. The time that is necessary to continue the cleaning process when the main engine is not running is the volume of the oil inside the sump tank divided by the flow through the purifier (Appendix 5 Calculations).

6.2.6 What is the best solution to solve the problem?

The best solution for the problem is ''Heat recovery by using the returning lubrication oil temperature'' This solution is the most cost-effective.

6.3 Recommendations

Heat recovery by using the returning lubrication oil temperature is the most cost-effective solution. To realize the heat recovery, an extra heat exchanger needs to be installed to use the heat of the lubrication oil after the purifier. The calculated minimal surface of the additional heat exchanger is 0,044 m2.

When installing the additional heat exchanger in reality, some extra surface can be added to experiment with the size of the additional heat exchanger to find the optimal surface. The bigger the additional heat exchanger, the more efficient the purifier installation will be. Only the maximum size needs to be determined by testing in cold ports, if the size of the additional heat exchanger is too big the oil temperature in the sump tank will drop too far which will lead to purifying on a too low temperature.

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7. Figures and tables

8. Appendix

Appendix 1 Illustrations to clarify the theoretical framework

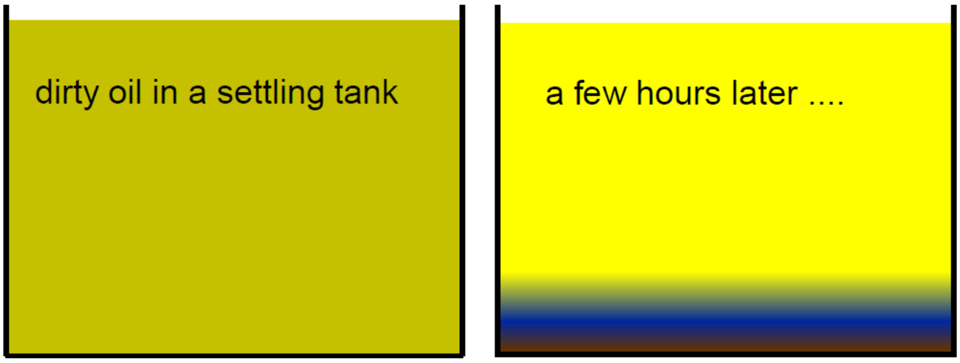


Figure 10 settling by gravity

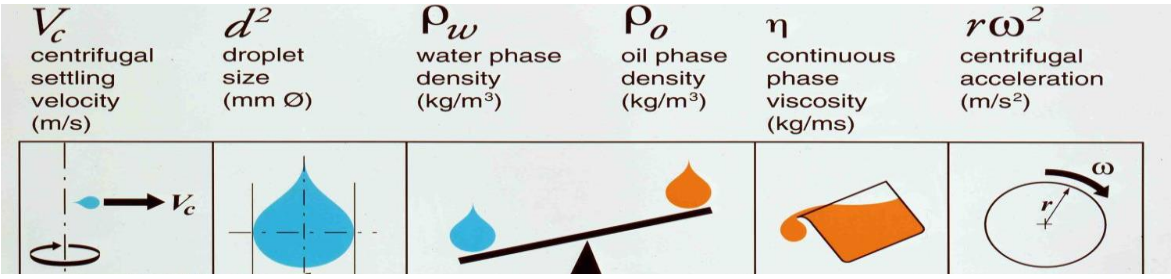


Figure 11 Explanation of the law of stokes

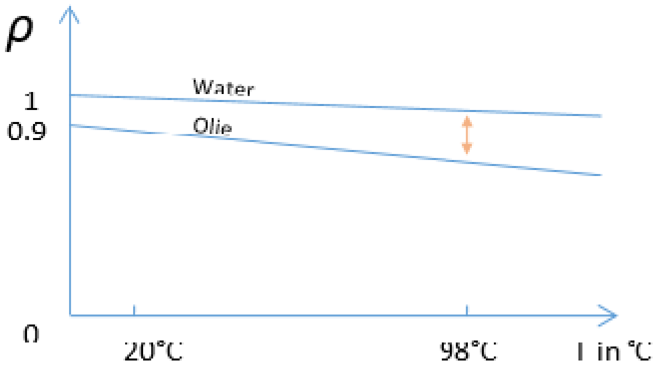


Figure 12 The density of oil and water

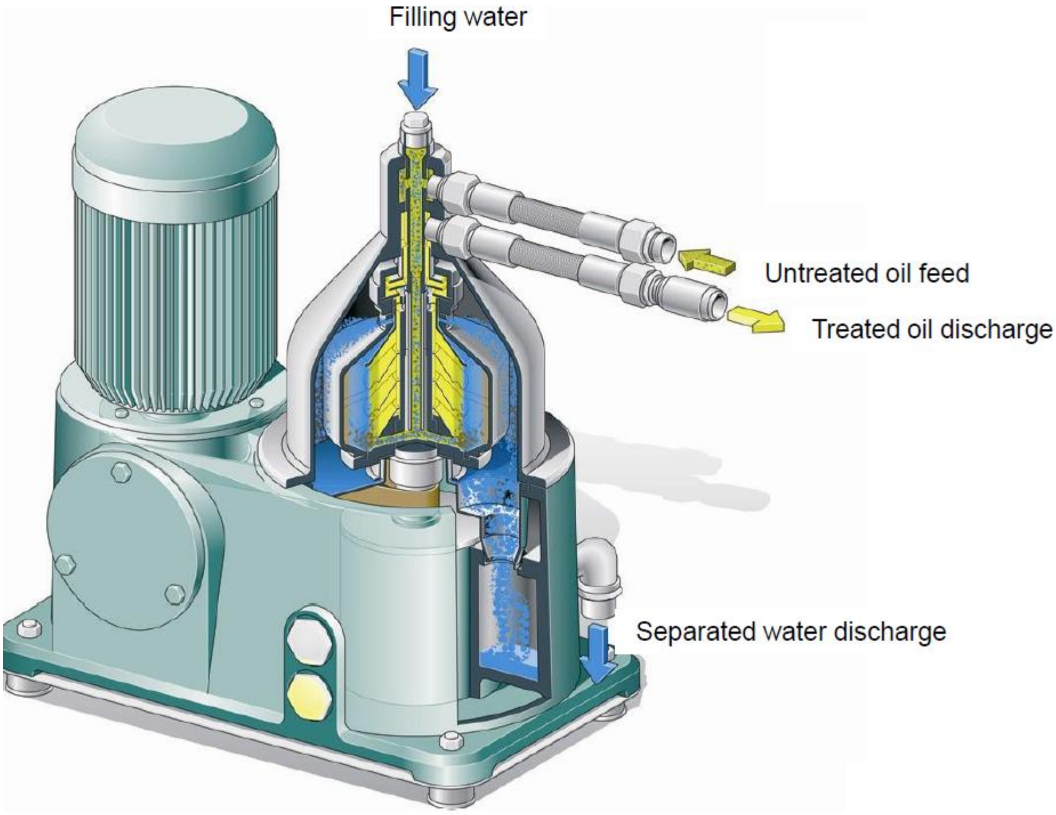


Figure 13 Not self-cleaning purifier

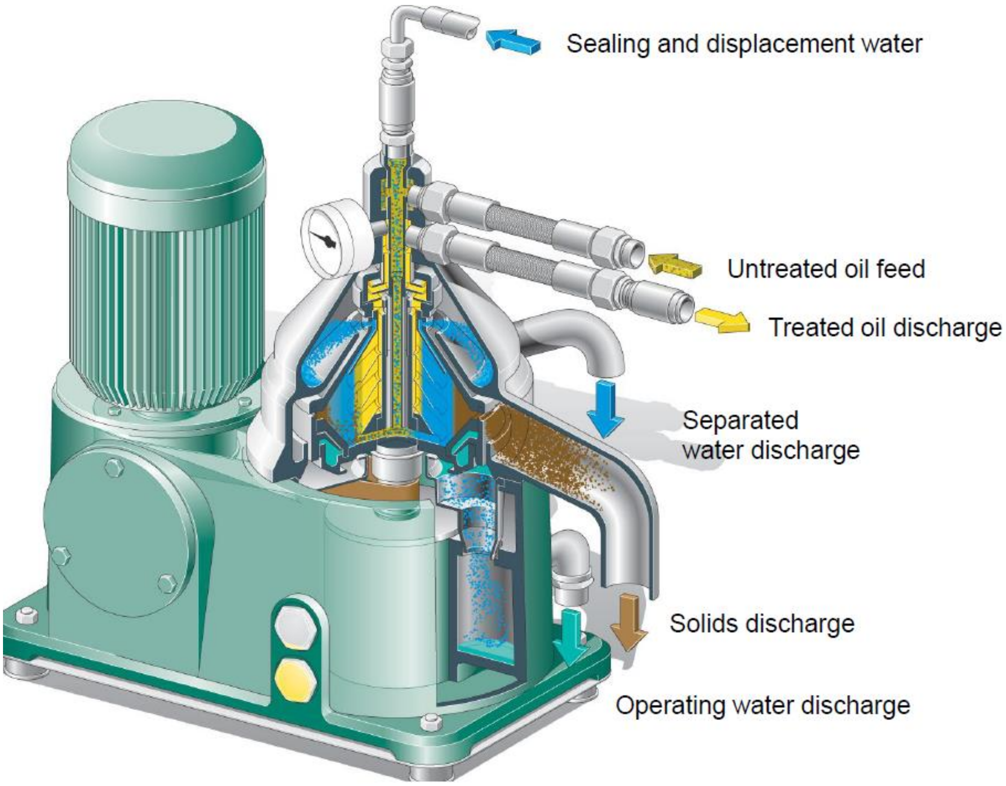


Figure 14 Self-cleaning purifier

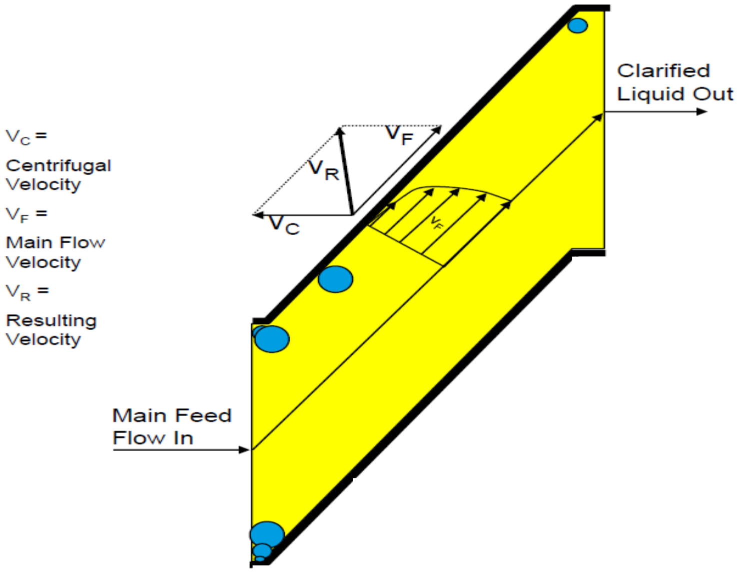


Figure 15 Forces on solid particles

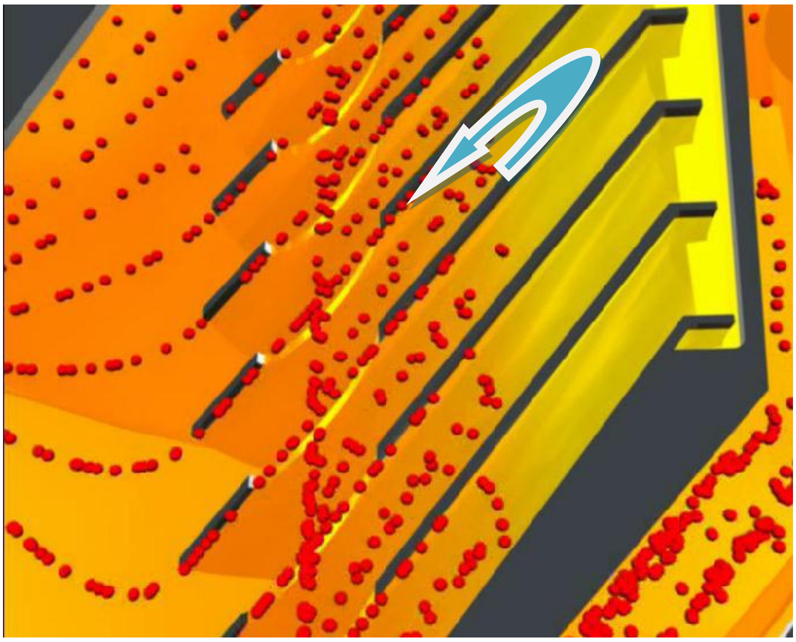


Figure 16 The route of solid particles between the discs

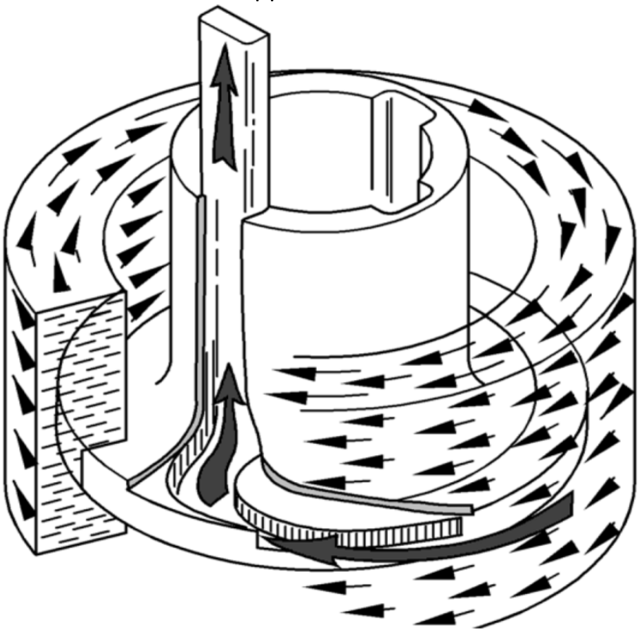


Figure 17 Centripetal pump

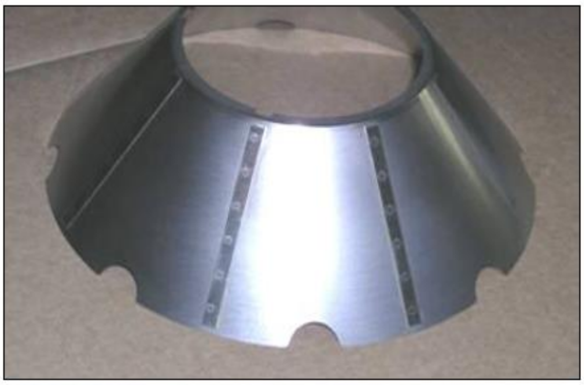


Figure 18 Disk from a purifier

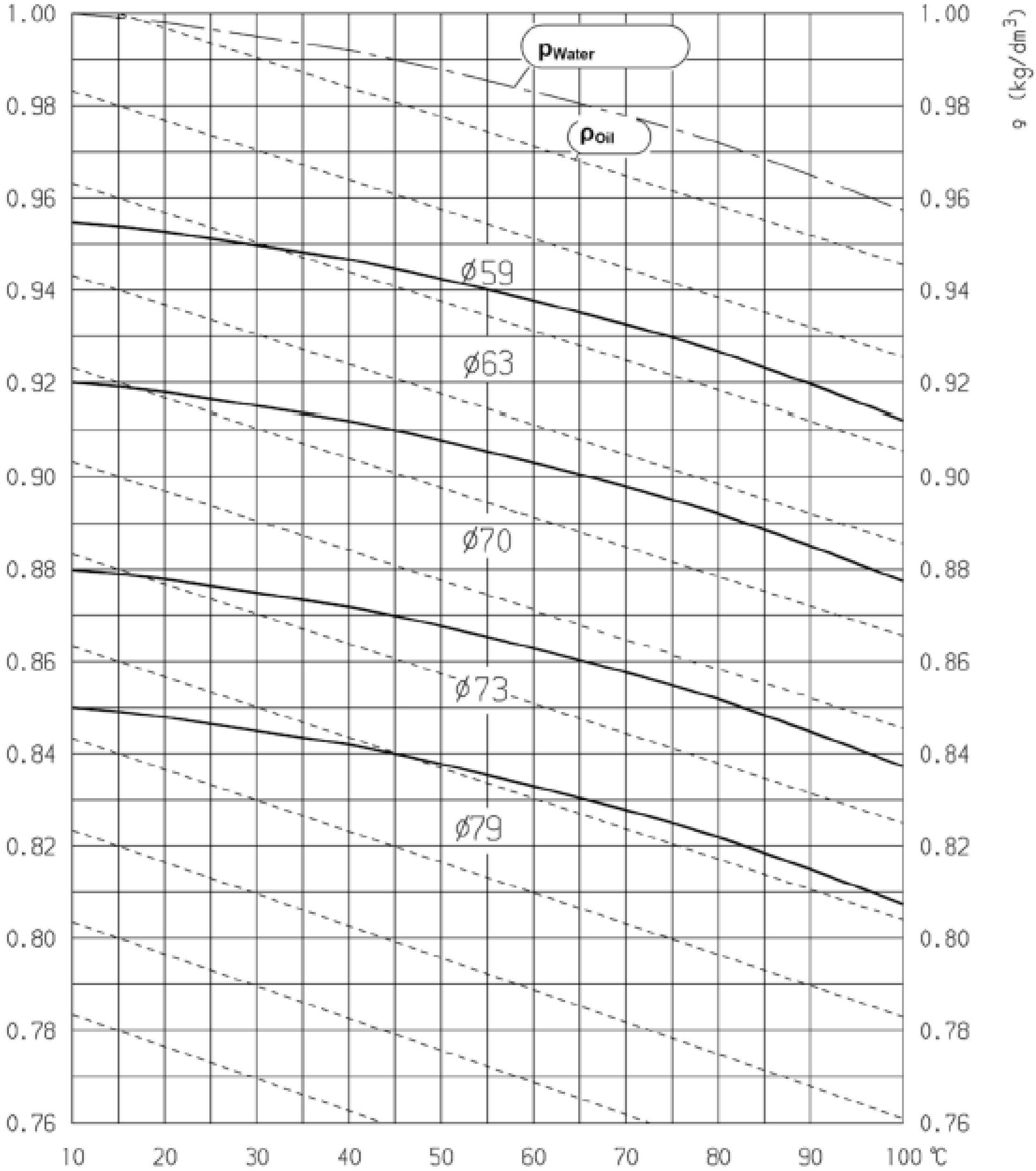


Figure 19 Diagram for determining gravity ring

Figure 20 A plate heat exchanger

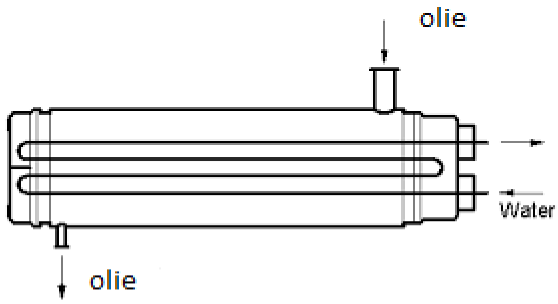


Figure 21 Pipe heat exchanger with bended pipes

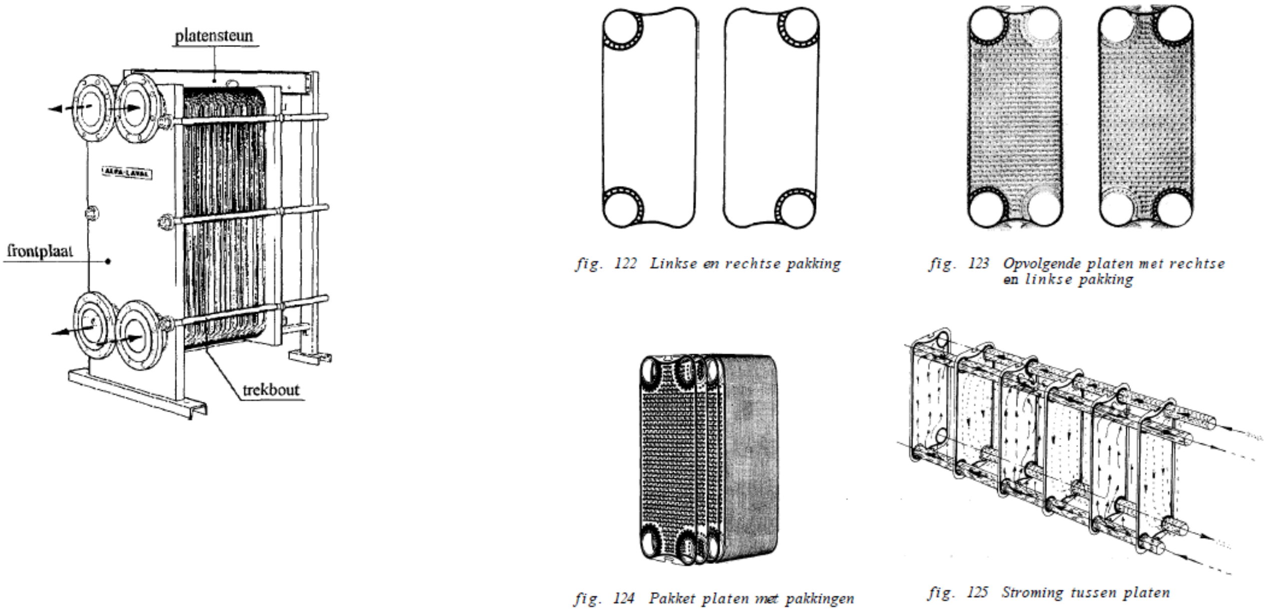


Figure 22 Working principle and exploded view plate heat exchanger

Table 3 K-value at different circumstances and coolers

	platen	pijpen
stoomcondensor	3500 W/m².K	2000 W/m².K
vriescondensor	2500	1500
smeeroliekoeler	2000	1000
koelwaterkoeler	4000	2500
ketelpijpen		100
autoradiator		50
gladpijpvriesverdamper (vrije convectie)		10
vinnenpijpvriesverdamper (gedwongen convectie)		15
brijnkoeler		500

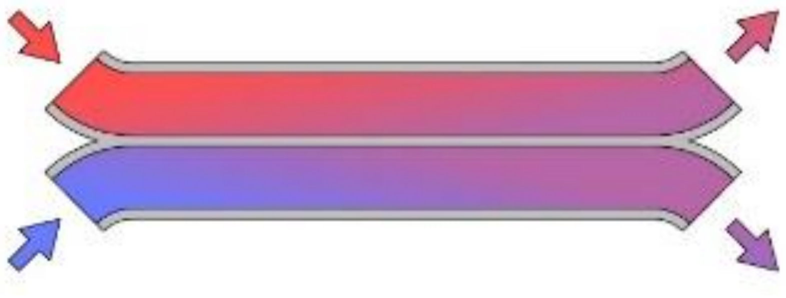


Figure 23 Flow in the same direction

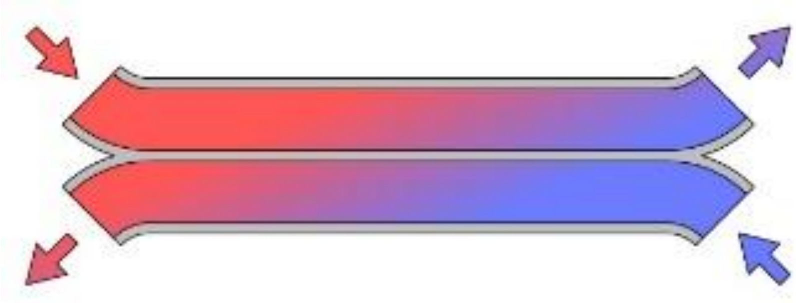


Figure 24 Flow against each other

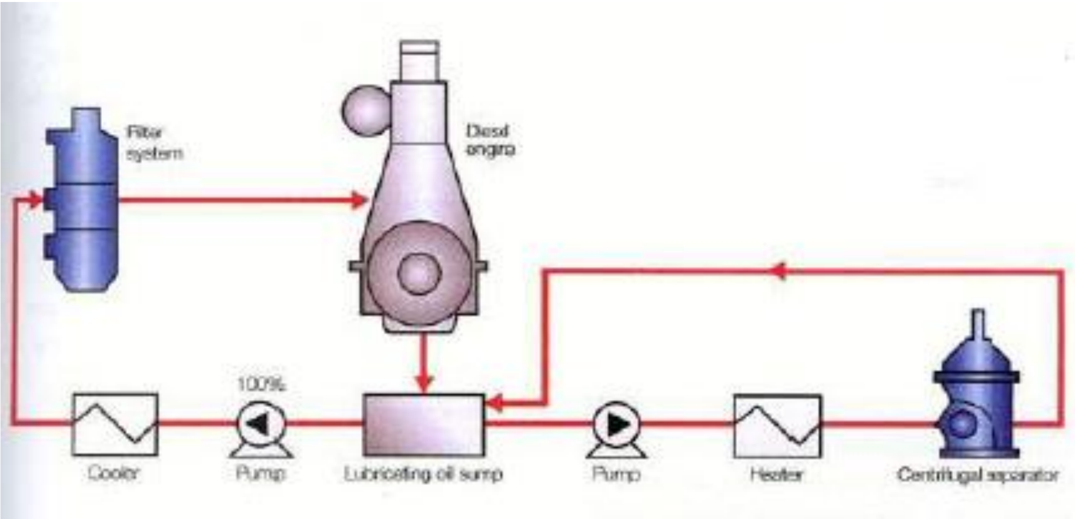


Figure 25 Oil system of the main engine

Appendix 2 Pipe schedule oil cleaning installation

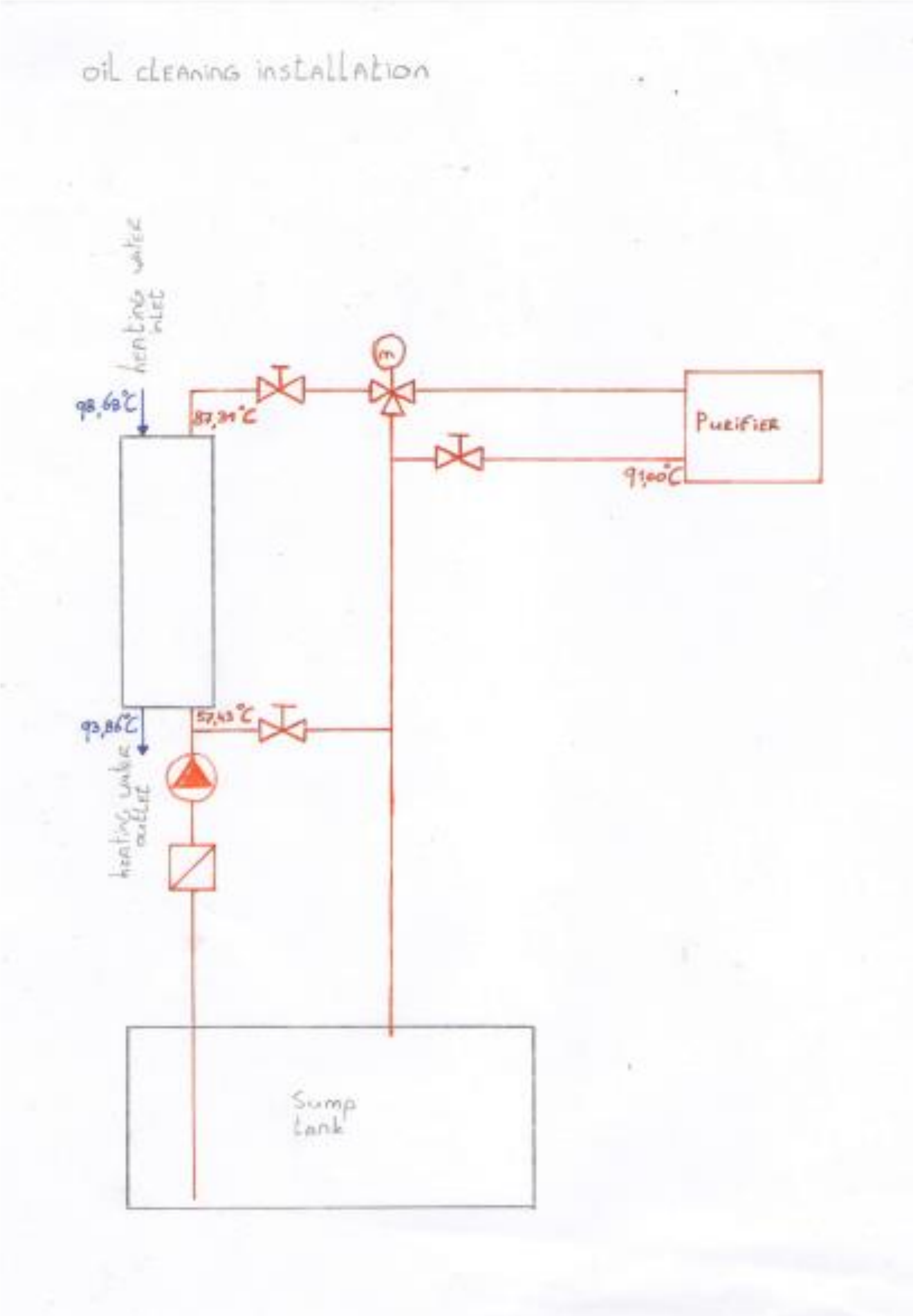


Figure 26 Pipe schedule oil cleaning installation

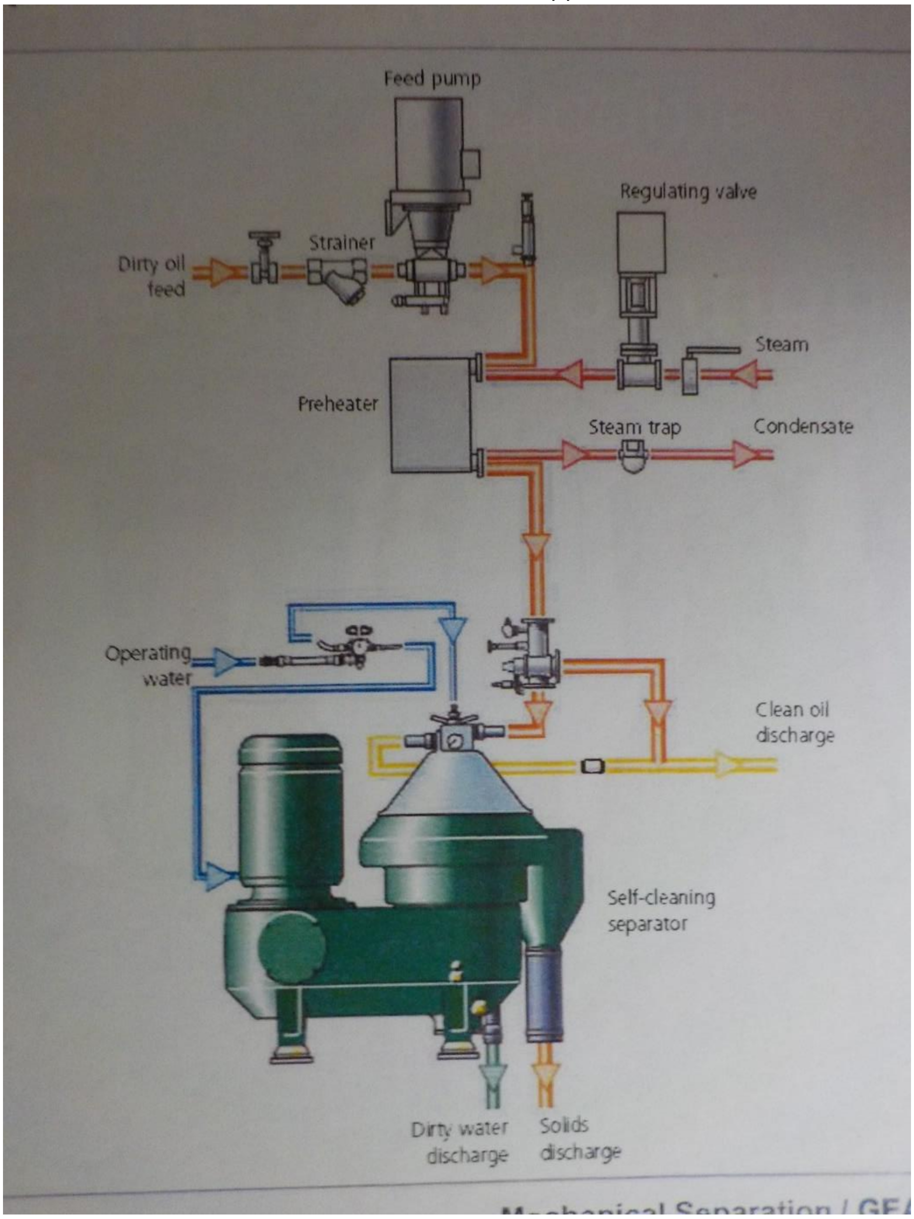


Figure 27 Pipe schedule out of manual

Appendix 3 Pipe schedules pressure and flow measurement

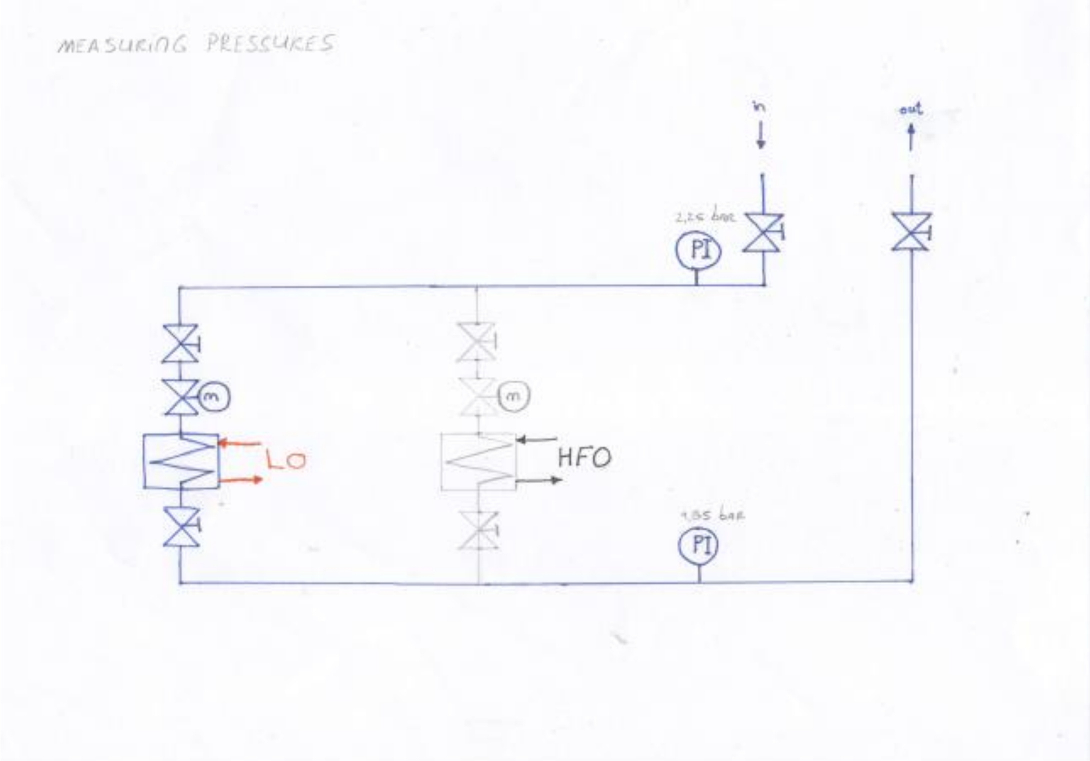


Figure 28 Pressure measurement

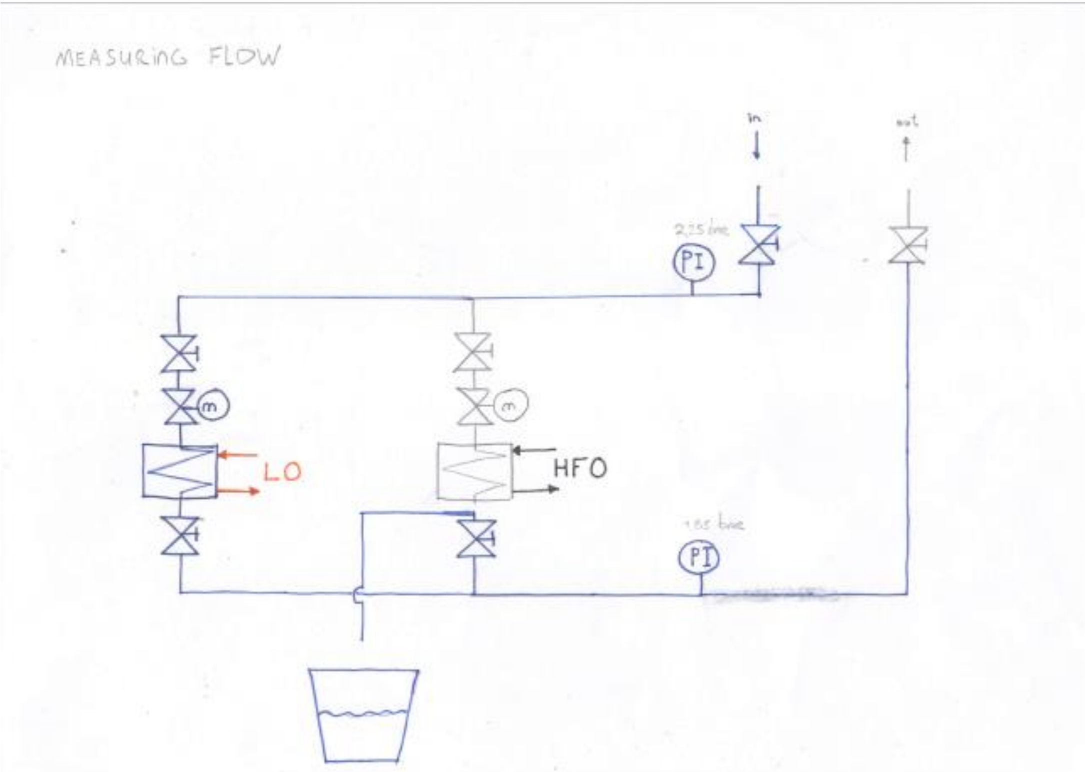


Figure 29 Flow measurement

Figure 30 Inlet pressure hot water

Figure 31 Outlet pressure hot water

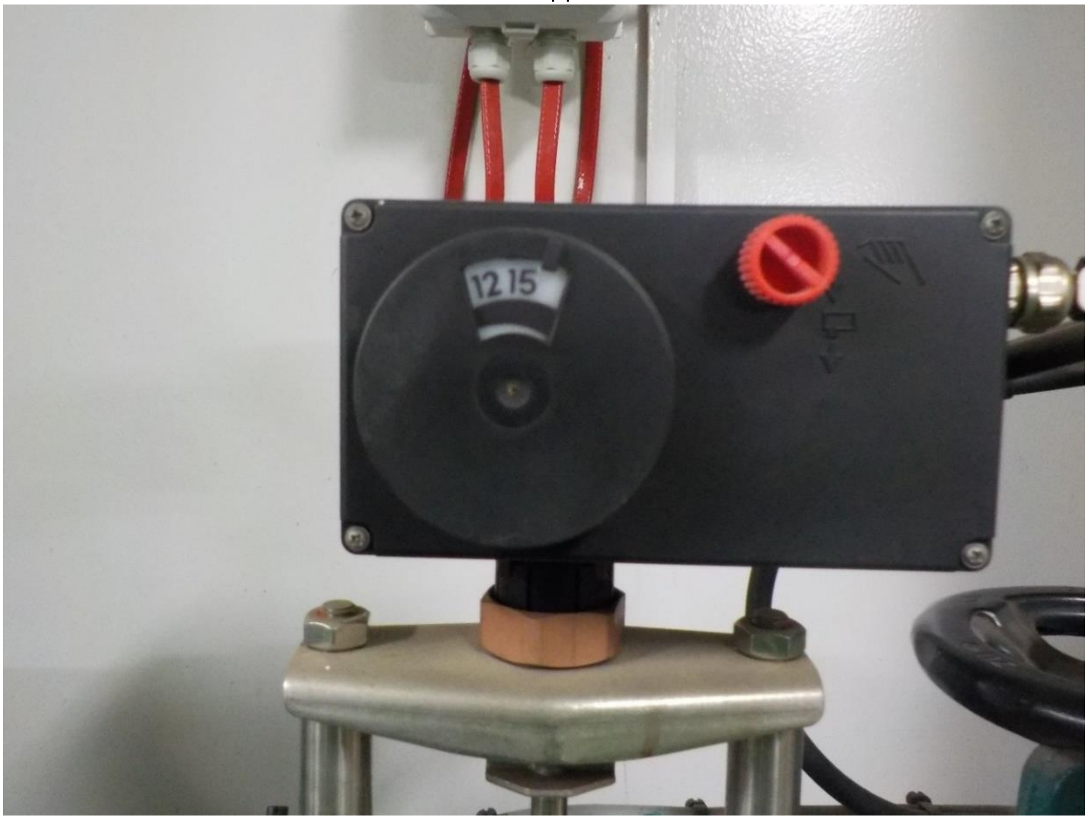


Figure 32 Fully opened regulation valve

Figure 33 Removed outlet pipe from HFO heat exchanger

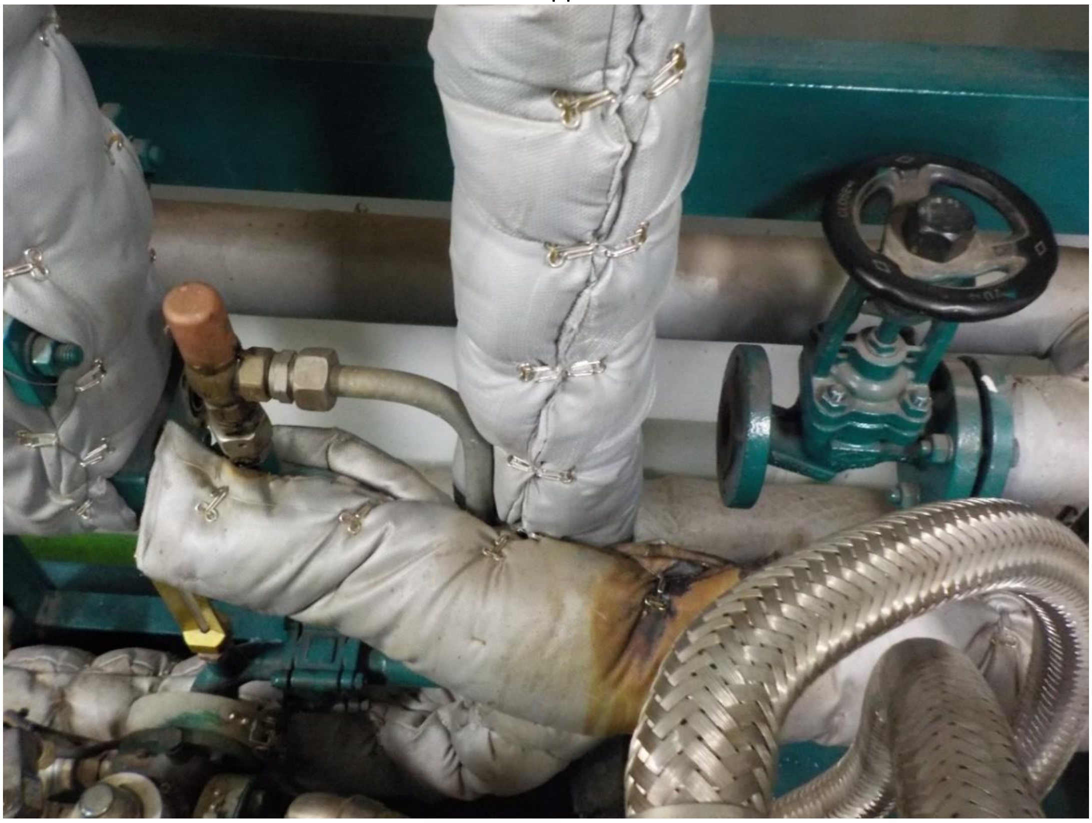


Figure 34 Hot water valve for HFO heat exchanger

Appendix 4 The water density

Table 4 The density of water

Temperature - *t* -	Absolute pressure - *p* -	Density - *ρ* -	Specific volume - *v* -	Specific Heat - c_p -	Specific entropy - *e* -
(^oC)	(kN/m^2)	(kg/m^3)	10^{-3} (m^3/kg)	(kJ/(kg K))	(kJ/(kg K))
0 (Ice)		916.8			
0.01	0.6	999.8	1.00	4.217	0
4 (maximum density)	0.9	1000.0		4.205	
5	0.9	1000.0	1.00	4.202	0.075
10	1.2	999.8	1.00	4.192	0.150
15	1.7	999.2	1.00	4.1855[1)]	0.223
20	2.3	998.3	1.00	4.182	0.296
25	3.2	997.1	1.00	4.180	0.367
30	4.3	995.7	1.00	4.178	0.438
35	5.6	994.1	1.01	4.178	0.505
40	7.7	992.3	1.01	4.179	0.581
45	9.6	990.2	1.01	4.181	0.637
50	12.5	988	1.01	4.182	0.707
55	15.7	986	1.01	4.183	0.767
60	20.0	983	1.02	4.185	0.832
65	25.0	980	1.02	4.188	0.893
70	31.3	978	1.02	4.191	0.966
75	38.6	975	1.03	4.194	1.016
80	47.5	972	1.03	4.198	1.076
85	57.8	968	1.03	4.203	1.134
90	70.0	965	1.04	4.208	1.192
95	84.5	962	1.04	4.213	1.250
100	101.33	958	1.04	4.219	1.307
105	121	954	1.05	4.226	1.382
110	143	951	1.05	4.233	1.418
115	169	947	1.06	4.240	1.473

Appendix 5 Calculations

Used value's

Water		**Oil**	
Flow	1774,65 litre/hour	Flow	560 litre/hour
Specific heat	4213 Joule/Kg/Kelvin	Specific heat	2279,51 Joule/Kg/Kelvin
ΔT	4,82 °C	ΔT	29,88 °C
Density	0,962 Kg/litre	Density	0,9089 Kg/litre

Lowest possible sump tank temperature 56 °C

Heat transmission coefficient (K-value) 2000 Watt/m2/°C

1. **Energy taken out of water: 9629,94 Watt**

$$Q\ (Watt) = flow\ (litres\ per\ hour) \times specific\ heat\ (Joule\ per\ Kg\ per\ Kelvin) \times \Delta\text{T}(\,°\text{C})$$

$$\left(\frac{1774{,}65 \times 0{,}962}{3600}\right) \times 4213 \times 4{,}82 = 9629{,}94\ Watt$$

2. **Specific heat of the lubrication oil: 2279,51 Joule / Kilogram / Kelvin**

$$\left(\frac{560 \times 0{,}9089}{3600}\right) \times 2279{,}51 \times 29{,}88 = 9629{,}94\ Watt$$

3. **Maximum required energy to the lubrication oil to 95 °C: 12569,20 Watt**

$$\left(\frac{560 \times 0{,}9089}{3600}\right) \times 2279{,}51 \times (95 - 56) = 12569{,}20\ Watt$$

4. **ΔT average during current operation conditions: 21,52 °C**

$$\Delta\text{T average} = \frac{(T1max - T2\max) - (T1min - T2\min)}{Ln * \left(\frac{T1max - T2max}{T1min - T2min}\right)}$$

$$\Delta\text{T average} = \frac{(98{,}68 - 87{,}31) - (93{,}86 - 57{,}43)}{Ln * \left(\frac{98{,}68 - 87{,}31}{93{,}86 - 57{,}43}\right)} = 21{,}52\ °C$$

5. **The surface of the current heat exchanger: 0,2237 square metre**

$$Q = K * A * \Delta Taverage$$

$$9629{,}94 = 2000 \times 0{,}2237\ m2 \times 21{,}52$$

The possibility of the following options to improve the availability of the purifier are calculated:

1. Replacing of the current heat exchanger by a heat exchanger with a bigger capacity or increasing the capacity of the current heat exchanger.
2. Heat recovery by an extra heat exchanger
3. Reduction of the oil flow

Replacing of the current heat exchanger by a heat exchanger with more capacity or expanding the capacity of the current heat exchanger calculations

1. **The maximum ΔT of the heating water : 6,291 °C**

$$12569{,}20 = \left(\frac{1774{,}65 \times 0{,}962}{3600}\right) \times 4213 \times 6{,}291\,°C$$

2. **ΔT average: 14,28 °C**

$$\Delta\text{T average} = \frac{(98{,}68 - 95{,}00) - (92{,}39 - 56{,}00)}{Ln * \left(\frac{98{,}68 - 95{,}00}{92{,}39 - 56{,}00}\right)} = 14{,}28\,°C$$

3. **The minimal surface of the bigger heat exchanger: 0,4402 m2**

$$Q = k * A * \Delta Taverage$$

$$12569{,}20 = 2000 \times 0{,}4402 \times 14{,}28$$

Heat recovery by using the returning lubrication oil temperature calculations

4. **Maximum heating recovery energy required out of the purified oil: 2939,26 Watt**

$$maximum\ required\ energy = recovered\ energy\ out\ of\ oil + energy\ out\ of\ heating\ water$$

$$12569{,}20\,Watt = 2939{,}26\,Watt + 9629{,}94\,Watt$$

5. **ΔT of the purified oil and of the oil inside the additional heat exchanger: 9,12 °C**

$$Q\ \ (Watt) = flow\ (litres\ per\ hour) \times specific\ heat\ (Joule\ per\ Kg\ per\ Kelvin) \times \Delta\text{T}(\,°\text{C})$$

$$2939{,}26 = \left(\frac{560 \times 0{,}9089}{3600}\right) \times 2279{,}51 \times 9{,}12\,°C$$

6. **ΔT average of the additional heat exchanger: 33,57 °C**

$$\Delta Taverage = \frac{(T1max - T2\max) + (T1min - T2\min)}{2}$$

$$\Delta Taverage = \frac{(98{,}69 - 65{,}12\,) + (89{,}57 - 56)}{2} = 33{,}57\,°C$$

7. **The minimal surface of the additional heat exchanger for heat recovery: 0,04378 m2**

$$Q = k * A * \Delta Taverage$$

$$2939{,}26 = 2000 \times 0{,}04378\,m2 \times 33{,}57$$

Reduction of the oil flow calculations

1. **The maximum ΔT that can occur during operation: 39 °C**

$$The\ maximum\ \Delta T = 95 - 56 = 39\,°C$$

2. **The maximum flow of the lubrication oil when 95 °C still has to be reached: 429,05 litre per hour**

$$9629{,}94 = \left(\frac{429{,}05 \times 0{,}9089}{3600}\right) \times 2279{,}51 \times 39$$

Time to clean the complete sump tank

$$\frac{volume\ inside\ the\ sumptank}{flow\ trough\ the\ cleaning\ installation}$$

3. **Time to clean the complete sump tank: 13,4 hour**

$$\frac{7491\ litre}{560\ litre\ per\ hour} = 13{,}38\ hour\ to\ clean\ the\ complete\ sumptank$$

Appendix 6 Information plate reducing the oil flow

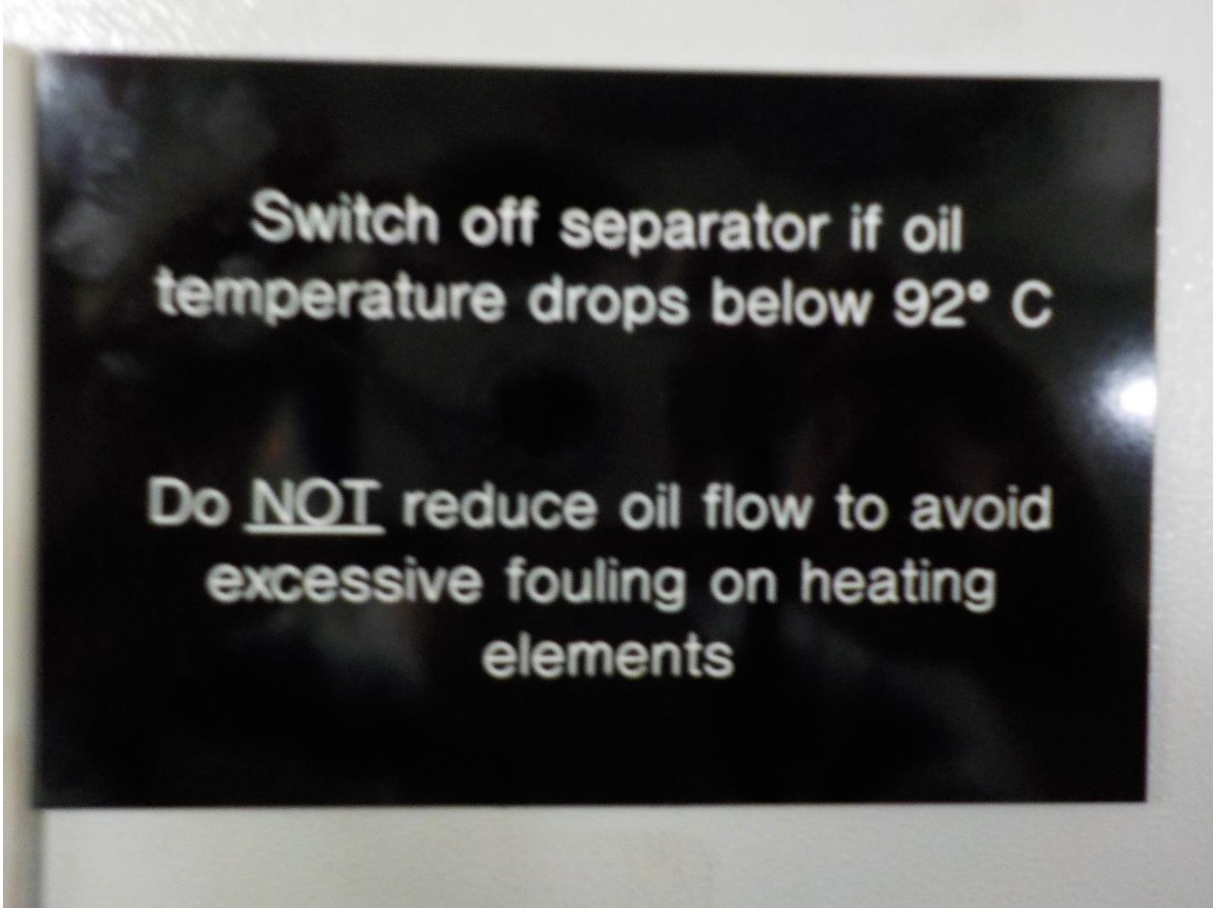
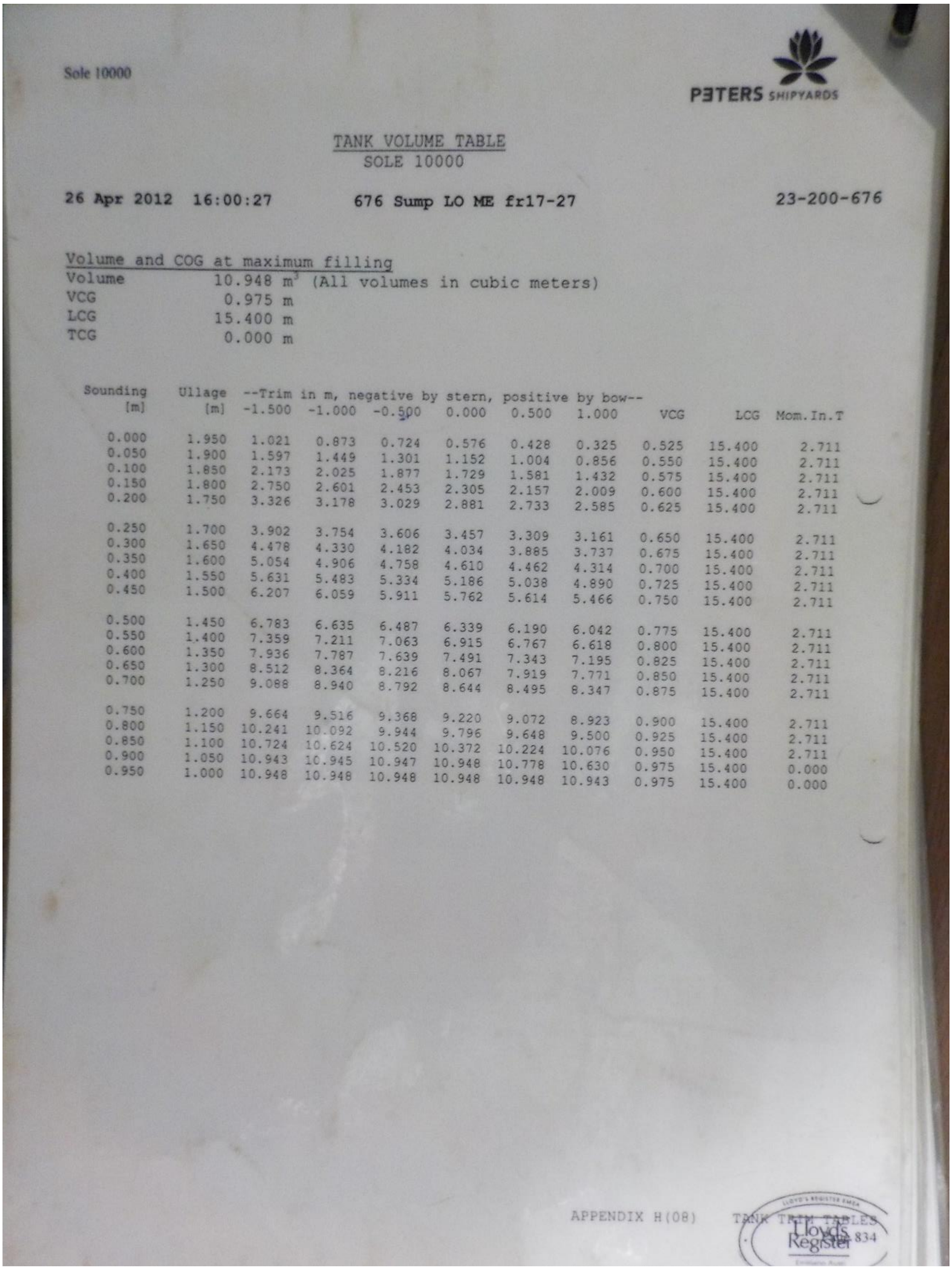


Figure 35 Warning plate for reducing the oil flow

Appendix 7 Sounding table sump tank



Sole 10000

PETERS SHIPYARDS

TANK VOLUME TABLE
SOLE 10000

26 Apr 2012 16:00:27 **676 Sump LO ME fr17-27** **23-200-676**

Volume and COG at maximum filling

Volume 10.948 m^3 (All volumes in cubic meters)
VCG 0.975 m
LCG 15.400 m
TCG 0.000 m

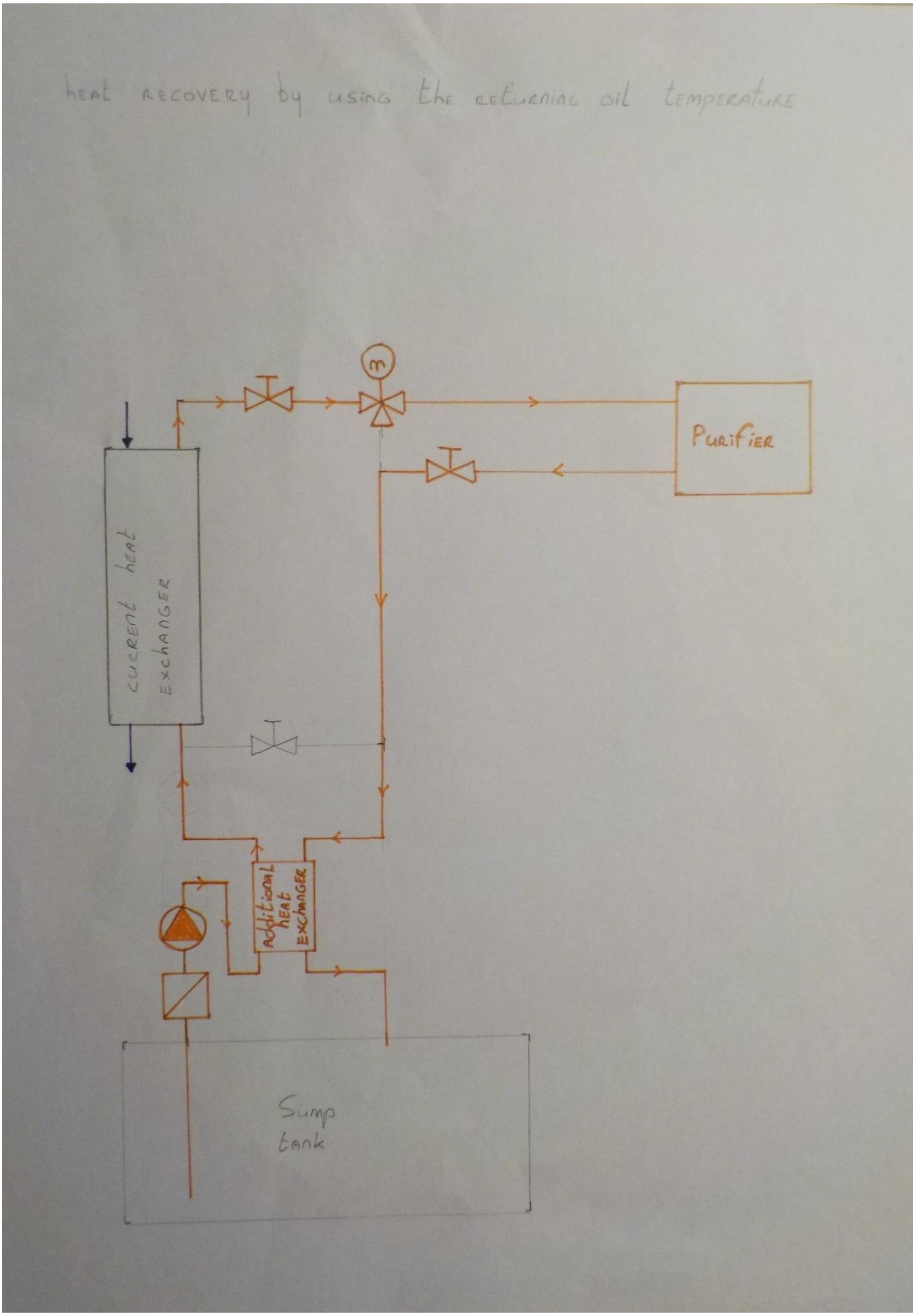
Sounding [m]	Ullage [m]	--Trim in m, negative by stern, positive by bow-- -1.500	-1.000	-0.500	0.000	0.500	1.000	VCG	LCG	Mom.In.T
0.000	1.950	1.021	0.873	0.724	0.576	0.428	0.325	0.525	15.400	2.711
0.050	1.900	1.597	1.449	1.301	1.152	1.004	0.856	0.550	15.400	2.711
0.100	1.850	2.173	2.025	1.877	1.729	1.581	1.432	0.575	15.400	2.711
0.150	1.800	2.750	2.601	2.453	2.305	2.157	2.009	0.600	15.400	2.711
0.200	1.750	3.326	3.178	3.029	2.881	2.733	2.585	0.625	15.400	2.711
0.250	1.700	3.902	3.754	3.606	3.457	3.309	3.161	0.650	15.400	2.711
0.300	1.650	4.478	4.330	4.182	4.034	3.885	3.737	0.675	15.400	2.711
0.350	1.600	5.054	4.906	4.758	4.610	4.462	4.314	0.700	15.400	2.711
0.400	1.550	5.631	5.483	5.334	5.186	5.038	4.890	0.725	15.400	2.711
0.450	1.500	6.207	6.059	5.911	5.762	5.614	5.466	0.750	15.400	2.711
0.500	1.450	6.783	6.635	6.487	6.339	6.190	6.042	0.775	15.400	2.711
0.550	1.400	7.359	7.211	7.063	6.915	6.767	6.618	0.800	15.400	2.711
0.600	1.350	7.936	7.787	7.639	7.491	7.343	7.195	0.825	15.400	2.711
0.650	1.300	8.512	8.364	8.216	8.067	7.919	7.771	0.850	15.400	2.711
0.700	1.250	9.088	8.940	8.792	8.644	8.495	8.347	0.875	15.400	2.711
0.750	1.200	9.664	9.516	9.368	9.220	9.072	8.923	0.900	15.400	2.711
0.800	1.150	10.241	10.092	9.944	9.796	9.648	9.500	0.925	15.400	2.711
0.850	1.100	10.724	10.624	10.520	10.372	10.224	10.076	0.950	15.400	2.711
0.900	1.050	10.943	10.945	10.947	10.948	10.778	10.630	0.975	15.400	0.000
0.950	1.000	10.948	10.948	10.948	10.948	10.948	10.943	0.975	15.400	0.000

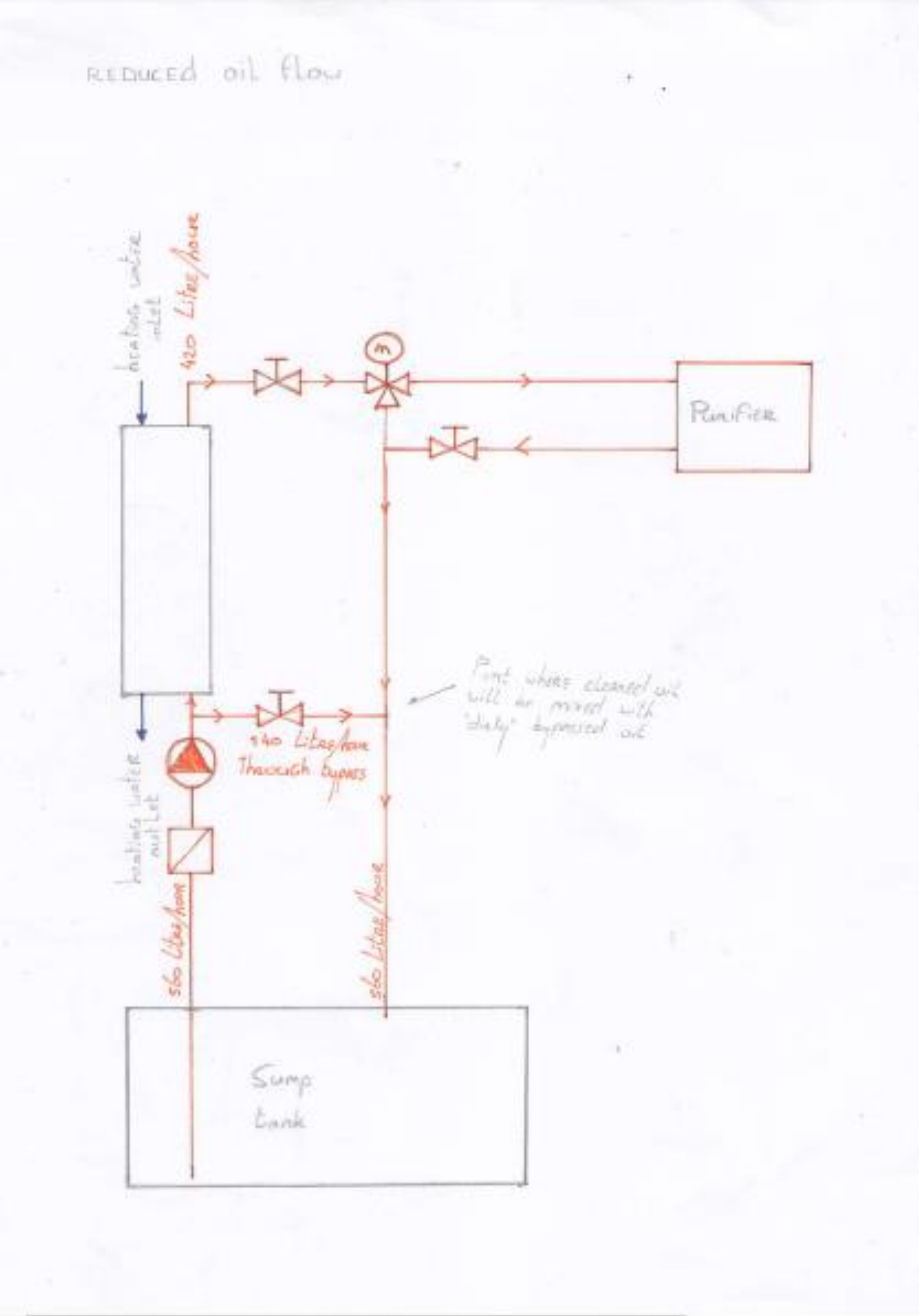
APPENDIX H(08) TANK TRIM TABLES

Lloyd's Register

Figure 36 Picture of sounding table sump tank main engine

Appendix 8 Pipe schedules of option two and three




REDUCED oil flow
heating water inlet
420 Litre/hour
Purifier
Point where cleaned oil will be mixed with "dirty" bypassed oil
140 Litre/hour Through bypass
heating water outlet
560 Litre/hour
560 Litre/hour
Sump tank

Appendix 9 Evaluation from mentor

Training record book 2014-2015 De Ruyter Academy

Name: Dirk Robertus Wilhelmus Vermorken
Ship: Industrial Maya

Form F Signature report of the assignment by training officer (mentor)

All reports of the assignments must be checked and signed by the training officer.
When the student send his report digital to the school please use this form for signing the report.

Name report	Improving Possiblities for the Purifier installation
Content of report	Searching for improvement possibilities of the purifier installation to reach the preferred temperature of 95 °C.
	1 Replacing heat exchanger
	2 Heat recovery
	3 Reducing the flow
Date	17-4-2016
Name Training Officer	Vitalii Migas
Signature Training Officer:	[signature]
Remarks:	Excelent

Figure 37 Evaluation from mentor