Good speed is low speed

Efficient low speed sailing

Place, Date:	Shipping and Transport College Rotterdam, March 31th 2011
Made by:	Project group three: Christiaan Muilwijk 0824085@student.hro.nl Wouter den Boer 0817477@student.hro.nl Laurens van der Kooij 0825346@student.hro.nl Koen Stroomberg 0822900@student.hro.nl
Principal: Group managers:	Mr. Dokman dokman@stc-r.nl Mr. Van Kluijven kluijven@stc-r.nl Mrs. Toemen toemen@stc-r.nl

1. Index

2. Preface

Inside our project group we divided the project in tasks for every project member. This led to the following tasks:

Koen Stroomberg: Lubricating oil system and engine wear
Wouter den Boer: The cooling system
Laurens van der Kooij: The combustion process
Christiaan Muilwijk: The fuel consumption and general editing of the report

We couldn't have finished this project without the support of several external persons. We would like to thank them in this preface for their support.

In general we would like to thank Mr. Michael van der Meer, Senior specialist - Marine Operations of Maersk Benelux BV. He was our 'contact' person inside of Maersk and helped us in a great way with getting in contact with our information providers inside the Maersk company.

We would also like to thank Mr. Dirk Verloop, first Maritime Officer of the MV. Maersk Salalah. We had the opportunity to ask him questions about our topic. He helped us with the project by answering the questions and sent test results of the mv Maersk Salalah all based on the daily experience with the system on board of the mv Maersk Salalah. .

Another person we would like to thank is Miss. Valentijn, Junior Project Manager of the STC-group. With her background in Maersk she provided us the general email addresses and telephone numbers of contact persons in Maersk BV related to our project.

Rogier van Gucht, Service coordinator 2-stroke engines of Wärtsilä Netherlands B.V. provided us with very useful information and presentations about Wärtsilä's slow steaming techniques.

Finally we would like to thank Mr. Arie Taal, employee of MAN B&W. After having contact with him he searched the MAN B&W information database for any articles, internal presentations and brochures related to our project. This led to a huge amount of information about the MAN B&W slow steaming projects.

3. Introduction

The aim of this project is to do research regarding a certain technical subject. The main theme of the project is speed. A topic had to be found for this project. This topic also has the requirement that it has to be about propulsion systems and auxiliary engines. We have chosen for the topic slow speed sailing after a recommendation by our project principal, Mr. Dokman.

Nowadays ships mostly sail at the most economic speed. This is the speed where the engines are originally designed for. The engine has the highest efficiency running on this speed. This means that this is the speed where you reach the highest speed, with the lowest amount of fuel needed to reach this. Of course you can run at lower speeds, but then you sail at a lower efficiency. Recently more ships demand to sail at lower speeds because the high speed is no longer needed. The problem is that this is not useful to do because of the lower efficiency on these speeds. Therefore our main question is: how is it possible to sail at a low speed without losing any efficiency?

For the realisation of slow speed sailing some adjustments have to be made on the engine. This could give either negative or positive results to the engine. It is very important to know what those influences will be. Because the engine consists of various systems we divided it into several parts which we will investigate: the cooling system, the lubrication oil system, the combustion process and the engines wear. A second factor we'd like to investigate is the engines fuel consumption with the adjusted engine. These are all important factors in the decisions to sail at low speed, or to maintain the present sailing speed. If there are many negative influences on the engine, like excessive wear, an increase of fuel or a wrong combustion process a shipping company can decide to maintain its present speed.

As we said earlier, the engine consists of a large amount of various systems. Therefore we decided to pick a few of the engine parts to research, otherwise our research will get too extensive which will have influence on its quality. We will only do research which is needed to answer our main- and sub questions. We will do this by technical investigations which we will do based on literature, studies and visiting a company involved with the subject. All this research will be done for practical usage on sea-going vessels. Our research is mainly based on MAN B&W and Wärtsilä engines because these are the most known engine manufacturers and are market leaders in the slow steaming market.

There are also a few important items to mention which will not be investigated. These are:

- The economical motivation for slow speed sailing
- We don't include any generator sets or auxiliary engines in our main and sub-questions.
- Building of a test set-up by the members of the project group.
- The usage on non-sea-going vessels or any other forms of transportation

In this report you can find the results of our desk and field research for our project. An overview of the content can be found in the index. After the index you can find this introduction. After these parts the real report starts with the main and the sub question. Followed by a conclusion, abstract and list of references.

4. Main question

Due to economical reasons given in the introduction it has become profitable for vessels to slow down. Our main question is as follows:

How is it possible to sail at a low speed without losing any efficiency?

Engine's on big vessels have their own optimal load on which the efficiency of the engine is highest. When we slow down and without any adjustments to the propulsion system, the efficiency will drop down enormously. The following subjects are the most interesting to investigate when we sail at a lower speed: the cooling system, the combustion process, the turbocharger, the lubrication oil system and the engines wear and the fuel consumption. The first four subjects will be discussed on how they can be adjusted to raise the efficiency on a lower speed.

5. Sub questions

5.1 Sub question 1

What are the negative and/or positive influences on the following parts, while sailing at a low speed?

5.1.1 The cooling system

When sailing at a low speed, the cooling system doesn't need that many adjustments. There is a negative effect: The cooling water temperature lowers quite a bit. This is because of the lower RPM of the main engine which results in lower temperatures in the cylinder. That is why the cooling water is also colder when it comes out of the cylinder. There are no negative effects to the wearing of the cooling system and there is also no extra corrosion.

Problems:
When the engine runs on lower load the mean cylinder temperature drops to a temperature where cold corrosion can occur in de cylinder. (Cold corrosion is explained in 4.1.4).

Another problem is when the cylinder temperature is lower the combustion process will not be that efficient as it should be.

Solution:
The solution to both of these problems is to make sure the temperature of the cylinder is high enough to have a good combustion process and to prevent cold corrosion. This can be done by heating the high temperature water system (HT-system) and by re-circulation of the water by a Thermostatic valve.

During field research we found out that container vessel Maersk Salalah also has these problems when low speed steaming. They heat the HT-system with steam to a water temperature between 86 and 96 degrees if in order to outcome these problem.

The LT-system is not heated because of the purpose of that system. This is because the LT-system cools al kind of systems onboard of a ship.

5.1.2 The lubricating oil system

The lubricating system has multiple functions: lubricating, cooling, cleaning, sealing and noise reduction.
Lubricating is an obvious function. A film of lubrication oil will form between the moving parts of the engine, preventing that engine parts will slide against each other. There are lubricating oils which are used for cooling some engine parts. For example: The piston is often cooled by oils. The oil is the lubricant and at the same time the coolant. By using oil as coolant you can prevent a spilling of water in your sump if you use water.
Lube oil also has a purifying function. When hard particles, like carbon deposits and metal particles, will end up between moving parts of the engine, they will cause abrasive wear on the surface of those parts. If you have a constant or regular flow of lubricant, the lubricant will wash away those hard particles.

Sealing engine parts with lube oil is mostly seen by the shaft. When the shaft is sealed with a lubricant, mostly grease is used. They use grease because lube oil is mostly too tin. The oil will just flow out of the shaft. Grease is a bit thicker and stays in the shaft. When the teeth of the gears touch each other, they produce a lot of noise. When a small layer of lube oil is between, the noise is reduced. The film of lube oil will act as a cushion.

Nowadays the lubricating oil system of the larges two-stroke engines consists of two separate systems. The main lubrication system lubricates the moving parts like the crankshaft, crankpin, camshaft, etc. The lube-oil used in this system can be clean, filtered and then re-used. The other part is the cylinder lubricating oil system. This system provides the oil for the cylinder liner.
The liner is lubricated with another type of lube-oil, because most of lube oil for the liner is burnt during the process. This is the reason that lube-oil for the cylinder can not be re-used. Lube-oil for the liner needs other properties compared with the lube oil used for the crankshaft and other engine parts. For example: the oil may not include chemicals that are bad for the environment and air.

The negative effects on the lubricating oil system when running at low power loads.

A negative effect that could occur is that the viscosity of the lube-oil will change. This will especially affect the main lubrication system. Because the lube-oil of the main system flows through the whole engine. When an engine runs at a lower load, the engines temperature will decrease. This can result in lube oil with a higher viscosity. Pumping the lube-oil through the engine becomes now more difficult. This will result in a loss of certain functions.
One of the functions the lube-oil will lose, is the cooling of certain engine parts. The oil does get too thick to flow easily through the engine.
The decreasing temperature of the engine will have minimal effect on the cylinder lubricating system. The lube-oil, used for the liner, will still experience the high temperatures of the combustion process. Therefore the viscosity of the lube-oil will not change in the cylinder lubricating system.

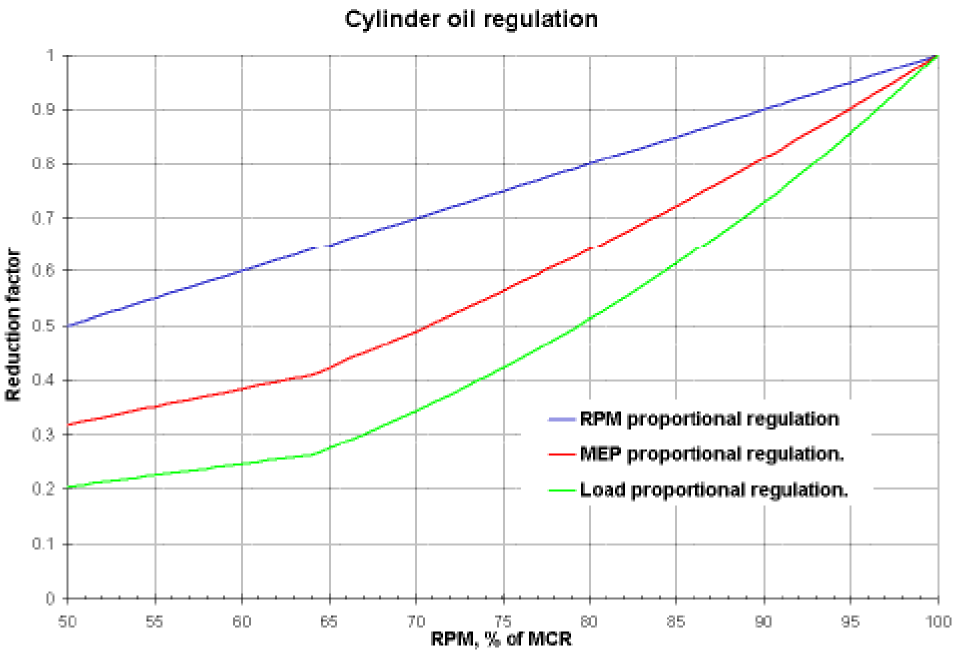
The positive effects on the lubricating system when running at low power loads

The most positive effect of running at lower loads is that the cylinder lubricating system will consume less lube-oil. The engine is running at a lower RPM, thereby reducing the amount of oil needed to create an oil film on the cylinders surface. Also the film of lube-oil has more time to recover.
The lube-oil consumption of the main lubricating system will not change. This lube-oil is not being burned during the combustion, because the lube-oil is in a closed system and is re-used.

Changes to the lubricating system when fitting an upgrade kit.

Normally a certain amount of lubricant is injected into the cylinder to lubricate the liner; this happens at a constant amount each stroke.

MAN B&W tries to prevent the built up of soot with Alpha lubricators. This lube-oil system electronically controls the amount of lube-oil pumped into the cylinder.
By controlling the amount of lube-oil, a lot of lube-oil can be saved. Another manner to reduce the amount of consumed lube-oil is by reducing the diameter of the lubrication pump. Now less lube-oil can be injected into the engine.
When the amount of lube-oil is already electronically controlled only the software, which steers the lube-oil pump has to be changed. And this is a quick and simple fix.



Graphic 1

In graphic 1 you can see the reduction of lube-oil by the different methods. When running at 80% RPM of MCR results in a reduction of 50%. Significant savings can be made on the cylinder lube oil consumption. These different methods are RPM, MEP and Load proportional regulation.

- RPM proportional regulation: With this method the cylinder lube-oil pump is directly driven by the engine. For example, when the RPM of the engine is reduced to half of the total, also half of the amount of lube-oil will be injected into the cylinder.
- MEP proportional regulation: The injection of the lube-oil into the cylinder is now controlled by the camshaft with this method. At fixed times the lube-oil is injected.
- Load proportional regulation: The injection is controlled electronically. The lube-oil is no longer just injected. The system looks at the condition of the liner and the load of the engine.

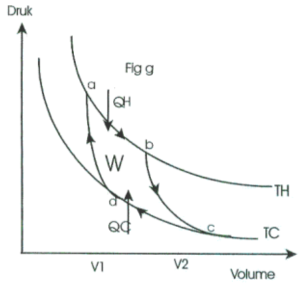
When Wärtsilä installs their upgrade kit, they also make the lube-oil injection of the cylinder lubricating system variable. They call this Pulse Jet or Alpha and whom are electronically controlled.
The cylinder will now only be lubricated when needed. They try to keep the lube-oil flow below 1,2 g/kWh. In periods of stable running the cylinder doesn’t need more lube-oil. This is only possible in stable periods of the running the engine. An example of a stable period is an ocean crossing with a calm sea. Only during manoeuvring, changing power load of the engine or the cylinder conditions deteriorate the feedrate of the lube-oil will be increased. During periods of manoeuvring the load of the engine can change any minute. Also by manoeuvring the vessel will bend and flex. The piston will than hit the liner harder and at other places on the liner. To prevent wear, caused by friction between the cylinder and the piston more lube-oil will be injected in the cylinder.
Mainly they lower the feedrate of the lube-oil to prevent the flooding of the scavenging air ports with lube-oil. If you keep the scavenging air space clear of lube-oil and combustion residues, the scavenging air will flow more easily into the cylinder. In this way the combustion process will be more efficient. An engineer on board has to check frequently for these residues, like soot, coke and unburned fuel and if needed clean the scavenging air space.

5.1.3 The combustion process

In this sub question we will describe the influence of the low steaming on the engines combustion process. If the Maximum Continues Rate (MCR) of a vessel is lowered, which means lowering the RPM of the engine. There may be changes to the engines combustion process. This can be either positive or negative.
An example of these changes are:

- Air usage of the engine
- Exhaust gas temperatures
- Mean cylinder pressures
- Fuel consumption

When an engine is running on economical speed this means the efficiency is optimal at this power load. This means that the combustion cycle of this engine approaches the Carnot process as close as possible at this power load.



Graphic 2

The Carnot process is a theoretical process which has the highest efficiency without any losses. This process can't be achieved in reality. When sailing at low speed it is important to maintain or even improve the combustion efficiency. To a value as close as possible to the Carnot process. The Carnot process is shown in graphic 2

Air
The efficiency of the combustion process depends on many things. The air consumption of an engine is an important factor in the combustion process. The air is used to ignite with fuel that is injected just before the piston reaches its top death center in the cylinder. This air is supplied by turbochargers which are driven by the exhaust gasses of the engine.

The negative effects on the Combustion process system when running at low power loads.

Insufficient air
Applies for Wärtsïla and MAN B&W
The reduction of the RPM gives problems when sailing at low speed. A turbocharger (TC) compresses inlet air to a high pressure and after cooling this compressed air it results in higher mass of air in the cylinder. But when running at a low power load this air reaches temperatures that are too low for an optimal combustion process.

The main issue of slow speed steaming is the low RPM of the turbochargers (TC). On large vessels the engine is driven by 3 and sometimes 4 TC's to supply the engine with enough inlet air.

A turbocharger is a centrifugal pump that compresses air. The compressor is driven by a turbine which is driven by the exhaust gasses from the cylinder. The air that is delivered by the TC depends on the amount of exhaust gasses. When the revolutions of the TC drop due to less exhaust gasses when operating on low power load it is logical that the amount of air compressed is less than on a higher power load. Due to the characteristic of a Turbo-compressor is not linear the amount of air compressed when the RPM drops is not enough to sustain an optimal combustion.

Changes to the engine to improve combustion process for low load operation

Another solution comes from the company Wärtsilä. They install so called low steam engine kits. When this kit is installed it allows the engine operators to cut off one turbocharger of the engine, this result's in a higher RPM for the operating turbochargers. The higher load of the other turbochargers will result in higher inlet air temperatures but this is no problem for the overall process. When the remaining TC's have a higher RPM their efficiency improves and gives the engine more air for combustion.
Note that this is only suitable for engines with multiple turbochargers.

The solution to cut off one turbocharger is also done by MAN B&W. MAN B&W achieves to cut out a turbocharger with blind plates or valves. The following information is received from MAN during field research

Valves:
The following information is received from MAN during field research. The best way to cut of a turbocharger is done by valves.

Construction:
Butterfly valves:

These valves can be operated simply by hand after the operators have slowed down the engine to low load operation.

Swing-gate valves:

Image 1

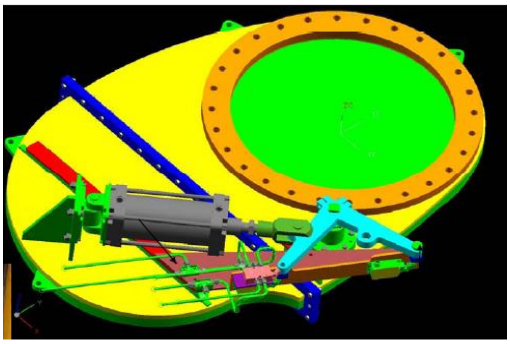


Image 2

These valves shown in the images 1 and 2 have a height of 1,5 meter and weigh 850 Kg. They are opened and closed by a pneumatic cylinder that is driven by working air. The cylinder is air controlled and works with a pressure difference of 0.2 bar. This means that the valve is open or closed.

When the valve opens or closes the lever which is connected to the covering plate gets locked by a locking pin. This prevents the valve to open or close unwanted.

Price info
The budget price for Turbocharger Cut-Out System to 12K98MC-C is EUR 128,000.00.

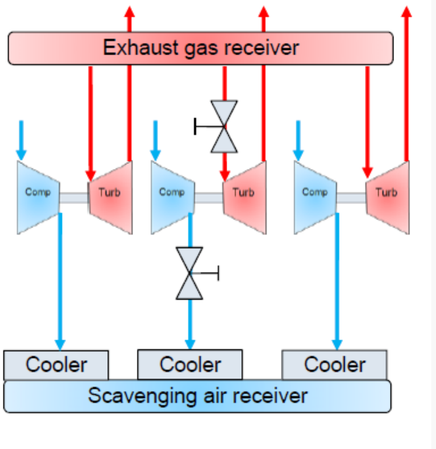


Image 3

Installation info
The Turbocharger Cut-out system can be installed by MAN Diesel PrimeServ with 3 day of off hire, in less than one week.

Placement of the valves:

These valves are fitted after the inlet air compressor and before the exhaust gas outlet in the turbocharger. Also see image 4 and 5 below.

Photos of placed valves:

Image 4
After compressor

Image 5
After turbine

The valves are covered with isolation because of high temperatures after the compression of air in the turbo compressor and of the exhaust gases from the cylinders.

Operating the valves:
Procedures going low speed:
-Ship officers decide for low load operation and TC cut out.
-Engine goes to stop or dead slow
-Engineers close TC cut out valves from a control panel located next to TC.

When valves are in operation operators should avoid:
-Over speed of remaining turbochargers due to high power load. This is when valves are closed and the power load is increased.
-Having the valve on turbine side open and compressor side closed. This is because of the exhaust gasses that bypass other TC's.

VTA Technology

To increase the efficiency at low power loads an extra step can be made by installing VTA if not already installed on the MAN B&W engine.
VTA stands for Variable Turbine Area Turbocharger Technology. With VTA the amount of scavenging air entering the cylinder is more precisely matched to the amount of fuel injected, so that the combustion process can be optimized at all points on the engine's operating profile. This is made possible by replacing the ring with static vanes in the turbocharger with a ring with vanes which have a variable pitch. This ring is placed on the exhaust gas side of the turbocharger. By adjusting the pitch of the vanes they can control the speed of the turbocharger and in this way control the amount of air, which

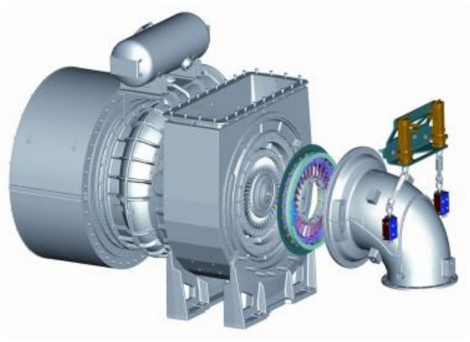


Image 6

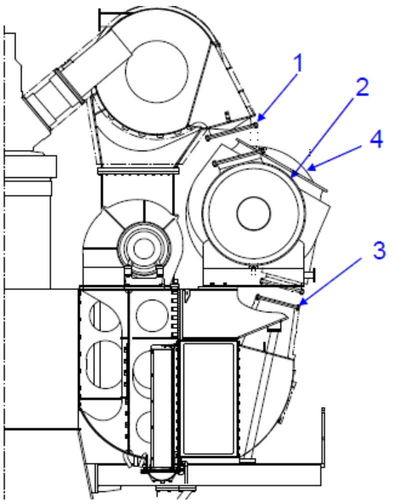
has to be forced into the cylinder.
The system also made it possible to switch off the auxiliary blower's at 5% lower engine load, because the turbocharger can now deliver more pressure. It also has the benefit to a significant reduction in soot and smoke generation at low power loads.

In image 6 is shown that the ring with vanes is modular and can easily replace the ring with the static vanes. The rings can be retrofitted to turbochargers, which are already in use.

Wärtsïla
As stated before the solutions brought by both of the major engine companies are about the same. Wärtsïla also offers so called "slow steaming kits" that do about the same. The kit can include a valve system and a more permanent solution which is covering the TC with blind plates on certain positions. The automated valve system comes with a price tag of EUR 310,000.00.

Blind plate Cut off method:

As for some ships the economical speed is too high for a certain purpose it is possible to remove one of the turbochargers. This is because the ship is already built but the owner wants to slow down due to high fuel prices. Wärtsïla grants the owner the possibility to remove one of the TC's and store the parts onboard of the vessel. This solution is not permanent but can only be restored by the fabricator which would mean downtime again. The removal of a turbocharger is done in procedures:



Blinding turbocharger with blanks before removal
First the turbocharger had to be excluded from the engine. This is done with blinding off the following and is visualized in image 7:

1. Exhaust side
2. Exhaust gas outlet
3. Scavenge air receiver
4. Suction air inlet (depends of kind of vessel)

Image 7

When these ports are sealed the compensators are removed. Compensators are also called expansion joints and are needed due to high gas temperature cause by combustion and compression. The compensators connect the scavenge air receiver with the compressor and the exhaust gas turbine with the exhaust side from the engine.

The TC is decommissioned and completely stored onboard. Because of the removal of one turbocharger it is not possible for the engine to run on the old economical speed because this would overspeed the remaining TC's. Therefore the engine is fitted with a limitation system. This makes is impossible for the engine to go above a certain power load.

Maximum load:
Every turbo cut out system makes the maximum possible working load of the engine drop lower because of overspeeding of remaining TC's. But this also depends on the number of turbochargers installed. This is because when an engine has four TC's, cutting

out one has a smaller effect then an engine that uses only two turbochargers. The following are guidelines given by Wärtsïla

• One out of two turbochargers blinded
Continuous operation between 10% and 40%-47%* load
• One out of three turbochargers blinded
Continuous operation between 10% and 55%-60%* load
• One out of four turbochargers blinded
Continuous operation between 10% and 60%-70%* load

Smaller vessels with les turbochargers become more limited during slow steaming systems in operation than vessels with bigger propulsion systems.

Emission

Pollution is a big issue in the shipping industry. Is it possible to reduce the emission of especially the NO_x when running the engine with one less turbocharger?

Here are some test results with one turbocharger cut out and normal conditions:

Table 1 and 2

12K98MC-C6 with 1/4 Turbochargers

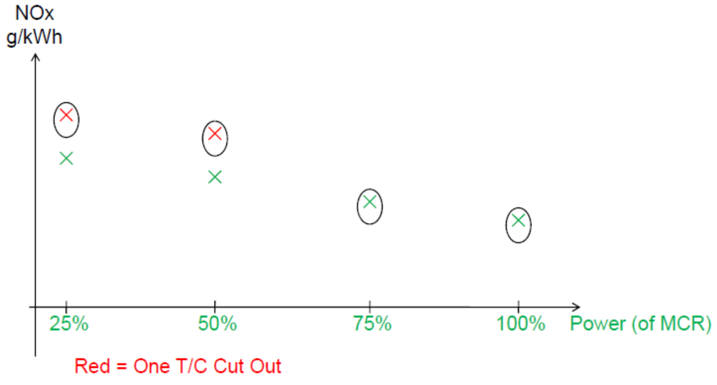
Item	Unit	25%	50%	75%
Pscav	Bar	+0.15	+0.41	+0.52
SFOC	g/kWh	-7	-7	-3
NOx	g/kWh	+2.7	+3.6	+1.5

12K98MC-C6 with 1/3 Turbochargers

		25% "MC Style"	25% "ME Style"	50% "MC Style"	50% "ME Style"
Pscav	Bar	+0.25	+0.25	+0.59	0.52
SFOC	g/kWh	-5.7	-5.6	-2.9	-3.3
NOx	g/kWh	+5.7	+4.3	+1.4	+0.3

As mentioned before the turbocharger cut out improves the combustion process because of more scavenging air delivered by the remaining turbochargers. This can be seen in the graphic 3. Because of the increased air usage of the engine resulting in a better combustion process there will be more Emission of NO_x. This is relative to normal operation without a TC cut out and a lower efficiency.

When running at economical speed the green crosses are referred to the normal conditions: you can see that when the power of the main engine rises, the NO_x emission will reduce. This is also when one turbocharger cut off, but at 25% power there is an extra emission of 5,7 g/kWh. At 50% running there is an extra emission of 4.8 g/kWh. At higher power it is not necessary to cut off a turbocharger, so this is not tested. Some crosses are in ovals. This means that the values were not constantly the same.



Graphic 3

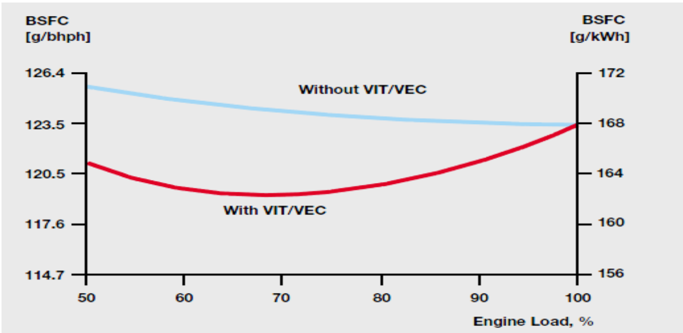
Fuel injection

Applies for Wärtsïla and MAN B&W
Fuel is injected by a high pressure nozzle which can be supplied in two ways:

-A fuel pump driven by the camshaft
-A common rail system

The atomizers inject fuel in such a way that the fuel mixes optimal with the combustion air. This is done by having precise valve timing and the right injecting angle. With common rail technique the valve timing can be done more accurate then with camshaft driven valves. This is done by a valve time control unit.
When sailing at low speed the fuel gets injected in such a way that it will cause carbon deposit in the cylinder. This carbon deposit can obstruct exhaust valves, and cause damage to the cylinder itself.
A solution for this problem is to replace the atomizer tips with new atomizer tips. These atomizer tips are specially made for the slow speed steaming. While these tips improve the forming of carbon deposit it is still necessary to run the engine at high load (above 70%) for a short time; this is to 'clean' the engine from the remaining carbon deposit.

For an overall more efficient combustion process variable injection timing(VIT) and variable exhaust valve closing (VEC) is installed on their engines.
The VEC system allows better timing of the exhaust valve which results in a better compression ratio. The VIT improves engine efficiency in the upper load range by maintaining the maximum cylinder pressure at the full-load value by injection timing advance. This is less noticeable in the lower load ranges due to a lower RPM (see graphic 4)



Graphic 4

VIT and VEC is not necessary to overcome the efficiency reduction for low load operation but it is still a big improvement for the overall efficiency of the combustion process.

5.1.4 The engines wear
There are 3 types of wear; Corrosive, Abrasive and wear caused by friction.

- Corrosive wear can occur when the combustion process is not perfect and produces acidic substances. These acids will corrode the cylinder liner which causes damage.
- Abrasive wear is caused by carbon deposits that mix with lube oil. Because of the moving piston the carbon particles in the lubrication oil will scratch the cylinder surface causing damage.
- Wear caused by friction occurs when two moving parts of the engine slide against each other because of the absent of a lubricating film. Because of this small particles will be scratched of each part.

The negative effects on the wear of an engine when running at low power loads

Due to the low cylinder temperatures acidic gases with a high temperature will condensate more easily on the surface of the liner. This results in more corrosive wear in the cylinder. This is also called: cold corrosion. Those acidic gases are produced in the combustion process due to the sulphide in the fuel.

The positive effects on the wear of an engine when running at low power loads

When running at low load, engine parts run slowly. This results in a better lubrication. The lube-oil film has more time to recover from each stroke of the engine. Normally better lubrication result in less wear. Another positive effect is that the built up of soot does not become worse, when running at low power loads.
When running on low power loads, the force of the power stroke on the engine parts, for example the bearings and the crankshaft are less. The lube-oil get pushed out the small spaces between the engine parts with less force. The lube-oil film will stay intact. The engine parts will not hit each other, which results in less wear.

Changes to the wear of an engine when fitting an upgrade kit

When a upgrade kit of Wärtsilä is installed, it will have a positive effect on the combustion process. Because there is more air forced in the cylinder, the process will be cleaner. Less carbon deposits and acidic substances will be formed, so there will be less corrosive and abrasive wear.

The upgrade kits of the engine manufactures are all based on the same principle: they are all forcing more air into the cylinder with their turbochargers on low power loads. This principle is explained in paragraph 5.1.3.

Because the engine manufactures cut off the turbochargers, the turbochargers will be used in a different manner then engine manufactures anticipated. The turbochargers are more subjected to wear. Therefore the wear has to be checked more frequently.

The VTA system of MAN B&W, explained in paragraph 5.1.3, brings more moving parts into the turbocharger. They examined the rings with the vanes after 10,000 running hours of the engine on wear. The result of this was that there was almost no wear found on the vanes. The dimensions of the vanes were the same as before the running hours.

Another problem of the lower RPM's of the turbochargers is that particles, which form in the combustion process, will stick more easily to the vanes of the turbocharger. It is not certain yet if it will happen, but the risk of happening is greater at lower RPM's of the turbochargers. MAN B&W advices to clean the turbochargers more often. Originally every 250 running-hours the turbocharger had to be checked and/or cleaned. MAN B&W now advices to check and/or clean the turbocharger every 100 running-hours.

Ship propulsion systems are frequently suited with auxiliary blowers for the power loads on which the turbochargers do not produce enough air. The auxiliary blowers undergo two problems during slow steaming under 50% MCR. MCR stands for Maximum Continues Rate. This is the power load on which the engine is designed.
The first problem is that auxiliary blowers are subject to more wear, because the auxiliary blowers will be used more under the 50% MCR to compensate for the turbochargers.
The second problem is caused by the constantly switching on and off of the auxiliary blowers. This will concur when an engine is running at certain power load-points. At these points an extra auxiliary blower has to be switched on or off. This has a bad effect on the electric motor. To solve this you can adjust the controller of the auxiliary blowers. When an auxiliary blower is switched on, the already running auxiliary blower has to run slower. In this way the second auxiliary blower will not be switched on and off constantly and the second blower will experience less wear.

A solution for the problem with cold corrosion, mentioned in paragraph 5.1.1, is to hold the temperature of the cooling water at a higher temperature. The temperature will be around 86 to 96°C. At this temperature the acidic gases can not condensate against the liner and they will not damage the liner. The higher temperature of the engine caused by the warmer cooling water will result in a smaller temperature difference between the hot acidic gases and the colder liner.

5.2 Sub question 2

What will be the influence on the fuel consumption of the vessel?

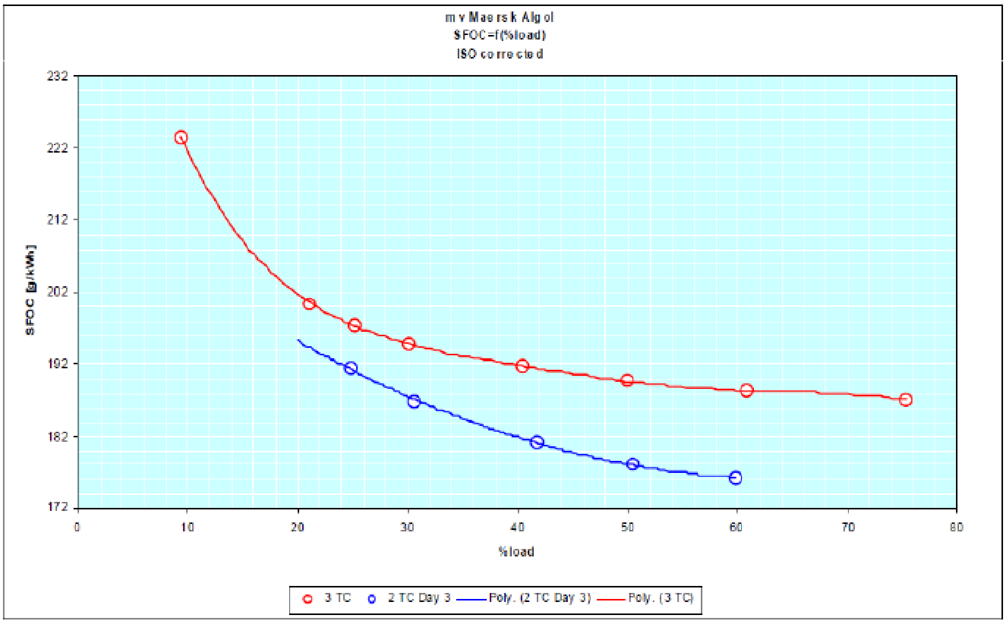
5.2.1 Fuel consumption

The fuel consumption of the ships is an important factor nowadays. With the high, and still rising fuel prices sailing becomes an expensive operation. Therefore it is important to know what influences there will be on the ship's fuel consumption when the, so called, slow steaming kits are used.

Wärtsilä

While researching our subject we found out that Wärtsilä is one of the leaders in the slow steaming market. After some research we noticed Wärtsilä's slow steaming kits. These are kits which can be ordered by shipping companies and then will be installed on the ship's engines by Wärtsilä. The kits can be installed on Wärtsilä RTA and RT-flex engines. These engines are mainly used on large container vessels. In this market there is a high demand for the slow steaming kits, see our main question for the reason of this demand. The first main customer of the kit is A.P. Moller Maersk Group (APMM), one of the world's largest shipping companies. APMM ordered 34 slow steaming kits for their large container vessels which are propelled by 10, 11 and 12 cylinder RT-flex96C and RTA96C engines.

The slow steaming kits have influence on the ship's fuel consumption. For example we use the Wärtsilä 12 cylinder RTA96C engine. This engine has 68,640 kW at 102 revolutions per minute. For this example the engine will run at an engine load of 45%. When the slow steaming kit is installed this will result in a saving of 8,8 g/kWh brake specific fuel consumption. Brake specific fuel consumption (BSFC) is a measure of fuel efficiency within a shaft reciprocating engine. BSFC allows the fuel efficiency of different reciprocating engines to be directly compared. It is the rate of fuel consumption divided by the power produced in kWh. This results in a 0,272 tons/hour fuel saving on its brake specific fuel consumption. If the engine runs approximately 7000 hours/year at this engine load, the slow steaming kit will result in an annual fuel saving of 1903 tons fuel. This is caused because of several processes in the whole process which are better then when using the engine without a slow steaming kit. This fuel saving is just an extra fuel saving in the whole slow steaming process. The main fuel saving is made by just running on a low engine load which normally reduces the ships fuel consumption by approximately 58% when reducing ship's speed from 27 knots to 22 knots. Unfortunately there are no test results available showing this fuel consumptions. Graphic 5 is made with test results of the mv Maersk Algol, equipped with a



Graphic 5

12RT-flex96-C engine with 9352 running hours. In graphic 5 you can see that the test results of the mv Maersk Algol match in a great way with the general test results of Wärtsilä.

MAN B&W
Another large engine manufacturer is MAN B&W. This company thinks its VTA system can be used for the slow speed steaming. VTA stands for variable turbine area turbocharger technology. MAN tested this application on the 70,000 ton shallow draught tanker Stena President. This ship is propelled by two 46 cm bore MAN B&W brand type 6S46MC-C. For testing the application one of these engines is used.

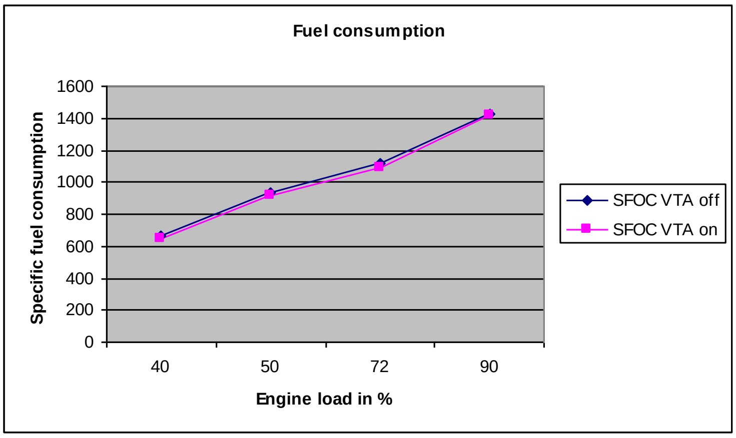
For slow steaming the VTA technology should be used. With VTA the quantity of charge air entering the cylinder can thus be more precisely matched to the quantity of fuel injected, so that combustion can be optimized at all points on the engine’s operating profile. In this way specific fuel consumption can be minimized at all engine speeds and loads, combined with improved dynamic behavior of the engine-turbocharger system i.e. better engine response. This means that by editing the engine with the VTA technology extra fuel savings are realized.

The fuel advantage of the VTA system is also tested by MAN B&W, the results can be found in table 3. SFOC stands for specific fuel oil consumption. The unit of SFOC is liters/hour. This unit is not the same as BSFC. The difference is that BSFC is calculated in grams in relation with one kWh, with SFOC only the amount of fuel used in a certain time base is measured. If you have all the details of the fuel you can convert this value to BSFC. Unfortunately we did not have the fuel details.

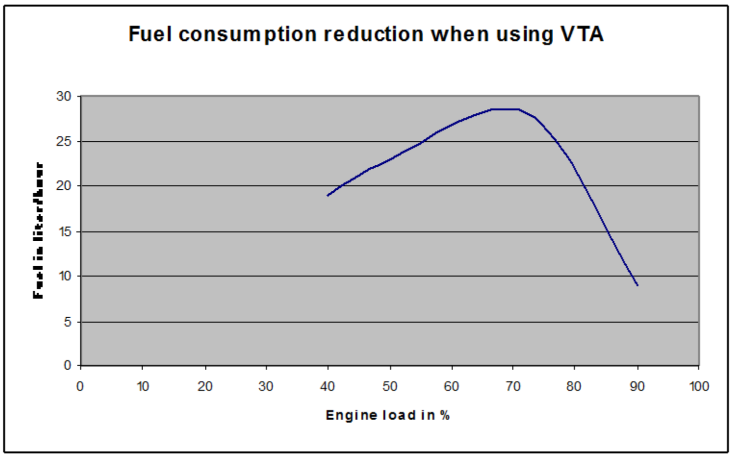
As you can see in the MAN B&W test result table, a low engine load has a huge effect on the ship’s fuel consumption. The difference between running at 90% and running at 40% is huge. When you have a better look at it, it shows that running on 90% engine load costs 2,19 times more fuel than running on 40% engine load. With the MAN B&W test results we created graphics showing the engine load in relation with the total fuel consumption of the ship and the engine load in relation with the fuel oil reduction.

Table 3

Engine Speed [rpm]	Engine Load [%]	SFOC VTA off [l/h]	SFOC VTA on [l/h]	Reduction [l/h]	Reduction [%]
100	40	666	647	19	2.85
113	50	937	914	23	2.45
120	72	1114	1086	28	2.51
129	90	1427	1418	9	0.63



Graphic 6 and 7

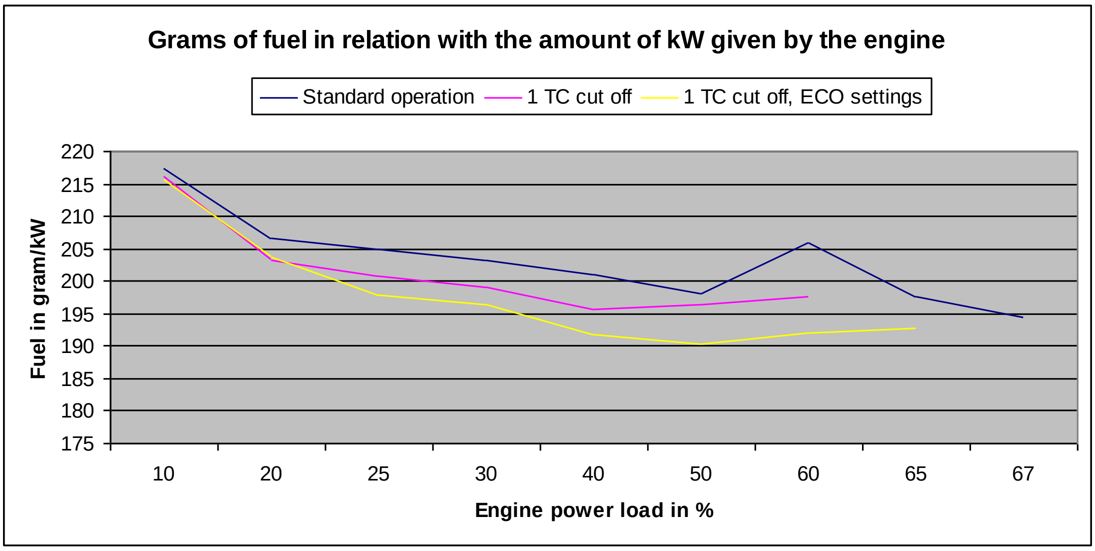


Maersk Salalah
In theory many things look good, but the truth is that in reality things will never be the same as calculated. Therefore it is important to investigate what the results of the techniques are when it is really used onboard of vessels.

The container vessel Maersk Salalah was one of the first ships equipped with a MAN B&W slow steaming technique. The engine onboard of the Maersk Salalah is a MAN B&W 12K98 ME-C engine and has 3 turbochargers. This engine is one of the biggest engines produced by MAN B&W. For a good overview of the results of the slow steaming technique, the first maritime officer of the Maersk Salalah decided to do a number of tests. Hereby the vessel sails for either 60 or 30 minutes on a certain RPM. This results in various amounts of delivered kilowatts and on each RPM its fuel consumption. The engine is tested in 3 modes: standard operation, a situation where 1 turbocharger is cut off and a situation where 1 turbocharger is cut off and ECO settings are working.

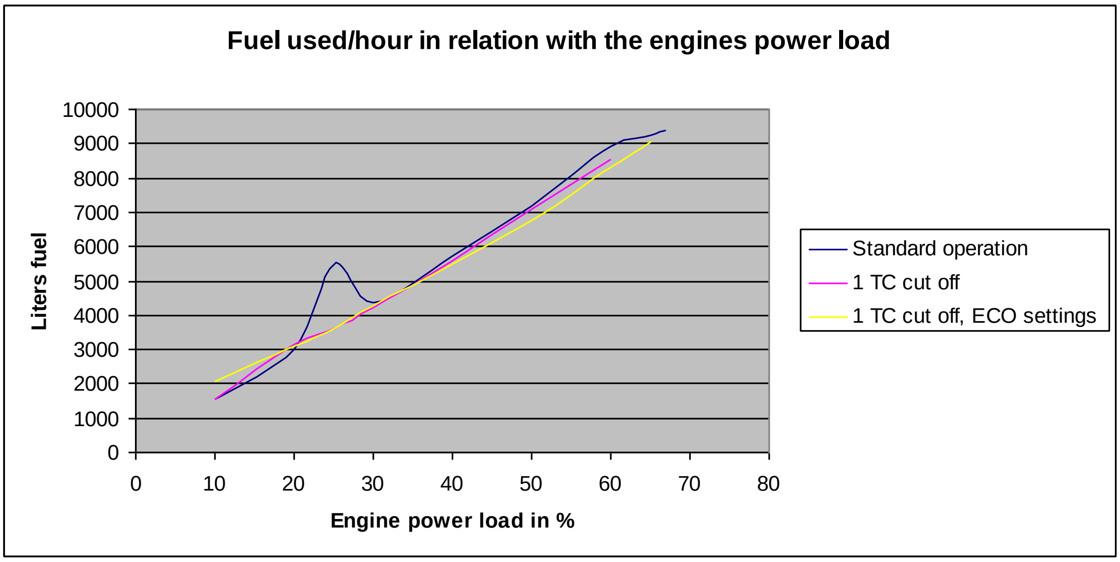
In the ECO settings mode changes were made to the fuel injection timing. In this case earlier injection to increase the maximum combustion pressure Pmax inside of the engine. The engine has electronically controlled fuel injection and exhaust valve timing which allows the engineers to monitor and adjust those settings. The Pmax value for the 3 T/C setting was based on test results from the testbed trails. The NOx emission is the main reason for limiting the allowed Pmax for lower load ranges. With the turbo cut out valve closed, scavenging air pressure (and amount) rises in these load ranges, thus also changing the NOx emission. During the tests MAN technicians and a surveyor measured the NOx values in the exhaust gasses and came to the conclusion that with 2 T/C's these values were lower, enabling them to increase the Pmax (earlier injection) and with that increasing the efficiency of the engine, while still complying with our IAPP certificate. This results in even a higher efficiency of the engine, which eventually results in fuel savings.

The outcomes of the tests are shown in de graphic stated below.



Graphic 8

After all we can conclude that there is a significant change in the ship's fuel consumption when using the slow steaming technique. Optimal fuel reduction occurs when the ship sails with the adjustable ECO settings.



Graphic 9

Graphic 8 doesn't really give a good overview of what the real fuel consumption now will be, this is because it shows the amount of grams fuel needed to provide the engine with 1 kilowatt. On the first sight you won't really know how many liters of fuel are actually saved. Therefore graphic 9 is made. It shows the total amount fuel used in an hour when running at several power loads. On the first sight this graphic gives the impression that there are nearly no differences, but when you have a closer look, for example at 60% power load, it shows that the difference between running with ECO settings and a cut off turbocharger and running on standard operations is 636 liters of fuel oil. And this is just in 1 hour time.

Test results of the mv Maersk Salalah can be found in Appendix I.

6. Conclusions

If the engine runs more slowly, then the combustion temperature in the cylinder is lower. The cooling water, which runs next to the cylinder wall and to the jacket, is because of the lower temperature in the cylinder also lower. The temperature will be too low to sustain a optimal combustion process and thereby is kept at a higher temperature. As for lower revolutions made by the engine this also has a great impact on the RPM of the TC's which are driven by the exhaust gasses. Due to efficiency loss of the TC's the amount of air supplied by the engine is lower. To solve this problem we cut off a turbocharger. This can be done by a so called: 'slow steaming kit' for turbochargers, made by Wärtsilä and MAN B&W. This kit allows to cut off one turbocharger. This will result in a higher rpm in the other turbochargers, because they have to maintain the old capacity. Which gives the engine enough air for a high efficient combustion. The other important part in the combustion process is the fuel. The fuel is injected by high pressure nozzles. This is also a problem when we lower the speed. If the timing stays the same, then there will be extra carbon deposit in the cylinder. This problem can be solved by modern high pressure injection systems like variable fuel injection timing (VIT).

The main lubrication oil system must also be adjusted. The viscosity will be higher because of the lower temperature in the engine. To solve this problem the oil has to be cold down less. There is also a positive part. The consumption of the lubrication oil will be less in the cylinder lubricating system. Because, when they install the upgrade kit, they also make the cylinder lube-oil injection variable. By doing this less lube-oil will be consumed. When running at a lower load, the parts will run more slowly. This will result in less wear of the moving engine parts. But there will be more corrosive wearing, because of the lower temperature in the cylinder. This problem can be solved by increasing temperature of the cooling water as done by steam on the vessel: Salalah.

The fuel consumption is probably the most important item in an economy where the price for fuel is high. When just lowering the speed without the adjustments above, the fuel consumption will not reduce that much. The biggest improvement is cutting off a turbocharger. When one turbocharger cut off the other turbochargers will raise their RPM which result in a higher efficiency of the remaining TC's.

Our main question was: "How is it possible to sail at a low speed without losing any efficiency "? In the cooling system it is required to raise the temperature of the cooling water. Thanks to among others the butterfly valves which cut off the turbocharger the efficiency will raise in the combustion process. The cylinder lubricating oil system will use less oil when we are running with lower RPM, the viscosity will be a bit lower, but this problem is solved by the heat of the combustion process. The fuel consumption will slightly reduce when running slower; the most efficient setting is to run on 60% of maximal load.

Our conclusion is: The efficiency will raise, but with investments that will pay off in the future.

7. Recommendations

As found in the conclusions a higher efficiency can be acquired when steaming low. But whether we would recommend owners to invest in slow steaming also depends on their vision of the future. Smaller vessels will experience less reduction of fuel making an investment in slow steaming only profitable when this vessel will sail on low speed for a long period of time.
As for the vessels with big engines we think the investment will pay itself back in a short amount of time. These swing-gate valves to cut off the turbocharger can be opened and closed with a simple press on a button.

When the vessel doest have modern lubrication and modern fuel injection systems the investment in slow speed steaming can be much more costly.

8. Abstract

The essence of the report is to investigate if it's attractive to make some adjustments in a sector with high competition to lower the costs of the voyage of a ship what makes the position better to the rivals in the business. We investigated the most important aspects of the technical system which have the most influence when sailing at a lower speed. We did this by desk research. After the desk research we wanted to know if there are any vessels running with the solutions which we have already found. Maersk is the leader in this business and they were willing to help us with cooperation of MAN B&W and Wärtsila. At these companies we did our field research. With all these information we have made this report and made our conclusions described in paragraph 6.

9. References

Articles, presentations and brochures

MAN B&W articles, internal presentations and brochures are provided by Mr. Arie Taal, employee of MAN B&W. All documents are in our information database. Presentations are mainly made by Martin Lambert Sørensen, employee of MAN Diesel & Turbo – Copenhagen.

Most of the Wärtsilä articles and brochures are provided by Rogier van Gucht, service coördinator 2-stroke engines of Wärtsilä Netherlands B.V. Other documents are found on the Wärtsilä website. All documents can be found in our information database.

Several articles related to lubricating oil are found on:
http://www.brighthub.com/engineering/marine.aspx

Test results and graphics

Mv Maersk Salalah engine test results are provided by the first maritime officer of the Maersk Salalah.

Other test results and graphics are found in the articles, presentations and brochures or either are self-made with results given in the documents.

General knowledge

Any other information we have obtained comes from specific persons and is based on their general knowledge about the topic. By answering our questions they provided us with new specific information which is used in this report.

10. Appendix I

Table of the test results of the MV Maersk Salalah used on page 19, 20 and 21.

17-6-2009	22-6-2009				Fuel	Dens @15	1003,8			
h			Meter			Dens @ 90	954,7			
Start time	End	Tot min	Fuel S	Fuel E	Total liter	Total Kg	RPM	Kw	gr/Kw	***Savings***
8:50	9:50	60	1552190	1553750	1560	1489,332	45,98	6850	217,42	
10:30	11:30	60	1555260	1558250	2990	2854,553	58,58	13820	206,55	
11:55	12:25	90	1559680	1565160	3653	3487,5191	62,96	25540	136,55	
14:00	15:00	60	1567566	1571916	4350	4152,945	66,97	20430	203,28	
15:40	16:40	60	1575418	1581162	5744	5483,7968	73,79	27280	201,02	
8:15	9:15	60	1651282	1658450	7168	6843,2896	78,76	34540	198,13	
10:00	11:00	60	1664380	1673315	8935	8530,2445	83,26	41450	205,80	
14:15	15:15	60	1819230	1828625	9395	8969,4065	86,95	46130	194,44	
			With Valve Closed							
16:45	17:45	60	1835473	1837026	1553	1482,6491	45,43	6862	216,07	0,62%
8:25	9:25	60	1908815	1911943	3128	2986,3016	59,97	14700	203,15	1,65%
9:55	10:55	60	1913760	1917385	3625	3460,7875	59,97	17230	200,86	-47,09%
11:21	12:21	60	1919120	1923365	4245	4052,7015	66,95	20350	199,15	2,03%
13:30	14:30	60	1929524	1935115	5591	5337,7277	73,95	27270	195,74	2,63%
15:20	16:20	60	1940808	1947875	7067	6746,8649	79,78	34360	196,36	0,89%
17:15	17:50	30 min fuel)	1955865	1960144	4279	4085,1613	84,45	41360	197,54	
			After new Eco setting 2TC running							
13:30	14:00	30	2161598	2162640	1042	1492,1961	46,18	6919	215,67	0,81%
11:30	12:00	30	2154708	2156512	1804	1722,2788	63,44	17410	197,85	-44,89%
10:30	11:00	30	2151338	2153478	2140	2043,058	67,46	20800	196,45	3,36%
15:00	16:00	60	2042780	2048295	5515	5265,1705	73,67	27450	191,81	4,58%
16:40	17:40	60	2052624	2059387	6763	6456,6361	78,96	33930	190,29	3,95%
20:03	21:03	60	2077460	2086528	9068	8657,2196	86,25	44890	192,85	