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Introduction of Turbocharger water injection for NOx reduction

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Abstract:

Marine engines are consuming heavy fuel oil, which contents harmful elements to the environment. During combustion process nitrogen molecular (N) and Oxygen (O2) are both combined and form NOx at very high temperature. Therefore, reducing the air temperature that is going into the combustion chamber would help in reducing NOx content. The cubic device technology would be based on increasing humidity of the inlet air, which will result in reducing the air temperature up to 33%. The water will be pressurised and sprayed in form of vapour through a small nozzles in a cubic box to mix with engine room ambient air at 45 degrees Celsius and 30% relative humidity. The aim of this project is to reduce NOx that produced in the combustion chamber by reducing the inlet air temperature, as there is a relationship between them (Kyrtatos et al, 2009). The calculations are based on selected engine runs on a full load mode and based on Arabian Gulf weather. A comparison was made on the engine running with installing the device and without the device. The result shows that the air temperature that entering combustion chamber is 54.3℃ without installing the device, whereas the air temperature after installing the technique is reduced to about 36.3℃. Therefore, the reduction in temperature will result in lowering NOx emissions and hopefully will reduce the damage to environment.

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I. Introduction

1.1 Background Information

85% of trading goods worldwide are transported through the use of marine transport and more than two-third of such transportation is within 400Kms area of the coastline, causing adverse effects on the air quality near coasts as per Eyring et al (2007). Two/four strokes of diesel engines are amongst the most accepted systems in the propulsion of ships. Fuel consumption in majority of marine engines is close to 180g/kWh, while that of gas turbines is more than 200g/kWh. Diesel engines are economical, making them the preferred choice in commercial transportation system in spite of their emission of high amount of sulphur and nitrogen contents (Lövblad and Fridell, 2006).

Marine engines produce NOx and SOx during their combustion process, which are harmful elements against the environment (Yoshida et al., 2008). Therefore it seems desirable to find out the measures to keep control over emission of such harmful elements. The research here has been carried out in order to identify the measure to keep a check against the emission of such harmful elements and ensure that the environment is least affected by such gases. Although it does not seem possible to completely control emission of such harmful gases, but minimising such emission may be helpful to the environment (Calinescu et al., 2008). Thus the project here discusses about the current engines of marine engineering in order to identify the most suitable technique that can help in enhancing the temperature control and reduce the NOx and SOx emission.

1.2 Humidification of inlet air

In a structure like this the charge air is humidified by mixing water in fine shower into the channel air with the desire to inundate it (Roy et al., 2009). Routinely this is completed close to the compressor outlet where the temperature is high which is a proper system to vanish the water. Tests have been done with mixture of water on diverse spots like before the compressor channel which can reduce the weight work in view of the cooling effect of scattering and upgrade the dispersing of the water/vapour however in these cases huge robustness issues of the compressor have happened (Tajima et al, 2007)

The humidification of the channel air is a for the most part clear plan with incredible potential to diminish NOx radiations and no engine modification beside utilization affirmation of the bay which makes this advancement to an engaging one. Yet more moved systems exist in this class like the HAM system. A substitute point of interest is that the vapor tends to give a cleaner ignition chamber and turbines which can abatement engine wear and enable longer organization interval (Pal and De, 2009). The possible water implantation entirety is limited of temperature and weight of the charge air. Extended temperature will allow higher incomparable sogginess since the drenching point will augment with the higher temperature while extended weight will have the opposite impact and decrease the possible aggregate moisture (Roy et al., 2009). Exactly when the submersion point is landed at or if the charge air is cooled to the dew point the vapour will condensate and whichever way the overabundant water gets drained out.

Normally the most compelling allowed charge air temperature is controlled by a Charge Air Cooler (CAC) and if the same temperature is used as a piece of customary operation (around 40-50 ºC) without humidification, the NOx diminish potential is limited to a biggest of 20-30% depending upon the charge pneumatic power used. With extended temperature higher diminishment is possible anyway it will grow the warm load and an extended beneficiary temperature will fabricate the NOx again yet not as much as the extended water entirety decreases it. The water usage is high when water is familiar with the sound air since all the air into the ignition chamber is humidified and not simply the air close to the flame as in the other wet-propels. The temperature diminish in the chamber is in like manner less resulting to the vanishing occurring in the sound structure before entering the ignition chamber where the CAC sets the temperature (Pal and De, 2009). High water usage bump clearly be a noteworthy issue depending upon the openness of suitable water. Humidification of the delta air requires in any occasion twofold the measure of water to get the given NOx diminish as Emulsion or DWI would do and routinely moreover depending after vanishing efficiency and diverse upgrades (Tajima et al, 2007)

1.3 NOx mechanism

The scattered water in the charge air changes both the association and properties of the working media. Right when the water vanishes the charge pneumatic anxiety increases due to the extended stream which will construct the mass got in the engine chambers (Androulakis et al., 2005). This impacts the temperatures in the barrels subsequent to the extended mass needs more imperativeness to be warmed up which will diminish the temperature given that the measure of fuel is predictable. Another reason behind the lessened temperature is the way that the water vapor has twofold the specific warmth utmost of dry air (1.86 versus 1.0 kJ/(kg*K)) which will grow the general specific warmth of the blend and thusly reduce the temperature exhaustively in the blazing chamber. The extended mass and the debilitating effect is the inspiration driving why exhaust gas distribution (EGR) furthermore decreases NOx outpourings however for the circumstance when just EGR is used (no extension of water) the specific warmth limit for the vapor gasses is about the same as for dry air.

The NOx decreasing contact with the presentation of water vapour is expert by diminishing the best blazing temperatures in the ignition chamber besides lessening the gathering of oxygen by the extension of unmoving media with high specific warmth. NOx course of action is dependent on the availability of oxygen and by diminishing the oxygen centre the NOx transmissions will along these lines be reduced (Tajima.et.al, 2007).

A disadvantage with this development is that the temperature is reduced at the flame and in addition at the edge of the ignition chamber closer to the barrel dividers which can stifle the flame in this area and augmentation distinctive radiations like hydro carbons and furthermore the fuel usage (Pal and De, 2009). This is however only obligated to happen when the measure of vapour into the ignition is really broad. Conventionally distinctive releases are relative negligible affected yet diverse spreads like PM/smoke and HC tend to be fairly extended with extended water total. It is all the more intense in NOx diminishment perspective to mix the water into the flame than to add water to the whole chamber charge following NOx is formed on the incline side of the scattering flame and in the hot post fire gasses, even after fuel-imbuement is done (Takasaki, 1988).

In any case as the spread flame is thin, the greater part of the NOx is organized in the post fire gasses and by reducing the temperature in the scattering fire simply will bring about the temperature in post fire gasses to be reduced and smothering NOx plan (Androulakis et al., 2005). This is one of the reasons why water mixture into the flame is more convincing than to incorporate water to the whole barrel charge. The water or vapor has an effect on the timing and term of the ignition as well and in this way the aggregate and the water imbuement timing is basic which can't be adjusted when the charge air is humidified. The adjustment in copying and warmth release will be depicted all the greater amount recently in the entertainment results (Takasaki, 1988).

1.4 Difficulties and issues

The guideline challenge with humidification of the bay air is when in doubt the vanishing of the mixed water (Kaspar et al., 2003). The dissemination is a troublesome issue which is liable to various things like drop size, weights, stream field allocation and the allowed recipient temperature et cetera. Further, utilization in the narrows system/gatherer and impeding of CAC and water haze catchers is a common issue with this advancement (Roy et al., 2009). The halting up and stores is as often as possible a consequence of too much minimal bled off from the re-coursed channel water or unreasonably terrible water quality while the utilization issue consistently is outcome of past the final turning point or lacking dissemination. Another reason can be too much cool dividers in the bay structure and that is the reason assurance may be essential to stay far from manufacture up now and again (Kohketsou et.al, 1996).

Note that there are a couple names for this development, for case Continues Water Injection (CWI), Fumigation and essentially Humidification thus on so it can be somewhat overwhelming when examining the composition concerning this subject.

1.5 Project Aim

The dissertation would aim to reduce the NOx by cooling the inlet air before turbo charger. As the oxygen (O2) and molecular nitrogen (N_2) are both in the combustion chamber will react to produce thermal NOx at very high temperature. The rate of reaction that produces NOx is mainly depending on the high temperature that resulted from the chemical combustion in the engine. Therefore, there is a relation between NOx and the temperature and it can be shown in the graph below.

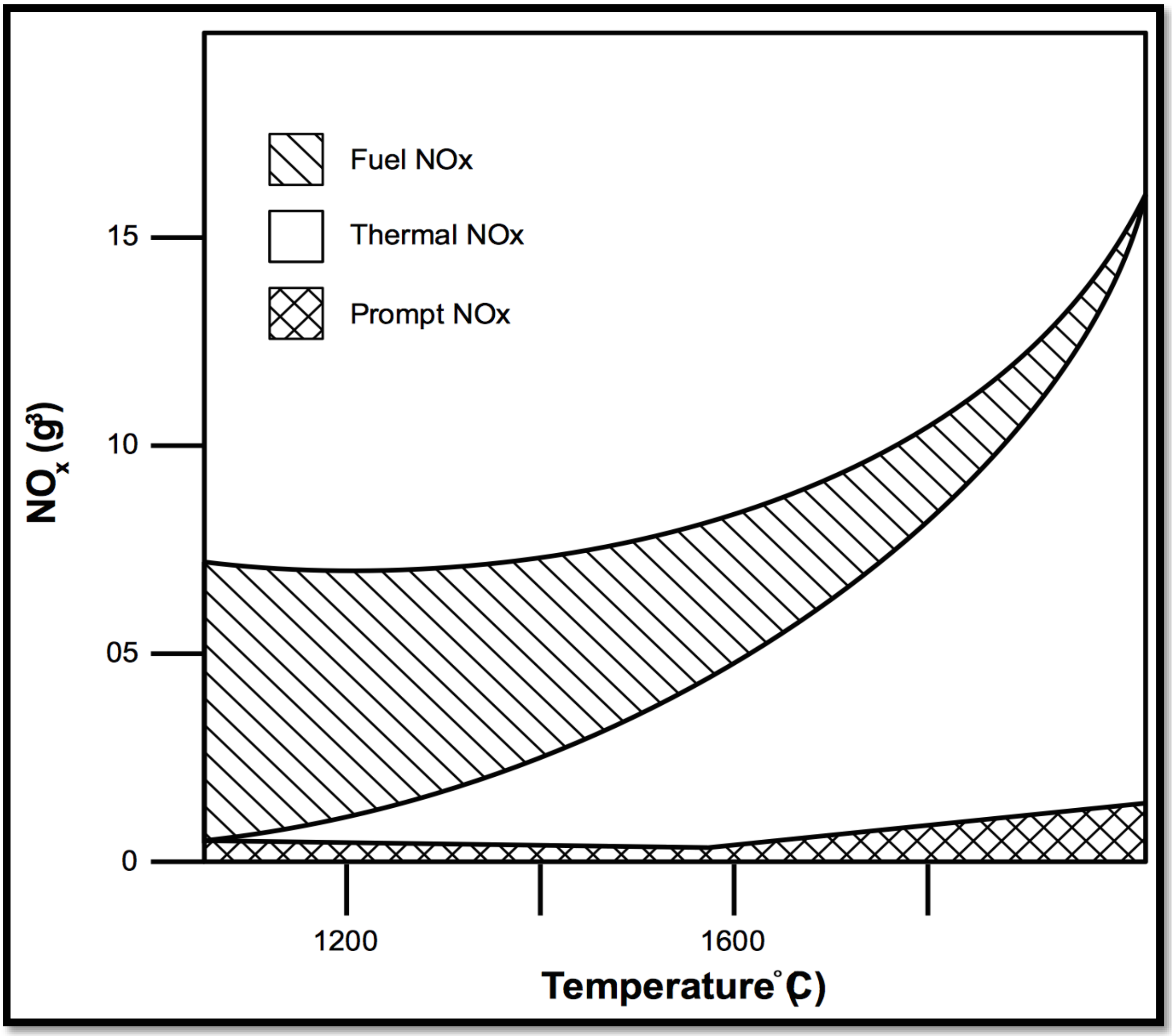


Figure 1.5: relation between NOx and temperature*1

From the graph, it can be noticed that there is a direct correlation between the temperature and NOx. So the less temperature result in the combustion chamber the less NOx will form.

In order to attain the aim of this study, the innovative approach of the system design has been done for this project. Under this technique, the extent to which the NOx emissions can be reduced by injecting water before the turbocharger compressor. The ambient air will be sucked by turbocharger through the cubic box device in which the air will be mixed with water. Therefore, the air temperature will be reduced, as the humidity will be increased before reaching the turbocharger thus all temperatures in scavenge air will be reduced. The impact of water on the air would also be studied through this project.

[1]http://www.innovativecombustion.com

II. Literature review

2.1 Adverse effects on the environment

Nitrogen oxide is produced as a result of burning of fuel at high temperature and emits from the motor vehicle exhaust. This oxidising agent can react with air resulting into formation of toxic organic nitrates and nitric acid (Eyring et al., 2007). The ozone at ground level is formed with the help of this gas. Similarly, sulphur oxide is also a harmful element causing adverse effects on the environment. The air quality is affected by this element.

NOx can cause serious irritation in lungs and reduce the resistance power of respiratory system causing diseases such as influenza (Shimizu and Satsuma, 2006). Continued exposure to it may cause acute respiration illness amongst children. The aquatic and terrestrial ecosystem can be adversely affected due to formation of ozone layer by NOx (Lövblad and Fridell, 2006). The production of high amount of NOx and SOx by marine engines may cause adverse effects on aquatic life, raising the need to identify measures to minimise the emission of this harmful element in the environment. The fish and other animals of sea may suffer from this due to reduction in the quantity of oxygen in the sea water (Calinescu et al., 2008).

2.2 Emulsion

There are fundamentally two separate sorts of emulsion utilized as a part of huge diesel motor
Operation, in particular (Walker, 2004):

- Water-in-fuel, W/F
- Fuel-in-water

Two unblendable substances when get combined they make emulsion. According to the Kasper in 2003, in this emulsion stage two substances are in scattered and persistent stages respectively. The scattered substance which has a unique characteristic to not get mixed with other here by exception decently blended in to other substance which is in persistent stage. This signifies that the water in fuel emulsion where water is in scattered stage and blended over fuel where fuel in water emulsion has totally opposite characteristics. Among these water in fuel emulsion has more regular usage and especially it is used to diminish the emission of NOx where fuel in water emulsion is made chiefly to make itself capable of using HFO with high thickness. According to Kohketsou in 1996, it has additionally profitability regarding the diminishing emission of NOx.

Difficulties and impediments with emulsion

According to Pal and De in 2009, the fundamental limits for utilizing the emulsion for lessening the emission of NOx is the fuel pump limit and fuel pump spout sizes. With high water to fuel emulsion the pump will be subjected to high load. For this reason bigger pumps are needed to determine the vitality which in turn determines the cost and utilization through optimum usage. According to Fraser in 2004, the motor has great execution power with and without framework like this. Extension of fuel spouts by engineering means will also raise the emanations at low load when the framework is exchanged off and if the standard size of fuel spout is still used the utilization will be increased because of the framework is still used. According to the experience of Wartsila, more fuel will be drawn out opening the span to infuse the bigger mass in high load. Heating and limit of water creation is subjected to the usage of emulsion and its capacity to use it legitimately. A hindrance with water in fuel emulsion is an unwanted decrease of temperature can happen and can heavily influence the delay in ignition as water accompanies the fuel in infusion in beginning. However according to Murotani in 2007, when the burning begins it has a tendency to be at more speed with higher warmth discharge and the timing of fusion is made up in such a way that it must confirm to make the delay of the ignition. It is known widely that substantial temperature of fuel infusion must not cross 140 degree Celsius since at this high temperature the o-rings used in fuel pumps will start to endure according Hamdi in 2004. According to Fraser in 2004, if the temperature is kept in the limit of 140 degree Celsius there can be more extravagant fixing material can be used. To work smoothly in this vast temperature gradient the framework of the emulsion must be pressurized to maintain a strategic distance from the vanishing of water and bubbling according to Birch in 2004. Expansion of the framework will make it more muddled and costly if the temperature is concerned. According to Walker in 2004, this issue regarding the fuel in water emulsion is not an issue because all things considered the thickness is decreasing as per the capacity of included water sum. The blending of fuel in water or water and fuel is just mode of alternate test and they must be legitimately combined and relying upon how and when they are combined they must make a steady emulsion. The tank used for making the emulsion and it must be taken care that the infusion must be carried out successfully and the emulsion must not corrode the tank metal. According to Wang in 2008, in this way it is advantageous if the blending is happening late and as much as close to the infusion point of the chamber.

MAN proposed the greatest size of the water droplet is 5 micro meter yet it may not be important to blend fuel and water in micrometer size droplets because as per Murotoni in 2007, different tests showed that there were little effect on the discharge diminishment with less propelled blending.

2.3 Fuel injector valves and nozzles

The recent development in the engines regarding the low emission of the NOx is based on the philosophy of fine-tuning of fuel injector system. According to Burch in 2004, the manufacturers successfully tested the burning fuel spray in the engine combustion chamber based on the model of CRFD to achieve the lower emission of NOx. Slow speed engines can have two three fuel injectors located at the outer edge of the combustion chamber and each of the fuel injectors can have many holes.

There is a significance of the sprays from the individual holes of the nozzle spray. There are an optimum number of holes for lower NOx emission. According to Lövblad, and Fridell, (2006) there is a very important relation between the flame zones and metal surfaces for controlling the emission of the NOx in medium speed engines. The hottest zone is near cylinder head and piston and cooling of the burnt gases and flames from the surfaces reduces the emission of the NOx. But too much cooling or impingement of the metal surfaces by the un-burnt fuel can increase smoke. According to Lövblad, and Fridell (2006), the optimum combustion place for low emission for NOx is favourable and a new computational method was introduced to reduce the space around the burning areas in medium speed diesel engine. According to them much space is there around the burning areas for the production of NOx and there is also way to shrink and relocate the layer where NOx formation is greatest. The new design is done in such a way that it can enhance the mixing of later stages of combustion and turbulence, which improves the lower emission of the NOx and also increase the fuel efficiency.

The MAN B&W introduced slide type fuel valves as the standard for the low speed engines. It has zero sac volumes so that entry to the combustion chamber after injector ceases can be minimized (Shimizu and Satsuma, 2006). This automatically leads to the low emission of CO or HC if due to any fuel leakage the combustion process is gone incompletely. The development of the slide valve was done along with optimization of the fuel nozzle for NOx. Mitsubishi used a low NOx fuel injection valve in its UC 52 LSE low speed engine and it reduced the emission of NOx from 18.5g/kWh to 15g/kWh with 2 percent fuel penalty (Nadia and Hamdeh, 2003).

2.4 Electronically controlled camshaft

Newly developed electronically controlled camshaft less engines has proved that they have great flexibility regarding the optimization and very broad spectrum in the operation capability as per Wang in 2008. Though few engines have these type controls with numerical methods but camshaft less electronically controlled engines have more control flexibility than the conventional engines (Ji et al., 2006). The main features of it are variable injection timing or VIT, variable injection pressure, injection rate shaping and variable exhaust valve closing or VEC. The variable exhaust valve closing system mechanism gives affect on changing of compression ratio. It is possible with VIT and VEC to optimize the increased compression ratio in a broader range with interplay in the injection timing retard. It helps to maintain pick pressure at low speed and avoiding excessive peak pressure at high speed (Yoshida.et.al, 2008). Common rail injection system gives good characteristics at low loads with high injection pressure.

2.5 Injection timing retard

The formation of the NOx depends on the temperature along with the residence time (Breen et al., 2005). The burnt gas comes from the part of the combustion before the peak pressure due to rise of pressure in the combustion chamber. It signifies that burnt gas stays longer than other burnt gas from the later stages results the formation of NOx. Delayed injection can cause lower pressure and temperature throughout the process (Tajima et al, 2007). The delay in the fuel injection can cause in the increment of fuel consumption because of the later burning. It happens due to the lesser amount of combustion energy release with free expansion process and the temperature of the gas will get much higher in the expansion stroke. It results not only in the rise of the temperature but a substantial heat loss in the wall and formation of smoke because there is combustion taken place in low temperature and less oxidation in the soot produced in the earlier combustion process in the engine cylinder.

2.6Injection rate shaping

As per Tajima et al (2007), there are many types of injection systems are there such as RT-flex common rail, slow speed engine. A small amount of fuel charged before the main charge in the pre –injection system. In triple injection system, which is also known as pulsed injection process the fuel, is sprayed in separate, short sprays in succession (Lövblad, and Fridell, 2006). In the sequential injection process, each of the three nozzles in a cylinder is given separate timing. For pulse injection it is actually can cause 20 percent less emission of NOx with 7 percent increase in the fuel consumption (Breen et al., 2005). The pre- injection and sequential injection process gives less NOx reduction thus less fuel consumption increase. The effects are the results between the overall change in the pressure development and interaction between the fuels sprays (Tajima etal, 2007). To shorten the delay period in the medium speed engine pre-injection system can be used as it can cause decrease in the temperature and pressure in the early stages of the combustion thus reduction in the NOx. For the less emission of NOx pre-injection is proved to be better than other systems as it can reduce the particulates than the other systems (Ji et al., 2006).

2.7Injection timing, compression ratio and the rate of injection

According to Park and Boyd in 2005, the most common method of tuning is to increase the compression ratio with decrease in injection timing. The peak pressure is the same as standard engine and same crank angle. According to Shimizu and Satsuma in 2005, it is also same for all standard engines may be they are starting late. The increase in the compression ratio can increase the consumption of the fuel because the retarded fuel injection system can contribute significantly into it. According to Takasaki in 1988, motor with medium speed engine increased the compression ratio 15.5 to 17 while retarding injection timing to the limit that can cause increment in the peak cylinder pressure is about 20 bars. It gave NOx reduction from 12g/kWh to 8g/kWh without increasing the fuel consumption. According to Yoshida in 2008, in slow speed engine, the maximum reduction in the emission of the NOx can be achieved by increase in the compression ratio with retarded timing 25 percent along with 1 percent fuel consumption penalty. The compression ratio can be increased by means of geometric compression ratio and by means of exhaust valve closing in a controlled manner. But this will also increase the mass available to absorb the combustion energy along with the concentration of oxygen inside the cylinder thus all will contribute to the formation of the NOx. According to Breen in 2005, The Wartsila NSD has found from its studies and research that, increase in the scavenge air pressure along with the retard in the fuel injection that may increase or decrease the amount of the emission that is dependent on the design of the engine. If the geometric compression ratio is increased by decreasing the clearance volume, then the combustion place will flatter which can result more and efficient means of cooling of the flame of the surface and the soot will also increase with additional decrease in formation of NOx due to cooling as per Kasper in 2003. The combustion chamber shape and the fuel spray geometry pattern type are the most important parameters to determine the adjustment to be done with decreasing the height of the combustion chamber. As per Park and Boyd in 2005, a very high compression ratio is needed for the medium speed four stroke engine to reduce the valve overlap. Due to overlap between valves and pistons there are also significant chances of the decrease of the overall efficiency of the engine as it also reduces the scavenging efficiency and the cooling of the exhaust valve. The significant amount of the scavenged air present inside the engine is also very useful because it can decrease the amount of the NOx emission inside the cylinder. Leading engine manufacturer of Japan, Mitsubishi said its all engines are manufactured according to the Marpol annex IV NOx level norms by fine tuning of the engine with injection time retard, low NOx fuel injection valve etc. MTU has reported its new MTU 8000, four kilowatt per cylinder; 1150 RPM series has new NOx emission control system. MTU said they are achieving it by fuel injection timing retard, increased compression ratio along with optimized injection.

2.8 Scavenge air temperature, miller super charging

The reduction in the scavenged air temperature is very important because it can reduce the combustion temperatures so gradual decrease in the emission of the NOx (Irani et al., 2009a). It is seen that for every 3 deg. C decrease in the scavenged air temperature there is 1 percent less NOx emission and SOx. Reduction of charged air temperature helps a lot to decrease the overall temperature, decrease in the heat losses, finally that result to increased thermal efficiency for the engine. The potential for this measure is the technique of cooling by means of standard air is very limited. According to Murotoni , the Miller technique can be used in four stroke engine to achieve the lower scavenged air temperature. The Miller concept is based on the fact on using the turbocharger of higher than normal pressure. The inlet valve is closed before the piston reaches the bottom dead centre or BDC in intake stroke as per Park and Boyd in 2005. The charged air then expands inside the cylinder and pushes further the piston to bottom dead centre, which in turn actually decreases the temperature. The Sulzer ZS40S medium speed engine uses the Miller system of supercharging. As per the report of Wartsila NSD, the early inlet valve closing mechanism was introduced in its medium speed engines. Caterpillar motoren or MaK has introduced the Miller supercharging system in their engines by early inlet valve closing with slightly increase in the pressure of the charge. The degree of reduction of the NOx reduction is restricted by means of available pressure of the single stage turbocharger. According to Irani in 2009, the excess cooling of the air is not supported because the soot formed by the oxidation during the combustion and the smoke. The caterpillar motoren has found out that the increased smoke formation at low load is limited on the usage of the Miller supercharger. It is found that by using the Miller supercharging technique the NOx emission can be reduced up to 20 percent without any growth in the fuel consumption for the overall operation (Ji et al., 2006).

2.9 Exhaust gas recirculation

For lowering the temperature of combustion exhaust gas recirculation is important. It also reduces the amount of NOx and SOx emission. Increment of specific heat capacity of the combustible gas inside the cylinder and by reducing the overall oxygen concentration the exhaust gas circulation or EGR reduces the temperature of the gas (Ji et al., 2006). It is also very important to be noted that the exhaust gas recirculation increases the smoke due to reduction of oxygen concentration, increasing the duration of combustion and decreasing the temperature of the combustion (Kee et al., 2003). It is also related to the thermal load and exhaust temperature of the engine because due to reduction of combustion rate these two increases (Murotani.et.al, 2007). Engines operation on poor quality fuel can have exhaust gas recirculation as a major issue because it can lead to corrosion of the parts even to fouling also. The residue from the cooling and exhaust area of the ships, which use heavy oil as fuel, has sulphur in it (Bowman, 1975). That is not very easy to get decomposed of. Japanese engine manufacturer Kawasaki has found 28 percent of the exhaust gas recirculation yielded 69 percent of NOx emission reduction in a MAN B&W 5S70MC engine with a slight rise is smoke and fuel consumption is also seen during the tests. Another engine manufacturer Wartsila with its Wartsila NSD found out 6 percent exhaust gas recirculation yielded 22 percent reduction of emission of NOx and SOx on 4RTX54 research slow speed engine. It was also found out a subsequent rise in the thermal load on engine components and rise the exhaust gas temperature (Després et al., 2003). Wartsila NSD is now developing a new concept where exhaust gas recirculation will be worked internally in two stroke engine as extended measure beyond the tuning of engines method. By reducing the height of scavenge ports the incoming amount or flow of scavenge air into the cylinder can be reduced significantly (Markatou, 2005). It will lead to the availability of more combustible amount of gas in the cylinder that can be used to start another readily. Lowering the scavenge ports is also very interesting thing as it will increase effective stroke length that can lead to the reduction of the fuel consumption. Wartsila NSD has a developed a new method to overcome the increased thermal load on the engine with internal exhaust gas recirculation. This is known as “exhaust cooled residual gas” method. It is capable to bring back the temperature back to same earlier without internal exhaust gas recirculation. The temperature inside the combustion chamber is also very high during combustion and using this technique of the Wartsila NSD as the chances of deposit of acids also becomes very less nearing zero. This also helps in the reduction of NOx of the engine.

III. Methodology

3.1 Approach followed

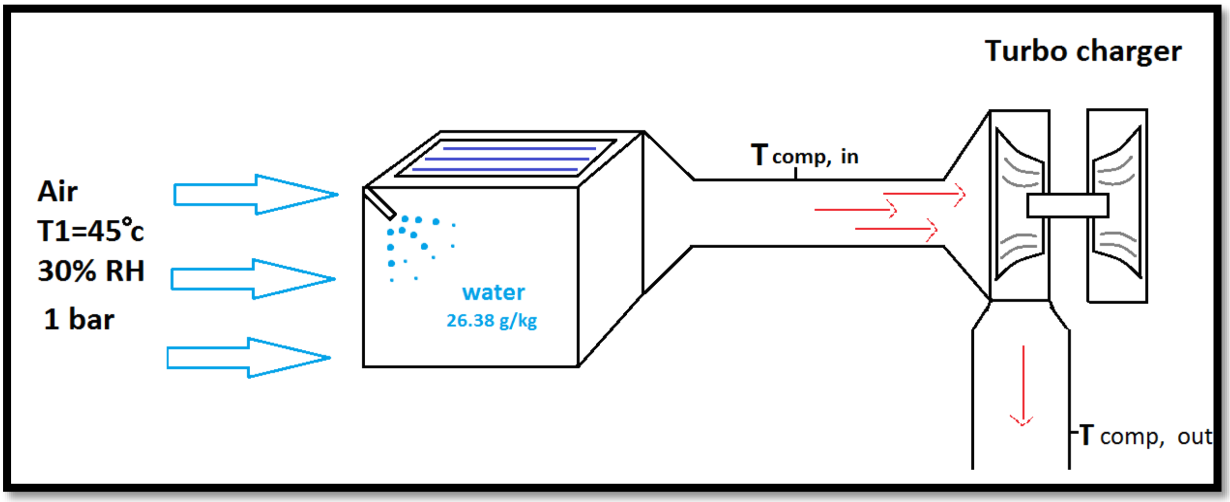


Figure 3.1: Device Sketch

Through the literatures there were some limitations in each method, so the idea was to develop a device that would work safely with main engine to insure high performance process and minimum possible cost. In this project there is no need for adjustments or any extra parts to be fitted for main engine.

The sketch of the device has been drawn above as a cubic device connected with turbochargerby a channel or passage that allows the cool air passes through to the turbocharger. In this project, the inlet air has been estimated according to Arabian Gulf weather to have an ambient air temperature of 45 degree Celsius with the pressure of 1 bar and RH 30% in the engine room. In the process, cold water of 25 degree Celsius would be injected to the ambient air through the small-pressurised nozzle that are located at the top of the cubic box. The air would be sucked into the cubic box where it will be mixed with water.Theair/water mixtureleaves the devices at lower temperature due to increase in humidity.This mixture would thereafter be sucked through the turbocharger and then compressed at lower temperature. The cool air would be passed through scavenge cooling air for a further cooling and finally to the combustion chamber resulting into reduction in the NOxlevel.

In the combustion chamber, level of inlet air temperature would be reduced through the process, as there is a relationship between NOx and the inlet air temperature.The affect of low intake air temperature and high humidity on internal combustion chamber has been approved, as a higher humidity results in lower NOx emissions (Brown et al, 1970).

The process would thus be expected to reduce the amount of NOx emissions. After injecting water into the air, the fall in temperature would be noted as well as that before/ after the turbocharger. The amount of air flowing inside the device and the quantity that can be cooled is given by selecting the type of engine that would be used for this project. However, the amount of water that would be used in order to cool down the inlet air and increase humidity can be calculated through the project.

3.2Calculations

The calculations would be carried out to identify the NOx level prior to before installation of device and after its installation. The difference between both these states would be compared through this project.

In this project, the calculation firstly would be carried out before installing the device. Then,a calculation made for after installing the devise in order to compared and analyse the different that the device would provide. The engine selected will be MAN Diesel turbocharged 7L60MC-C7.1-TI (MAN Diesel & Turbo, 2015).

The very fine water sprayed into the inlet air will increase the humidity and reduce the temperature. A study by El-Sinawi et al (2012) has shown that the water of 30% of consumption fuelis injected into the cylinder. The injected water will raise the air humidity and lower the air temperature inside the devise thus will NOx elements. To identify the new relative humidity and temperature, the Psychrometric chart will be used.

During the calculations, the efforts are made to identify the percentage by which NOx is reduced when the water is applied before the turbocharger. The calculations would be done based on the inlet air temperature of the cylinder. The flow rate of air and temperature prior to entering the box would also be noted. Thus, comparison would be made to find out the extent to which the NOx content is reduced due to the usage of water spray under this technique.

IV. Analysis and Evaluation

4.1Injection of water

Engine manufacturers could be able to bring down the emission of the NOx and SOxbelow the Marpol annex IV level by means of improvisation in tuning mechanism of the engines. Water injection, fuel/water emulsion, humidification and selective catalytic reactors are used for further reductions of the NOx emission (Burch et al., 2002). Water injection can reduce the temperature because of absorption of energy of evaporation and increase in the specific heat capacities of cylinder gases. Water can be introduced in charged air by means of humidification through the direct injection into the cylinder or by fuel/water emulsion mechanism. The difference between the humidification and fuel / water emulsion is the humidification can increase the smoke where the fuel/water does exactly the opposite. Water/fuel emulsion or direct water injection can be used directly to the cylinder region of the engine where the chance of formation of NOx is more (Kee et al., 2003). Generally it is found out that water/fuel injection or direct water injection can reduce 1 percent of NOx for every 1 percent of water to fuel ratio. Humidification is different from these two systems because it will need two times more water to reduce the same amount of NOx done by them. It is a very interesting fact that all water around the cylinder doesn't end into combustion process rather than it can be said that it totally depends on the spraying pattern of the water. Humidification is a process, which can reduce the emission of the NOx up to 2 to 3 g/kWh without lowering the fuel consumption. Humidification is extensively tested by different engine manufacturers mostly on the medium speed engines, which is most common as per the usage throughout the world (Burch et al., 2002). The adaptability, flexibility and optimized operation effects about humidification on slow speed engine is going on and feasibility is yet to be proved. Engine manufacturer MAN B&W offers humidification for their four-stroke engine propulsion system range. Direct injection of water system is also available in Wartsila NSD medium speed engines. Its NOx level is restricted up to 5-6 g/kWh without having any significant increase in the fuel consumption (Irani et al., 2009b). Japanese engine manufacturer Mitsubishi uses a very interesting mechanism known as stratified water fuel injection as an option for its UEC LS2 slow speed engines. MAN B&W also offers fuel water emulsion system for its slow speed and medium speed engines. MAN B&W has claimed by using fuel water emulsion system as a combination of injection timing retard on its medium speed engines, the emission of NOx is restricted up to 7g/Kwh.

4.2 NOx and SOx control

Water emulsion has the immense profit of lessening both NOx and SOxfurthermore PM discharges, which are unrealistic with humidification of the gulf air (Roy et al., 2009). Ordinarily the diminished temperature because of the cooling impact from vanishing and the expanded warmth limit will diminish NOx and SOxemanations additionally build PM discharges in the same path as impeded SOI would do. Low temperature and low oxygen fixation will give low NOx and SOxemanations yet all these parameters will in the meantime build the ash and PM emanations. The sediment arrangement is thought to be reliant on the forward response of particularly acetylene (C2H2) as a presoot particle for bigger sediment atom arrangement. In any case the development of sediment by acetylene is likewise thought to be adjusted by the obliteration (oxidation) of residue by the hydroxyl radical, OH. It is this hydroxyl radical that is thought to be the explanation behind the PM lessening when emulsion is utilized since when water is acquainted with the ignition fire (as in emulsion) it will cool the fire which ordinarily build the ash arrangement yet since the test have demonstrated a decline in residue development an active concoction response with the water must happen and have an impact on the development (Wang et al., 2008). It is demonstrated that lessening of ash is created by the expanded centralization of hydrogen and oxygen since water at temperature regular of the fire zone separates into O, H, H2and OH (and not acetylene, C2H2) (Markatouetal, 2005).

Yet tests have likewise demonstrated that the NOx and SOx decrease has a tendency to be littler and littler with expanded water sum and at a certain level when the measure of water is excessively high, the fire temperature will be excessively low and reason a ton of damage to the burning by extinguishing (Pal and De, 2009). This sensation happen for all the wet advances however the impact on the PM arrangement is bigger for emulsion since the water is decently blended with the fuel which makes the response in and close to the fire more influenced for emulsion than in the other advancements (Kaspar et al., 2003). The worldwide diminishment of the temperature in the burning chamber for the other wet-advancements influences the PM more contrarily than the positive influence of the increment in hydroxyl radical and increments with expanded measure of water.

a. Calculations

The details below is taken by MAN diesel turbocharger 7L60MC-C7.1-TI engine specifications (MAN Diesel & Turbo, 2015):

Engine Power	15,610 kW
RPM at full load	123.0
Scavenge air pressure at full load	3.5 bar
Main engine Specific Fuel Oil consumption (SFOC)	174.2 g/kWh
Main engine Air consumption:	40.9 kg/s
Main engine intercooler Sea water cooling system flow rate	217 m^3/h = 60.28 kg/s
Turbocharger efficiency	75%

Engine Room Condition:

Engine Room Ambient Temperature	45 ℃
Relative Humidity	30%
Atmospheric pressure	1 bar
Sea water temperature	32 ℃

First of all, in order to increase the humidity of the inlet air, a quantity of water is calculated based on the study conducted from El-Sinawi et al (2012) showed that water of 30% of fuel consumption is injected in the combustion chamber to reduce NOx level. Therefore, the fuel consumption can be converted to g/s as shown below:

SFOC = 174.2 g/kWh at 15,610 kW full load (from MAN engine data)

So, Fuel flow rate = (174.2 x 15610) / 3600

Fuel flow rate = 755.4 g/s (1)

Then, the water of 30% of fuel flow rate can be calculated:

The water flow rate of 30% of fuel flow rate is:

= 755.4 x 30% = 226.6 g/s (2)

From Main engine weather condition, the ambient temperature is 45℃ at 30% RH. That would result in water is carried by the air entering the cubic box, and by using a Relative humidity calculating program from Lenntech, can calculate the grams of H_2O per kg of air. At temperature of 45℃ and 30% of relative humidity:

The grams of water per kg of air = 20.84g/kg (from Lenntech software) (3)

More over, by dividing the water of 30% of fuel flow rateby main engine air consumption (40.9 kg/s), the amount of water is then calculated. Therefore, the required relative humidity is then found by Lenntech program.

Dividing (2) by the air consumption 40.9 kg/s:

226.6 / 40.9 = 5.54 g/kg (4)

This is water needed to be injected in the device in order to increase the air humidity thus will reduce the inlet air temperature.

The total water will be carried by the intake air and water injection at the device that is going to the turbocharger then to the combustion chamber can be found by adding the (3) and (4):

20.84 + 5.54 = 26.38 g/kg (5)

By injecting this amount of water (26.38g/kg) into the air, the new relative humidity is calculated from Lenntech program. Thus, by using the Psychrometric Chart, the new inlet air temperature is reduced to 33.5℃ and relative humidity increased to 71% (see page 25).

Turbocharger Air compressor:

The two stroke slow speed marine engines are equipped with two sets of turbochargers. The intake air temperature of air compressor $T_{Comp,\ in}$ (K) is considered to be equal to the ambient air temperature of engine room condition. The outlet temperature of turbocharger compressor $T_{Comp,\ out}$ is calculated from (Zhu, 2008):

$$T_{Comp,\ out} = \frac{T_{Comp,in}}{\eta} \left[(\text{pressure ratio}^{(k-1)/k} - 1\right] + T_{Comp,\ in} \quad (6)$$

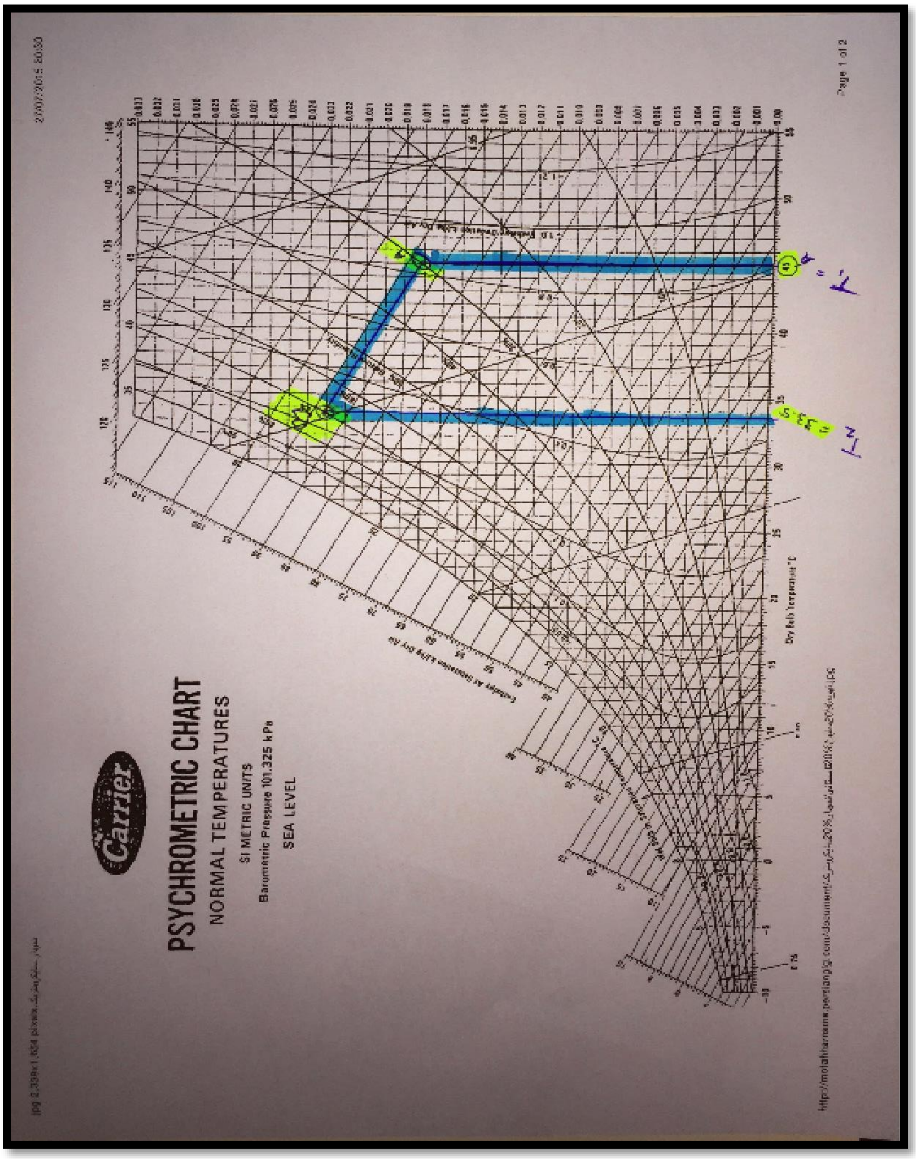
Where η is the turbocharger efficiency, k is the ratio of Cp/Cv for air, Cp and Cv (J/kg.K) are the constant pressure and constant volume specific heat of air respectively. The pressure ratio is the absolute outlet pressure divided by the absolute inlet pressure and this is given by engine specifications.

Quantity of heat transferred in intercooler scavenge air:
Intercooler is a typical heat exchanger that helps scavenge air to increase the efficiency of the engine by reducing the temperature of the compressed air from turbocharger. Reducing intake air charge temperature will help in reducing the combustion chamber temperature thus will reduce the NOx level. In order to calculate the inlet air temperature that heat exchanged with intercooler, the following equation is used:

$Q = \dot{m}.\ Cp.\ \Delta T$ (7)

Where Q is the quantity of heat transferred in the intercooler, m is the mass of the object needs to be calculated and ΔT is the temperature change of the object.

The Psychrometric Chart below shows the new relative humidity and temperature that would content water of 26.38 g/kg of air at constant Enthalpy:



There are two cases of calculations:
A-Before installing the device:
To calculate the outlet air temperature of turbocharger compressor ($T_{Comp,\ out}$), ambient air temperature is known as engine room temperature, which is $T_{Comp,\ in}$ = 45℃ as assumed earlier. The following equation is used (6):

$$T_{Comp,\ out} = \frac{T_{Comp,in}}{\eta}\left[(\text{pressure ratio}^{(k-1)/k} - 1\right] + T_{Comp,\ in}$$

Where, $T_{Comp,\ out}$ = air outlet temperature of turbocharger compressor
$T_{Comp,\ in}$ = ambient air (engine room condition) = 45℃ (318 K).
$\eta = Turbocharger\ effienciy$ = 75% as given from engine data (MAN Diesel & Turbo, 2015).
Pressure ratio = 3.5(as given from engine data)
K = Cp/Cv = 1.4 for air
Now, $T_{Comp,\ out}$ =318/0.75 [$3.5^{0.286}$ – 1] + 318
$T_{Comp,\ out}$ = 227.7℃ (500.7K) (8)

Now, need to find the air inlet temperature after the scavenge air cooler. Therefore, some assumption are made for sea water intercooler temperatures in order to find the quantity of heat transferred and using equation (7) at efficiency of 78% (Heim, 2008):

$$Q_{SW} = \dot{m}_{SW} . Cp_{SW} . (T_{SW,out} - T_{SW,in})$$

Where, Qsw is Seawater quantity of heat transferred in the intercooler
$\dot{m}_{SW}$ = Sea water flow rate= 60.28 kg/s (as given from engine data)
Cp_{SW} = Specific heat of sea water = 4.011 kJ/kg.K
$T_{SW,\ in}$ = seawater temperature entering intercooler = 32℃ (assumed)
$T_{SW,out}$ = seawater temperature leaving intercooler = 55℃ (assumed)
Intercooler efficiency = 78%
So,
Q_{SW} = 60.28 x 4.011 x (55 – 32)
Q_{SW} = 5561.01 / 78% = **7129.5 kJ/s** (9)
For balancing the system,
$Q_{SW} = Q_{air}$

$$Q_{air} = \dot{m}_{air} . Cp_{air} . (T_{Comp,\ out} - T_{Cyl,\ in})$$

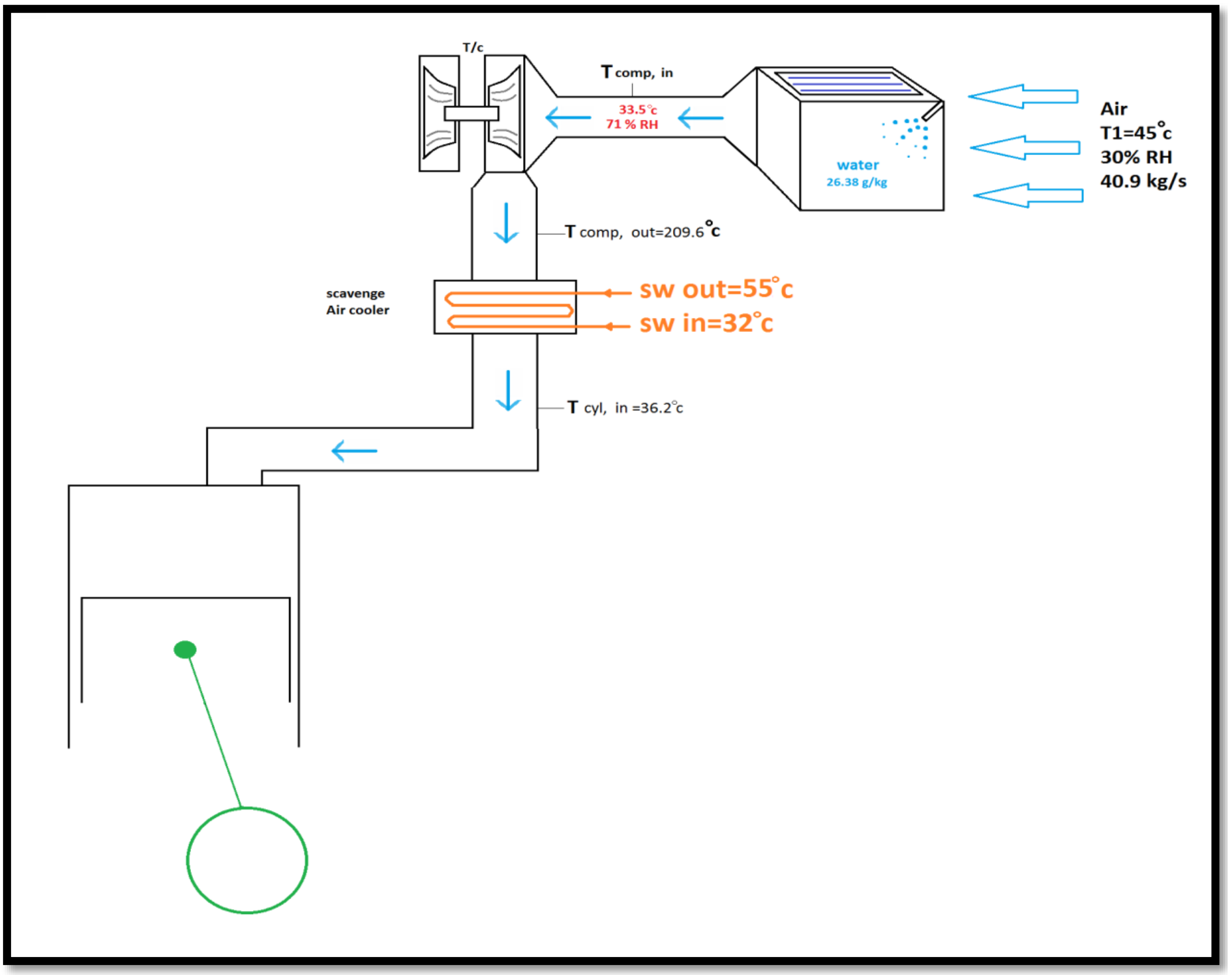
Where, Qair = heat loss of air
$\dot{m}_{air}$ = Mass flow rate of inlet air = 40.9 kg/s (is given from engine data)
Cp_{air} = specific heat of air = 1.005 kJ/kg.K
$T_{Comp,\ out}$ = air outlet temperature of turbocharger = 227.7 ℃(from (8))
$T_{Cyl,\ in}$ = air temperature leaving intercooler
7129.5 = 40.9 x 1.005 x (227.7 – $T_{Cyl,\ in}$)
$T_{Cyl,\ in}$ = 54.3 ℃ the inlet temperature enters cylinder (10)

B- After installing the device:
According to the amount of water that was calculated at (5), by using Lenntech program and using Psychrometic Chart, the new air intake temperature is $T_{Comp,\ in}$ = 33.5℃ and Relative humidityis 71% at constant enthalpy.
The outlet air temperature of turbocharger compressor is calculated from equation (6), Wherethe new $T_{Comp,\ in}$= 33.5℃:

$$T_{Comp,\ out} = \frac{T_{Comp,in}}{\eta}\left[(\text{pressure ratio}^{(k-1)/k} - 1\right] + T_{Comp,\ in}$$

Where, $T_{Comp,\ out}$ = air outlet temperature of turbocharger compressor
$T_{Comp,\ in}$ = inlet air temperature to turbocharger which is coming from the devise after increasing its humidity and reducing the temperature = 33.5 ℃ (306.5 K)
η = Turbocharger efficiency = 75% (as given from engine data)
Pressure ratio = 3.5 (as given from engine data)
K = Cp/Cv = 1.4 for air
Now,
$T_{Comp,\ out}$ =209.6 ℃ (482.6 K) (11)
As previously calculated at (9), the quantity of heat transferred in seawater side intercooler Q_{SW} = 6789.3 kJ/s and for balancing the system:

$Q_{SW} = Q_{air}$
$Q_{air} = \dot{m}_{air} \cdot Cp_{air} \cdot (T_{Comp,\,out} - T_{Cyl,\,in})$
Where, Qair = heat loss of air
$\dot{m}_{air}$ = Mass flow rate of inlet air = 40.9 kg/s (is given from engine data)
Cpair = specific heat of air = 1.005 kJ/kg.K
$T_{Comp,\,out}$ = air outlet temperature of turbocharger = 209.6 ℃ (from (11))
$T_{Cyl,\,in}$ = air temperature leaving intercooler and entering the cylinder.
7129.5= 40.9 x 1.005 x (209.6 – $T_{Cyl,\,in}$)
$T_{Cyl,\,in}$ = 36.2 ℃ the inlet temperature enters cylinder (12)



Thus, we have
Inlet air temperature before installing the devise = 54.3 ℃.
Inlet air temperature after installing the devise = 36.2 ℃.
The difference in the heat inlet to the cylinder without the device and the heat inlet to the cylinder with the use of the technology is noted as
= 54.3 – 36.2
= 18.1℃
Thus, it can be interpreted that 33.3% in inlet air temperature reduction. A study conducted by Roessler et al (1974) stated that for every 37.8℃ in intake air temperature drop; there would be 20% reduction in NOx emissions. Therefore NOx level will be reduced by 9.6% when the inlet temperature is dropped 18.1℃.
Nitrogen (N_2) and oxygen (O_2) are reacted and combined together at high temperature in the combustion chamber to form thermal NOx.These emissions can be reduced to a harmless by-product constituting of nitrogen and water vapour. Reducing the inlet air temperature will result in preventing the combination of nitrogen and oxygen to occur, thus will help in reducing NO molecules causing less negative impact on the environment. As a result of temperature reduction, the oxygen elements get apart resulting into release of nitrogen and oxygen.

This oxygen is not a harmful gas, making it an appropriate choice for using water spray for cooling down the inlet air in combustion engine.

The technique can therefore be viewed to benefit the environment by reducing the amount of NOx emission by 9.6%.
Comparison between the air temperatures conditions before/after installing the device at air ambient temperature of 45 ℃:

Before		After	
$T_{Com, in}$	45 ℃	$T_{Com, in}$	33.5 ℃
$T_{Com, out}$	227.7 ℃	$T_{Com, out}$	209.6 ℃
$T_{Cyl, in}$	54.3 ℃	$T_{Cyl, in}$	36.2 ℃

V. Conclusion

5.1 Conclusion

Overall, the efforts have been made to identify most suitable strategy that can result into benefiting the environment through control over the emission of nitrogen contents. This can aid in favour of the environment as the harmful gas emission can be controlled by utilising the most suitable technique in marine engines.

Two-stroke marine engines run in varies modes and load conditions. Therefore, the engine piston movement causes different changing in temperatures and pressures occurring inside combustion chamber. These unstable conditionsof burning fuels cause a chemical reaction that would result in forming NOx molar and thus would increase NOx level.

On the basis of calculations carried out in this project, it is important to note that the reduction in inlet air temperature can be of immense help for reducing the temperature for combustion engine. From the result that obtained previously, the air temperature interring the cylinder without using this technique is much higher than the air temperature inlet that cooled by sprayed water.

This reduction in air temperature can be attained by installing the cubical device prior to turbocharger. The device would be used for spraying water over inlet air so that this air is cooled prior to entering into the turbocharger. The humidity would be increased through the approach for reduction of air temperature. This technique can be of immense help as it can affect around 29% of cooling the air resulting into controlling the emission of that part of the air.

The water injected would affect the 29% of reduced air temperature and thus the nitrogen and oxygen content cannot be combined together, resulting in reduction of NOx by 9.6%. This technique can be viewed of immense help for the combustion chamber. Marine engines can thus make use of this technique in order to keep control over their harmful gas emission. This approach can be beneficial without compromising against the efficiency of engine.

5.2 Scope for further studies

Although this study has been carried out in the best possible manner based on the available details, there is the need of further efforts. The project here helps in identifying the extent to which NOx contents can be reduced for the engines of marine engineering. However, the study does not take into account the extent to which there is an impact on the efficiency of an engine using this technique. The side effects of the technique on overall mechanical system need to be further studied carefully. This is to ensure that no adverse effects take place in the real life settings on the combustion engines. It is not ideal to directly use this system in the practical environment, but there is the need to conduct further experiments in this arena to identify the exact influence that the technique of installing this device can have on the engines.

In addition to this, there is the need of further research into this field to identify the relationship between external environment and the technique. There is the need to identify if this technique can work under different circumstances that vary for the geographic location or can it be used as a universal method to benefit marine engines. The next research can be conducted by taking this study ahead and supported by appropriate funds to ensure that the research is conducted in-depth to identify the best means of controlling the release of NOx contents into the environment.

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