REDUCTION OF DIESEL EXHAUST EMISSION BY USING FIRST STAGE SEAWATER SPRAY SYSTEM

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2012

M.AZMI SITAM BACHELOR OF MECH. ENG. (AUTOMOTIVE) 2012 UMP

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: REDUCTION OF DIESEL EXHAUST EMISSION BY USING FIRST STAGE SEAWATER SPRAY SYSTEM

SESI PENGAJIAN: 2011/2012

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REDUCTION OF DIESEL EXHAUST EMISSION BY USING FIRST STAGE SEA WATER SPRAY SYSTEM

MOHD AZMI BIN SITAM

Thesis submitted in partial fulfillment of the requirements
for the award of Bachelor of Mechanical Engineering with Automotive Engineering

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JUNE 2012

EXAMINER’S APPROVAL DOCUMENT

UNIVERSITY MALAYSIA PAHANG

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I certify that the project entitled “*Reduction of Diesel Exhaust Emission by Using First Stage Seawater Spray System”* is written by *Mohd Azmi Bin Sitam*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ACKNOWLEDGEMENT

I am grateful and would like to express my sincere gratitude to my supervisor Dr. Agung Sudrajad for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a bachelor program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my lab mates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to member final year project group for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my friends. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

Air pollution from the diesel exhaust emission gives a bad effect to health and environment around the world. The content of the emission mostly harmful gases such as Nitrogen Oxide (NOx), Carbon Monoxide (CO), Hydrocarbon (HC) and Particulate Matter (PM). This thesis is aim to reduce diesel exhaust emission by using first stage seawater spray system. A spray chamber designed to setup together with the diesel engine for diesel experiment. The chamber is connected to the exhaust manifold to collect emission gas by using particle trap. Then, the emission data without seawater (WOS), with seawater (WS), and with electrolyzed seawater (WES) spray system for five variable engine speeds is analyzed using exhaust gas analyzer. The temperature change is also measured. The result had shown the comparison of emission concentration for three condition seawater sprays system in form of graph of emission concentration versus engine speeds. Most of the emission is reduce after flow through the spray chamber except for the oxygen that is increasing because of the additional oxygen in the seawater. The other emission is absorb by the alkaline seawater and dissolved in the seawater. The research had shown the effectiveness of alkaline seawater as a medium to reduce diesel exhaust emission. The emission WES spray is reducing more compares WS spray system. Furthermore, this research would also plan to add crank angle sensor on the engine to measure engine performance and study on content of waste seawater of this system.

ABSTRAK

Pencemaran udara dari pelepasan ekzos diesel memberi kesan buruk kepada kesihatan dan alam sekitar di seluruh dunia. Kandungan pelepasan kebanyakannya gas berbahaya seperti Nitrogen Oksida (NOx), Karbon Monoksida (CO), Hidrokarbon (HC) and Partikulat Terampai (PM). Tesis ini adalah bertujuan untuk mengurangkan pelepasan ekzos diesel dengan menggunakan sistem semburan air laut peringkat satu. Sebuah kebuk semburan direka bentuk untuk persediaan bersama-sama dengan enjin diesel bagi eksperimen diesel. Ruang itu disambungkan kepada pancarongga ekzos untuk mengumpul gas pelepasan dengan menggunakan perangkap zarah. Kemudian, data pelepasan mengunakan sistem semburan tanpa air laut (WOS), dengan air laut (WS), dan dengan terelektrolisis air laut (WES) untuk lima kelajuan enjin dianalisis menggunakan penganalisa gas ekzos. Perubahan suhu juga diukur. Keputusan menunujukkan perbandingan kepekatan pelepasan untuk tiga keadaan sistem semburan air laut dalam bentuk graf kepekatan pelepasan melawan kelajuan enjin. Kebanyakan pelepasan berkurangan selepas melalui ruang semburan kecuali oksigen yang semakin meningkat kerana oksigen tambahan di dalam air laut. Pelepasan lain juga diserap oleh air laut beralkali dan dilarutkan di dalam air laut. Penyelidikan menunjukkan keberkesanan air laut beralkali sebagai medium untuk mengurangkan pelepasan gas ekzos diesel. Pelepasan menggunakan semburan WES mengurangkan lebih banyak berbanding sistem semburan WS. Selain itu, kajian ini juga merancang untuk menambah sensor sudut engkol enjin untuk mengukur prestasi enjin.

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LIST OF SYMBOL

%	Percent
≤	Less than or equal
µ	Micro
^0C	Degree Celsius
d_D	Diameter of water droplets
e^-	Electron
H^+	Hydrogen’s Ion
K	Kelvin
kg	Kilogram
kWh	Kilowatt hour
m	Meter
nm	Nanometer
N_t	Impaction number
ø	Equivalence ratio
X_s	Stop distance

LIST OF ABBREVIATIONS

ATDC	After Top Dead Center
$Ba(NO_3)_2$	Barium Nitrate
$BaCO_3$	Barium Carbonate
BDC	Bottom Dead Center
Ca^{2+}	Calsium’s ion
CFPP	Cold Filter Plugging Point
CI	Compression Ignition
Cl^-	Chlorine’s ion
Cl_2	Chlorine gas
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
H^+	Hydrogen’s ion
H_2S	Hydrogen Sulfide
HC	Hydrocarbon
HFRR	High-Frequency Reciprocating Rig
JSME	Japan Society of Mechanical Engineering
K^+	Potassium’s ion
L/sec	Litter per second
LNC	Lean Nox Catalyst
MECA	Manufacturers of Emission Controls Association

Mg^{2+}	Magnesium’s ion
N_2	Nitrogen gas
Na^+	Sodium’s ion
NaOH	Natrium Hydroxide
NO	Nitric Oxide
NO_2	Oxide of Nitrogen
NOx	Nitrogen Oxide
O_2	Oxygen
OH^-	Hydroxide’s ion
PMs	Particulate Matter
ppm	Part per million
rpm	Revolution per minute
SAE	Society of Automotive Engineers
SCR	Selective Catalyst Reduction
SI	Spark Ignition
SO_2	Sulfur Dioxide
SO_4^{2-}	Sulfate ions
SOF	Soluble Organic Fraction
SOx	Oxide of Sulfur
TDC	Top Dead Center
USA	United State of America
WES	With Electrolyzed Seawater
WOS	Without Seawater
WOT	Wide Open Throttle
WS	With Seawater

WSD	Wear Scar Diameter

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Diesel emission contained dangerous gases such as Nitrogen Oxide (NOx), Carbon Monoxide (CO), Hydrocarbon (HC) and Particulate Matter (PM). These gases give bad effect to human health and environment, for example respiratory irritant, ozone-forming and others. There are three area can be improved to control or reduce the emission for a better life in future. One of the areas is out of engine cleaning technologies or after treatment technology that use some form of scrubber or reactor to remove contaminants from the exhaust stream. These technologies can remove most of the contaminants from the exhaust gases, but maybe heavy, bulky and expensive and hence are not used unless needed (Jingbo Yu, Shulin Duan, Wenxiao Zhang, Gongzhi Yu et al. 2011). One of these technologies is use Selective Catalyst Reduction (SCR) to control NOx. SCR system use ammonia or urea as the reductant compound because of diesel lean burn combustion. This reductant is also help by an auxiliary oxidation catalyst to modify NOx ratio.

In other hand, NOx adsorbers technology was originally developed for lean-burn, low-emission gasoline engines but is now being adapted for diesel engines. The adsorbers are incorporated into a catalyst wash coat and chemically bind NOx during normal lean (oxygen-rich) engine operation. After the adsorber capacity is saturated, the system is regenerated. The released NOx is catalytically reduced during a short period of rich engine operation, using a conventional 3-way catalytic converter (Jingbo Yu, Shulin Duan, Wenxiao Zhang, Gongzhi Yu et al. 2011). By using Exhaust Gas

Recirculation (EGR), NOx emissions can be reduced. EGR function is recirculate portion of the engine’s exhaust back to the intake manifold.

In this project, the use of seawater spray system will introduce a new technology to reduce the diesel emission. Seawater has interesting possibility due to the strong acidity and alkaline seawater play an important role in NO oxidation and CO absorption respectively (Sukheon An & Osami NISHIDA, 2003). This system allows the exhaust gases thorough a mixer with seawater spray to remove SOx, CO_2, NOx, CO and PM.

1.2 PROBLEM STATEMENT

Today in this modern world, there are many application of diesel engine on the road or on the sea. Diesel engine usages give the advantages but also disadvantages in the same time due to diesel exhaust emission. The main problem is the negative effect of the emission toward the environment and human’s health especially if there no emission control.

One of the ways to reduce the emission is by using seawater spray system. This system is considered new technology for exhaust emission after treatment. This system use seawater to make contact with exhaust gases using spraying method. The problem using this seawater is the effectiveness of seawater as a medium to reduce the emission. So, this project will analyze the emission characteristic comparison with or without reduction system.

1.3 PROJECT OBJECTIVE

There is one objective for this project which is to measure reduction of diesel exhaust emission such as CO, CO2, O2, and NOx by diesel experiment using seawater spray system. The analysis is to compare between system with and without seawater spray for diesel engine operation.

1.4 PROJECT SCOPE

This project is to analyze the emission characteristic before and after use seawater spray system during direct contact with seawater. This project also to design and construct sea water spray system, setup sea water spray into diesel experimental rig, experimental by diesel engine and then analysis of exhaust emission by the application of exhaust gas analyzer.

CHAPTER 2

LITERATURE REVIEW

2.1 EXHAUST GAS AFTERTREATMENT TECHNOLOGY

From Jingbo Yu, Shulin Duan, Wenxiao Zhang, Gongzhi Yu (2011), one of the three technologies to reduce diesel emission is out of engine technology. This technology also calls exhaust gas aftertreatment technology that used to reduce NOx and other harmful compound in exhaust. For this technology, it have several method can be used for control the dangerous gas produce by diesel engine combustion. Selective Catalyst Reduction (SCR) is one the effective method to control NOx. This method has been installed for the first marine SCR in 1989 and 1990. SCR system is use ammonia or urea as the reductant compound because of diesel lean burn combustion and wide used as a source of nitrogen in agricultural application. This reductant is also help by an auxiliary oxidation catalyst to modify NOx ratio. But effect of difficulty in handling ammonia, urea is used because it can decompose to ammonia by heating in 2 -3 meter hot exhaust pipe. This SCR is effective to reduce the NOx about 92%. While For medium- speed diesel engine application, 90 to 95% NOx reduction (EPA 2009) is possible under steady-state conditions where the exhaust gas temperature is above 270 °C. Another NOx reduction option is Exhaust Gas Recirculation (EGR). EGR help by recycled the exhaust gas back into the engine charge air (intake valve) and then reduce the peak combustion chamber temperature. From the laboratory research, the NOx reduction can reach 10% - 30% with marginal increasing the fuel consumption. Other than that, EGR also can achieve 40% reduction of NOx (MECA 2006). But for experiment of 4T50ME- X low speed engine with EGR system by MAN B&W, the NOx reductions can up to 70%. The same result has been report by EPA (2009) with combination of intake air humidification.

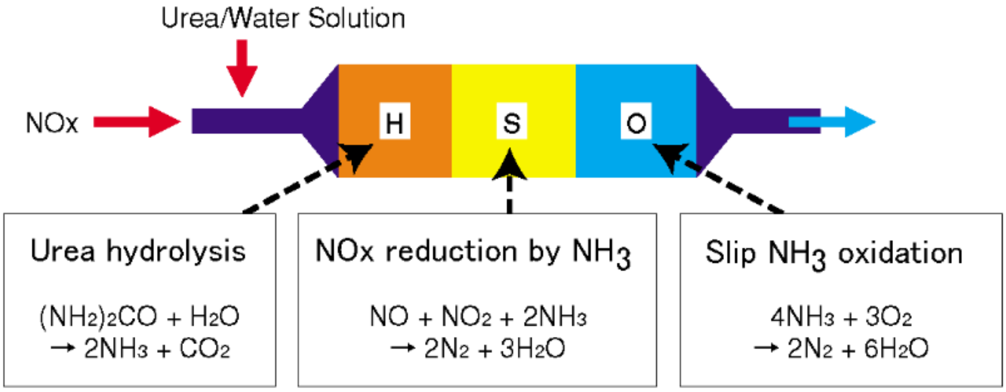


Figure 2.1: the Scheme of a Generic Selective Catalyst Reduction (SCR) System.

Source: Hideaki HAMADA, (2009)

NOx adsorbers are the newest control technology being developed for diesel NOx control. The technology was originally developed for lean-burn, low-emission gasoline engines but is now being adapted for use in diesel engines. The adsorbers are incorporated into a catalyst wash coat and chemically bind NOx during normal lean (oxygen-rich) engine operation. After the adsorber capacity is saturated, the system is regenerated. The released NOx is catalytically reduced during a short period of rich engine operation, using a conventional 3-way catalytic converter. The reaction steps for lean NOx conversion are shown schematically in Figures 2.2 and Figures 2.3. The NO is adsorbed and chemically binds with barium carbonate ($BaCO_3$) to form barium nitrate ($Ba(NO_3)_2$). During regeneration the diesel exhaust gas is rich in CO and unburned hydrocarbons. These chemicals reduce $Ba(NO_3)_2$ back to $BaCO_3$, in the process releasing NOx. In a downstream 3-way catalytic converter the NOx is reduced by the rich exhaust gases to Nitrogen (N_2).

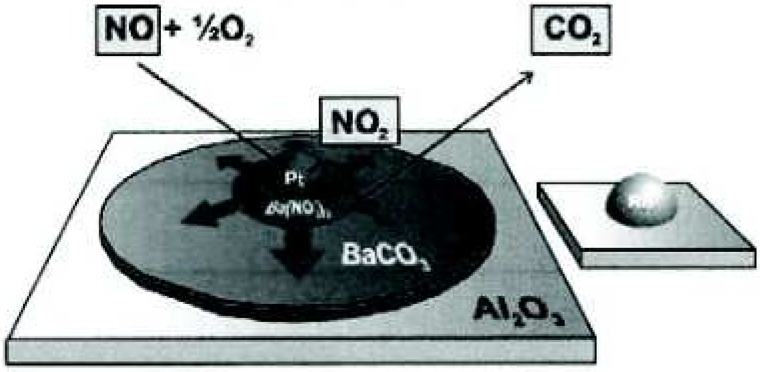


Figure 2.2: Lean Condition

Source: From Jingbo, Y. et al. (2011).

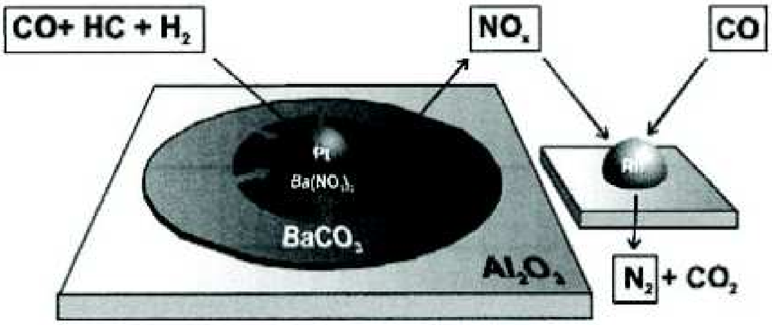


Figure 2.3: Rich Condition

Source: From Jingbo, Y. et al. (2011).

Lean NOx Catalyst (LNC) system help in control exhaust emission by inject a small amount of diesel fuel or other reductant into the exhaust upstream of the catalyst (MECA 2006). The fuel or other hydrocarbon reductant serves as a reducing agent for the catalytic conversion of NOx to N_2. Without the added fuel and catalyst, reduction reactions that convert NOx to N_2 would not take place because of excess oxygen present in the exhaust. As the result of this system, the efficiency of NOx conversion for the system is around 10% - 30%. A same method have reported by Cauda, E.G. et al.

(2010) explained that , in a few applications, unburned hydrocarbons from the engine chamber are sufficient to obtain the desired NOx conversion, otherwise a post-injection of hydrocarbon in the exhaust is necessary (Dorriah 1999). Besides that, the convection of NO and NO_2 depends mostly on the catalyst chemical formulation and configuration. This LNC system reported that can achieved maximum NOx convection until 60% for diesel engine operate over real duty cycle (Kharas et al. 1998). But it has the weakness of this system which high complexity of the chemical reactions employed by these systems and the requirement of a constant emissions monitoring and tuning, can delay the introduction of these technologies in mining equipment.

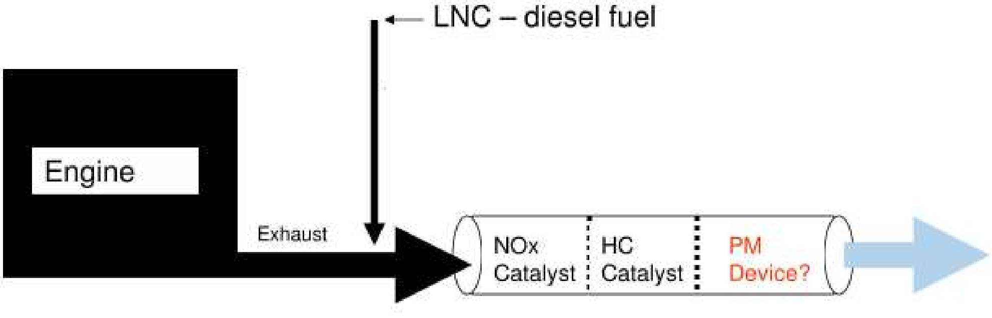


Figure 2.4: Scheme of LNC System.

Source: Hideaki Hamada, (2009).

2.2 SEAWATER SCRUBBER

From Sukheon AN and Osami NISHIDA (2003), explained about the usage of seawater and its electrolysis for the exhaust emission control in diesel engine. For a slow speed diesel engine operating on heavy fuel oil and at normal service load, the composition of the exhaust gases is contain higher NOx 1220 ppm, compare to other gases such as SO_2 660 ppm, HC 120 ppm and CO 50 ppm. So the method of wet scrubber system using seawater is performed to control exhaust emission. This system is used to spray the seawater to contact with exhaust gases. By spray naturally seawater at pH around 8.1, the SO_2 and SO_3 can be remove because high solubility with seawater.

The other exhaust pollutant such as Particular Matter (PMs) removed when through direct contact with the seawater droplets. Then, chemical reaction between oxygen and water was form sulfate ions (SO_4^{2-}) and hydrogen ions (H+) as shown Eq. (2.1).

$$SO_2 + H_2O + 1/\,2O_2 \longrightarrow SO_4^{2-} + 2H^+ \qquad (2.1)$$

For the PM, the removal effect is proportional to the impaction number (N_t) between particles and water droplets where X_s is stop distance, d_D is diameter of water droplets as shown in Eq. (2.2).

$$N_t = X_s / d_D \qquad (2.2)$$

In other hand, NOx and CO_2 can absorption by electrolysis seawater that contain with NaOH and other alkali metal ion. But for NOx's case, it must to oxidize NO to NO_2. They were introducing the seawater scrubber system and name it as Two- Stage Wet Scrubber System. For the first- stage, it used only seawater to remove SOx and PMs. The chemical reaction of SO_2 with seawater can form sulfate ions (SO_4^{2-}) and hydrogen's ion (H^+). They also expect the reduction of SOx is 93 -98 %, 85 -90% PMs, 20- 30% NOx and 5- 10% CO_2. In other case, SO_2 emission reduction of 66% has been found to require approximately 40 – 63 kg of seawater per kWh depending on the salinity and alkalinity of the seawater used in the scrubber. Report by Dr. Brigitte Behrends and Prof. Dr. Gerd Liebezeit (2003) said that 90 – 95% SO_2, 10 – 20% NOx, 80% particulate and 10 -20% hydrocarbon can remove by apply seawater scrubber system on ship while for plant it can remove SO_2 up to 99%.Continue with the second-stage which is seawater electrolysis is use to absorb the remaining NOx and CO_2 untreated in first –stage. In that treatment, it forms chemical reaction to form nitric acid (HNO_3) from NOx as shown in Eq. (2.3). Their experiment was conduct by link the exhaust gases from the combustor to the scrubber with the exhaust pipe. Then, in the scrubber the 3 nozzle spray the seawater to wash the gases before it discharge to atmosphere. During the exhaust gases through the scrubber, the data was obtained from two points at inlet and outlet of the scrubber. The data taken was exhaust gas temperature and pH value. Lastly, as their conclusion, the SOx removal could be achieved nearly perfect and same as PMs. The seawater electrolysis is suitable for absorption of NOx and CO_2.

$$2NO_X + H_2O + (2.5 – x) O2 = 2HNO_3 \qquad (2.3)$$

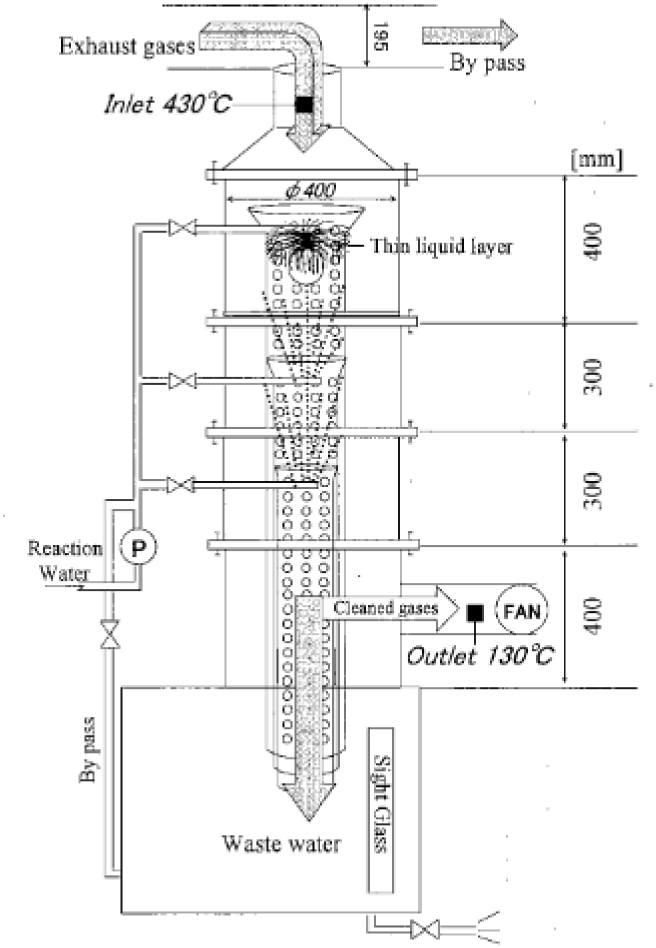


Figure 2.5: Seawater Scrubber System Diagram.

Source: An, S. and Nishida, O. (2011)

2.3 CHARACTERISTIC OF DIESEL ENGINE

2.3.1 Diesel Engine History

Martynn Randall (2004) stated that the first commercially – successfully compression – ignition engine was invented by Rudolf Diesel at the end of the 19th century. Compared to spark ignition engine, diesel engine had the advantages of lower fuel consumption, the ability to used cheaper fuel, the potential to much higher power output. Over the following two or three decades, diesel engine were widely used for stationary and marine applications, but the fuel injection system used were not capable of high – speed operation. This speed limitation, and considered the considerable weight of the air compression needed to operated the injection equipment, made the first diesel engine unsuitable for use in road- going vehicle.

In the 1920s, the in – line injection pump was develop by German engineer Robert Bosch. The use of hydraulic system to pressurize and inject the fuel did away with the need for a separated air compressor, and made possible much higher operating speed. This engine was manufacture in two stroke and four stroke versions.

In the 1930s, they slowly began to be used in a few automobile. Until 1950s and 60s, diesel engine increasingly popular for use in taxis and vans, but it was not until the sharp rises in oil price in the 1970s. So, at the end 1977s the introduction of diesel – powered Golf come out with the first “user – friendly” diesel car. Then, the used of diesel engine in large on – road and off – road vehicle in the USA increased. As of 2007, about 50 percent of all new car sales in Europe are diesel.

2.3.2 Basic Principle of the Diesel Engine

Sean Bennett (2010) stated that the diesel cycle is by definition a four – stroke cycle. A cycle is a sequence of event. So, the diesel engine is best introduced by outlining of the four strokes of the pistons made as an engine in turned through two revolutions. A full cycle of diesel engine requires two complete rotations. Each rotation requires turning the engine through 360 degrees, so a complete diesel cycle translates into 720 crankshaft degrees. Then, each of the four strokes that make up the diesel cycle involve moving a piston either from top of its travel to its lowest point of travel or vice versa. For each, strokes of the cycle can translate into 180 crankshaft degrees. The four strokes for the four – stroke cycle are: 1) intake, 2) compression, 3) power, 4) exhaust.

4 – Stroke cycle

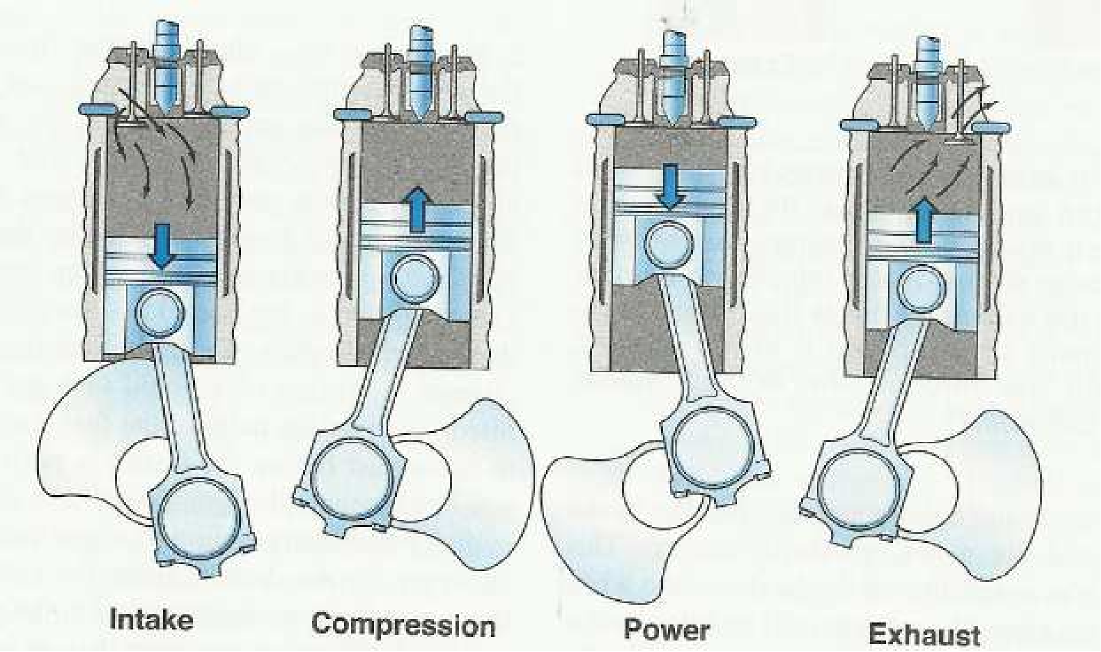


Figure 2.6: Four – Stroke Cycle Diagram

Source: Barry Hollembeak (2005)

Stroke 1 “intake”: The piston is connected to the crankshaft throw by means of a wrist pin and connecting rod. The thrown is an offset journal on the crankshaft. Therefore, as the crankshaft rotates the piston is drawn from top dead center (TDC) to bottom dead center (BDC). While the piston moves through its downstroke, the cylinder head intake valves are held open and air filled into the cylinder. The completion of intake stroke is when the intake valve closed and the cylinder will be filled with the air. The air is contain with one – fifth oxygen where is required to combust the fuel.

Stroke 2 “compression”: After completion of the intake stroke, the piston is now driven upward from BDC to TDC with the intake and exhaust valves closed. The quantity of air in the cylinder is still the same but compressing the air gives it much less space and heats it up considerably.

Stroke 3 “power”: Shortly before the completion of compression stroke, atomized fuel is introduced directly into the engine cylinder by multi – orifice nozzle assembly. The fuel exits from the nozzle at very high pressure and in liquid stage. Then, the liquid emitted by the injector must size appropriately for ignition and combustion. Once exposed to the heated air charge in the cylinder, the fuel droplets are first vaporized and the ignited. The ignited occur just before the piston is positioned at TDC. Effect of the power stroke, the piston driving it downward and call as expansion.

Stroke 4 “ exhaust” : Somewhere after 90 degrees after top dead center (ATDC) during the expansion, most of the heat energy that can be convert to kinetic energy has been converted and the exhaust valves open. The product of cylinder combustion is known as end gas or exhaust gas.

2.3.3 Diesel Fuel Characteristic

High-quality diesel fuels are characterized by the following features (Challen and Baranescu, 1999):

- High cetane number
- Relatively low final boiling point
- Narrow density and viscosity spread.
- Low aromatic compounds (particularly polyaromatic compounds) content
- Low sulfur content.

In addition, the following characteristic are particularly important for the service life and constant function of fuel-injection systems.

- Good lubricity
- Absence of free water
- Limited pollution with particulate.

The most important criteria are explained in detail:

Cetane Number/ Cetane Index

Cetane number (CN) expressed the ignition quality of the diesel fuel. The higher quantity of cetane number gives the greater tendency of fuel to ignite. As the diesel engine dispenses with an externally supplied ignition spark, the fuel must ignite spontaneously (auto-ignition) and with minimum delay (ignition lag) when injected into the hot, compressed air in the combustion chamber.

Boiling Range

The boiling range of a fuel is the temperature range at which the fuel vaporizes, depends on its composition. A low initial boiling point makes a fuel suitable for use in cold weather, but also means a lower cetane number and poor lubricant properties. This raises the wear risk for central injection units. On the other hand, if the final boiling point is situated at high temperatures, this can result in increased soot production and nozzle coking (deposit caused by chemical decomposition of not easily volatized fuel constituent on the nozzle cone, and deposits of combustion residues. For this reason, the final boiling point should not be too high.

Filtration Limit (Cold-flow Properties)

Precipitation of paraffin crystals at low temperature can result in fuel-filter blockage, ultimately leading to interruption of fuel flow. In worst-case scenarios, paraffin particles can start to form at temperatures of 0˚C or even higher. The cold-flow properties of a fuel are assessed by means of the “filtration limit” (Cold Filter Plugging Point (CFPP)). European Standard EN 590 (Bosch, 2005) defines the CFPP for various classes, and can be defined by individual member states depending on the prevailing geographical and climatic conditions.

Flash Point

The flash point is the temperature at which the quantities of vapor which a combustible fluid emits to the atmosphere are sufficient to allow a spark to ignite the air/vapor mixture above the fluid.

Density

The energy of diesel fuel per unit of volume is increase with the density. Assuming constant fuel-injection-pump settings (i.e. constant injected fuel quantity) the use of fuels with widely different densities causes variations in mixture ratios due to fluctuation in calorific value.

When an engine runs on with fuel that has a high type – dependent density, the engine performance and soot emissions increases as fuel density decreases, these parameter drop. As a result, the requirements call for a diesel fuel that has a low type-dependent density spread.

Viscosity

Viscosity is a measure of a fuel’s resistance to flow due to internal friction. Leakage losses in the fuel-injection pump result if diesel-fuel viscosity is too low, and this in turn results in performance loss. Much higher viscosity causes a higher peak injection pressure at high temperatures in non-pressure-regulated systems. For this reason, mineral oil diesel may not be applied at the maximum permitted primary pressure. High viscosity also changes the spray pattern due to the formation of larger droplets.

Lubricity

In order to reduce the sulfur content of diesel fuel, it is hydrogenated. In addition to removing sulfur, the hydrogenation process also removes the ionic fuel components that aid lubrication. After the introduction of desulfurized diesel fuels, wear-related problems started to occur on distributor fuel-injection pumps due to the lack of lubricity. As a result, they were replaced by diesel fuels containing lubricity enhancers. Lubricity is measured in a High-Frequency Reciprocating Rig (HFRR method). A fixed, clamped steel ball is ground on a plate by fuel at high frequency. The magnitude of the resulting flattening, i.e. the Wear Scar Diameter (WSD) measured in µm, specifies the amount of wear, and thus a measure of fuel lubricity. Diesel fuels complying with EN 590 must have a WSD of ≤ 460 µm.

Sulfur Content

Diesel fuels contain chemically bonded sulfur, and the actual quantities depend on the quality of the crude petroleum and the components added at the refinery. In particular, crack components mostly have high sulfur contents. To desulfurize fuel, sulfur is removed from the middle distillate by hydrogenation at high pressure and temperature in the presence of a catalyst. The initial by product of this process is hydrogen sulfide (H_2S) which is subsequently converted into pure sulfur. Exhaust gas treatment systems for NOx and particulate filters use catalysts. They must run on sulfur-free fuel since sulfur poisons the active catalyst surface.

Alternative Fuels

Water and alcohols are difficult to dissolve in diesel. Emulsifiers are required to keep the mixture stable and prevent it from demulsification. Wear-and corrosion-inhibiting measures are also necessary. The use of emulsifiers reduces soot and nitrogen-oxide emissions since the combustion mixture is cooler due to the water content.

2.4 EXHAUST EMISSION CHARACTERISTIC

The number of internal combustion engines in the world was small enough at the middle of the 20th century. So, the pollution they emitted was tolerable and the environment stayed relatively clean (Willard W. Pulkrabek 2003). As the world population grew, power plants, factories and an ever increasing number of automobiles began to pollute the air to the extent that it was no longer acceptable. During the 1940s, air pollution was first recognized as a problem in the Los Angeles basin in California. Two causes of this were the large population density and the natural weather conditions of the area. The large population created many factories and the power plants, as well as one of the largest automobile densities in the world. Smoke and other pollutants from the many factories and automobiles combined with the fog that was common in this ocean area, and smog resulted. During the 1950s, the smog problem increased along with the population density and automobile density. It was recognized that the automobile was one of the major contributors to the problem, and by the 1960s emission standards were beginning to be enforced in California. This is because the exhaust emission are contain of pollutant gases which is hydrocarbon (HC), carbon monoxide (CO), oxide of nitrogen (NOx), and not pollutant gases which is oxygen (O_2) and carbon dioxide (CO_2) (Hollembeak, B. 2005). During the next decades, emission standards were adopted in the rest of the United States and in Europe and Japan. By making engines more fuel efficient, and with the use of exhaust aftertreatment, emissions per vehicle of HC, CO and NOx were reduced by about 95% during the 1970s and 1980s. Lead, one of the major air pollutants, was phased out as a fuel additive during the 1980s. More fuel-efficient engines were developed, and by the 1990s the average automobile consumed less than half the fuel used in 1970s. However, during this time, the number of automobiles greatly increased, resulting in no overall decrease in fuel usage. In 1999, petroleum consumption in the Unites States amounted to 16500 L/sec, a large percentage of which was fuel for internal combustion engine.

2.4.1 Carbon Monoxide (CO)

Carbon monoxide, a colorless, odorless, poisonous gas, is generated in an engine when it is operated with fuel – rich equivalence ratio. When they’re not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO as write in Eq. (2.4). Typically the exhaust of an SI engine will be about 0.2% to 5% carbon monoxide. Not only is CO considered an undesirable emission, but it also represent lost chemical energy that was not fully utilized in the engine. CO is a fuel that can be combusted to supply additional thermal energy.

$$CO + \frac{1}{2} O_2 \longrightarrow CO_2 + heat \qquad (2.4)$$

Maximum CO is generated when an engine runs rich, such as when starting or when accelerating under load. Even when the intake air – fuel mixture is stoichiometric or lean, some CO will generate in the engine. Poor mixing, local rich regions, and incomplete combustion will create some CO.

2.4.2 Oxides of Nitrogen (NOx)

The oxides of nitrogen tend to settle on the hemoglobin in the blood. The most undesirable toxic effect oxides of nitrogen in their tendency to join with the moisture in the lungs form dilute nitric acid. NOx is one of the primary causes of photochemical smog (smoke + fog). Smog is form by the reaction expressed as in Eq. (2.5).

$$NO_2 + \text{energy from sunlight} \longrightarrow NO + O + \text{smog} \qquad (2.5)$$

Monatomic oxygen reacts with O_2 to form ozone (O_3) as follow Eq. (2.6).

$$O + O_2 \longrightarrow O_3 \qquad (2.6)$$

Ozone is harmful to lungs and other biological tissues. It is harmful to crops and trees. It reacts with the rubber, plastics, and other material causing damage.

Most of oxides of nitrogen comprise nitric acid (NO), a small amount of nitrogen dioxide (NO_2) and traces of other nitrogen oxides. These are all grouped together and the group is called NOx. NOx is mostly formed from atmospheric nitrogen.

There are a number of possible reactions that form NO. NO form in both the flame front and the post flame gases. Some of the NO forming reactions as expressed in Eq. (2.7).

$$
\begin{aligned}
O + N_2 &\longrightarrow NO + N \\
N + O_2 &\longrightarrow NO + O \\
N + OH &\longrightarrow NO + H
\end{aligned}
\tag{2.7}
$$

N, O, OH is formed from dissociation of NO_2, O_2 and H_2O vapor at high temperatures that exit in the combustion chamber (2500 – 3000 K). The higher combustion reaction temperature, the more diatomic nitrogen (N_2) will dissociate to monatomic nitrogen (N) and more NOx will be formed. At low temperatures, a very small quantity of NOx is created.

The flame temperature is maximum at the stoichiometric equivalence ratio (ø = 1.0) but maximum NOx is formed slightly at a lean equivalence ratio (ø = 0.95). At this condition the flame temperature remain very high but excess oxygen help in the formation of more NOx. The most important engine variables that effect NOx emission are the fuel/air equivalence ratio, the burn gas fraction, and combustion duration within the cylinder.

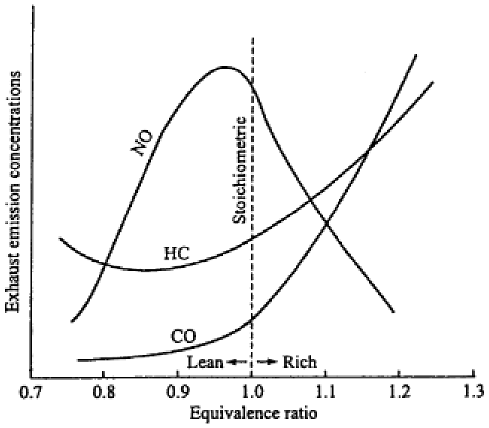


Figure 2.7: Variation Of CO, NO, HC Concentration In The Exhaust Of An SI Engine Versus Equivalence Ratio.

Source: Gupta, H.N. (2009)

2.4.3 Hydrocarbon (HC)

Hydrocarbon consists of hydrogen and carbon atom in various combinations. The CI engine operate with an overall fuel – lean equivalence ratio, therefore they emit only about one – fifth of the hydrocarbon emission of a SI engine (Gupta, H.N. 2009). The following are the major causes for hydrocarbon emissions in the exhaust of CI engine:

1. The diesel fuel contains components of higher molecular weight on average than those in a gasoline fuel, resulting in higher boiling and condensing temperatures. This causes some hydrocarbon particle to condense on the surface of the solid carbon soot generated during combustion. Most of this is burned as mixing continues and the combustion process proceeds but a small amount is exhausted out the cylinder.

2. The air – fuel mixture in a CI engine is heterogeneous with fuel still being added during combustion. It causes local spot to range from very high to very lean and many flame front exist at the same time unlike the homogenous air – fuel mixture of an SI engine that essentially has one flame front. Incomplete combustion may caused by undermixing or overmixing. With undermixing, in fuel - rich zone some fuel particle do not find enough oxygen to react with, and in fuel - lean zone some local spot s will be too lean for combustion to take place properly. With overmixing, some fuel particles may be mixed burned gases and it will therefore lead to incomplete combustion.

3. A small amount of liquid fuel is often trapped on the tip of injector nozzle even when injections stop. This small volume of fuel is called sac volume. This sac volume of liquid fuel is surrounded by a fuel – rich environment and therefore it evaporates very slowly causing hydrocarbon emission in the exhaust.

4. CI engine also have hydrocarbon emission for some of the same reasons as SI engine do. For example: flame quenching, crevice volume, oil- film and deposits on the cylinder wall, misfiring.

2.4.4 Particulates

The exhaust of CI engine contains solid carbon soot particle that are generated in the fuel – rich zones within the cylinder during combustion. There seen as exhaust smoke and is an undesirable odorous pollution. Maximum density of particulate emissions occur when the engine is under load at WOT. At this condition maximum fuel is injected to supply maximum power, resulting in the rich mixture and poor fuel economy. Soot particle are clusters of solid carbon spheres. This spheres have diameter 10 nm to 80 nm (1 nm = 10^{-9} m), with most within the range of 15 – 30 nm. The spheres are solid carbon with HC and traces of other component absorbed on the surface. A single soot particle will contain up to 4000 carbon spheres.

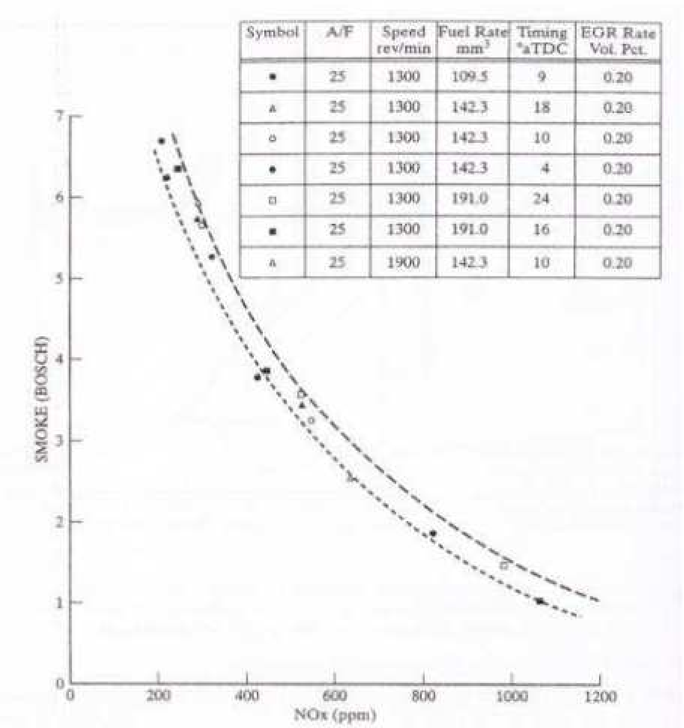
Carbon spheres are generated in the combustion chamber in the fuel – rich zones where there is not enough oxygen to convert all carbon to CO_2 as expressed in Eq. (2.8).

$$CxHy + zO_2 \longrightarrow CO_2 + bH_2O + cCO + dC(s) \tag{2.8}$$

Then, as turbulence and mass motion continue to mix the component in the combustion chamber, most of these carbon particles find sufficient oxygen to further react and are consumed to CO_2 write in Eq. (2.9).

$$C(s) + O_2 \longrightarrow CO_2 \tag{2.9}$$

Over 90% of carbon particle originally generated within an engine are thus consumed and never get exhausted. If CI engine would operate with an overall stoichiometric air – fuel mixture, instead of overall lean as they do particulate emissions in the exhaust would far exceed acceptable levels. Up to 25% of the carbon in the soot comes from lubricating oil component which vaporize and then react during combustion. The rest come the fuel and the amount to 0.2 – 0.5% of the fuel. Because of the high compression ratio of CI engine, a large expansion occurs during the power stroke, and the gases within the cylinder are cooled by expansion cooling to a relatively low temperature. This cause the remaining high-boiling point component found in the fuel and lubricating oil to condense on the surface of the carbon soot particle. This absorbed portion of the soot particle is called soluble organic fraction (SOF), and the amount is highly dependent on cylinder temperature. At low cylinder temperature (200 ^{0}C), SOF can be 50% of the total mass soot, while during not so low temperature, SOF can be as low as 3%. SOF consists mostly of hydrocarbon component with some hydrogen, SO_2, NO, NO_2, and trace amount of sulfur, calcium iron, silicon, phosphorus, zinc, and chromium. Diesel fuel contains sulfur, calcium, iron, silicon, and chromium. For lubricating oil additives contain zinc, phosphorus, and calcium.



Symbol	A/F	Speed rev/min	Fuel Rate mm^3	Timing °aTDC	EGR Rate Vol. Pct.
■	25	1300	109.5	9	0.20
▲	25	1300	142.3	18	0.20
○	25	1300	142.3	10	0.20
●	25	1300	142.3	4	0.20
□	25	1300	191.0	24	0.20
■	25	1300	191.0	16	0.20
△	25	1900	142.3	10	0.20

Figure 2.8: Nitrogen Oxide (NOx)-Smoke (Particulates) Trade-Off at Various Engine Operating Conditions.

Source: Pulkrabek W.W (2003)

2.4.5 Sulfur

Many fuel in CI engine contain small amount of sulfur that when exhausted; contribute to the acid rain problem. Unleaded gasoline generally contains 150 – 600 ppm sulfur by weight. Some diesel fuel contain up to 5000 ppm by weight. At high temperature, sulfur combines with hydrogen to form H_2S and with oxygen to form SO_2 as expressed in Eq. (2.10).

$$\begin{gathered} H_2 + S \longrightarrow H_2S \\ O_2 + S \longrightarrow SO_2 \end{gathered} \tag{2.10}$$

Engine exhaust can contain up to 20 ppm of SO_2. SO_2 the combine with oxygen in the air to form SO_3 as write in Eq. (2.11).

$$2SO_2 + O_2 \longrightarrow 2\ SO_3 \tag{2.11}$$

These combine with water vapor in the atmosphere to form sulfuric acid (H_2SO_4) and sulfurous acid (H_2SO_3), which are ingredients in acid rain as write in Eq. (2.12).

$$\begin{gathered} SO_3 + HzO \sim HzSO_4 \\ SOz + HzO \sim HzSO_3 \end{gathered} \tag{2.12}$$

The amount of sulfur in natural gas can range from little (sweet) to large (sour) amount. This can be a major emission problem when this fuel is used in a CI engine or any other combustion system.

2.4.6 Carbon Dioxide (CO_2)

Carbon dioxide is one of the two major exhaust gases that are not considered as pollutant reported by Barry Hollembeak, (2005). CO_2 is a by – product of perfect combustion. It is form when one atom of carbon bond with two atom of oxygen from the air during combustion. An essentially harmless gas, it is present at levels of 14 percent to 15 percent in the exhaust of properly running engine. Carbon dioxide is also produce when carbon monoxide is oxidized in the catalytic converter. The amount of CO_2 in the exhaust is directly related to the air – fuel ratio. As the fuel mixture approaches stichoimetric, the level of CO_2 peaks. It decrease when the mixture become richer or lean. This fact makes CO_2 in the exhaust an excellent reference that can help determine how efficiency the engine is combusting its fuel. The higher CO_2 reading means the higher efficiency of combustion.

2.4.7 Oxygen (O_2)

Oxygen was stated by Barry Hollembeak, (2005), is not the pollutant gases that come out from the exhaust. Oxygen reacts with the fuel for combustion during combustion process. If the combustion chamber is delivered too much fuel for the amount of oxygen, all the available oxygen is used up and result in low O_2 contents in exhaust. As the air – fuel mixture move toward lean, the amount of oxygen in the exhaust steadily increase. When the air – fuel mixture is rich or lean, the levels of oxygen and carbon monoxide will be apposite one another where when the O_2 high, CO is low and vice versa. At the stoichiometric air –fuel ratio, the level of O_2 and CO in the exhaust approximately equal.

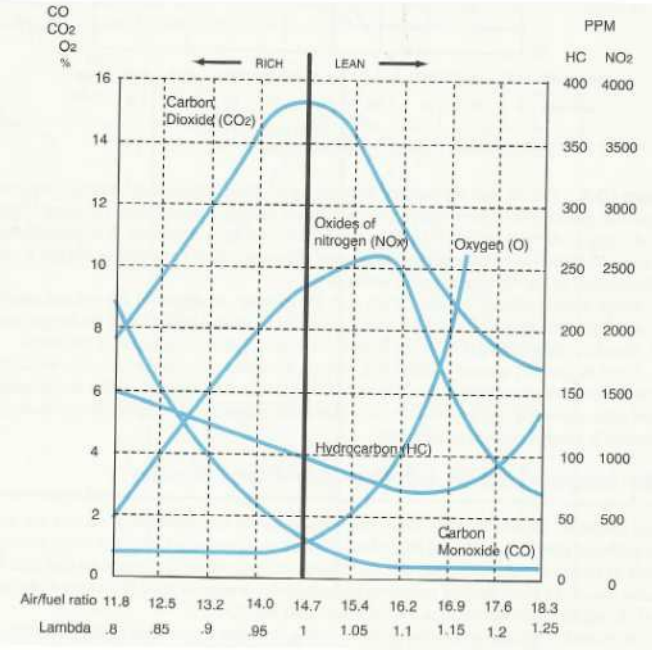


Figure 2.9: Total Effect of the Air – Fuel Ratio on Exhaust Gases

Source: Hollembeak, B. (2005)

2.5 ELECTROLYSIS

Electrolysis is a method of separating bonded elements and compounds by passing an electric current through them. Ions are available in a liquid such as seawater or saltwater solution. During the electrolysis process, electric current is applied between a pair of inert electrodes (metal plat) immersed in the liquid. The electrodes have two type charges which are called cathode (negative) and anode (positive). Each electrode attracts ions which are the opposite charge. Therefore, positive ions (cation) move toward cathode, while negative ions (anion) move toward anode. The ions will separate by electric energy from power supply and cause them to gather at the respective electrode. At the state, electrons are absorbed or release by the ions and forming a collection of the desired element or compound.

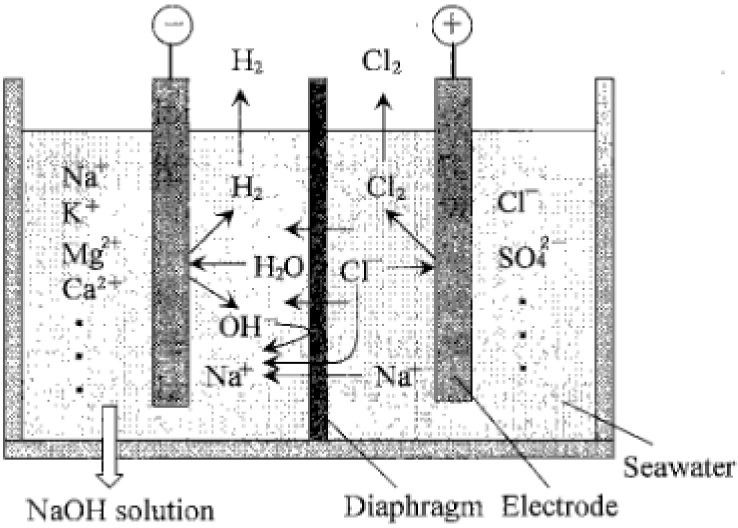


Figure 2.10: Seawater Electrolysis Diagram

Source: An, S. and Nishida, O. (2011)

Seawater is an electrolyte solution as a weak alkali normally at pH 8. Its chemistry is dominated by presence of six ions (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}) which constitute more than 99.5% of dissolved constituents. Production of electrolysis on seawater can produce hydrogen, oxygen, chlorine and alkalis. At negative side, Na^+ ions is gathered and react with OH^- ions that given by water to produce NaOH aqueous solution. The electrolysis is also produce H_2 at cathode and Cl_2 or O_2 at anode. The electrolysis reaction is showing below as expressed as in Eq. (2.13), Eq. (2.14), Eq. (2.15), and Eq. (2.16):

- Positive electrode (anode): $2Cl^- \longrightarrow Cl_2 + 2e^-$ (2.13)

  $6H_2O \longrightarrow O_2 + 4H_3O^+ + 4e^-$ (2.14)

- Negative electrode (cathode): $H_2O + e^- \longrightarrow 1/2H_2 + OH^-$ (2.15)

  $Na^+ + OH^- \longrightarrow NaOH$ (2.16)

CHAPTER 3

METHODOLOGY

3.1 FLOW CHART

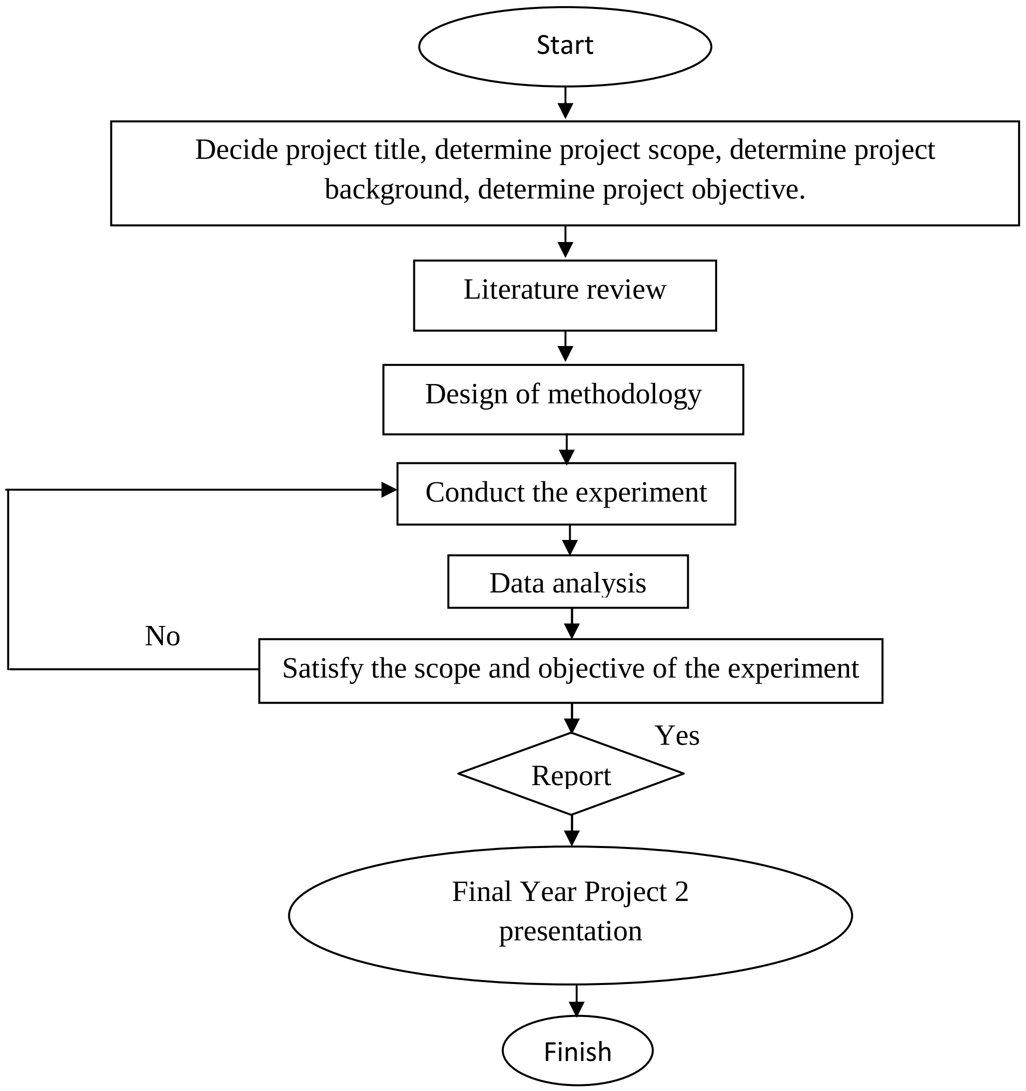


Figure 3.1: Project Flow Chart

3.2 FLOW CHART DESCRIPTION

Flow chart is the simplest way to show overall steps from beginning until finish for a project. At the beginning, it starts with understanding and decides project title. Next, determine the objective, scopes and background of the project.

After that, continue with the literature review. This is the method to get more information related to project from articles, journals, books, and other reading material. This knowledge help to gain more information to understand the project more detail with supported by project’s supervisor.

The next step is design the methodology to get the data and conduct the experiment before do the preliminary experiment test. This test is for checking whether the apparatus in good condition to conduct the experiment in Final Year Project 2 tasks. Then, complete the report proposal and slide presentation for Final Year Project 1. Next, go to final task for Final Year Project 1 which is a project presentation.

For Final Year Project 2, it starts with conduct the experiment for a several times by follow the experiment procedure to get more accurate data. The data was collected at before and after spray chamber. Then, analyze the data in form of graph with the detail explanations. After that, compare the analyze data with the project objective. If the data is satisfied, the project proceeds with the final report. But if the data not satisfied, repeat the experiment again to get the exact data.

The full report writing is dividing to five chapters and including all the process and activity to complete the project from the beginning. Lastly, make a presentation about the project to the examiner and summit the complete report to finish the Final Year Project 2 task.

3.3 LITERATURE ANALYSIS

Literature analysis is a combination of idea and elaboration of the literature review that have been collected from various sources such as articles, journals, books, and other result analysis from previous research as a guide for the project. The information must get from verify sources and really related to the project title and same goes to the main part which is the project objective. The objective is to measure reduction of diesel emission by using seawater spray system. So, the literature must about the emission, diesel engine and seawater spray system or seawater scrubber system. In case of that, the several method explain before is the normally method use by other researcher to gathering data for their project. Besides the information from the reading materials, the guide and information from the project's supervisor is important and very useful.

3.3.1 Journals

Journal is such a good source of knowledge and information. There are a lot of journals which commonly published by Society of Automotive Engineering (SAE), Japan Society of Mechanical Engineering (JSME) and other researcher that can be referred for this project. Journals may also provide the data and result analysis that can be a comparison and guideline for conducting the project.

3.3.2 Previous Researcher

Sometimes there are several researcher already finish the project that is precise to the project title or project objective. The data from their experiment can be used for making comparison with the result of the project. Most of researches are conducted by the university or institution outside of Malaysia. The researches papers can be downloaded from the internet and published in the form of (.pdf) format.

3.3.3 Books

Book is a very good reading material of getting information about the project. This is because it has been written by the established author which is provide experience and detail information in the related field. The suitable book for this project is Internal Combustion Engine book and diesel engine books. To get this kind of source, it usually provide by book store or library. Detail information such as concept, analysis, and calculation method can be easily found in the source.

3.3.4 Project Supervisor

Although it is lot of information can be obtained from the journals, books, and previous researcher, it cannot be easily to understand whether it related to the project. So, it is a role of the project supervisor to help in understanding the information and give the opinion to make sure the gathering knowledge is really useful to the project and also for written in the final project report. In other hand, discussion with the supervisor which is expert in the related field gives clear guideline to conduct a smooth project's progress. Furthermore, it also can generate the new idea for the future research or the next project.

3.4 SEAWATER SPRAY DESIGN

For the first step before conducting the experiment, the seawater spray chamber must be build because the emission analysis data were obtained at the inlet and outlet of the seawater spray chamber. In that case, the spray chamber is design by using SOLIDWORK software before proceed with the fabrication process. There is not specified guideline for the dimension but the chamber is design fitting based on emission quantity produce by YANMAR single piston engine.

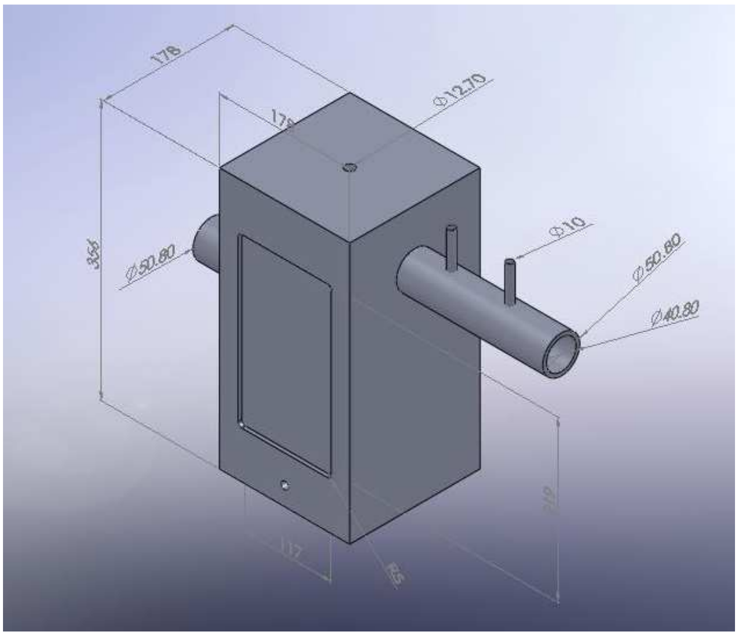


Figure 3.2: Seawater Spray Chamber Design.

3.5 FABRICATION

Fabrication is the important process that needs to be finished before preceding the experiment. There are several parts that need to be fabricated in order to start the experiment such as seawater spray chamber, and exhaust manifold.

3.5.1 Seawater Spray Chamber

After the seawater spray chamber design is finished, the fabrication process can be started. The material used to fabricate the seawater spray chamber is stainless steel, and prospect. The dimension of seawater spray chamber is shown in Figure 3.2.

3.5.2 Seawater Tank

The seawater tank is maker of plastic that can fill with 5 liter of water. The tank is providing with the slot area for electrode and diagram for the electrolysis. The material is combination of plastic and prospect. The design of the tank is shown in Figure 3.4 below.

Figure 3.3: Seawater Spray Chamber.

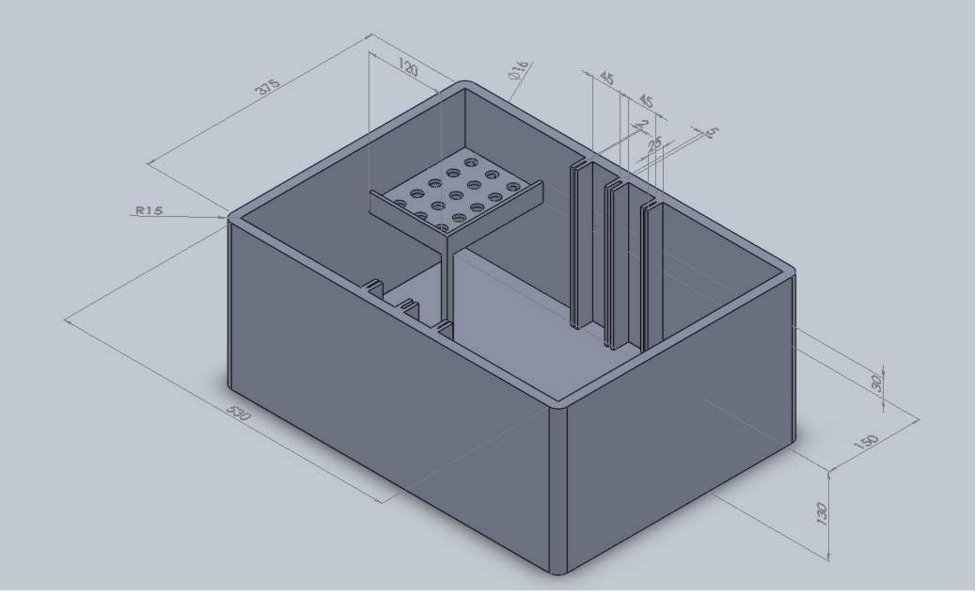


Figure 3.4: Design of Seawater Tank

3.5.3 Exhaust Manifold

Exhaust manifold have been modified to make sure a thermocouple hole and a valve can be installed, so that the exhaust gasses can be analyzed from the hole and valve.

Figure 3.5: Exhaust Manifold

3.6 APPARATUS

3.6.1 Diesel engine

In this project experiment, the engine used is YANMAR TF 120. The engine is water cooled and single cylinder diesel engine type.

Figure 3.6: Engine Side View

3.6.2 Exhaust Gas Particle Trap

Diesel engine produces soot as the product of combustion and come out through the exhaust valve together with the gas. This soot is dangerous to the exhaust analyzer because it can damage the analyzer. In case of that, the exhaust gas particle trap is used as the solution to avoid the soot reaching the exhaust analyzer. It worked by cooling the exhaust gas through the "water jacket" along the tube that going through by the gas. Affect of that action the particles in exhaust gas loosing energy and become heavier. So, the particles will drop to the bottom of the beaker that acts as the trap. The picture of the exhaust gas particle trap is shown next:

Figure 3.7: Water Reservoir Tank

Figure 3.8: Exhaust Gas Particle Trap

3.6.3 Fuel Flow Rate Analyzer

To obtain the fuel flow rate in this project’s experiment, the fuel flow meter used is from AIC – 1204 HR 2000 model with board computer from BC 3033 model. The picture of the model is shown below:

Figure 3.9: Fuel Flow Rate Meter and Board Computer

3.6.4 Engine Speed Sensor

To measure the speed of the engine, it have been used the engine speed sensor from 461957 photoelectric models and the display unit is from 461950 panel tachometer model. A marking is made on the engine flywheel to make sure the engine speed sensor can detect the engine speed. This photoelectric sensor is attached to the engine rig for measuring the engine speed. Both picture of the photoelectric sensor and tachometer unit panel are shown below:

Figure 3.10: Photoelectric Sensor

Figure 3.11: Panel Tachometer

3.6.5 Exhaust Gas Analyzer

The emission or exhaust gas from the engine is analyzed by using the exhaust analyzer. The model of this analyzer is Hand Held 4 & 5 Gas Analyzer Auto 4-2 & Auto 5-2 model. This model’s picture is shown below:

Figure 3.12: Exhaust Gas Analyzer

3.6.6 Exhaust Gas Temperature Sensor

Thermocouple is used as the exhaust gas temperature sensor to measure the gas temperature. This sensor is support by display unit to get the temperature reading. Thermocouple is placed at the exhaust manifold to make it function and it is shown by the picture below:

Figure 3.13: Thermocouple

Figure 3.14: Temperature Display Unit

3.6.7 Unregulated DC Power Supply

This apparatus is use to convert AC current to DC current and supply to the electrode for the electrolysis process. The current use is 12 Volt. The model of the apparatus is shown in figure below.

Figure 3.15: Unregulated DC Power Supply

3.7 EXPERIMENTAL PROCEDURES

3.7.1 Emission Analysis

Firstly, the engine speed was set at 1200 rpm and let it run without load for a while. Then, the exhaust gases that come out from the exhaust valve are collected for without seawater, with seawater, and with electrolyzed seawater spray system by let the exhaust gas flow through the exhaust particle trap. For electrolyzed seawater, direct current rectifier was use to supply electricity to the electrode that immersed in the seawater. The electric current will create electrolysis process. The water jacket was use around the particle trap cylinder to cool the exhaust gas and will cause the particle to fall at the bottom of the trap. After that, the "clean" exhaust gas was entering the exhaust analyzer and the gas contents were analyzed. The characteristic and amount of content was directly measured from the exhaust analyzer display unit. The engine speed was set for 1200, 1500, 1800, 2100 and 2400 rpm. For each increased engine speed, the same procedures for the 1200 rpm were repeated. All the data obtained were filled in the table. Lastly, the graph of exhaust gas emission versus engine speed was plotted and explained.

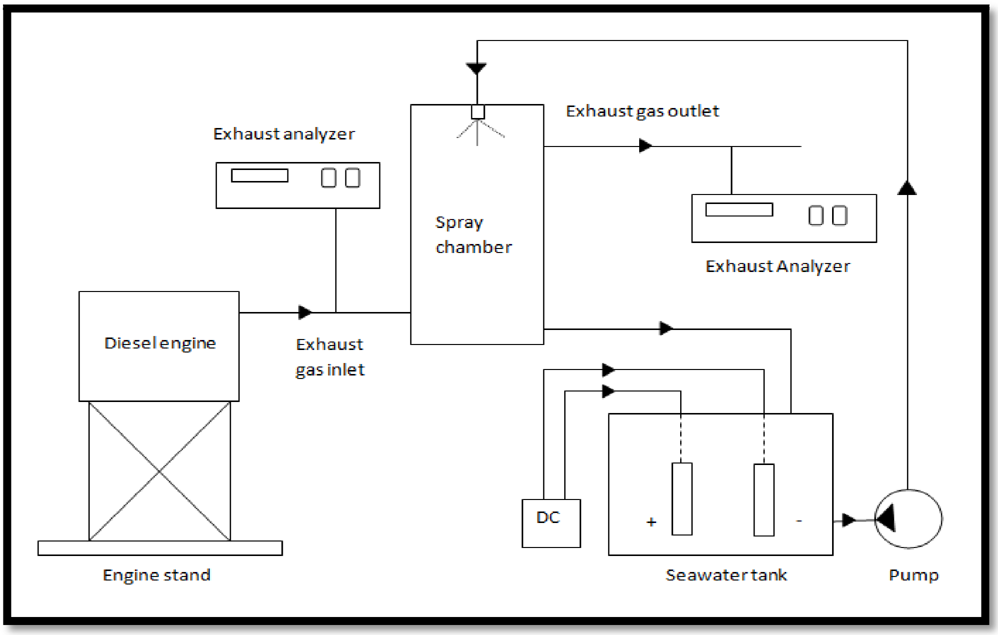


Figure 3.16: Diagram of the Experiment setup

CHAPTER 4

RESULT AND DISCUSSION

4.1 EFFECT OF EXHAUST TEMPERATURE ON ENGINE SPEED

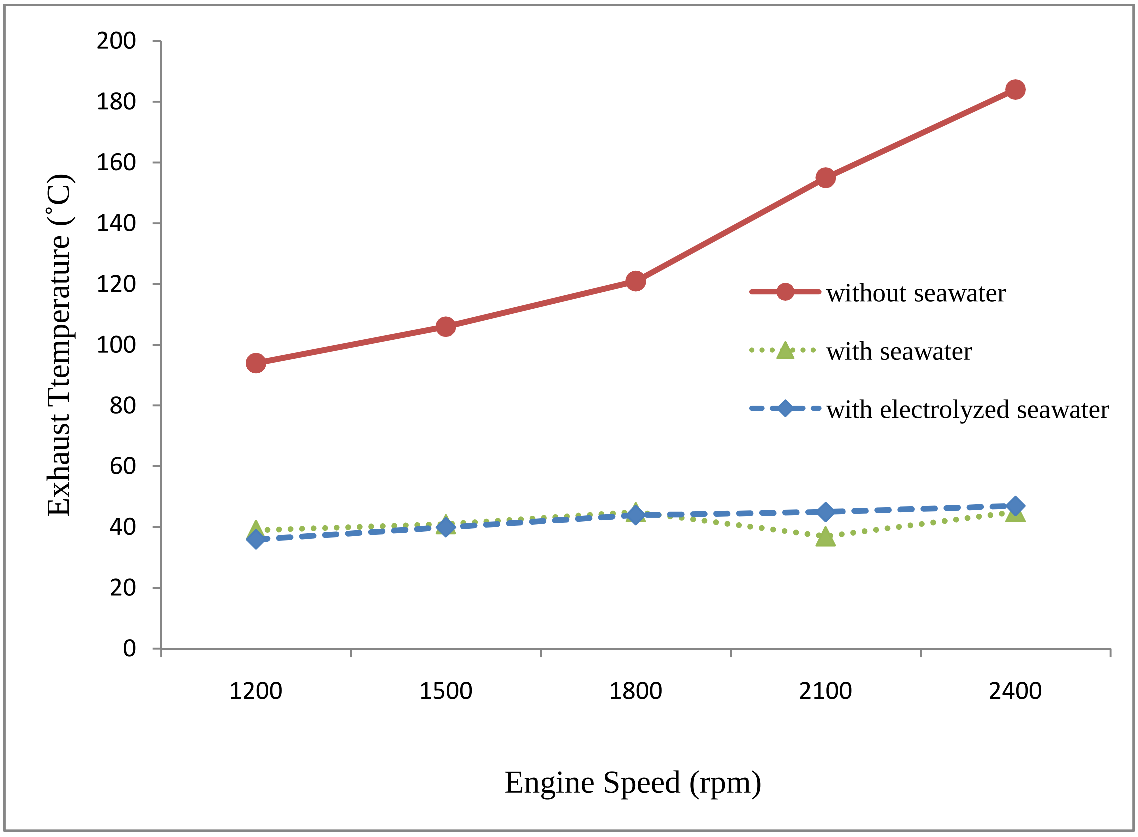


Figure 4.1: Graph of Exhaust Temperature versus Engine Speed

The effect of engine speed on the exhaust gas temperature is measured by a thermocouple attached to the outlet manifold before and after spray chamber. The variation of temperature with the increase of engine speed for both cases is measured and shown in Figure 4.1.The exhaust gas temperature increases with the increase of engine speed in all cases. This is due to a greater amount of fuel combustion inside the combustion chamber at higher speed compared to lower speed. At higher speed complete combustion of the fuel is happened (Mohanamurugan, S and Sendilvelan, S. 2011).

The reduction of exhaust temperature after applied seawater spray system was more than half with the average percent reduction equal to 66.86 %. This is due to the water characteristic that was a good heat absorber. Seawater absorbs the exhaust gas heat and brings it together to the drain. In case of that, reduction by spray with electrolyzed seawater is nearly same compare to spray with seawater. The reduction of exhaust temperature by spray with seawater (WS) are 58.5 %, 61.3 %, 62.8 %, 72.1 % and 75.5 % respectively to increasing five engine speed. Meanwhile, for spray with electrolyzed seawater (WES) the reduction are 61.7 %, 62.2 %, 63.6 %, 71 %, and 74.5 %.

4.2 EFFECT OF NOx EMISSION ON ENGINE SPEED

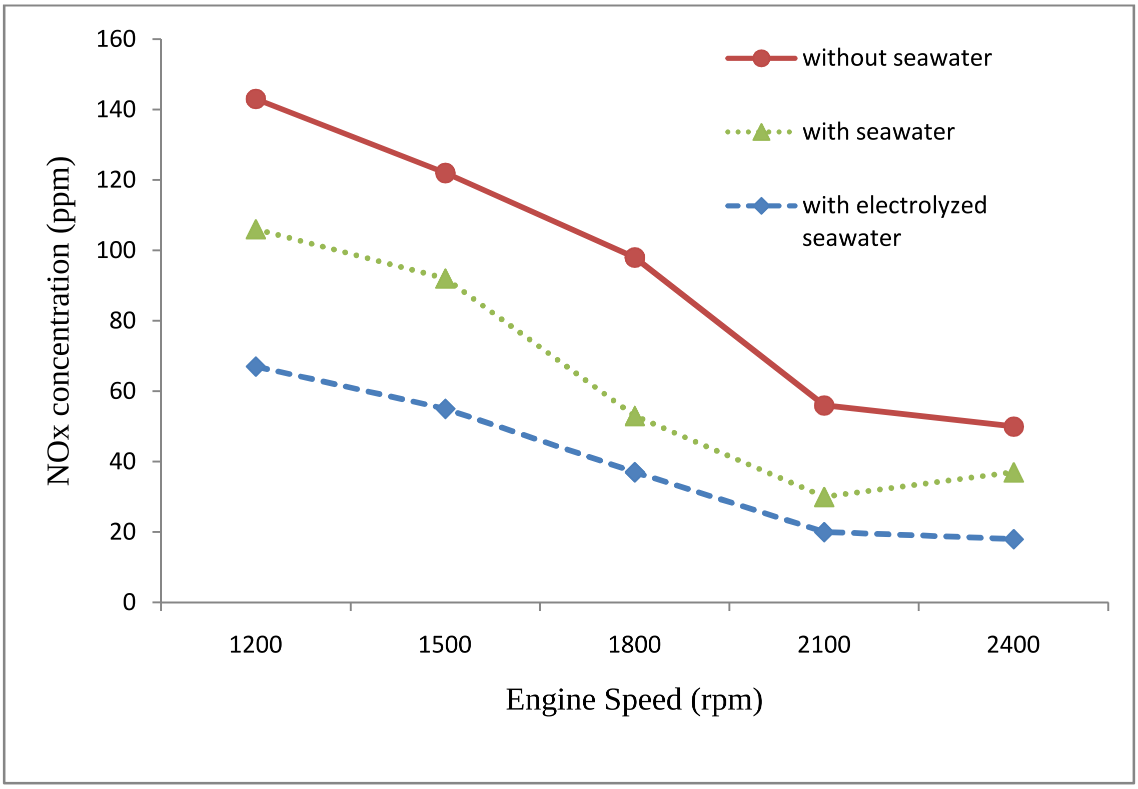


Figure 4.2: Graph of NOx Concentration versus Engine Speed

Figure 4.2 shown the effect of NOx gas's concentration due to variation engine speed. The NOx concentration decrease with the increase of engine speed. This is caused by the condition of the engine that is lean and caused the composition of the NOx decreasing as the engine speed is increased (Hamzah, 2010). Although the energy of burned gas is a nearly linear function of temperature but the same cannot be said of NOx since the chemical rates are nonlinear functions of temperature. The dependence on engine speed cannot be stated simply and one has to consider the variations in combustion duration and heat loss with engine speed (Jindal, S. 2010). Then, the reduction got was 25.9 %, 24.6 %, 46 %, 46.4 % and 26 % for spray WS by five tested engine speed. But when spray WES, the reduction are 53.1 %, 55 %, 62.2 %, 64.3 % and 64 %. This may caused by absorption of the seawater during contact with the NOx gases in the spray chamber. NOx gases are dissolving in the alkaline seawater to form HNO_3 solution. But for WES, the HNO_3 formation is more because of increasing alkaline level in seawater by the electrolysis process. So the trapped NOx is more than WS.

4.3 EFFECT OF NITRIC OXIDE EMISSION ON ENGINE SPEED

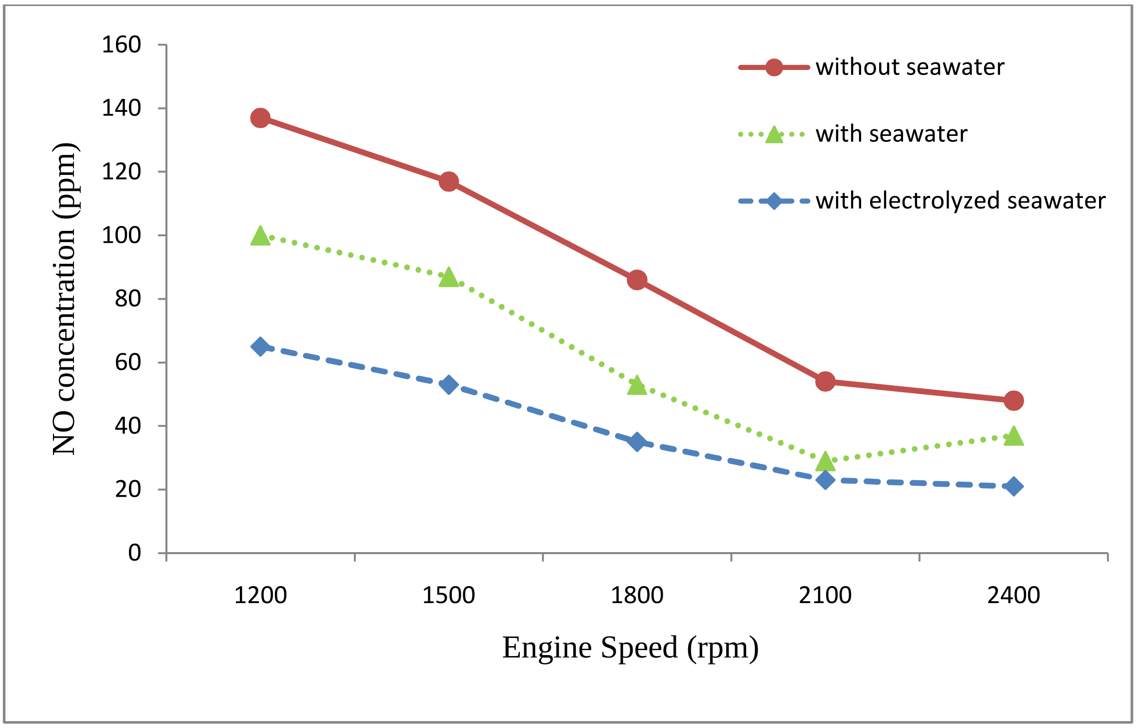


Figure 4.3: Graph of NO Concentration versus Engine Speed

By examining Figure 4.3, the increase of engine speed will decrease the NO concentration produced. This is caused by the condition of the engine that is lean and caused the composition of the NOx decreasing as the engine speed increased (Herzwan, 2010). In fact of that, the decreasing of NOx will influence the formation of NO because NOx is consist of NO and nitrogen gases. The principal NOx species in diesel engine exhaust gases is NO (Sidney, G. 1996). Comparison between spray with seawater (WS) and spray with electrolyzed seawater (WES) show the electrolysis seawater reduce more NO emission. Then, NO concentration reduced with an average 30.05 % for WS while for WES is 56.04 %. The reductions for WS are 27 %, 25.6 %, 38.4 %, 46.3 % and 23 %. For WES, the reductions are 52.6 %, 54.7 %, 59.3 %, 57.4 % and 56.3 % respectively to increase engine speed. These conditions may cause some NO gases dissolved with the seawater when emission is sprayed by seawater because concentrated alkali solutions were only partially effective in removing NO from gas streams (Sidney, G. et al. 1996). However, when use WES it because more NO oxidized NO_2 and absorb by electrolyzed seawater and cause more reduction.

4.4 EFFECT OF CO_2 EMISSION ON ENGINE SPEED

Comparisons between CO_2 concentration without seawater (WOS), WS and WES spray in Figure 4.4 give the information that CO_2 concentration WES was less than CO_2 concentration WS and WOS due to reduction when applied the system. At engine speed 1200 rpm until 2400 rpm, the reductions for WS are 21.8 %, 31.7 %, 34.8 %, 46.2 % and 22.6 %. Besides that, for WES reduction are 54.5 %, 56.5 %, 74 %, 80.1 % and 61.3 Then, the average reduction from the experiment is 31.41 % and 65.41 % for both cases WS and WES. The reduction occurred because of trapped CO_2 gases in seawater particle drop during sprayed in spray chamber. The portion of CO_2 is stripped by passing quick cooling of the scrubbing to some degree and evaporated to the atmosphere, so it has adequately absorbs into seawater (An, S. and Nishida, O. 2003). The contact of seawater with the CO_2 gases will form bicarbonate. For that, the used seawater had become the acidic seawater.

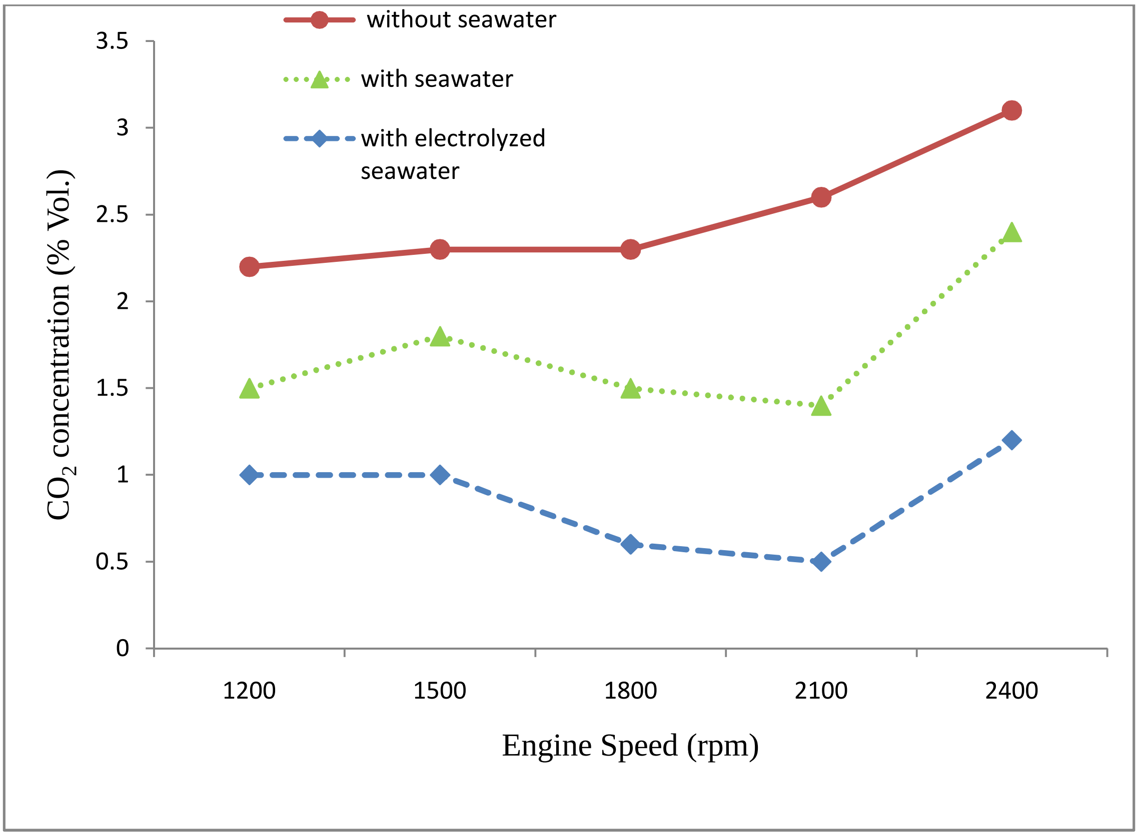


Figure 4.4: Graph of CO_2 Concentration versus Engine Speed

4.5 EFFECT OF CARBON MONOXIDE EMISSION ON ENGINE SPEED

Production of CO gas during the internal combustion engine is because of not enough air or O_2 to convert the carbon element in the diesel fuel to become CO_2. The graph in Figure 4.5 had shown the increase CO at the beginning and decrease at the end for the five engine speed. This is due to unbalance quantity air and fuel at the starting speed which is fuel was more than air compare to stoichiometric of complete combustion. But, approaching the maximum speed the combustion reaching to complete combustion which is reduces the CO emission.

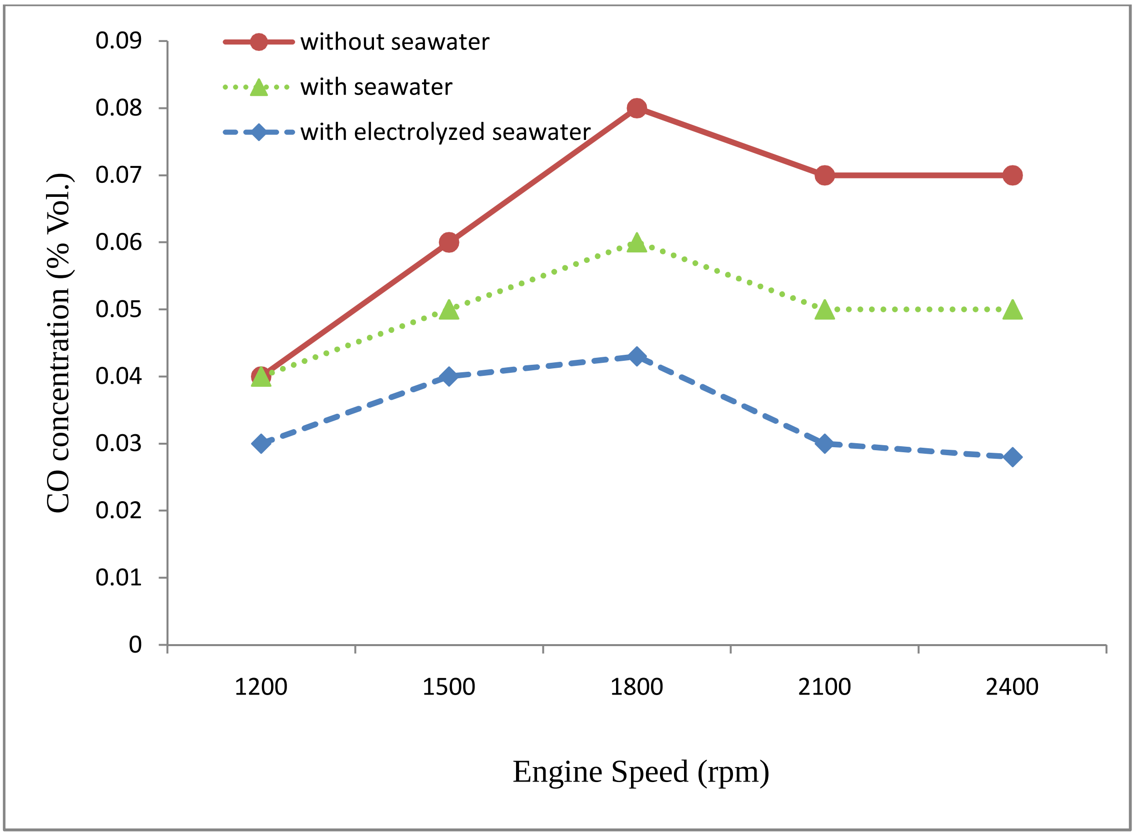


Figure 4.5: Graph of CO Concentration versus Engine Speed

Besides that, by examined Figure 4.5 CO concentration WES is reduced more than WS spray. The reduction was not occurring at the low engine speed which is 1200 rpm for WS but reduce from 0.04 % volume to 0.03 % volume for WES. Meanwhile, at speed 2400 rpm, the reduction was from 0.07 % volume to 0.05 % volume and from 0.07 % volume to 0.03 % volume for both WS and WES. So, the reductions of WS are 0 %, 16.7 %, 25 %, 28.6 % and 28.6 % respectively to engine speed increment. Moreover, WES was reducing CO emission as much as 25 %, 33.3 %, 46.3 %, 57.1 % and 60 %. Then, WS average reduction give 19.76 % and WES give 44.34 %. CO gas was dilute in seawater and causes the reduction for the WS spray. However, WES was producing the O_2 by the electrolysis process that increasing the seawater solubility and dissolved more CO in seawater.

4.6 EFFECT OF O_2 EMISSION ON ENGINE SPEED

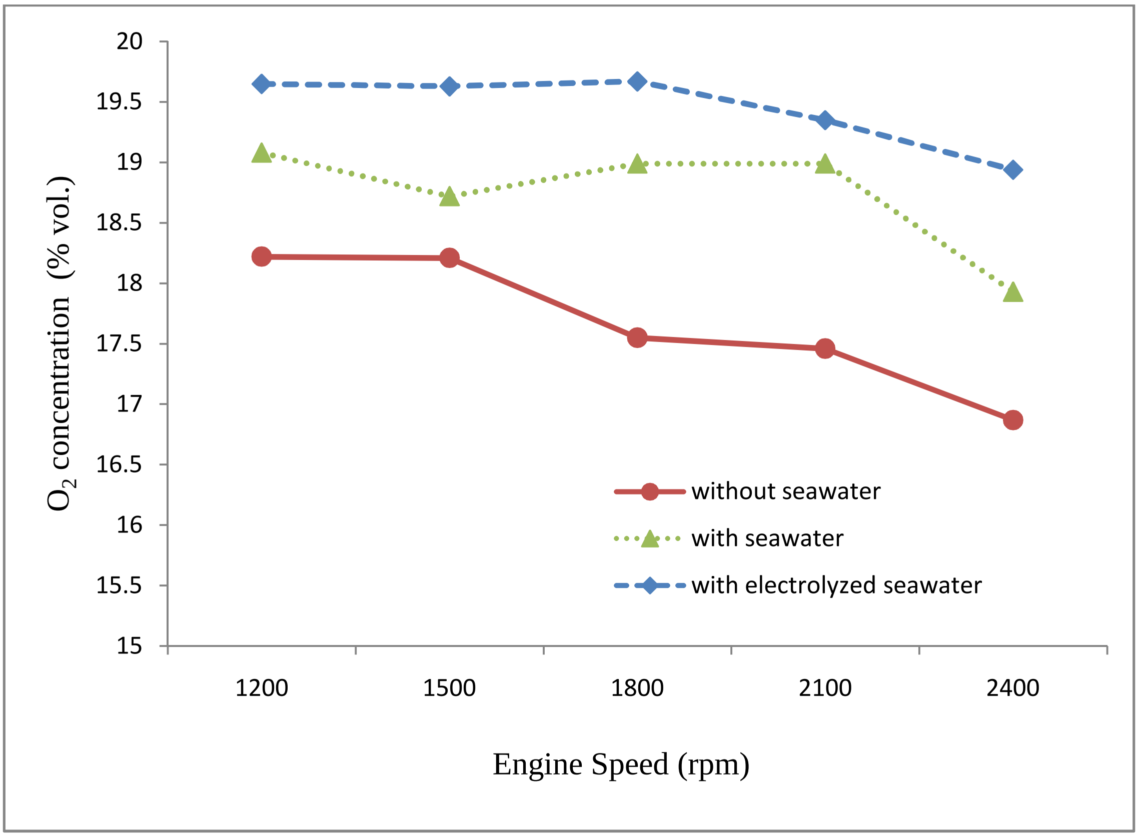


Figure 4.6: Graph of O_2 Concentration versus Engine Speed

Oxygen (O_2) is one of the emissions produce by the internal combustion engine. But O_2 is categorized in un dangerous emissions. Figure 4.6 shows O_2 decrease when the engine speed increase. This is because during low speed the O_2 used for the combustion only a few portions, but at the high speed the O_2 portions used is more with the same quantity air supply to intake manifold. Besides that, Result for O_2 emission was different with the other emissions explains before because O_2 concentration was increase after applied seawater spray system. The WS were increase O_2 emission to 4.7 %, 2.8 %, 8.2 %, 8.8 % and 6.3 %. Then, WES was increase to 7.8 %, 7.8 %, 12 %, 10.8 % and 12.3 % for five engine speed. The increment was low by 6 % and 10 % on average. For WS spray system, the O_2 emission contact with the additional O_2 gas in the seawater of the spray chamber itself. But, when using WES, the additional O_2 usage is more because electrolysis produce O_2 gases instead H_2 gases. So, the quantity for O_2 emission for WES is more than WS spray system.

CHAPTER 5

CONCLUSION

5.1 CONCLUSIONS

In the first stage seawater spray system experiment, the solubility of diesel exhaust gas emission such as NOx, NO, CO_2, CO and O_2 was studied for the five variable engine speed test start on 1200 rpm until 2400 rpm. The objective was to measure the reduction of diesel exhaust emission by using this system. The experiment concludes that all measured gases were experience the reduction except for O_2 that was increasing after applied seawater spray system. These results show that seawater or electrolyzed seawater was effective to reduce diesel exhaust gas emission. Seawater also can use as a cooling medium to remove exhaust gas heat. This system can be applied in marine field as the seawater supply is easier to get and store.

5.2 RECOMMENDATION

In order to make some improvement or for the future study, the suggestion is to apply load on the engine by the hydraulic dynamometer and pressure sensor analysis to measure the engine performance. Secondly, study the content of waste seawater from the spray system to know it effect to the environment.

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APPENDIX A

ENGINE SPECIFICATION

Brand	: YANMAR
Model	: TF 120
Displacement	: 636 cc
Maximum Output	: 12 Bhp @ 2400 rpm
Continuous Output	: 10 Bhp @ 2400 rpm
Fuel Tank Capacity	: 11 Liter
Cooling System	: Water Cooled, Radiator
Starting System	: Starter or Manual Cranking
Dimension (L/W/H)	: 685 cm/ 350 cm/ 530 cm
Weight	: 102 kg

APPENDIX B

BOARD COMPUTER AND FUEL FLOW METER SPECIFICATION

Board Computer	
Voltage supply : 11 to 30 VDC	11 to 30 VDC
Current consumption of system (U in = 24 V)	
- Normal operation and standby	40 MA
- With illumination	60 mA
- With sensors connected	100mA
- Supply for sensors	U out 7 V I max 40 mA

Fuel Flow Rate	
Dimension	115 × 55 ×55 mm (incl. non-return valve)
Weight	0.600 kg
Measuring rate	1 to 80 l/h
Pulse rate	2000 ppm

APPENDIX C

TECHNICAL SPECIFICATION OF PANEL TACHOMETER

Model 461950 Panel Tachometer	
Dimension Range	5 to 99 990 RPM
Accuracy	0.1 (5 to 999.9); 1 (1000 to 9999); 10 (10.000 to 99.990)
Display	0.5 “(13mm) 4 digit (9999 count) LED display
Display update rate	Once per second
Power	110/220 VAC; 50/ 60 Hz + 15%
Panel cutout dimensions	3.62 × 1.77” (92 × 45mm)
Bezel dimensions	3.78 × 1.89 × 2.36” (96 × 48 ×60mm)

APPENDIX D

TECHNICAL SPECIFICATION OF PHOTOELECTRIC SENSOR

Model 461957 Photoelectric Sensor	
Range	Up to 6000 RPM (100 Hz)
Power : 12- 24 VDC + 10%; :Consumption40 mA max	0.1 (5 to 999.9); 1 (1000 to 9999); 10 (10.000 to 99.990)
Response time	< 1 ms
Range	Up to 6000 RPM (100 Hz)
Power	110/220 VAC; 50/ 60 Hz + 15%
Output	NPN transistor; Max load 80 mA
Photo beam color	Green
Photo beam wavelength	5500 Angstroms
Cable length	1.8 meters

APPENDIX E

SPECIFICATION OF EXHAUST ANALYZER

Parameter	Resolution	Accuracy	Range
Oxygen	0.01 %	±5% of reading	0 - 1 0 %
Carbon Monoxide	0.01 %	±5% of reading	0-21%
Carbon Dioxide	0.1 %	±5% of reading	0-16%
Nitrogen Oxide			
Oxide Of Nitrogen	1 ppm	±4% of reading	0-5000ppm

APPENDIX F

Gantt chart for Final Year Project 1

WEEK Project activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Meet the super visor, get the title, and get the log book from FKM office.	■	■													
2. Determine the project objective, scope, and background		■	■	■											
3. Determine the flow chart of the project				■	■										
4. Literature review					■	■	■	■	■	■					
5. Design the methodology.										■	■	■	■		
6. Make a complete draft report and sent it to supervisor.													■	■	
7. Prepare for the Final Year Project 1 presentation.														■	
8. Presentation of Final Year Project 1															■

APPENDIX G

Gantt chart for Final Year Project 2

WEEK Project activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Setup the experiment	■	■												
2. Conduct the experiment and collecting data.			■	■										
3. Data analysis and conclusion.				■	■	■	■							
4. Make a complete draft report and sent it to supervisor.								■	■	■				
5. Make a thesis report.										■	■	■		
6. Prepare for the Final Year Project 2 presentation.													■	
7. Presentation of Final Year Project 2 and sent complete thesis.														■