PERFORMANCE AND EMISSIONS ANALYSIS OF MARINE DIESEL ENGINES DURING SHIP MANEUVERING

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Murat YAPICI, M.Sc. student of Piri Reis Maritime Transportation and Management Engineering student ID 138013001, successfully defended the thesis entitled "PERFORMANCE AND EMISSIONS ANALYSIS OF MARINE DIESEL ENGINES DURING SHIP MANEUVERING" which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my familiy

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Finally, I owe a debt of gratitude to my beloved family, who always supported me.

LIST OF SYMBOLS/ABBREVIATIONS

UK	United Kingdom
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
H_2SO_4	Sulphuric Acid
CO_2	Carbon dioxide
CO	Carbon monoxide
NO_X	Nitrogen oxides
PM	Particule matter
pH	Power of hydrogen
ECA	Emission Control Area
SECA	Sulphur Emission Control Area
MARPOL	International convention for the prevention of pollution from ships
ISO	International Organization for Standardization
DMX	Pure disilate marine oil
DMA	Gas Oil
DMB	Clean Diesel
DMC	Blended Disel Oil
cSt	CentiStokes
Al	Aluminum
m/m	Mass matter
IMO	International Maritime Organization

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ABSTRACT

PERFORMANCE AND EMISSIONS ANALYSIS OF MARINE DIESEL ENGINES DURING SHIP MANEUVERING

Sea transport is the most economical and convenient transportation option for long distance transport. From the 19th century with the realization of the industrial revolution, it has entered into a rapid development of maritime transport.

Developing technology and international treaties necessiated more sensitive to changes in the environment of this technology. In this context, IMO (the International Maritime Organization) MARPOL annex 6 (1997 protocol) was enacted in 2005. Air pollution is causing global warming, the depletion of the ozone layer, acid rain, damage to the human health.

Keping constantly under the control of the operation and performance of diesel engines with low air pollution is important. Due to variable loads during maneuvers of ships gases emitted into the atmosphere is damaging the air quality in the port environment. Therefore, they must perform the maneuver of the vessel as soon as possible. In addition, operation of the generators during their stay in the port causes air pollution. During the maneuver for main engine, 20% CO_2 and 800% emissions produced specific emissions more than normal operating conditions. In addition, the emissions produced by two generator at same power load is 16% CO_2 and 320% CO more specific emissions than one generator operating conditions.

In this study, ships exhaust harmful gases released into the environment while maneuvering and port stays are illustrated numerically. During the maneuvering to reduce emissions and port stays were made to run during the determination of the number of the generators. Annual and periodic emission calculations will be based on the calculations methods.

ÖZET

GEMİ DİZEL MOTORLARININ GEMİ MANEVRALARI SIRASINDAKİ EMİSYON VE PERFORMANSININ ANALİZİ

Deniz taşımacılığı uzun mesafe taşımalarda en ekonomik ve en kullanışlı taşımacılık seçeneğidir. Sanayi devriminin gerçekleşmesi ile beraber 19.yüzyıldan itibaren deniz taşımacılığı hızlı bir gelişim içine girmiştir.

Gelişen teknoloji ve Uluslararası antlaşmalar bu teknolojinin çevreye daha duyarlı değişimleri zorunlu kılmıştır. Bu bağlamda IMO (International Maritime Organization) Uluslararası Denizcilik Örgütü 1997 protokolüyle MARPOL'ün altıncı eki 2005 yılında yürürlüğe sokulmuştur. Hava kirliliği küresel ısınmaya, ozon tabakasının incelmesine, asit yağmurlarına, insan sağlığının zarar görmesine neden olmaktadır.

Dizel motorlarının düşük hava kirliliği ile çalıştırılması ve performansının sürekli kontrol altında tutulması önemlidir. Gemilerin manevralar esnasında değişken yükler nedeniyle atmosfereye yaydıkları gazlar liman çevresinin hava kalitesine zarar vermektedir. Bu nedenle gemilerin en kısa zamanda manevralarını gerçekleştirmeleri gerekmektedir. Ayrıca gemilerin limanda kaldıkları süre içerisinde jeneratörlerinin çalışması hava kirliliğine neden olmaktadır. Manevrada ana makine için, %20 CO_2 ve %800 CO emisyonlarının normal çalışma koşullarından daha fazla özgül emisyon üretildiği görülmüştür. Ayrıca jenereratör çalıştırma sayısı açısından aynı yükü karşılayan iki jeneratörün ürettiği emisyonun bir jeneratörün ürettiğinden % 16 CO_2 ve % 320 CO daha fazla özgül emisyona sahip olduğu tespit edilmiştir.

Bu çalışmada gemilerin manevra ve liman kalış sürelerinde çevreye yaydıkları zararlı gazlar sayısal olarak örneklenmiştir. Manevra süresince emisyonları azaltmak ve liman kalış süresince çalıştırılacak jeneratör sayısı hakkında tespitlerde bulunulmuştur. Örneklemeler üzerinden yapılacak hesaplar ile limanların yıllık ve dönemsel emisyon hesaplamaları gerçekleştirilebilmektedir.

1. INTRODUCTION

The first air pollution from burning has been seen in England. In 1301, 1^{st} King Edward banned the burning of coal for heating on the ground that caused the smoke and smell in London. Large increases in air pollution-induced deaths were seen in the UK in 1875 [1].

Ship-source pollution began with the industrial revolution when using the machine power instead of manpower. This engine technology began to use steam for carrying cargo by ships. John Fitch (1743-1798) was built the first steamboat on Delaware River in 1787 [2].

The first ship in excess of the ocean; Savannah has been reached from Savannah-Georgia to Liverpool-England in 1819. First steam ship was built in Britain in 1827 for Turkish shipping industry. ‘‘Eser-i Hayr Ferry’’ was launched on 26th of November 1837. This steamship has begun to be used in our maritime trade. Therefore, the first ship-source pollution was occurred in Turkey [3].

1.1. Historical Development of Ecology and Air Pollution

Human hunted and gathered plants to resume life in ancient times. This reality was seen in archaeological activities carried out by use of the environment to create these conditions [4]. These people have emigrated to move away from non-productive environments. The first information about the ecology and the environment was began by the study of Aristotle and students in the 4th century BC by the Theophrastus [5]. Leibig has researced the most important study about ecology in 1840. He demonstrated the development of plants in the environment of chemical substances. The first time, the term ecology was used by Haeckel in 1869 [6].

1.2. Sulfur Cycle

Sulfur, which is present in the soil is the basic building blocks of pyrite and chalcopyrite rocks and decomposed plant material. Creatures are using sulfates dissolved sulfur. The volcano, swamp land and the water are the resources of hydrogen sulfide gas. Differently source sulphur in the air combines with oxygen to create Sulphur dioxide (SO_2) or Sulphur tri-oxide (SO_3) formations. These compounds constitute the resulting sulfuric acid when combined with humidity. Sulfur compound in acidic structure rotates ground with precipitation.

Population growth in recent years, the impact of sulfur cycle was increased by increasing urbanization and industrialization negatively. The consumption of fossil fuels with a high percentage of sulfur in the atmosphere increases the amount of sulfur dioxide and acid [5].

1.3. Anthropogenic Influences on Air Pollution

In the literature; it is called anthropogenic effects caused by human. Pollution caused by ships in the maritime transport is considered as anthropogenic effects. In the air composition is described as natural; 78% nitrogen, 21% oxygen, 0.93% argon, neon, helium, methane, hydrogen, krypton, xenon, diozat monoxide, water vapor, ozone and carbon dioxide. Major polluters pollute the atmosphere; carbon monoxide; (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X) and particulate matter (PM) [7].

1.3.1. Carbon monoxide (CO)

The oxygen level of carbon contains fuel (coal, wood, natural gas, gasoline, cooking gas, etc.) and toxic gases resulting from the combustion in exactly low setting. Carbon monoxide poisoning, inhalation of oxygen gas contained in the hemoglobin of red blood cells in the blood are connected. to pass much more quickly after the lungs. This leads to cell death. Nausea, dizziness, vomiting, weakness cause the death at advanced level [8].

1.3.2. Carbon dioxide (CO_2)

Carbon dioxide is an important gas for photosynthesis. However, this gas in fossil fuels increases global warming due to industrial activities [9].

1.3.3. Sulfur dioxide (SO_2)

Each year anthropogenic and natural formations are involved by the volcanos and combustion of fossil fuels with tons of sulfur dioxide atmosphere. The high concentration of sulfur dioxide into the body causes of cough, bronchitis, asthma and lung disease. Discoloration due to reduction of chlorophyll in plants, leaves of institutions, inhibition of growth and development, seed and fruit formation damage, pulmonary animals, illustrates the effect on lung diseases [9].

1.3.4. Sulfur trioxide (SO_3):

Sulfur trioxide life cycle is so short in the atmosphere. It combines with water and vapor to form sulfuric acid. Sulfuric acid is one of reason caused acid rain and damage to living and nonliving environment. Especially in terms of corrosion on metal weight and structure of the bridge can be seen by acid rain. It damages to large agricultural areas as product damage [8].

1.3.5. Nitrogen Oxides (NO_X)

Airborne concentrations due to human activities are the main cause of warming and increased nitrogen oxide by motor vehicles. Nitrogen oxides cause acid rain in the air. The sulphuric acid is converted to nitric acid. Acid rains change the structure of ground as chemical, physical and biological, wise.

Potassium, calcium, sodium and magnesium elements as a result of interference by the substrate through the ground water caused to decrease soil fertility. Acid rain lowers the pH, increasing the acidification of soils and wetlands affected area and cause the dissolution of heavy metals in the food chain [9].

1.3.6. Particulate Matter:

In the atmosphere, consisting of a mixture of liquid and solid particles available is called particulate matter. It can be seen at some activites such as volcanoes, oceans, natural phenomena such as pollen and industrial activities [8].

1.4. Anthropogenic Impacts on Ship-source Pollution

Air pollution is a natural effect of the use of fossil fuels by merchant ships. International Maritime Organisation's 1997 protocol MARPOL Annex six has established guidelines for the prevention of air pollution, enacted in 19th May 2005. ECA (Emission Control Area) created especially in Europe with ship exhaust resulting from the SO_X were trying to determine the fuel used by ships in order to reduce the impact of harmful gases containing NO_X [10].

The main causes of air pollution caused by toxic exhaust flue gases from ships. In addition, leakage may occur in the refrigeration and air-conditioning system that cools the gas stores with air conditioning systems cause air pollution. Gas usage must be recorded and the use of gas that does not harm the ozone layer as possible. Also, it includes harmful gases consisting of cargo transported in cargo holds or tanks [11].

1.5. International Regulations for Air Pollution from Ships

Marpol 73/78 is one of the most important international marine environmental conventions. It was designed to minimize pollution of the seas, including dumping, oil and exhaust pollution. Its stated object is to preserve the marine environment through the complete elimination of pollution by oil and other harmful substances and the minimization of accidental discharge of such substances.

The original MARPOL was signed on 17th February 1973, but did not come into force due to lack of ratifications. The current convention is a combination of 1973 Convention and the 1978 Protocols. It entered into force on 2 October 1983. May 2013, 152 states, 99.2 percent of the world's shipping tonnage are representing parties to the convention.

All ships flagged under countries that are signatories to MARPOL are subject to its requirements, regardless of where they sail and member nations are responsible for vessels registered under their respective nationalities.

Annex I: Prevention of pollution by oil & oily water,
Annex II: Control of pollution by noxious liquid substances in bulk,
Annex III: Prevention of pollution by harmful substances carried by sea in packaged form,
Annex IV: Pollution by sewage from ships,
Annex V: Pollution by garbage from ships,
Annex VI: Prevention of air pollution from ships [12].

As a result of several interviews in order to reduce air pollution from ships; it is provided in accordance with a specific timetable for the reduction in the sulfur content of the fuel. This chart presented when the ship machinery manufacturers in terms of reduction of both emissions and fuel companies. According to MARPOL Annex VI Regulations for the prevention of air pollution from ships, Rule 14, Section 3 ship's fuel oil must comply with the following limits for maximum sulfur content:

- 4.50% respectively prior to 1^{st}January 2012 m/m
- After 1^{st} January 2012 3.50 % m/m
- After 1^{st} January, 2020 at 0.50 % m/m

End of 2015, in special emission control areas, fuel oil sulfur content is % 1 m/m (expressed in terms of % m/m – that is by mass matter). And end of 2020, the sulfur content of marine fuel oil Global limit will be 3.5 % m/m. The limit of sulfur content for ECA will be 0.50% m/m after 1^{st} January 2020. According to Figure 1.1., maximum sulfur content of fuel oil for all fuel used in maritime transport is shown.

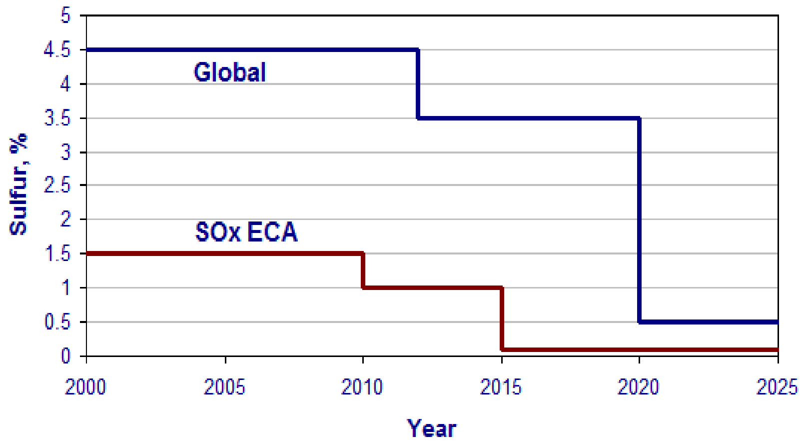

Figure 1.1. Year by year Sulfur Rates [12].

Fuel standards and limits used for ships according to the ISO 8217 standard is shown in Table 1.1. If the value of fuel specifications is between minimum and maximum limits, it will not be a problem for ship equipment as main engines, diesel generators or boilers.

Table 1.1. ISO 8217 Fuel Standards [15].

Characteristic	Unit	Limit	Category				Test Method Referance
			DMX	DMA	DMZ	DMB	
Density at 15^{0}C	kg/m^3	max.	-	890	890	900	ISO 3675or ISO 12185
Viscosity at 40^{0}C,	mm^2/s*	min. max.	1.40 5.50	2.00 6.00	3.00 6.00	2.00 11.0	ISO 3104 ISO 3104
Cetane number	-	min.	45	40	40	35	ISO 4264
Flash point,	^{0}C	min. max.	- 43	60 -	60 -	60 -	ISO 271 9
Pour point (upper,) -Winter quality -Summer quality	^{0}C	max. Max.	-6 0	-6 0	-6 0	0 6	ISO 3016 ISO 3016
Sulphur,	% (m/m)	max	1.0	1.5	1.5	2.0	ISO 8754 or ISO 14596
Hydrogen Sulfide	mg/kg	max.	2.00	2.00	2.00	2.00	IP 570
Acid Number	Mg KOH/g	max.	0.5	0.5	0.5	0.5	ASTM D664
Total existent sediment,	% (m/m)	max.	-	-		0.10	ISO 10307-1
Stability	g/m^3	max.	25	25	25	25	ISO 12205
Carbon residue on %10 (V/V) distillation bottoms, Carbon residue,	% (m/m) % (m/m)	max. max.	0.30 -	0.30 -	0.30 -	- 0.30	ISO 10370 ISO 10370
Cloud point,	^{0}C	max	-16	-		-	ISO 3015
Ash,	% (m/m)	max.	0.01	0.01	0.01	0.01	ISO 6245
Sediment	% (m/m)	max.	-	-		0.10	ISO 10307-1
Water,	% (v/v)	max.	-	-		0.3	ISO 3733
Vanadium,	mg/kg	max.	-	-		-	ISO 14597
Aluminum plus silicon,	mg/kg	max.	-	-		-	ISO 10478

Where;

*mm^2/s = cSt,

DMX: Pure Disillate Marine Oil,

DMB: Clean Diesel,

DMA: Gas Oil,

DMC: Blended Diesel Oil.

Some properties of ultra-low sulfur fuel currently used in ECAs are shown in Table 1.2.

Table 1.2. Properties of Ultra Low Sulfur Fuel Oil [15].

Characteristic	IFO-180 RMD80LS	IFO-180 RME180
Density at 15^{0}C kg/cm^3	Max. 980	Max. 991
Viscosity at 50^{0}C cSt	Max. 80	Max. 180
Flash point^{0}C	Min. 60	Min. 60
Upper Pour Point^{0}C	Max. 30	Max. 30
Micro Carbon Residue % (m/m)	Max. 14	Max. 15
Ash % (m/m)	Max. 0.1	Max. 0.1
Water % (m/m)	Max. 0.50	Max. 0.50
Sulfur % (m/m)	Max. 0.10	Max. 3.50
Vanadium mg/kg	Max. 350	Max. 200
Total Sediment Potential % (m/m)	Max. 0.10	Max. 0.10
Al+Si mg/kg	Max. 80	Max. 80

Seaborne Trade Routes are shown in Figure 1.2.

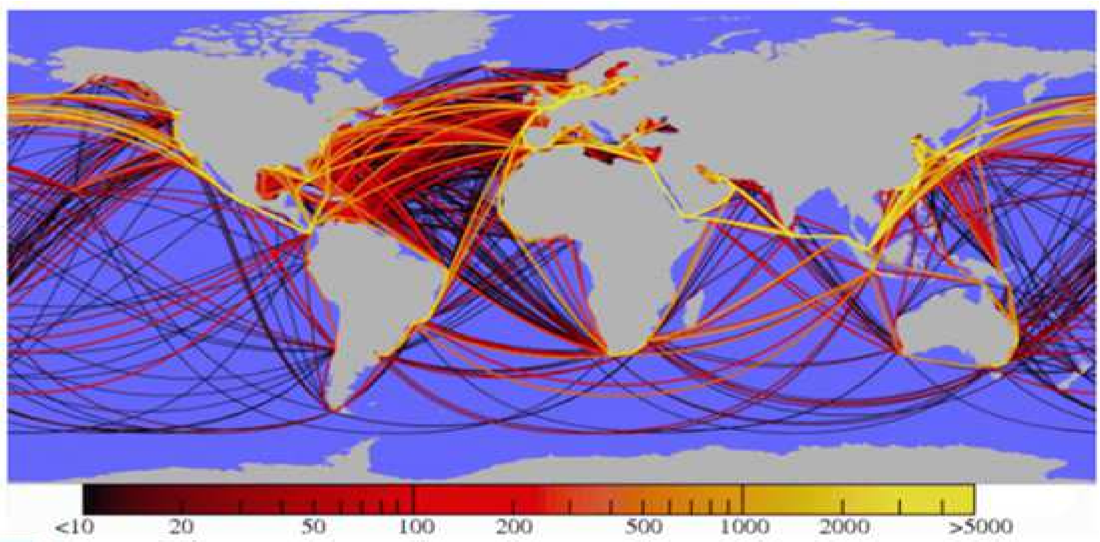

Figure 1.2 Seaborne Trade Routes [26].

In the near future, MARPOL Annex VI subcommittee is scheduled to take place in specially designated areas as the Black Sea, Mexico, the Mediterranean Sea of Japan, Mediterranean Sea, China Sea, South Africa, and Persian Gulf.

According to MARPOL Annex VI, the operation of each diesel engine to which this regulation applies is prohibited, except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits:

(i) 17.0 g/kW·h when n is less than 130 rpm
(ii) 45.0 x $n^{-0.2}$ g/kW·h when n is 130 or more but less than 2000 rpm
(iii) 9.8 g/kW·h when n is 2000 rpm or more
where n = rated engine speed (crankshaft revolutions per minute).

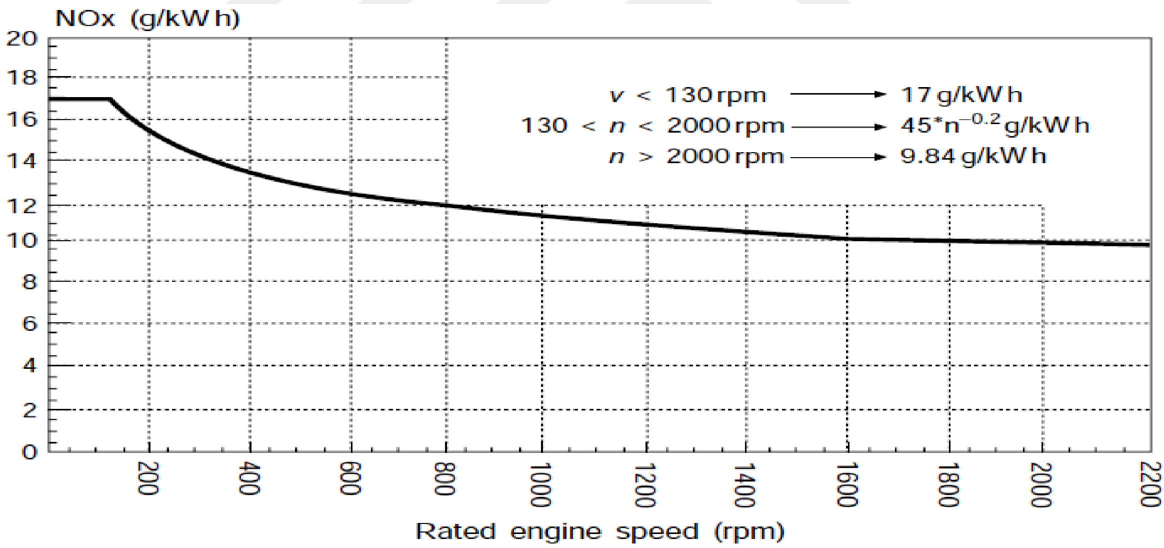

Figure 1.3. Diesel Engine NOx Limitations [12].

When using fuel composed of blends from hydrocarbons derived from petroleum refining, test procedure and measurement methods shall be in accordance with the NOx Technical Code, taking into consideration the test cycles and weighting factors outlined in appendix II to this Annex.

2. METHODOLOGY

In this thesis, the primary source of the research is data collection about the research subject. The data were obtained from the ship engine emission test results. Secondary source of the research is based on literature survey. The articles about the thesis were investigated.

2.1. The Aim of the Research

The primary aim of this research is to examine the effects of ship maneuvering upon the performance and emissions of the ship diesel engines. To do this, performance and emission tests results of diesel engines are analaysed and relationship between power output and emissions are investigated.

2.2. Problem of Research

The ship owners and governments are faced with the following problems due to the air pollution from ships:

- There is compliance with the fuel quality emission rules,
- Special ship emissions control areas are known or unknown by employees and companies,
- The effect of ship emissions of alternative technologies,
- Insufficient marine education about air pollution awareness.
- Evaluate the performance during maneuvers emissions,
- The relationship between emissions and number of generator.

In this study, four different types of emission for marine diesel engines values were obtained in the test report. Also, using the numerical interpolation, intermediate values of emissions are calculated with the given only four or five load changes.

Emissions can easily be calculated corresponding to each speed or load change of the engine. Total emissions can be calculated during the maneuvering at full speed, half, dead slow, slow operations. Total emission is given as,

$$\sum_{Emission} = \sum_{EM} + \sum_{EG} + \sum_{EB} + \sum_{EW} + \sum_{EA} + \sum_{EC} + \sum_{EF} + \sum_{EK}$$

Where;

$\sum_{EM}$ = Total Emission of Main Engine(s)

$\sum_{EG}$ = Total Emission of Generator(s)

$\sum_{EB}$ = Total Emission of Boiler(s)

$\sum_{EW}$ = Total Emission of Waste Oil Incinerator

$\sum_{EA}$ = Total Emission of Air Condition & Ref. System(s)

$\sum_{EC}$ = Total Emission of Cargo

$\sum_{EF}$ =Total Emission of Fire System

$\sum_{EK}$ =Total Emission of Kitchen

There are many publications in the literature about emissions. In particular, few studies have assessed the performance and compute the change during maneuvering. A.K. Gupta, R.S. Patil and S.K.Gupta, were investigated Emissions of Gaseous and particulate Pollutants in a Port and Harbour Region in India in 2002. This is the first study as known how calculate or estimate total emissions [19]. One year later, Yang. D. & Kwan, S.H. researched emission inventory of marine vessels in Shanghai in 2003. This is an important study for sampling Shanghai port for other Chinese ports [20]. In 2006, California Environmental Protection Agency made Emission Reduction Plan for Ports and Goods Movement in California [21].

Also, in Port of Oakland, seaport air emission inventory were done in 2005 [18]. Saxe, H. & Larsen were researched air pollution in three Danish Ports. It had been the last study before Baltic Sea ECA zone rules entered to force for all ships [17]. In England, Marr and others made their survey about air quality and emissions inventory at Aberdeen harbor in 2007. In this study, pollutant gases were started to categorized and counted amount of greenhouse gases [16].

In Turkey, Deniz C. and others made some studies around Ambarlı port, İzmit port, and Çandarlı gulf. Their method was taken from The European Commission Directorate General environment service contract on ship emissions calculations [22, 23, 24]. In 2010, Saraçoğlu H. made his thesis as ‘‘Investigation of exhaust gas emissions of ships calling İzmir Port and their environmental impacts’’. In this study, also, the same coefficients were used for calculations as Deniz C and others did.

This study aims to demonstrate the analytical instant case of ship diesel engine performace and emissions during different maneuvering conditions. United States Enviromental Protection Agency (EPA) identified emission factors based on different operating conditions in 2002 [25]. These emission factors are provided with a general approach. Test value were derived from this study aimed to compare with EPA’s data.

Fuel sulfur content in 2005 was updated using today's rates. Loads (below 10%) are aimed to build on the trend line for the emission. This will be realistic emission estimation in the maneuver. Power changes during maneuvers focused on changes in emissions.

3. DIESEL ENGINE PERFORMANCE AND EMISSON TEST

3.1. Diesel Engine Cycles

Internal combustion engines are power producing machines that work in a thermodynamic heat engine cycle. In an internal combustion engine cycle, the input energy is provided by burning fuel in the system limits. The fuel's energy is converted into mechanical work at a high rate. The ratio of mechanical power output to the fuel's energy is defined as thermal efficiency and depends on the thermodynamic state changes occurring in the engine.

During the cycle, the piston returns to its initial position at the end of each revolution. Diesel engines are divided into two groups according to the operating principles.

3.1.1. Four Stroke Diesel Engines

There are four strokes in a cycle as; intake, compression, combustion and exhaust strokes and power is produced at the end of two revolutions of the crankshaft. Then, 720 degrees crank angle contains four strokes of the engine. A four stroke piston movement at different times is shown in figure 3.1.

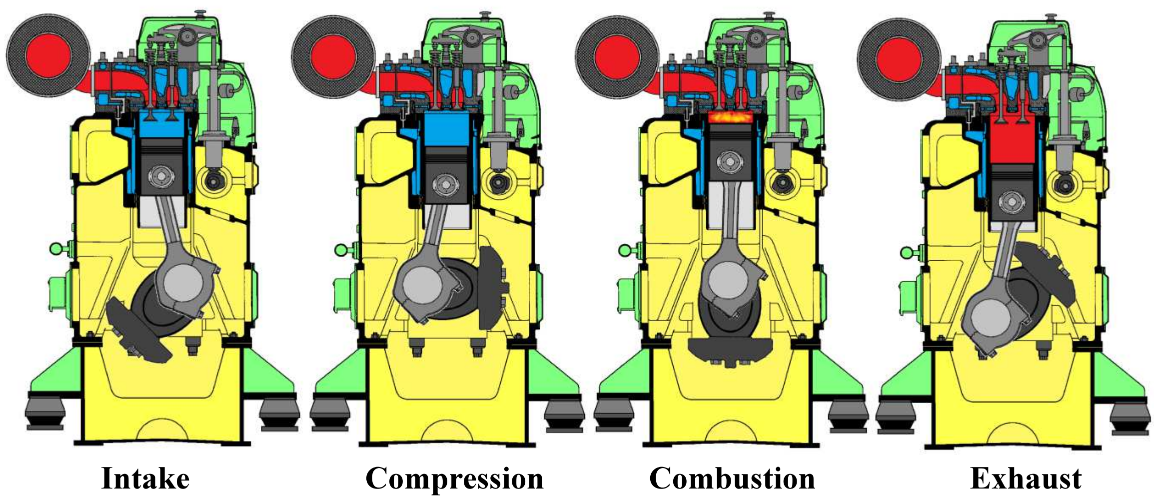

Figure 3.1. A Marine Type Four Stroke Diesel Engine.

3.1.2. Two Stroke Diesel Engines

Intake, compression, combustion and exhaust strokes are performed at each 360 degrees revolution of the crankshaft. A two stroke Diesel Engine is shown in figure 3.2. More than 30 years ago, two-stroke marine diesel engines used exhaust ports for exhaust gases. Today's modern diesel engine, exhaust valves are used for exhaust gases.

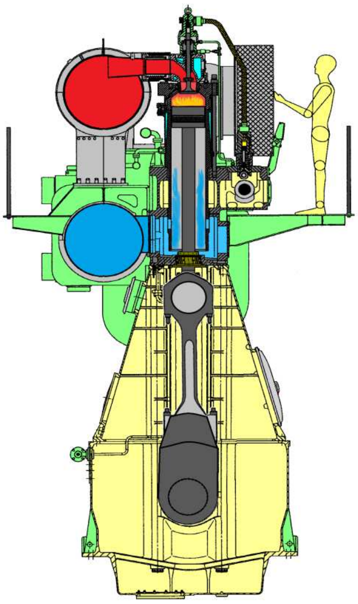

Figure 3.2. Man Engine Cross Section of S35MC7. Marine Type Modern Two Stroke Diesel Engine.

Comparison of two-stroke and four-stroke Diesel Engines;

- Two-stroke engines have about twice the power in the same size because there are twice as many power strokes per cycle.
- Two Stroke Diesel Engines don't need a heavy flywheel for torque ripple in terms of the engine. Four-stroke machines are made with heavy flywheel for balancing crankshafts.
- Two Stroke Diesel Engines have a higher mechanical efficiency than Four Stroke Diesel Engine.
- When the two-stroke engine uses insufficient amount of supercharging air, exhaust gases in the cylinder cannot be cleaned well. This causes a pressure drop and bad combustion.

- Generally, Two Stroke Diesel Engines are manufactured for more than 1000 hp power requirements.

Figure 3. 2 shows two stroke marine diesel engine as internal-combustion engine in which air is compressed to obtain a sufficiently high temperature to ignite diesel fuel injected into the cylinder. This marine engine converts the chemical energy stored in the fuel into the mechanical energy, which can be used to power marine vessels. Today, ultra long stroke length two-stroke Diesel engines are used for marine industry. Depending on the number of revolutions they have been working on the reduction of exhaust emissions. Studies are underway to achieve lower fuel consumption compared to outdated Diesel engine technology.

Proper operation of a marine diesel engine requires balanced power generation in each cylinder. Unbalanced power generation in the cylinder is due to the result of incomplete combustion of fuel. This leads to the creation of more exhaust emissions.

The power data in each cylinder of the diesel engine can be calculated by using an indicator diagram. Mechanical devices which plot the pressure versus cylinder pressure are called indicator device. Today, mechanical and electronical indicator devices together with the computer software are used to calculate performance of the engines.

3.2. Diesel Engine Performance Test

Marine Diesel Engines are tested after manufacturing. Performance parameters and emission values of the engines are measured at different loads [25]. A sea trial is the testing period of a new ship. Sea trial is the last period of construction and takes place on open sea for experience of seaworthiness. Sea trials are related to measure a vessel's Diesel engine performance and general seaworthiness. Vessel's speed, maneuverability, equipment and safety features are tested. Technical director or superintendent from the owner and engineer of shipyard are attends these trials.

3.2.1. Test Instruments

The performance measurements are conducted with the engine indicator which is connected to the engine cylinder indicator. Engine indicator is the device used to take the indicator diagram. The diagram is taken periodically from the indicator valve placed on the cylinder head. Indicator diagrams give efficiency of combustion in the cylinder, condition of the running gear, irregularities in fuel pumping and injection.

Pressure from the taps in the assembly is absorbed by the power spring. Indicator diagrams on a special paper are drawn. The compression pressure and maximum pressure in the cylinder can be measured from the indicator diagram. The area in the diagram is measured with the apparatus called planimeter. The figure 3.3. shows an engine indicator. The indicator diagram is very important to know the combustion in the cylinder and so as to adjust the engine.

Figure 3.3. Engine Indicator

The standard design of engine indicator is used for taking single diagrams for internal combustion engines. The indicator spring is a double-coiled, easily interchangeable tension spring. All springs are precisely calibrated and marked with the spring scale and the maximum pressure related to a piston size. The drum is returned by the spring. The paper drum is usually driven from the crosshead guide or from the connecting rods of engine.

The indicator should be mounted preferably near to the engine cylinder to be tested. An indicating valve must be provided. If the indicator connections are arranged at the side of the engine cylinder, the indicator will be in a horizontal position.

3.2.2. The Planimeter Test Instruments

The planimeter is a simple instrument for the precise measurement of PV diagram areas. To measure PV diagram area it is only necessary to trace the outline of the figure in a clockwise direction with the CenterPoint of the tracing lens and read off the result on the scales.

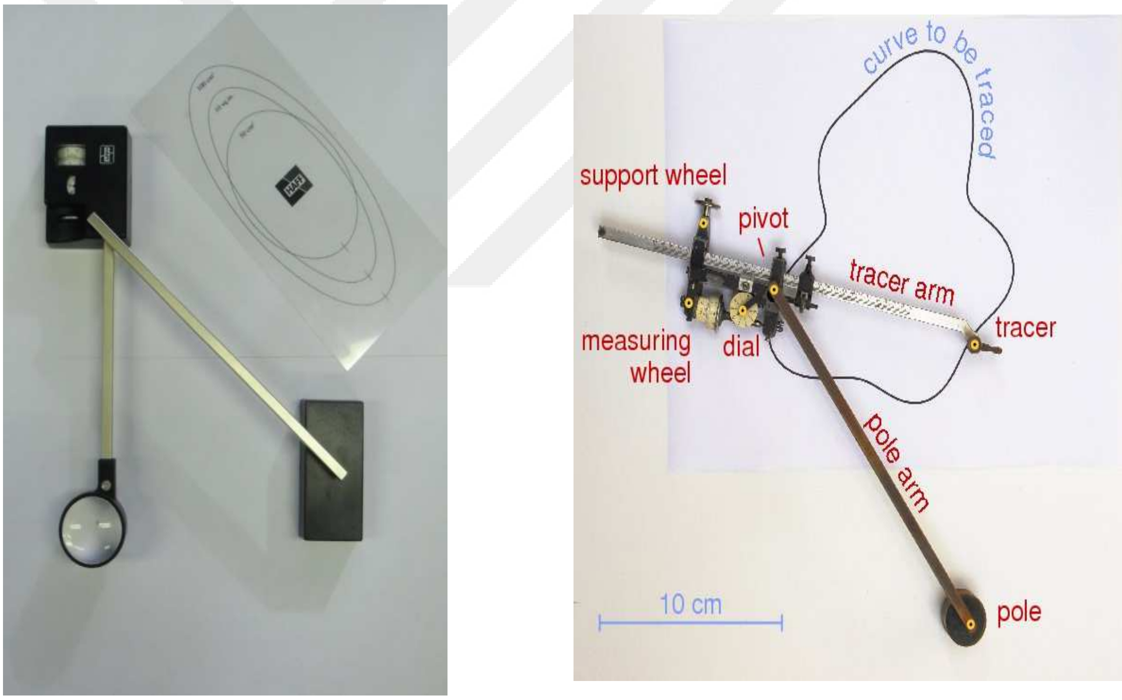

Figure 3.4. Planimeter

The planimeter consists of three separate parts; the tracing arm to which the roller housing the pole arm and the pole plate are attached. Three parts are packed separately in the case. The pole arm is simple beam. On each a ball end is fixed, fitting into the roller housing, the other into the pole plate. The roller housing rests on three supports; the tracing lens, the measuring roller and a supporting ball.

3.2.3. P-V and P-θ Diagrams

PV and P-θ diagrams are very important to determine the engine performance. It shows four cycle during operation of the diesel engine and illustrates the abnormal operating conditions. All turbocharged Marine Diesel Engines are susceptible to extreme torque and extreme thermal stress. Air flow from the turbocharger is sensitive to small changes in the speed of the engine. Total power and each cylinder's power can be found by using these diagrams. Maximum compression pressure (Pmax or Pcomp) and power are shown in Figures 3.5 and 3.6. The difference between the maximum pressure and compression pressure of the engine is identified as the deviation. Deviation condition is undesirable. A difference is tolerated between -3 and +3 bar. The abnormal pressure differences cause problems in machine condition. Thus, undesirable emission increases occurs. Figure 3.7. shows the deviations of measured indicated pressure.

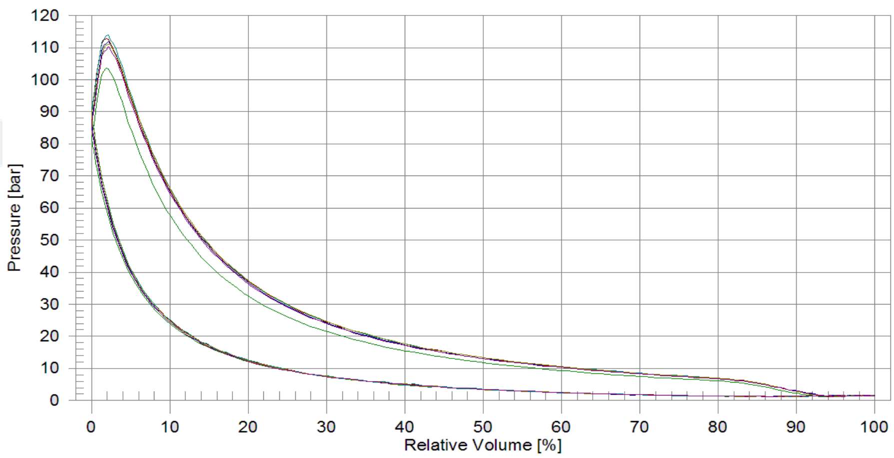

Figure 3.5. P-V Diagram

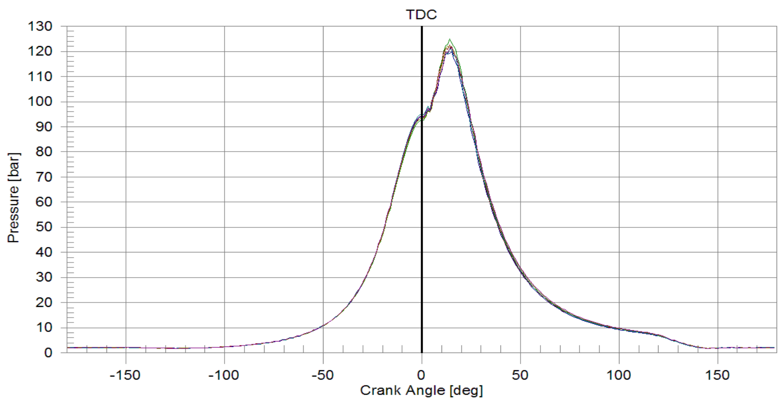

Figure 3.6. Pressuure vs. Crank Angle.

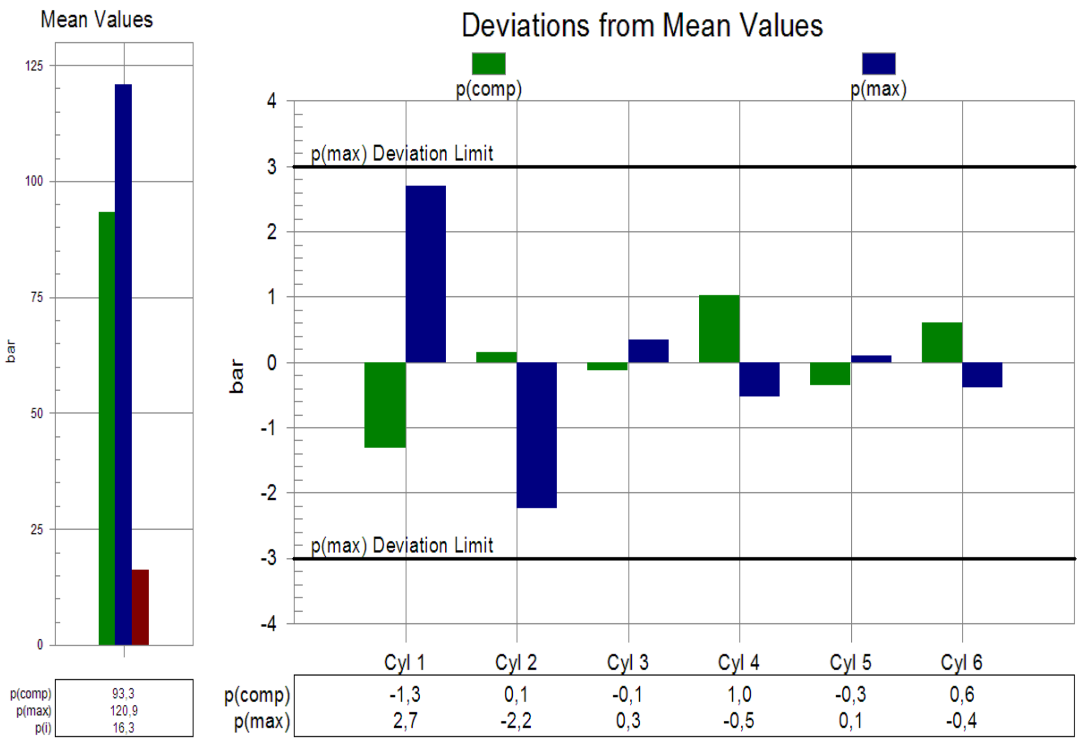

Figure 3.7. Deviations of Measured Indicated Pressure (bar)

3.3. Diesel Engine Performance Parameters

The indicator diagram of Marine Diesel Engines with indicator drive or electronic equipment, can be used to find the Mean Indicated Pressure (p_i). And, p_e is the effective pressure available after friction losses in the shaft. Calculation of the indicated and effective engine power consists of following steps:

- *Mean Indicated Pressure, p_i (kpa)*

$$p_i = \frac{A}{L \times Cs} \times 100 \qquad (3.1)$$

Where;

A: is the area of the indicator diagram measured with a planimeter in (mm^2)

Cs: Spring constant of the drive in mm/bar (vertical movement of the indicator stylus (mm) for a 1 bar pressure rise in the cylinder)

L: length of the indicator' diagram (atmospheric line) (mm)

- *The mean effective pressure, p_e (kpa)*

$$p_e = p_i - kt \ \ x\ 100 \tag{3.2}$$

kt : the mean friction loss (bar)

The mean friction loss has proved to be practically independent of the engine load.

- *Piston displacement*

$$V_D = \frac{\pi}{4}\ x\ D^2\ \ x\ L \tag{3.3}$$

Where;
D: cylinder diameter (m)
L: piston stroke (m).

- *Indicated and Effective Powers are:,*

$$N_i = p_i\ \ x\ \ n\ x\ V_D\ /60 \tag{3.4}$$

$$N_e = p_e\ x\ \ n\ x\ V_D\ \ /60 \tag{3.5}$$

Where;
N_i: Mean Indicated Power (kW),
P_i: Mean Indicated Pressure (kpa),
Ne: Mean Effective Power (kW),
Pe: Mean Effective Pressure (kpa),
n: Revolution per minutes (rpm),
V_D: Piston displacement

- Mechanically Efficiency

$$\eta = \frac{Ne\ x\ 100}{Ni} \tag{3.6}$$

- Indicated and Effective Fuel Consumptions (g/kWh) are;

$$ISFC = FC / N_i \tag{3.7}$$

$$ESFC = FC / N_e \tag{3.8}$$

Where;

FC: Fuel Consamption (kg/s),

3.4. Calculation of the Test Performance Parameters

Monthly routine performance test values are obtained by an electronic indicator device at 13 000 DWT general cargo ship. The ship has Controllable Pitch Propeller (CPP) and fixed main engine rpm [27]. Main engine's operational parameters are given below:

Main Engine rpm	: 173
Power (100%) (kW)	: 4440
Load	: 75 %
Mean Friction Press (bar)	: 1.15
Bore (cm)	: 35
Stroke (m)	: 1.4
Number of Cylinder	: 6
Heat Value (kCal/kg)	: 10224
SFC (g/kWh)	: 179 (Speed 100%, 173 r/min)
Fuel Consumption (kg/hr)	:643.52
MEP (bar)	: 19.1

Measured indicated pressures at 75% power load are given in Table 3.1.

Table 3.1. Measured Indicated Pressure (bar)

No. 1Cyl	No. 2 Cyl	No.3 Cyl	No. 4 Cyl	No. 5 Cyl	No. 6 Cyl	Mean
15.41	15.51	15.19	15.31	15.68	15.55	15.44

Power calculations are quite significant in terms of emissions calculations. Power decrease in the engine will cause incomplete combustion. In this case, emissions will increase due to incomplete combustion. Using the data given in Table 3.1 and Equations 3.1.-3.8, the main performance parameters can be calculated. All the calculated parameters are given in Table 3.2-3.8.

Using Equation 3.2. Mean Effective Pressure is calculated and the effective pressures in the each cylinder and the mean effective pressure is given in the Table 3.2.

Table 3.2. Calculation of Mean Effective Pressure.

Cylinder No	P_e
No. 1 Cyl	$Pe_{cyl.1}$ = 15.41 - 1.15=14.26 bar
No. 2 Cyl	$Pe_{cyl.2}$ = 15.51 - 1.15=14.36 bar
No. 3 Cyl	$Pe_{cyl.3}$ = 15.19 - 1.15=14.04 bar
No. 4 Cyl	$Pe_{cyl.4}$ = 15.31 - 1.15=14.16 bar
No. 5 Cyl	$Pe_{cyl.5}$ = 15.68 - 1.15=14.53 bar
No. 6 Cyl	$Pe_{cyl.6}$= 15.55 - 1.15=14.40 bar
Mean of Effective Pressure	Pe =14.29 bar

Using Equations (3.4) and (3.4), N_i (Indicated Power (kW) and N_e (Effective Power (kW)) can be calculates. Results are given in table 3.3.

Table 3.3. Calculation of Indicated Power (kW) and Effective Power (kW)

Cylinder No	$Ni_{cyl.i} = Pi_{cyl.i}$ x n x V_D /60
No. 1Cyl	$Ni_{cyl.1}$ =598.501 kW
No. 2Cyl	$Ni_{cyl.2}$ =602.385 kW
No. 3Cyl	$Ni_{cyl.3}$ =589.956 kW
No. 4Cyl	$Ni_{cyl.4}$ =594.617 kW
No. 5Cyl	$Ni_{cyl.5}$ =608.987 kW
No. 6Cyl	$Ni_{cyl.6}$ =603.938 kW
ΣNi	3598.387 kW

Cylinder No	$N_e = Pe_{cyl.i}$ x n x V_D /60
No. 1Cyl	$Ne_{cyl.1}$ = 553.837 kW
No. 2Cyl	$Ne_{cyl.2}$ =557.721 kW
No. 3Cyl	$Ne_{cyl.3}$ =545.293 kW
No. 4Cyl	$Ne_{cyl.4}$ =549.953 kW
No. 5Cyl	$Ne_{cyl.5}$ =564.323 kW
No. 6Cyl	$Ne_{cyl.6}$ =539.274 kW
ΣN_e	3330.401 kW

Indicated power and effective power are used to find mechanical efficiency. In order to find the mechanical efficiency of the engine equation (3.6) is used. Substituting the result from calculated data, we can find the mechanical efficiency as;

$$\eta = \frac{Ne \times 100}{Ni} \qquad \eta = \frac{3330.401 \times 100}{3598.387} \qquad \eta = 92.55\ \%.$$

After power and pressure calculations, indicated and effective specific fuel consumptions can be found for the engine as:

$$ISFC = FC / N_i = 643.52 / 3598.387 = 178.83 \text{ g/kW-h.}$$

And

$$ESFC = FC / N_e = 643.52 / 3330.401 = 193{,}22 \text{ g/kW-h.}$$

Indicated Specific Fuel Consumption (g/kWh) and Effective Specific Fuel Consumption (g/kWh) are calculated for each cylinder and given in table 3.4.

Table 3.4. Calculation of Indicated Specific Fuel Consumption and Effective Specific Fuel Consumption.

Cylinder No	ISFC x Ni / ΣNi	ESFC x Ne / ΣNe
No. 1Cyl	29.744 g/kW-h.	32.132 g/kW-h.
No. 2Cyl	29.937 g/kW-h.	32.357 g/kW-h.
No. 3Cyl	29.319 g/kW-h.	31.636 g/kW-h.
No. 4Cyl	29.551 g/kW-h.	31.907 g/kW-h.
No. 5Cyl	30.265 g/kW-h.	33.740 g/kW-h.
No. 6Cyl	30.014 g/kW-h.	32.447 g/kW-h.
Total	Total Indicated Specific Fuel Consumption=178.8 g/kW-h.	Effective Specific Fuel Consumption=193.2 g/kW-h.

Fuel Consumption (kg/hr) at 75% load for each cylinder is calculated below table 3,5. as:

Table 3.5. Calculation of FC (Kg/hr)

Cylinder No	FC = ESFC x $Ne_{cyl.i}$
No. 1Cyl	FC = 193.220 x 553.837=107.012 (kg/hr)
No. 2Cyl	FC = 193.220 x 557.721=107.762 (kg/hr)
No. 3Cyl	FC = 193.220 x 545.293=105.361 (kg/h r)
No. 4Cyl	FC = 193.220 x 549.953=106.261 (kg/hr)
No. 5Cyl	FC = 193.220 x 564.323=109.038 (kg/hr)
No. 6Cyl	FC = 193.220 x 559.274=108.063 (kg/hr)
Ni	Total Fuel Consumption= 643.500(kg/hr)

Measured average quantity of specific emissions of O_2, CO_2, CO, NO_x, HC, H_2O. (taken from the test bench report) of % 75 load condition for the engine and calculated emissions for each cylinder are given Table 3.6.

Table 3.6. Specific emissions of O_2, CO_2, CO, NO_x, HC, H_2O. (taken from the test bench report) of % 75 load.

Cylinder Number	Effective Power	CO_2 (kg/h)	O_2 (kg/h)	CO (kg/h)	NO_x (kg/h)	HC (kg/h)	H_2O (kg/h)
1	553.837	325.046	784.012	0.390	8.053	0.486	158.342
2	557.721	327.326	789.510	0.393	8.109	0.489	159.452
3	545.293	320.032	771.916	0.384	7.929	0.478	155.899
4	549.953	322.767	778.514	0.388	7.996	0.482	157.232
5	564.323	331.201	798.856	0.398	8.205	0.495	161.340
6	559274	328.238	791.709	0.394	8.132	0.490	159.897
TOTAL	3330.401	1954.613	4714.516	2.348	48.424	2.921	952.162

3.5. Test Results of Diesel Engine at Various Engine Loads

3.5.1. Test Bench Results of Main Engine

The diesel engine analysed in this work is two stroke marine MAN B&W S35MC7 Diesel engine with 4440 kW. Tests are performed at 25%, 50%, 75% and 100% loads. Generally, the values measured in the tests are conducted in the manufacturer's plant, delivered to the ship owner [27], (Appendix 1).

The following data were obtained from the manufacturer's test bench. Fuel consumption is increasing linearly. However, specific fuel consumption decreases continuously until 75% engine load as seen in the figure 3.8. At high engine load the fuel combustion is improved due to better mixing of fuel and air. Specific fuel consumption of around 75% load has minimum value and this load is taken as the most economical service load. The minimum value of specific fuel consumption is obtained at 75% engine load. Below %75 load and operating the engine at low loads specific fuel consumption increases. Especially, the value of the specific fuel consumption is the most important data for slow steaming.

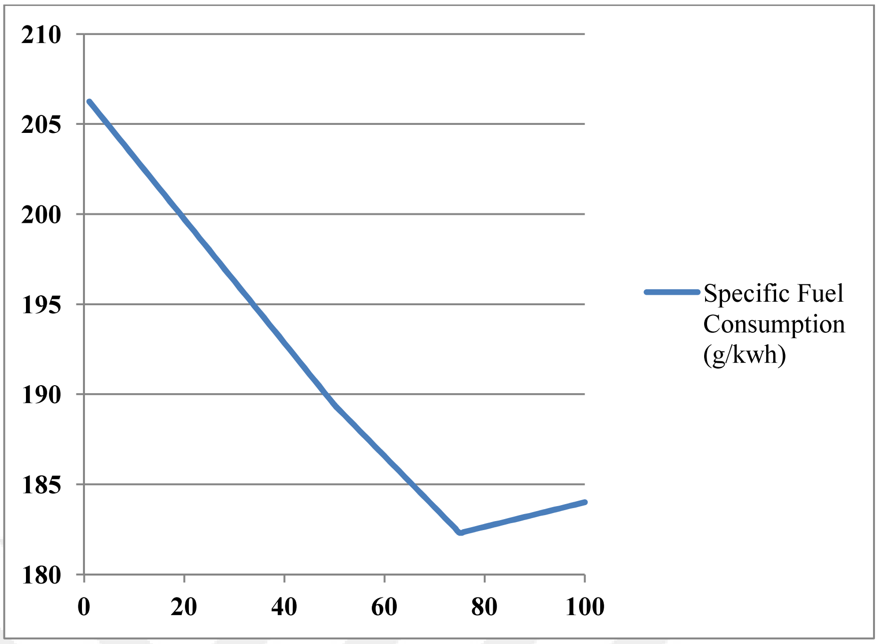

Figure 3.8. Specific Fuel Consumption.

From figure 3.8 and 3.9, fuel consumption changes per unit percentage of load change can be calculated as seen in Table 3.7. The slope of this line at a given load interval gives the magnitude of the fuel consumption changes.

Table 3.7. Fuel Consumption Changes per Unit Percentage of Load Change

	LOAD %25-50	LOAD %50-75	LOAD %75-100
Specific Fuel Cons. (Avarage) (g/kWh)	193.70	185.85	183.15
Total Fuel Cons. (Avarage) (kg)	322.51	515.73	711.53

A significant change of the specific NOx emissions are seen in the figure 4.10. NOx are produced during the combustion process via high temperatures between nitrogen and oxygen gases. Marine fuels contain small amounts of nitrogen gases. But heavy duty fuels contain more nitrogen than Diesel Oils. Nitrogenoxides occurs under the following conditions:

- Sufficient oxygen available.

  This case is always in marine Diesel engine.

- High Temperature.

  This case occurs when the temperature of combustion exceeds 1200 ^{0}C.
- Time in combustion process.

The total combustion process of two stroke marine Diesel engine includes expansion stroke generally 120 crank degrees. According to this study, sampled two stroke crosshead Diesel engine has 173 rpm. The time for combustion per 360 crank angle is (173 / 60) x 360/120 = 0.115 second. So, the combustion process takes only 0.115 seconds.

According to the survey, specific NO_X value is increased up to 75% engine load as shown in figure 3.9 and specific O_2 changes for Main Engine is shown in Figure 3.10.

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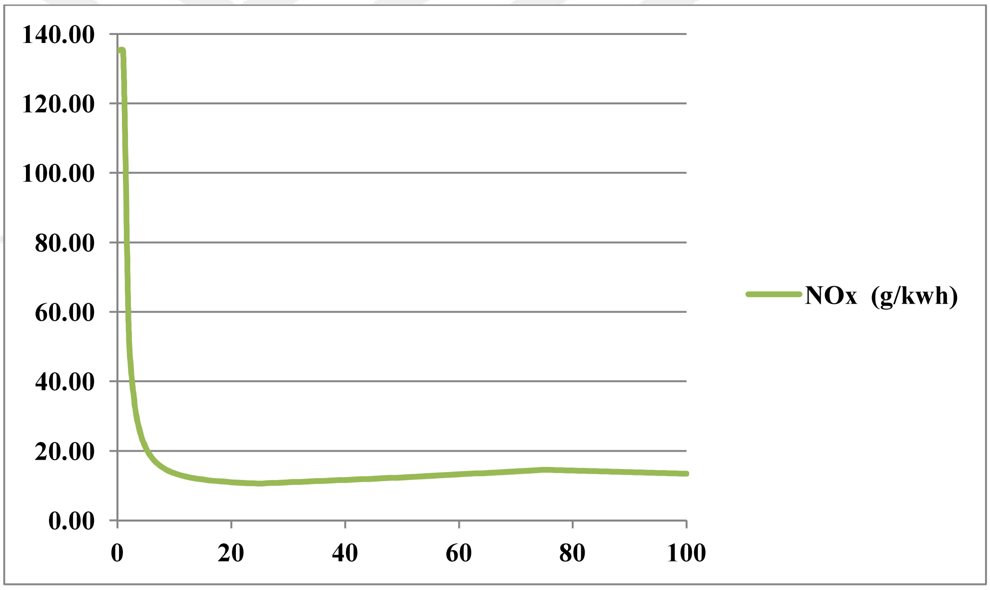

Figure 3.9. Specific NO_X changes in different Load for Main Engine.

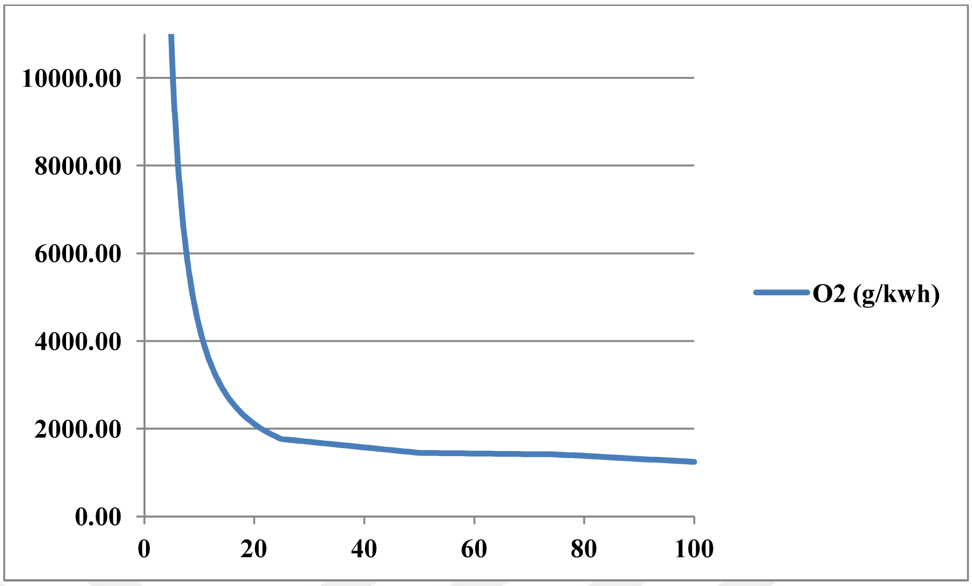

Figure 3.10. Specific O_2 changes in different Load for Main Engine.

In principle of marine Diesel engines, the carbon components in the fuel react with the oxygen. Carbon dioxide gases appear to contribute to the so-called greenhouse effect. CO_2 gas emissions are only possible to be minimized by using light fuels. According to figure 3.11, specific CO_2 gas emissions are reduced until %75 load. After %75 load for producing more power needs more fuels. So, more fuel means more CO_2.

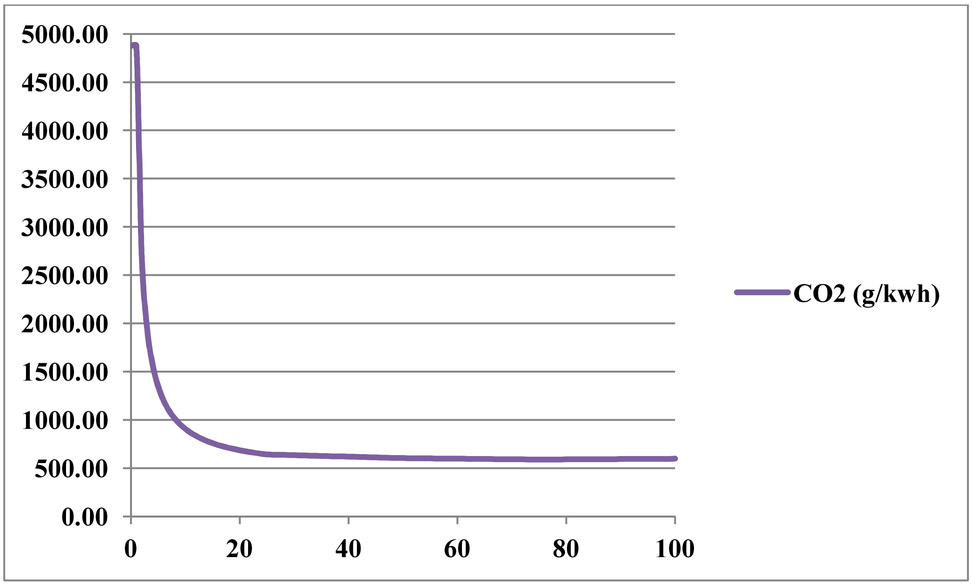

Figure 3.11. Specific CO_2 changes in different Load for Main Engine.

Carbon monoxide gases are produced during complete combustion of the fuel. Under perfect or stoichiometric combustion, fuel and oxygen are totally consumed. Then, no uncombined oxygen remain in the flue gases. When there is not enough oxygen available for perfect combustion, some of the fuel is left unburned, resulting undesirable emissions, such as carbon monoxide and smoke. Poor fuel and air mixture may also cause high carbon monoxide amount. Acoording to figure 3.12, specific CO decreases as load increases.

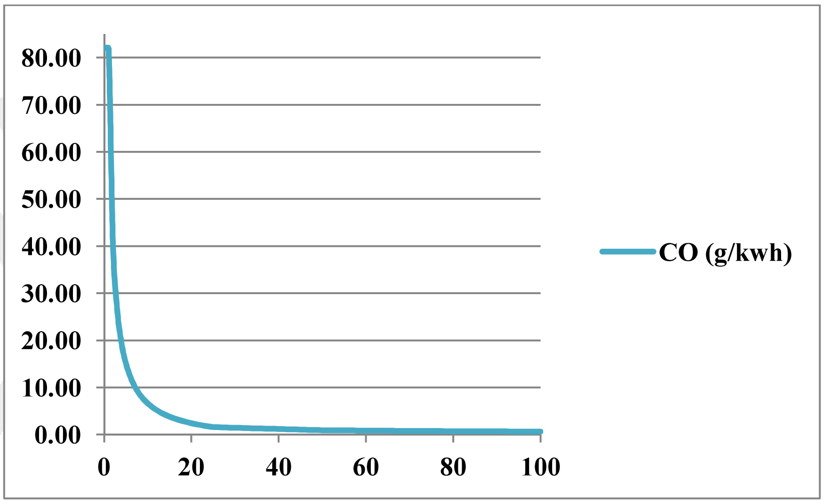

Figure 3.12. Specific CO changes in different Load for Main Engine.

High Hydrocarbon (HC) emissions generally in poor fuel ignition. This emission gases can be created by improper ignition timing, defective ignition components, lean fuel mixture and low cylinder compression. Figure 3.13 shows the specific HC changes in different load.

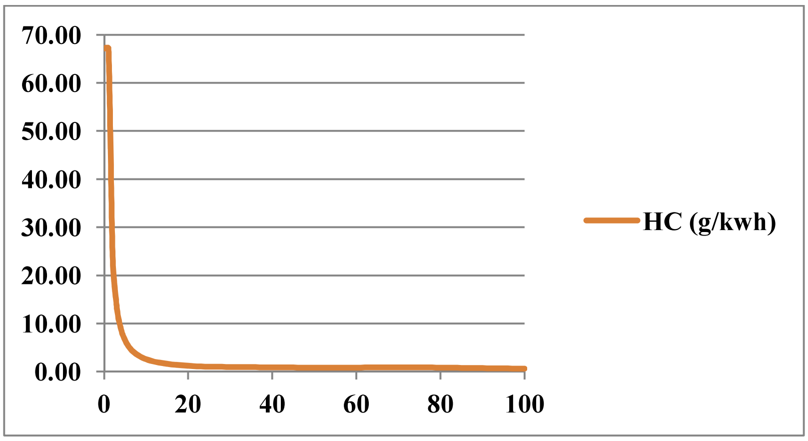

Figure 3.13. Specific HC changes in different Load for Main Engine.

Sulphur dioxide is produced with perfect combustion and is a reaction of sulphur with oxygen. SO_2 and SO_3 are formed in combustion. Sulphur dioxides gases can not carried long distance by air in atmosphere. So that means it quickly fells down to the sea. Acoording to figure 3.15, specific SO_2 changes in different load is not reduced linearly. Specific SO_2 emissions are reduced after %75 load.

Specific SO_2 changes between 25% -100% loads are shown in the figure 3.14. Specific SO_2 decreases continuously until 75% engine load. Specific SO_2 around 75% load has minimum value and this load is taken as the most economical service load. Below %75 load and operating the engine at low loads specific SO_2 increases.

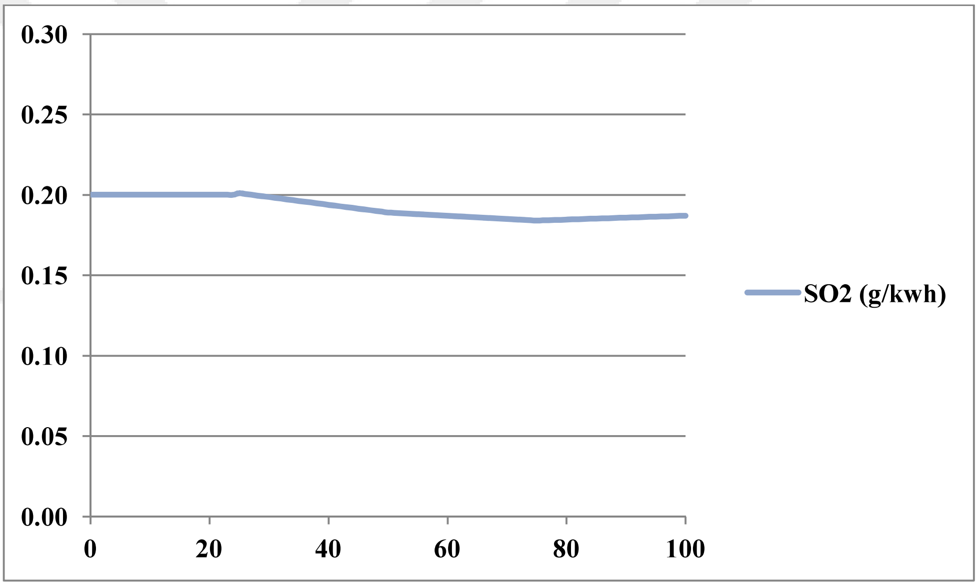

Figure 3.14. Specific SO_2 changes in different Load for Main Engine.

Acoording to figure 3.15, specific H_2O vapour reduces as load increases. The primary greenhouse gases in Earth's atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone. So, water vapour is the most important greenhouse gas. 95% of greenhouse gases are water vapour. If the sky is clear the heat will escape and the temperature will drop. If there is a cloud cover, the heat is trapped by water vapour as a greenhouse gas and the temperature stays quite warm.

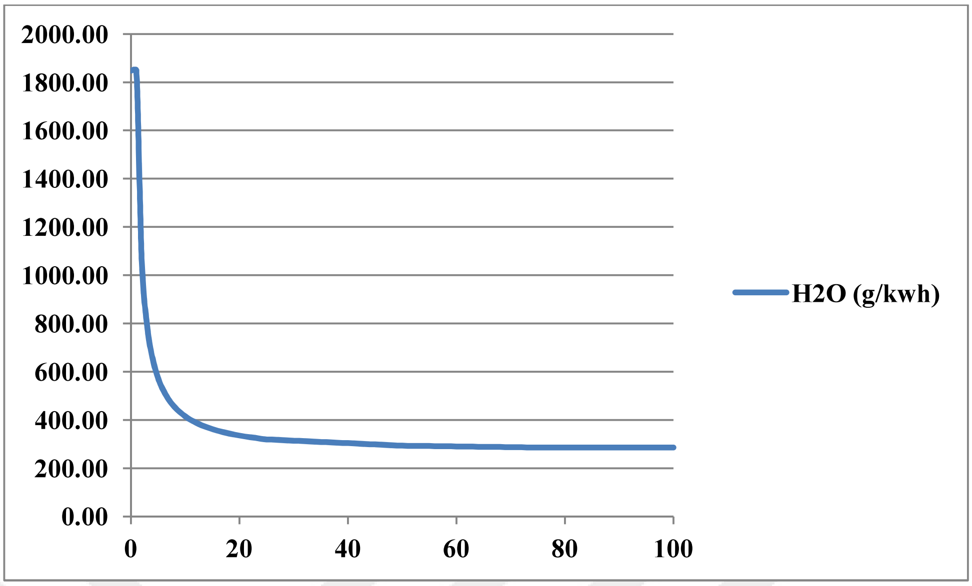

Figure 3.15. Specific H_2O changes in different Load for Main Engine.

Table 3.8 shows calculation of the different emissions in %1 load changes. In this study, NOx, O_2, CO_2, CO, HC, SO_2, H_2O changes are made using figures 3.9-3.15.

Table 3.8. Specific Emission Changes at Each interval Load (Main Engine).

	LOAD %25-50	LOAD %50-75	LOAD %75-100
NOx (g/kwh)	0.07	0.0884	-0.0444
O_2 (g/kwh)	-12.616	-1.4	-6.8
CO_2 (g/kwh)	-1.484	-0.6	0.332
CO (g/kwh)	-0.01084	-0.00712	-0.00444
HC (g/kwh)	-0.00772	0.00292	-0.01084
SO_2 (g/kwh)	-0.00048	-0.0002	0.00012
H_2O (g/kwh)	1.048	0.296	-0.008

The exhaust gases emitted through a combustion process are mainly a combination of N_2, CO_2, H_2O, CO, HC, SO_2 and O_2. Some of them are harmful and are considered major pollutants. One of the most dangerous of these is CO, carbon monoxide. This gas has the potential to kill people and animals if concentrations are high enough.

Hydrocarbons, HC come from unburned fuel. Nitrogen oxides, NOx, are released through the internal combustion process and have been linked to acid rain and ozone.

Air pollution can affect human health in both the short and the long term. So, exhaust gases are harmful for human. But It is important for turbochargers. Turbocharger exhaust supply is related with fresh air to engine cylinders. Turbocharging is critical for diesel engine performance and for emission control through a well designed exhaust gas recirculation (EGR) system. In gasoline engines, turbocharging enables downsizing which improves fuel economy by 5-20%.

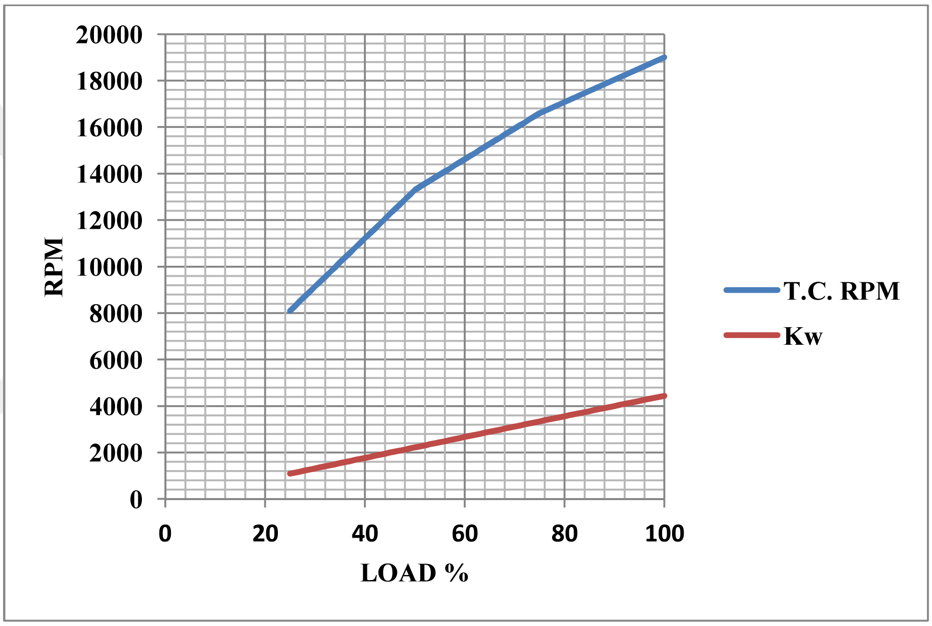

Figure 3.16. Turbocharger rpm changes in different load for Main Engine.

As can be seen from figures 3.9-3.15, optimal operating point is important both in terms of fuel consumption and emissions. In low load operation, incomplete combustion effects scavenge temperature increases. Therefore, auxiliary blower is activated to increase the amount of oxygen for ideal combustion and cooling air.Turbocharger air inlet and scavenge temperature changes and Diesel engine working pressure and turbocharger pressure changes are shown in Figures 3.17 and 3.18 in different load.

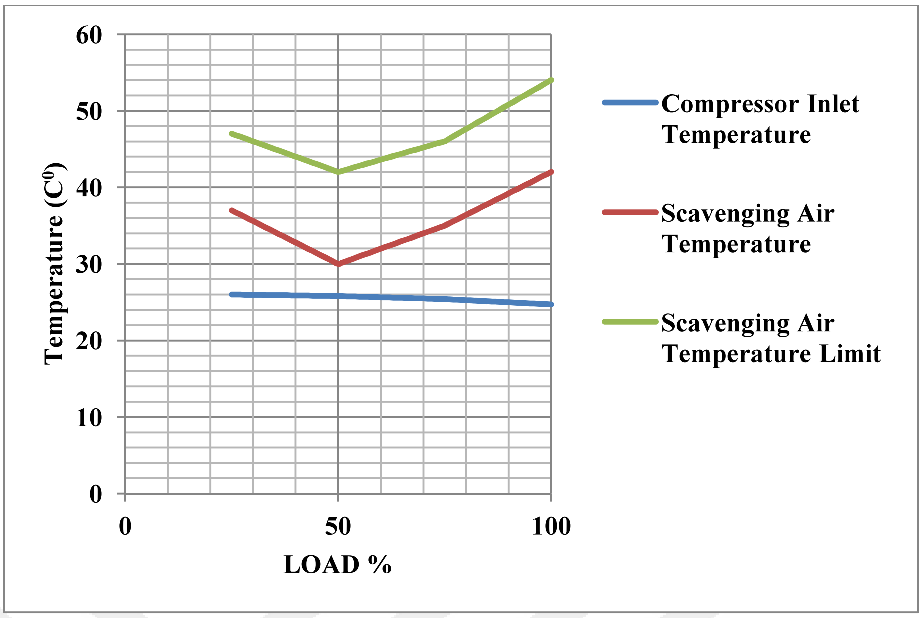

Figure 3.17. Turbocharger air inlet and scavenge temperature changes in different load.

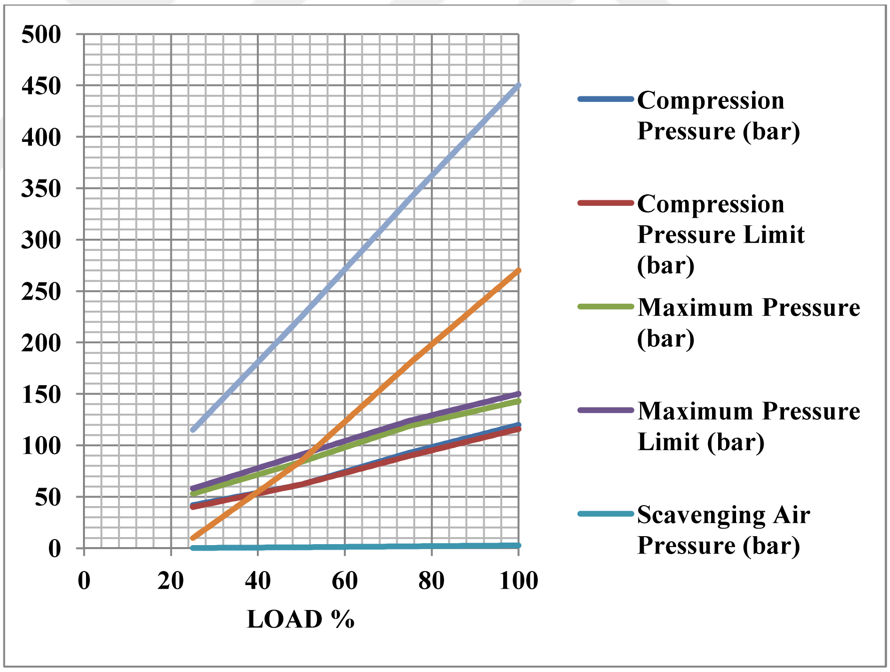

Figure 3.18. Diesel Engine Working Pressure and Turbocharger Pressure changes in different load.

3.5.2. Test Bed Results of Generator Diesel Engine

Four stroke Diesel Engine generator has a rate power of 345 kW. It is examined at %10, 25%, 50%, 75% and 100% loads. The test results are taken in the test bed. Tests are performed in the manufacturer's plant before it is delivered to the ship owner. The following data are obtained from the test results [28], (Appendix 2).

Rated Speed (rpm)	: 1800
Rated Power (100%), (kW)	: 345
Load	: 50 %
Compression Ratio	: 15, 5:1
Bore (mm)	: 125
Stroke (mm)	: 166
Number of Cylinder	: 6
Heat Value (kCal/kg)	: 10224
SFC (g/kWh)	: 215

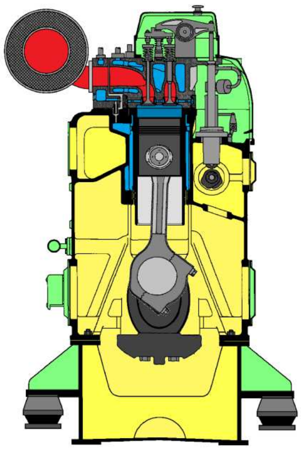

Figure 3.19. Four Stroke Diesel Engine

Fuel consumption is shown in the figure 3.20 between 0% - 100% loads. Fuel consumption decreases as load increases. Specific fuel consumption of around 80-100% load is the most economical service load. When the load is low, the specific fuel consumption increases. Especially, the value of the specific fuel consumption is the most important data for running two or one Diesel generator.

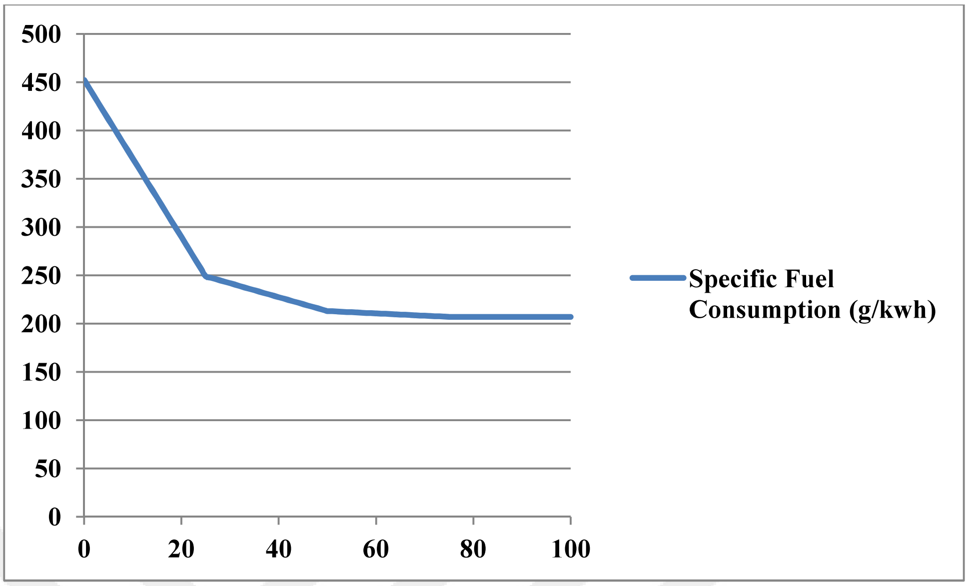

Figure 3.20. Specific Fuel Consumption changes in different Load for Diesel Genrator.

NOx, CO, CO_2, O_2, and emissions are shown in the figure 3.21 between 0% - 100% loads. The data obtained from the test results indicate that operation at low loads is not advantageous in terms of fuel consumption and emissions. Generator tests are similar to main engine test.

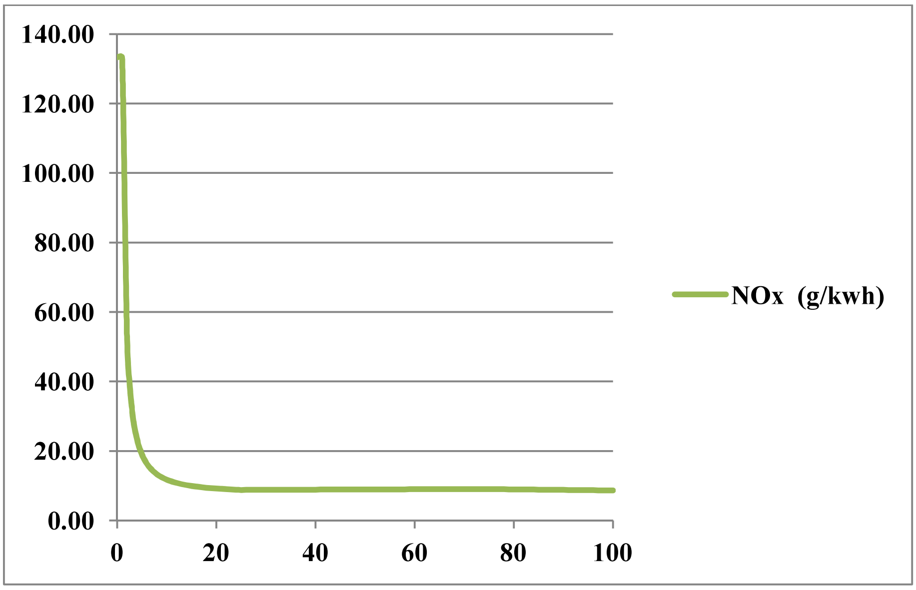

Figure 3.21. Specific NOx emissions for Diesel Generator.

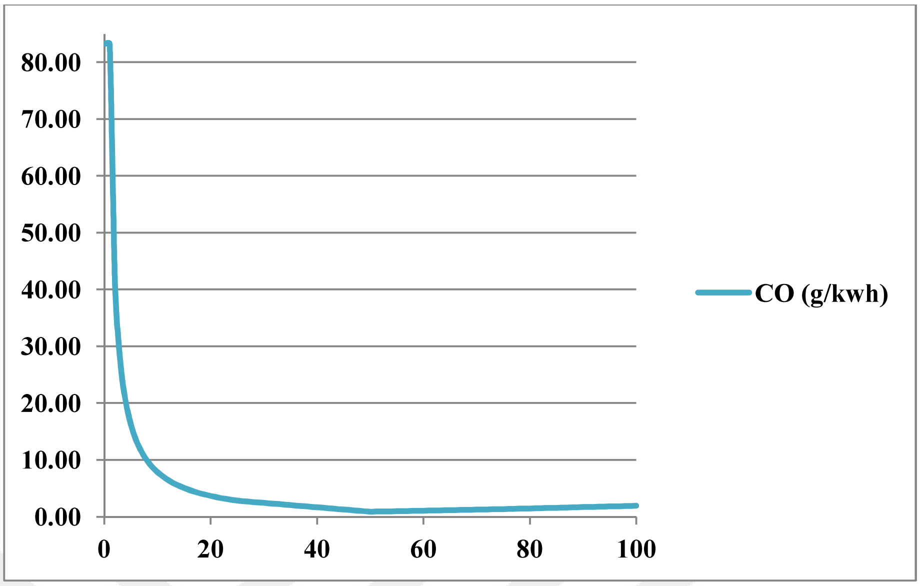

Figure 3.22. Specific CO emissions.

Specific emission changes at each load (diesel generator) is shown in table 3.9. The efficiency of the generator is the ratio of the energy used to the total output from the generator and it depends on operating load of the generator. In general, the efficiency of diesel generator decreases with decrease in load. The lower the efficiency of the diesel generator the higher is the amount of emissions by the generator. So, it is recomended to use the generator at 70-80% of full load. At that range of load the exhaust temperatures are high enough to keep cylinders clean.

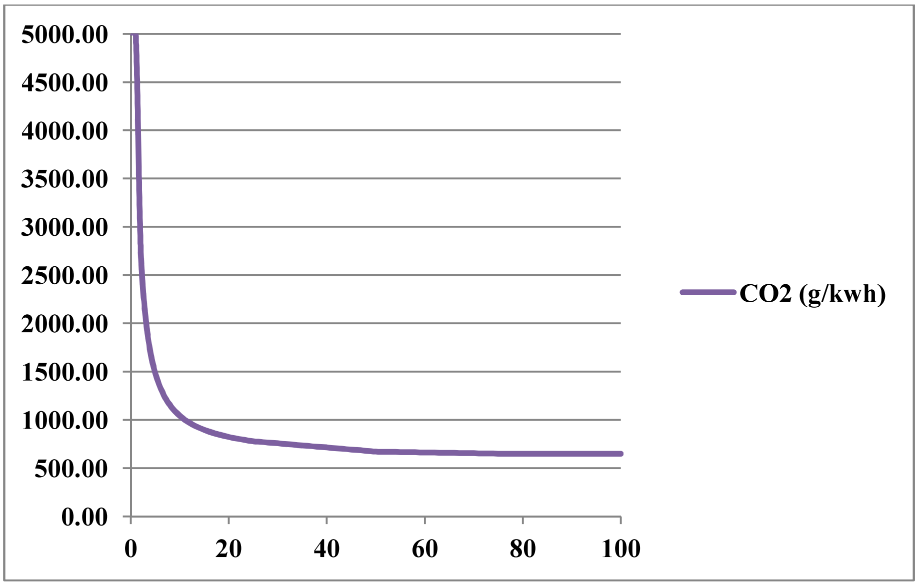

Figure 3.23. Specific CO_2 emissions.

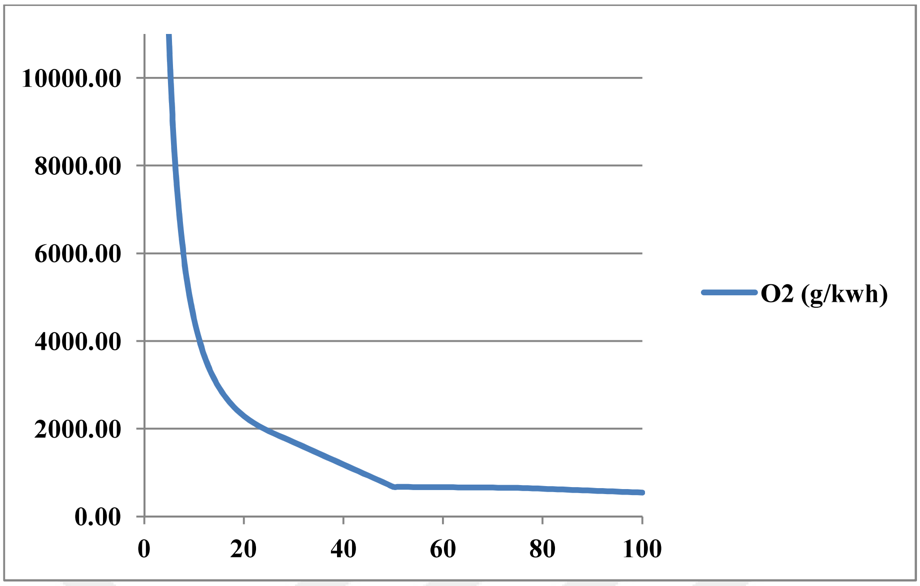

Figure 3.24. Specific O_2 emissions.

Running diesel engine at low loads can result in carbon buildup. This generally happens when the engine is left idling. Running engine under low loads results in soot formation which is due to poor combustion at low combustion pressures and temperatures. Also the unburnt fuel residues clogs the piston rings. This will reduce efficiency and can cause problems and the engine failure. This can be prevented by carefully selecting the generator according to the power requirements.

Table 3.9. Specific Emission Changes Each Load (Diesel Generator).

	LOAD	LOAD	LOAD	LOAD
	%10-25	**%25-50**	**%50-75**	**%75-100**
Nox (g/kWh)	-0.0418	0.0064	0.0032	-0.0150
CO (g/kWh)	-0.1607	-0.0452	-0.0100	-0.0012
CO_2 (g/kWh)	-24.889	-4.3024	-0.8326	-0.0513
O_2 (g/kwW)	-209.6261	-50.8479	-0.8326	-4.3839

4. MANEUVERING EMISSION TEST

After the manufacturer's workshop trials, emission estimates can be made by a model during maneuvering. At 28 different points on the maneuvering route with different loads during the maneuvering as seen from Fig 4.1 were chosen to calculate the total emissions.

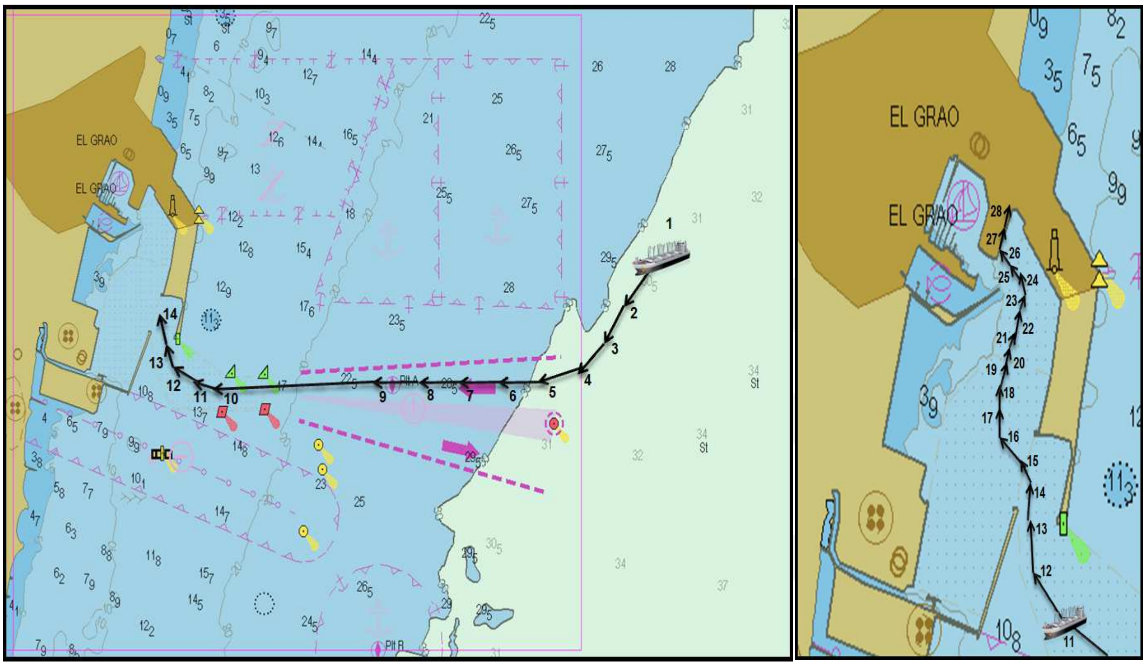

Figure 4.1. Castellon-Spain Port Map

Total emissions of ship maneuvers are generated by main engine(s), generator(s), boiler(s) and calculated as,

$$\sum_{\text{Ship Emission}} = \sum_{\text{Main Engine(s) Emission}} + \sum_{\text{Diesel Generator(s) Emission}} + \sum_{\text{Boiler(s) Emission}} \quad \text{................(4.1)}$$

The following general equation is used to calculate the amount of NOx, SOx, CO_2, CO in each maneuvering points for ships. This method allows us to calculate various emissions amount during maneuvers.

$$\sum_{\text{Main Engine Emission}} = [(\sum Ne_1 \text{ x } SE_1)/60 \text{ x } \Delta t] + [(\sum Ne_2 \text{ x } SE_2)/60 \text{ x } \Delta t] + \ldots + [(\sum Ne_n \text{ x } SE_n)/60 \text{ x } \Delta t] \quad (4.2)$$

Where;

$\sum_{\text{Ship Emission}}$: Total amount of emissions generated by ships during maneuvering (g, kg),

Ne : Effective power for a given load power (kW),

SE : NOx, SOx, CO_2 or CO specific emission (g/kWh),

Δt : Time elapsed (min),

n : Number of emissions occurring in each maneuver point.

The Figure 4.1. shows a map of Castellon-Spain port maneuvering points. There are 28 total points determined in accordance with this example. Total emissions mainly consist of main engines and generator engines. For this reason, only emissions form the main engine and diesel generator are calculated. After developing general emission data for the main diesel engine and diesel generators, emissions at the 28 maneuvering points can be calculated using these data at different engine loads.

The terms of the maneuvers carried out in Castellon-Spain port are outlined as follows;

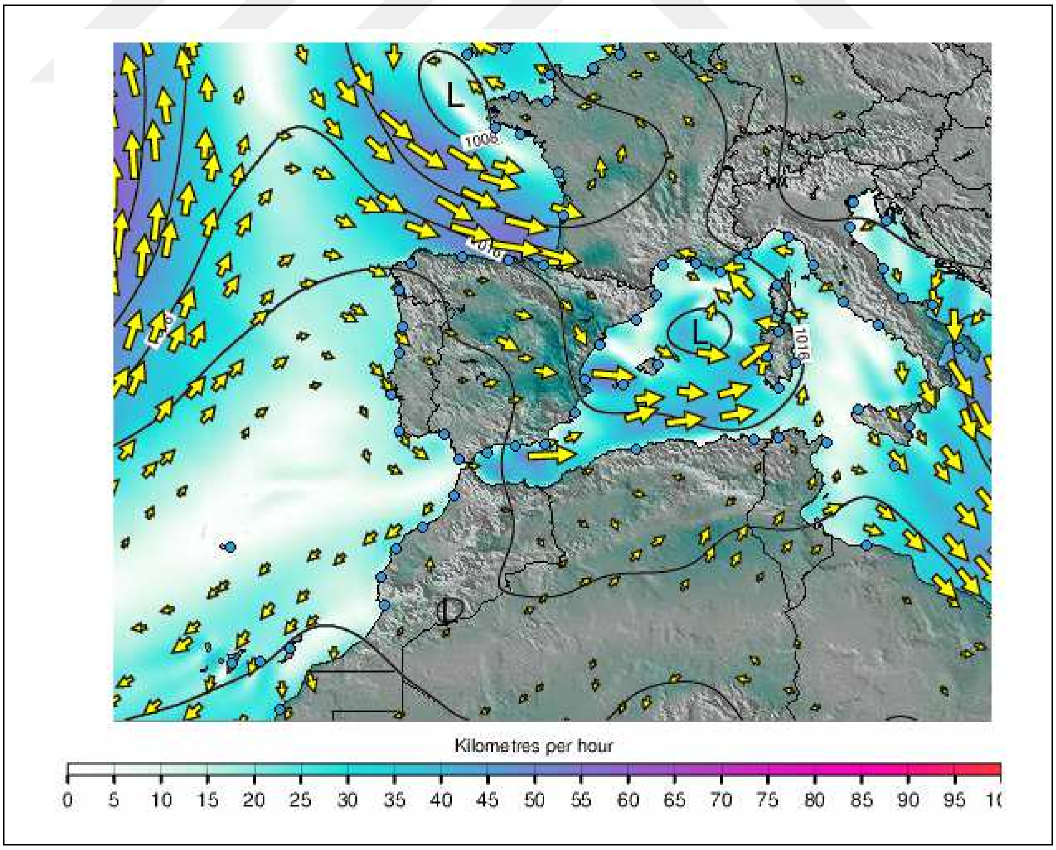

Figure 4.2. West Mediterranean Wind Map (15.09.2015).[29].

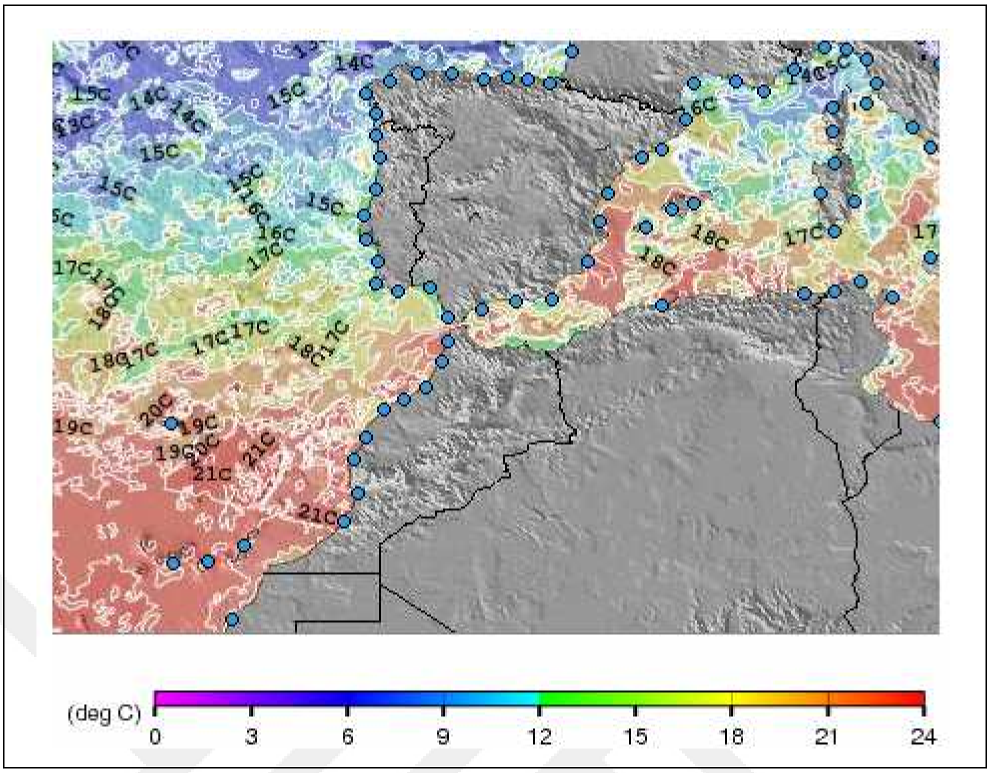

Figure 4.3. West Mediterranean Sea Temperature Map (15.09.2015), [30].

Wind and sea water temperature maps can be seen on figure 4.2. and 4.3.

- *Castellon Port Loaction:*

Lonitude: 0^0 1’ E (Greenwich)

Latitude : 39^0 58’ N

- *Wind Rate:*

Prevailing : N.E.

Dominant : N.E.

Wind : 40 kph

- *Storm Conditions in Deep Water:*

Large : 850 Km

Maximum heigh of wave (2h =Hs) : 6.5 m

Maximum length of wave (2L) : 293.60 m

- *Tides:*

Maximum Tidal Range : 0.7 m

Swell : 0.4 m

Period : 8 s.

- *Harbour Enterance Channel:*

Direction : E-ESE-SE

Width :400-735-376 m

Length : 1.815 m

Draught : 17 m

Sea Bottom Characteristics :Rocky

- *Harbour Enterance Mounth:*

Direction : S

Width : 346 m

Draught : 17 m

In 1906, José Serrano Lloberes has prepared the General Plan for the Port. In 1906, traffic through the port rise up to 60,000 tons. by 1912 this had grown to 80,000 tons. Oranges represented more than 80% of this annual traffic, but at the same time the export of tiles became a characteristic feature of the merchandise handled by the port in this early period. Most of these ceramic products came from the factories of Onda, a small town fifteen kilometres from Castellón and to this day the centre of the ceramics industry of the province [30].

The following table 4.1 has been developed using Eqn. 4.2. Table 4.1 shows emissions that can be used to calculate different maneuvering points for the main engine. Emissions and power are regarded as the different amount under the 25% of total load.

Table 4.1. Power and Emissions for the Main engine at 0-25 % load.

%LOAD	Power (Kw)	NOx (g/kwh)	CO2 (g/kwh)	CO (g/kwh)	SO2 (g/kwh)	HC (g/kwh)	H2O (g/kwh)
25	1110.0	10.58	639.60	1.54	0.20	1.00	319.50
24	1067.3	10.64	646.95	1.68	0.20	1.00	322.15
23	1024.6	10.71	654.94	1.83	0.20	1.04	325.04
22	981.9	10.79	663.65	1.99	0.20	1.08	328.18
21	939.2	10.88	673.20	2.17	0.20	1.13	331.63
20	896.5	10.98	683.70	2.37	0.20	1.18	335.42
19	853.8	11.09	695.31	2.59	0.20	1.24	339.61
18	811.2	11.22	708.20	2.84	0.20	1.31	344.26
17	768.5	11.37	722.61	3.11	0.20	1.39	349.47
16	725.8	11.54	738.83	3.42	0.20	1.48	355.32
15	683.1	11.74	757.20	3.77	0.20	1.58	361.95
14	640.4	11.97	778.20	4.17	0.20	1.71	369.53
13	597.7	12.25	802.43	4.63	0.20	1.86	378.28
12	555.0	12.60	830.70	5.17	0.20	2.04	388.49
11	512.3	13.02	864.11	5.80	0.20	2.26	400.55
10	469.6	13.54	904.20	6.56	0.20	2.55	415.02
9	426.9	14.22	953.20	7.49	0.20	2.91	432.71
8	384.2	15.12	1014.45	8.66	0.20	3.38	454.82
7	341.5	16.35	1093.20	10.15	0.20	4.04	483.25
6	298.8	18.12	1198.20	12.15	0.20	4.97	521.15
5	256.2	20.80	1345.20	14.94	0.20	6.40	574.22
4	213.5	25.26	1565.70	19.13	0.20	8.77	653.82
3	170.8	33.73	1933.20	26.11	0.20	13.27	786.49
2	128.1	53.95	2668.20	40.07	0.20	24.02	1051.82
1	85.4	135.08	4873.20	81.96	0.20	67.14	1847.82
0	42.7	135.08	4873.20	81.96	0.20	67.14	1847.82

Table 4.2. Power and Emissions for Diesel Generator at 0-25 % Load

%LOAD	Power (Kw)	O_2 (g/kwh)	NO_X (g/kwh)	CO_2 (g/kwh)	SO_2 (g/kwh)	CO (g/kwh)	HC (g/kwh)
25	121.0	1941.32	8.76	777.69	0.20	2.81	0.45
24	116.2	1995.83	8.83	785.04	0.20	2.95	0.48
23	111.4	2056.32	8.90	793.03	0.20	3.10	0.52
22	106.6	2123.77	8.98	801.74	0.20	3.26	0.56
21	101.8	2199.34	9.06	811.29	0.20	3.44	0.61
20	97.0	2284.48	9.16	821.79	0.20	3.64	0.66
19	92.2	2380.96	9.27	833.40	0.20	3.86	0.72
18	87.4	2491.02	9.40	846.29	0.20	4.11	0.79
17	82.6	2617.51	9.55	860.70	0.20	4.38	0.87
16	77.8	2764.06	9.72	876.92	0.20	4.69	0.96
15	73.0	2935.43	9.92	895.29	0.20	5.04	1.06
14	68.2	3137.94	10.16	916.29	0.20	5.44	1.19
13	63.4	3380.13	10.44	940.52	0.20	5.90	1.34
12	58.6	3673.79	10.78	968.79	0.20	6.44	1.52
11	53.8	4035.67	11.20	1002.20	0.20	7.07	1.74
10	49.0	4490.22	11.73	1042.29	0.20	7.83	2.03
9	44.6	5074.42	12.41	1091.29	0.20	8.76	2.39
8	40.2	5846.67	13.31	1152.54	0.20	9.93	2.86
7	35.7	6904.17	14.54	1231.29	0.20	11.42	3.52
6	31.3	8419.79	16.30	1336.29	0.20	13.42	4.45
5	26.9	10728.99	18.98	1483.29	0.20	16.21	5.88
4	22.5	14565.62	23.45	1703.79	0.20	20.40	8.25
3	18.1	21843.48	31.91	2071.29	0.20	27.38	12.75
2	13.6	39226.53	52.13	2806.29	0.20	41.34	23.50
1	9.2	108978.12	133.26	5011.29	0.20	83.23	66.62
0	4.8	108978.12	133.26	5011.29	0.20	83.23	66.62

Table 4.2 shows emissions at a given percentage of the generator load. This table can be used to calculate the total emissions during maneuvering for the Diesel Generators at 0-25% generator load. In this maneuvering period, two generators were running together with the main engine.

4.1. Main Engine Emissions at Maneuvering

The NOx emissions from the main engine are calculated from Table 4.1. In order to calculate the NOx emissions, emission amounts are formulated as a function of time elapsed and power at a given percentage of the load. Table 4.3 shows the NOx calculations for each maneuvering points and total amount of NOx emission after maneuvering. Representation of NOx emission of 28 maneuvering points are seen in Figure 4.4. and Table 4.3.

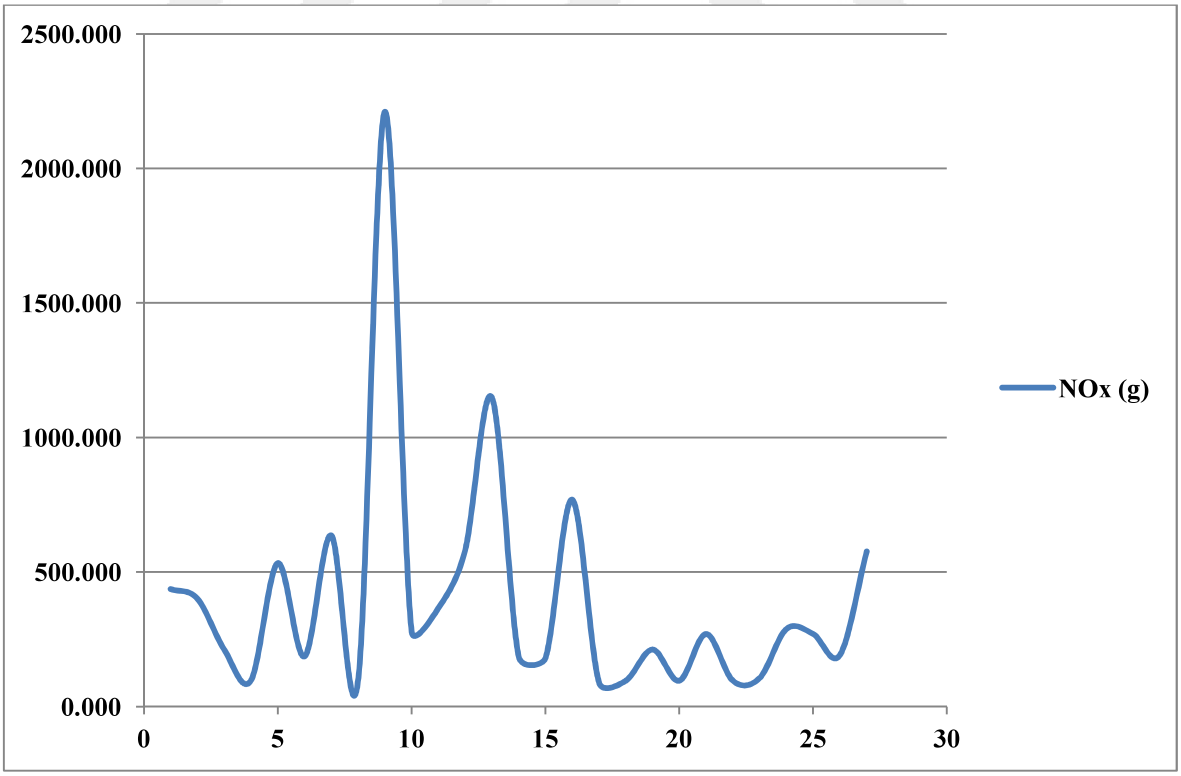

Figure 4.4. Test results at Maneuvering Points for NO_X

Table 4.3. Test Results of NOx Emission for the Main engine.

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x NO_x x Δt/ 60	NOx (g)
1-2	17	3	(768.5 x 11.37) x 3/60 =	436.735
2-3	15	3	(683.1 x 11.74) x 3/60 =	400.839
3-4	10	2	(469.6 x 13.54) x 2/60 =	212.026
4-5	8	1	(384.2 x 15.12) x 1/60 =	96.841
5-6	5	6	(256.2 x 20.80) x 6/60 =	532.827
6-7	7	2	(341.5 x 16.35) x 2/60 =	186.165
7-8	10	6	(469.6 x 13.54) x 6/60 =	636.078
8-9	7	1	(341.5 x 16.35) x 1/60 =	93.083
9-10	0	23	(42.7 x 135.08) x 23/60 =	2210.571
10-11	7	3	(341.5 x 16.35) x 3/60 =	279.248
11-12	23	2	(1024.6 x 10.71) x 2/60 =	365.916
12-13	8	6	(384.2 x 15.12) x 6/60 =	581.048
13-14	20	7	(896.5 x 10.98) x 7/60 =	1148.375
14-15	7	2	(341.5 x 16.35) x 2/60 =	186.165
15-16	4	2	(213.5 x 25.26) x 2/60 =	179.760
16-17	0	8	(42.7 x 135.08) x 8/60 =	768.894
17-18	4	1	(213.5 x 25.26) x 1/60 =	89.880
18-19	0	1	(42.7 x 135.08) x 1/60 =	96.112
19-20	10	2	(469.6 x 13.54) x 2/60 =	212.026
20-21	0	1	(42.7 x 135.08) x 1/60 =	96.112
21-22	4	3	(213.5 x 25.26) x 3/60 =	269.639
22-23	0	1	(42.7 x 135.08) x 1/60 =	96.639
23-24	10	1	(469.6 x 13.54) x 1/60 =	106.013
24-25	0	3	(42.7 x 135.08) x 3/60 =	288.335
25-26	4	3	(213.5 x 25.26) x 3/60 =	269.639
26-27	3	2	(170.8 x 33.73) x 2/60 =	191.993
27-28	0	6	(42.7 x 135.08) x 6/60 =	576.671
TOTAL TIME ELAPSED(MIN)		101	TOTAL NOx (g)	10607.103

Also, using the same method of calculation for NO_x emissions, the CO_2 emissions are calculated and results are given in Table 4.4. This table shows the CO_2 calculation at each points and total amount of CO_2 emission during the maneuvering having 28 points. The most important greenhouse effect emission gas is carbon dioxide.

Table 4.4. Test Results of CO_2 Emissions for the Main engine.

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x CO_2 x Δt/ 60	CO_2 (g)
1-2	17	3	(768.5 x 722.61) x 3/60 =	27764.967
2-3	15	3	(683.1 x 757.20) x 3/60 =	25861.292
3-4	10	2	(469.6 x 904.20) x 2/60 =	14154.208
4-5	8	1	(384.2 x 1014.45) x 1/60 =	6496.382
5-6	5	6	(256.2 x 1345.20) x 6/60 =	34457.815
6-7	7	2	(341.5 x 1093.20) x 2/60 =	12445.662
7-8	10	6	(469.6 x 904.20) x 6/60 =	42462.623
8-9	7	1	(341.5 x 1093.20) x 1/60 =	6222.831
9-10	0	23	(42.7 x 4873.20) x 23/60 =	79751.792
10-11	7	3	(341.5 x 1093.20) x 3/60 =	18668.492
11-12	23	2	(1024.6 x 654.94) x 2/60 =	22368.690
12-13	8	6	(384.2 x 1014.45) x 6/60 =	38978.690
13-14	20	7	(896.5 x 683.70) x 7/60 =	71512.390
14-15	7	2	(341.5 x 1093.20) x 2/60 =	12445.662
15-16	4	2	(213.5 x 1565.70) x 2/60 =	11140.558
16-17	0	8	(42.7 x 4873.20) x 8/60 =	27739.754
17-18	4	1	(213.5 x 1565.70) x 1/60 =	5570.279
18-19	0	1	(42.7 x 4873.20) x 1/60 =	3467.469
19-20	10	2	(469.6 x 904.20) x 2/60 =	14154.208
20-21	0	1	(42.7 x 4873.20) x 1/60 =	3467.469
21-22	4	3	(213.5 x 1565.70) x 3/60 =	16710.837
22-23	0	1	(42.7 x 4873.20) x 1/60 =	3467.469
23-24	10	1	(469.6 x 904.20) x 1/60 =	7077.104
24-25	0	3	(42.7 x 4873.20) x 3/60 =	10402.408
25-26	4	3	(213.5 x 1565.70) x 3/60 =	16710.837
26-27	3	2	(170.8 x 1933.20) x 2/60 =	11004.369
27-28	0	6	(42.7 x 4873.20) x 6/60 =	200804.815
TOTAL TIME ELAPSED(MIN)		101	TOTAL CO_2 (g)	565308.672

Graphical representation of CO_2 emission of 28 maneuvering points are seen in Figure 4.5.

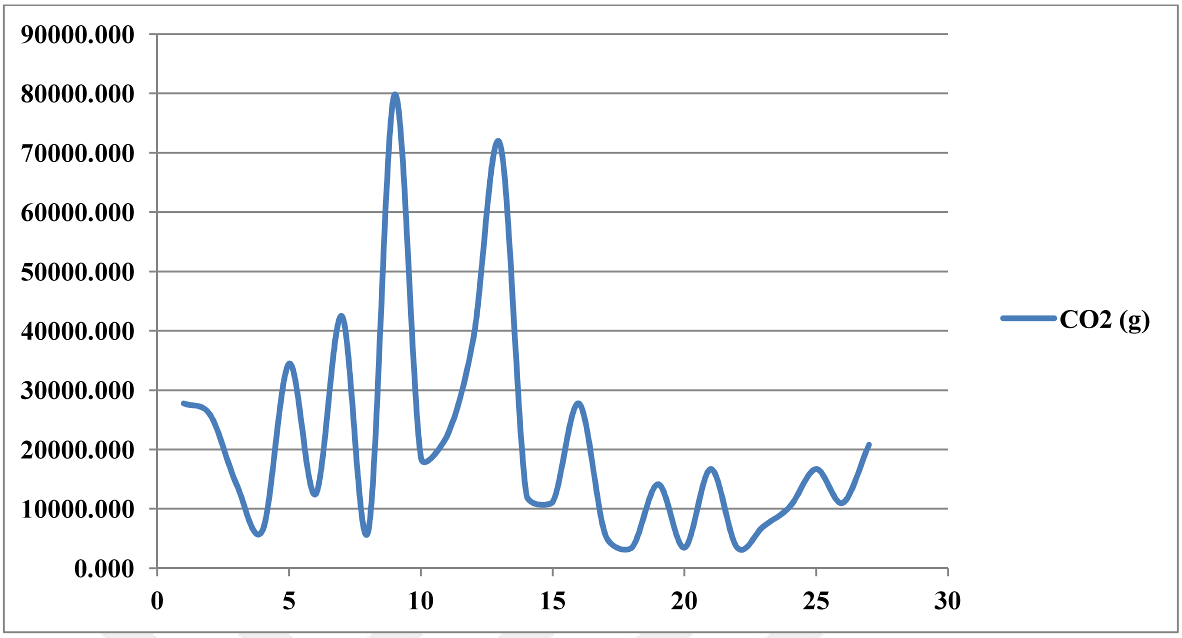

Figure 4.5. Test results at Maneuvering Points for CO_2

Similarly, using the same method of calculation for determining of emission values done above, one can calculate the other important emissions of CO and SO_2. Tables 4.5 and 4.6 show the CO and SO_2 calculations at each points and total amount of emissions during the maneuvering having 28 points, respectively. Also, figures 4.6 and 4.7 are the representation of the CO and SO_2 variations with respect to maneuvering points.

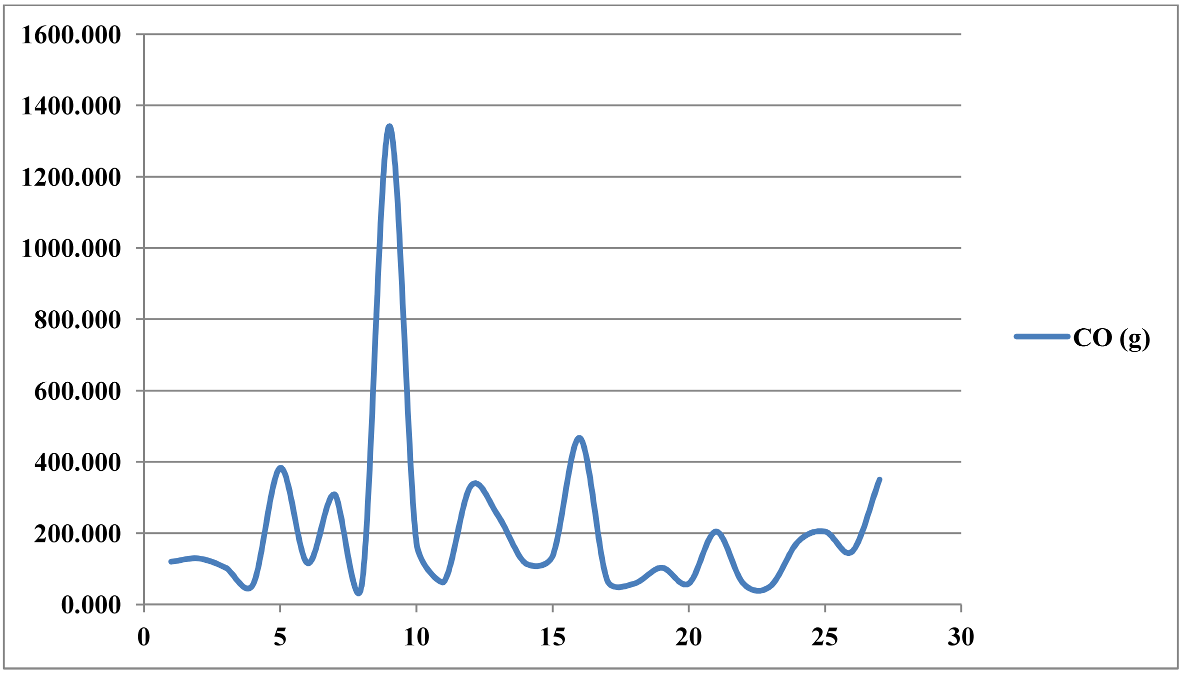

Figure 4.6. Test results at Maneuvering Points for CO.

Table 4.5. Test Results of CO Emission Table for Main engine

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x CO x Δt/ 60	CO (g)
1-2	17	3	(768.5 x 3.11) x 3/60 =	119.612
2-3	15	3	(683.1 x 3.77) x 3/60 =	128.765
3-4	10	2	(469.6 x 6.56) x 2/60 =	102.733
4-5	8	1	(384.2 x 8.66) x 1/60 =	55.440
5-6	5	6	(256.2 x 14.94) x 6/60 =	382.714
6-7	7	2	(341.5 x 10.15) x 2/60 =	115.592
7-8	10	6	(469.6 x 6.56) x 6/60 =	308.199
8-9	7	1	(341.5 x 10.15) x 1/60 =	57.796
9-10	0	23	(42.7 x 81.96) x 23/60 =	1341.385
10-11	7	3	(341.5 x 10.15) x 3/60 =	173.388
11-12	23	2	(1024.6 x 1.83) x 2/60 =	62.413
12-13	8	6	(384.2 x 8.66) x 6/60 =	332.640
13-14	20	7	(896.5 x 2.37) x 7/60 =	248.290
14-15	7	2	(341.5 x 10.15) x 2/60 =	115.592
15-16	4	2	(213.5 x 19.13) x 2/60 =	136.116
16-17	0	8	(42.7 x 81.96) x 8/60 =	466.569
17-18	4	1	(213.5 x 19.13) x 1/60 =	68.058
18-19	0	1	(42.7 x 81.96) x 1/60 =	58.321
19-20	10	2	(469.6 x 6.56) x 2/60 =	102.733
20-21	0	1	(42.7 x 81.96) x 1/60 =	58.321
21-22	4	3	(213.5 x 19.13) x 3/60 =	204.174
22-23	0	1	(42.7 x 81.96) x 1/60 =	58.321
23-24	10	1	(469.6 x 6.56) x 1/60 =	51.367
24-25	0	3	(42.7 x 81.96) x 3/60 =	174.963
25-26	4	3	(213.5 x 19.13) x 3/60 =	204.174
26-27	3	2	(170.8 x 26.11) x 2/60 =	148.635
27-28	0	6	(42.7 x 81.96) x 6/60 =	349.927
TOTAL TIME ELAPSED(MIN)		101	TOTAL CO (g)	5626.239

Graphical representation of CO emission of 28 maneuvering points are seen in Figure 4.6.

Table 4.6. Test Results of SO_2 Emission Table for Main engine

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x SO_2 x Δt/ 60	SO_2 (g)
1-2	17	3	(768.5 x 0.20) x 3/60 =	7.685
2-3	15	3	(683.1 x 0.20) x 3/60 =	6.831
3-4	10	2	(469.6 x 0.20) x 2/60 =	3.131
4-5	8	1	(384.2 x 0.20) x 1/60 =	1.281
5-6	5	6	(256.2 x 0.20) x 6/60 =	5.123
6-7	7	2	(341.5 x 0.20) x 2/60 =	2.277
7-8	10	6	(469.6 x 0.20) x 6/60 =	9.392
8-9	7	1	(341.5 x 0.20) x 1/60 =	1.138
9-10	0	23	(42.7 x 0.20) x 23/60 =	3.273
10-11	7	3	(341.5 x 0.20) x 3/60 =	3.415
11-12	23	2	(1024.6 x 0.20) x 2/60 =	6.831
12-13	8	6	(384.2 x 0.20) x 6/60 =	7.685
13-14	20	7	(896.5 x 0.20) x 7/60 =	20.919
14-15	7	2	(341.5 x 0.20) x 2/60 =	2.277
15-16	4	2	(213.5 x 0.20) x 2/60 =	1.423
16-17	0	8	(42.7 x 0.20) x 8/60 =	1.138
17-18	4	1	(213.5 x 0.20) x 1/60 =	0.712
18-19	0	1	(42.7 x 0.20) x 1/60 =	0.142
19-20	10	2	(469.6 x 0.20) x 2/60 =	3.131
20-21	0	1	(42.7 x 0.20) x 1/60 =	0.142
21-22	4	3	(213.5 x 0.20) x 3/60 =	2.135
22-23	0	1	(42.7 x 0.20) x 1/60 =	0.142
23-24	10	1	(469.6 x 0.20) x 1/60 =	1.565
24-25	0	3	(42.7 x 0.20) x 3/60 =	0.427
25-26	4	3	(213.5 x 0.20) x 3/60 =	2.135
26-27	3	2	(170.8 x 0.20) x 2/60 =	1.138
27-28	0	6	(42.7 x 0.20) x 6/60 =	0.854
TOTAL TIME ELAPSED(MIN)		101	TOTAL SO_2 (g)	96.342

Graphical representation of SO_2 emission of 28 maneuvering points are seen in Figure 4.7.

Table 4.7. Test Results of O_2 Emission Table for Main engine

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x O_2 x Δt/ 60	**O_2 (g)**
1-2	17	3	(768.5 x 2442.19) x 3/60 =	93836.373
2-3	15	3	(683.1 x 2760.11) x 3/60 =	94268.396
3-4	10	2	(469.6 x 4314.90) x 2/60 =	67544.743
4-5	8	1	(384.2 x 5671.35) x 1/60 =	36318.462
5-6	5	6	(256.2 x 10553.67) x 6/60 =	270336.301
6-7	7	2	(341.5 x 6728.85) x 2/60 =	76605.396
7-8	10	6	(469.6 x 4314.90) x 6/60 =	202634.229
8-9	7	1	(341.5 x 6728.85) x 1/60 =	38302.698
9-10	0	23	(42.7 x 108802.80) x 23/60 =	1780599.669
10-11	7	3	(341.5 x 6728.85) x 3/60 =	114908.094
11-12	23	2	(1024.6 x 1881) x 2/60 =	64243.541
12-13	8	6	(384.2 x 5671.35) x 6/60 =	217910.769
13-14	20	7	(896.5 x 2109.16) x 7/60 =	220609.885
14-15	7	2	(341.5 x 6728.85) x 2/60 =	76605.396
15-16	4	2	(213.5 x 14390.30) x 2/60 =	102392.519
16-17	0	8	(42.7 x 108802.80) x 8/60 =	619.339.015
17-18	4	1	(213.5 x 14390.30) x 1/60 =	51196.260
18-19	0	1	(42.7 x 108802.80) x 1/60 =	77417.377
19-20	10	2	(469.6 x 4314.90) x 2/60 =	67544.743
20-21	0	1	(42.7 x 108802.80) x 1/60 =	77417.377
21-22	4	3	(213.5 x 14390.30) x 3/60 =	153588.779
22-23	0	1	(42.7 x 108802.80) x 1/60 =	77417.377
23-24	10	1	(469.6 x 4314.90) x 1/60 =	33772.372
24-25	0	3	(42.7 x 108802.80) x 3/60 =	232252.131
25-26	4	3	(213.5 x 14390.30) x 3/60 =	153588.779
26-27	3	2	(170.8 x 21668.16) x 2/60 =	123341.860
27-28	0	6	(42.7 x 108802.80) x 6/60 =	464504.262
TOTAL TIME ELAPSED(MIN)		101	TOTAL O_2 (g)	5588496.803

Graphical representation of O_2 emission of 28 maneuvering points are seen in Figure 4.8.

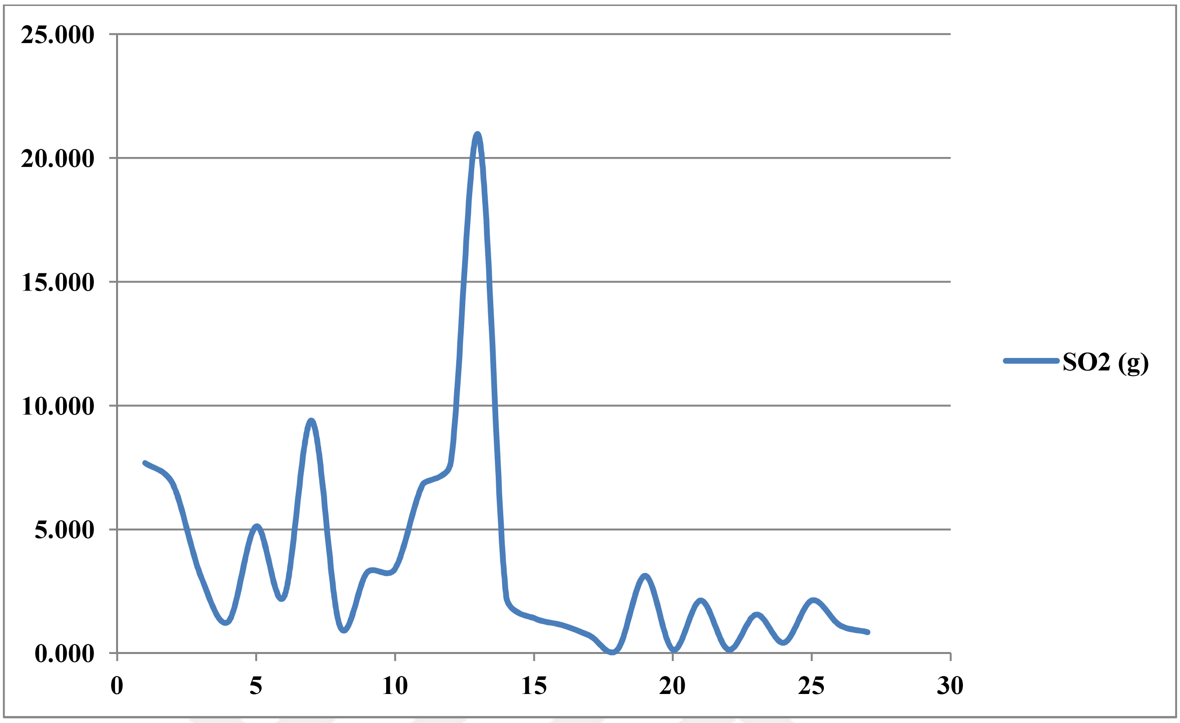

Figure 4.7. Test results at Maneuvering Points for SO_2

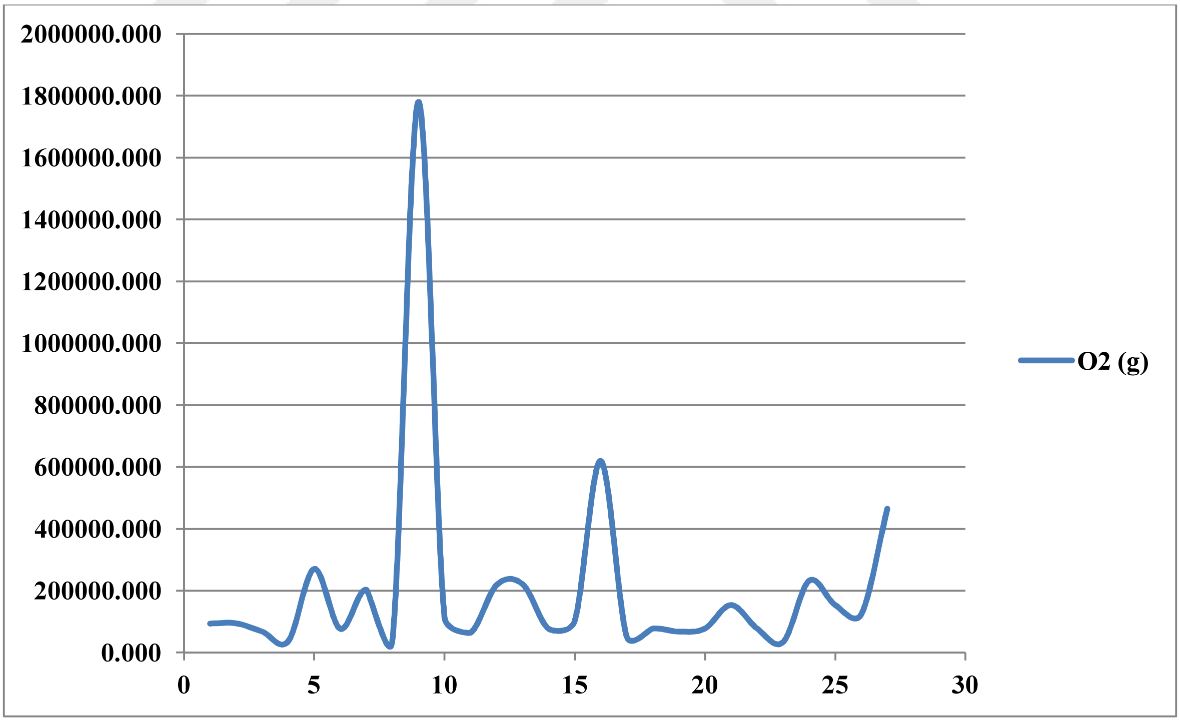

Figure 4.8. Test results at Maneuvering Points for O_2

Table 4.8. Test Results of HC Emission Table for Main engine

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x HC x Δt/ 60	HC (g)
1-2	17	3	(768.5 x 1.39) x 3/60 =	53.312
2-3	15	3	(683.1 x 1.58) x 3/60 =	54.101
3-4	10	2	(469.6 x 2.55) x 2/60 =	39.841
4-5	8	1	(384.2 x 3.38) x 1/60 =	21.668
5-6	5	6	(256.2 x 6.40) x 6/60 =	163.983
6-7	7	2	(341.5 x 4.04) x 2/60 =	45.964
7-8	10	6	(469.6 x 2.55) x 6/60 =	119.524
8-9	7	1	(341.5 x 4.04) x 1/60 =	22.982
9-10	0	23	(42.7 x 67.14) x 23/60 =	1098.705
10-11	7	3	(341.5 x 4.04) x 3/60 =	68.946
11-12	23	2	(1024.6 x 1.04) x 2/60 =	35.540
12-13	8	6	(384.2 x 3.38) x 6/60 =	130.010
13-14	20	7	(896.5 x 1.18) x 7/60 =	123.594
14-15	7	2	(341.5 x 4.04) x 2/60 =	45.964
15-16	4	2	(213.5 x 8.77) x 2/60 =	62.426
16-17	0	8	(42.7 x 67.14) x 8/60 =	382.158
17-18	4	1	(213.5 x 8.77) x 1/60 =	31.213
18-19	0	1	(42.7 x 67.14) x 1/60 =	47.770
19-20	10	2	(469.6 x 2.55) x 2/60 =	39.841
20-21	0	1	(42.7 x 67.14) x 1/60 =	47.770
21-22	4	3	(213.5 x 8.77) x 3/60 =	93.639
22-23	0	1	(42.7 x 67.14) x 1/60 =	47.770
23-24	10	1	(469.6 x 2.55) x 1/60 =	19.921
24-25	0	3	(42.7 x 67.14) x 3/60 =	143.309
25-26	4	3	(213.5 x 8.77) x 3/60 =	93.639
26-27	3	2	(170.8 x 13.27) x 2/60 =	75.550
27-28	0	6	(42.7 x 67.14) x 6/60 =	286.619
TOTAL TIME ELAPSED(MIN)		101	TOTAL HC (g)	3395.758

Graphical representation of HC emission of 28 maneuvering points are seen in Figure 4.9.

Table 4.9. Test Results of H_2O (Vapour) Emission Table for Main engine

Maneuvering points	LOAD %	Time Elapsed (MINUTES)	Ne x H_2O x Δt/ 60	H_2O g)
1-2	17	3	(768.5 x 1.39) x 3/60 =	13427.600
2-3	15	3	(683.1 x 1.58) x 3/60 =	12362.098
3-4	10	2	(469.6 x 2.55) x 2/60 =	6496.659
4-5	8	1	(384.2 x 3.38) x 1/60 =	2912.597
5-6	5	6	(256.2 x 6.40) x 6/60 =	14708.866
6-7	7	2	(341.5 x 4.04) x 2/60 =	5501.599
7-8	10	6	(469.6 x 2.55) x 6/60 =	19489.978
8-9	7	1	(341.5 x 4.04) x 1/60 =	2750.800
9-10	0	23	(42.7 x 67.14) x 23/60 =	30240.285
10-11	7	3	(341.5 x 4.04) x 3/60 =	8252.399
11-12	23	2	(1024.6 x 1.04) x 2/60 =	11101.277
12-13	8	6	(384.2 x 3.38) x 6/60 =	17475.584
13-14	20	7	(896.5 x 1.18) x 7/60 =	35083.642
14-15	7	2	(341.5 x 4.04) x 2/60 =	5501.599
15-16	4	2	(213.5 x 8.77) x 2/60 =	4652.181
16-17	0	8	(42.7 x 67.14) x 8/60 =	10518.360
17-18	4	1	(213.5 x 8.77) x 1/60 =	2326.090
18-19	0	1	(42.7 x 67.14) x 1/60 =	1314.795
19-20	10	2	(469.6 x 2.55) x 2/60 =	6496.659
20-21	0	1	(42.7 x 67.14) x 1/60 =	1314.795
21-22	4	3	(213.5 x 8.77) x 3/60 =	6978.271
22-23	0	1	(42.7 x 67.14) x 1/60 =	1314.795
23-24	10	1	(469.6 x 2.55) x 1/60 =	3248.330
24-25	0	3	(42.7 x 67.14) x 3/60 =	3944.385
25-26	4	3	(213.5 x 8.77) x 3/60 =	6978.271
26-27	3	2	(170.8 x 13.27) x 2/60 =	4476.924
27-28	0	6	(42.7 x 67.14) x 6/60 =	7888.770
TOTAL TIME ELAPSED(MIN)		101	TOTAL H_2O (g)	246757.609

Graphical representation of H_2O (Vapour) emission of 28 maneuvering points are seen in Figure 4.10.

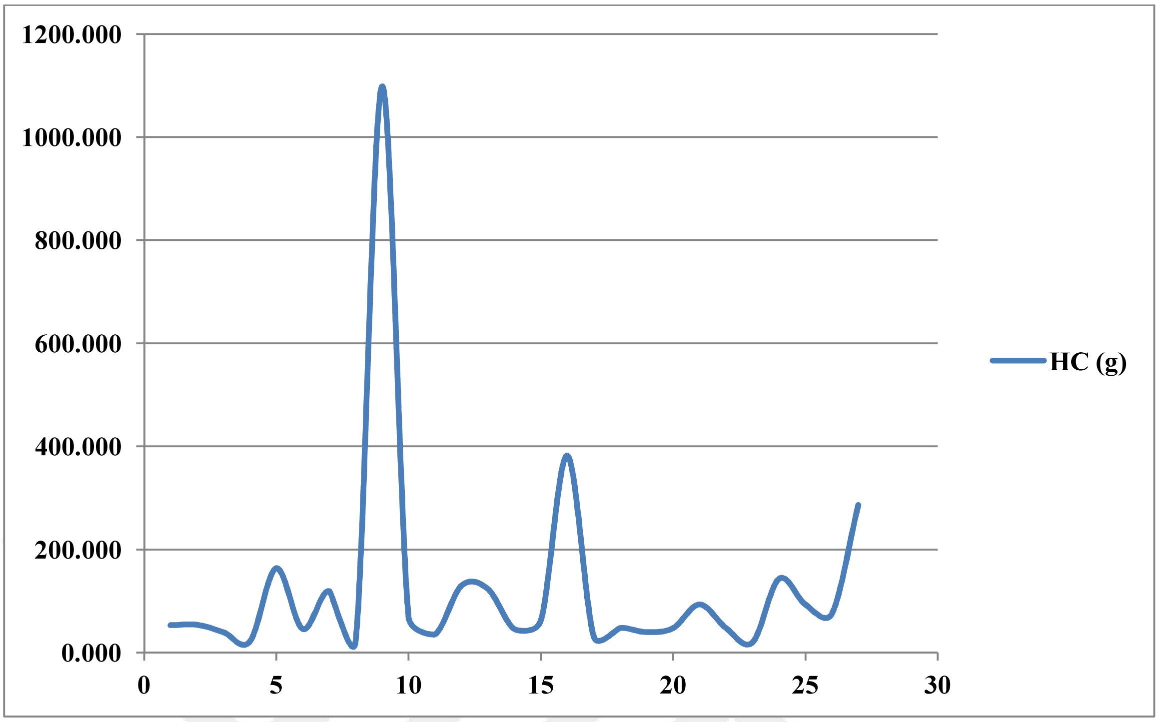

Figure 4.9. Test results at Maneuvering Points for HC

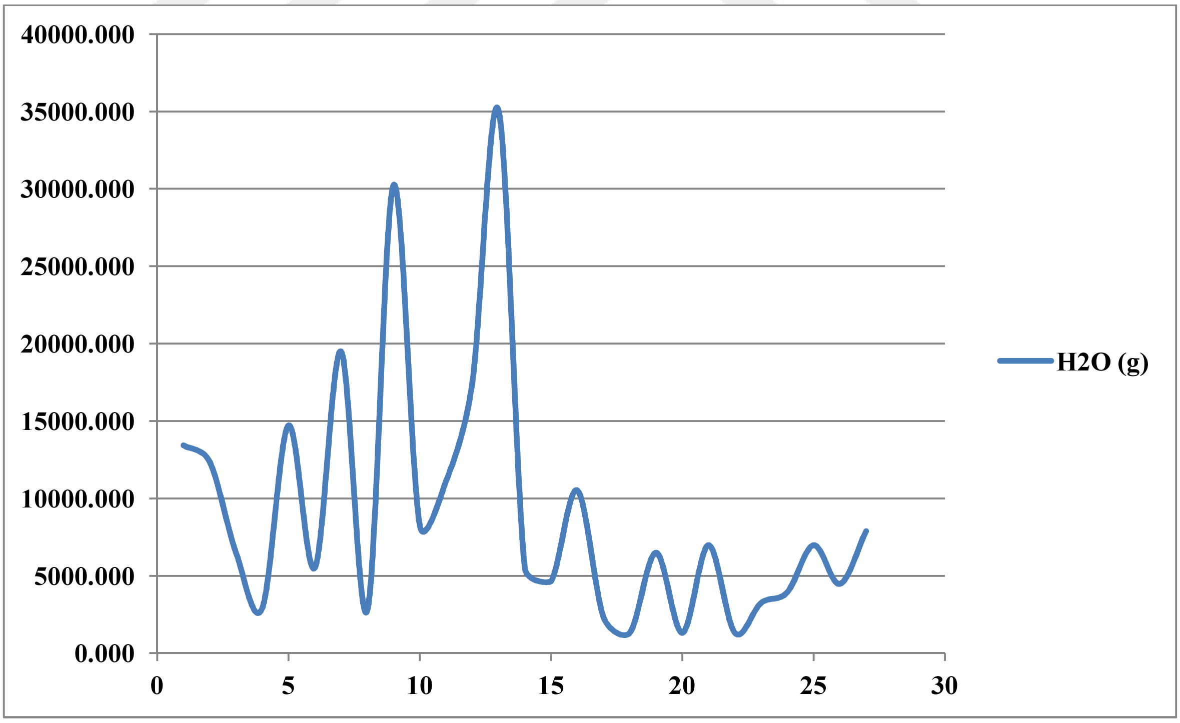

Figure 4.10. Test results at Maneuvering Points for H_2O

As explained before, Tables 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9 and Figures 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10 show emissions of NO_x, CO_2, CO, O_2, HC, SO_2, H_2O respectively, from the main engine based on Table 4.1. as a function of time elapsed and power at a given percentage of the load for each maneuvering points.

During maneuvers, average power is calculated as 481.711 kW. On the other hand, the average emissions (g, kg/kwh) during total maneuvering time can be found using below correlation,

$SE_{ave}=[(\sum SE)/(Ne_{ave} * \Delta t /60)]$

Where;

Ne_{ave} : Average power (kW) during maneuvering.

$\sum SE$: Total values of NO_x, CO_2, CO, O_2, HC, SO_2, or H_2O specific emission (g/kWh) during maneuvering.

Table 4.10. Comparison of the Test Bench Results (Total Emission) and average emissions during maneuvers.

	TEST BENCH RESULTS				CALCULATED EMISSIONS
	%25 LOAD	%50 LOAD	%75 LOAD	%100 LOAD	Average power and emissions during maneuvers
Power (kW)	1091	2220	3340	4440	481.711 (Mean Power at Maneuver)
NOx (g/kwh)	10.58	12.33	14.54	13.43	(10607 / (481.711* (101 / 60)) = 13.080
CO_2 (g/kwh)	639	601.9	586.9	595.2	(565308 / (481.711*(101 / 60)) = 697.153
CO (g/kwh)	1.154	0.883	0.705	0.594	(5626 / 481.711*(101 / 60)) = 6.938
SO_2 (g/kwh)	0.201	0.189	0.184	0.187	(69 / 481.711* (101 / 60)) = 0.12
O_2 (g/kwh)	1766	1450.6	1415.6	1245.6	(5588496 / 481.711* (101 / 60)) = 6891.882
HC (g/kwh)	1.540	0.883	0.705	0.594	(3395 / 481.711* (101 / 60)) = 4.187
H_2O (g/kwh)	319.5	293.3	285.9	286.1	(246757 / 481.711* (101 / 60)) = 304.308

Table 4.10 and 4.11 show the comparison of the Test Bench Results (Total Emission) and average emissions during maneuvers at different loads. It can be seen that values of

CO_2, CO, O_2, HC, H_2O emissions during maneuvers are greater than that of the test bench results. But, No_x is lower than that of the %75 and %100 test bench results. At this point, we can conclude that maneuvering period is an important parameter for calculating emissions and plays important role controlling the emissions within limits.

Table 4.11. Test Results Emission for Main engine

NOx (g per kW)	%25 LOAD < %50 LOAD < **Maneuver** < %100 LOAD < %75 LOAD
CO_2 (g per kW)	**Maneuver** > %25 LOAD > %50 LOAD > %100 LOAD > %75 LOAD
CO (g per kW)	**Maneuver** > %25 LOAD > %50 LOAD > %75 LOAD > %100 LOAD
SO_2 (g per kW)	%25 LOAD > %50 LOAD > %100 LOAD > %75 LOAD > **Maneuver**
O_2 (g per kW)	**Maneuver** > %25 LOAD > %50 LOAD > %75 LOAD > %100 LOAD
HC (g per kW)	**Maneuver** > %25 LOAD > %75 LOAD > %50 LOAD > %100 LOAD
H_2O (g per kW)	**Maneuver** > %25 LOAD > %50 LOAD > %100 LOAD > %75 LOAD

Summary of the analysis of the main engine is given in the table 4.8. The maneuver consists of higher CO_2, CO and SO_2 except NOx emissions than %25, %50, %75 and %100 main engine load.

During the manuvers, CO_2 specific emission is approximately 20%, CO is approximately 884% and NOx is approximately 25% greater than the %25 load. On the other hand, 3% NOx is less than %100 load.This results show the importance of the maneuvering propulsion power and time and the effect on emissions.

4.2. Diesel Generator Emission at Maneuvering

Table 4.2 shows emissions at a given percentage of the generator load to calculate the total emissions during maneuvering for the Diesel Generators at 0-25% generator load. In this maneuvering period, two generators were running together with the main engine. The amount of emissions (kg) at a given power during total maneuvering time can be found using below correlation,

$ME = Ne_e \times SE \times \Delta t / 60$

Where;

ME : Total amount of emissions (g, kg)

Ne_e : Electrical Power (kW) required during maneuvering.

SE : Specific emission (g/kWh) values of NOx, CO_2, O_2, HC or CO.

Table 4.12 shows the amount of NO_x, CO_2, CO, O_2, and HC emissions from the diesel generators based on Table 4.2 at 25% and 50% load.

Table 4.12. Test Result Emissions at 25 % and 50% load of a Diesel Generator

	$ME = Ne_e \times SE \times \Delta t / 60$ At 25% LOAD (121kW)	$ME = Ne_e \times SE \times \Delta t / 60$ %50 LOAD(241 Kw)
NOx (kg)	121 x 8.76 x 101 / 60 =1.784	241 x 8.92 x 101/60 =3.618
CO_2 (kg)	121 x 777.69 x 101 / 60 =158.402	241 x 670.12 x 101/60= 271.856
CO (kg)	121 x 2.81 x 101 / 60 =0.572	241 x 0.871 x 101/60 =0.353
O_2 (kg)	121 x 1941.32 x 101 / 60 =395.349	241 x 670.12 x 101/60 =269.164
HC (kg)	121 x 0.45 x 101 / 60 =0.09	241 x 0.12 x 101/60 =0.04

Diesel generators were run to meet the power needs of 241 kW for 101 minutes during the maneuvering. In this test, changes were negligible at load changes. Table 4.14 shows the amount of NO_x, CO_2, CO, O_2, and HC emissions from the diesel generators at 50% load using one or two diesel generators for comparison.

Table 4.13. Emission Test Results for % 50Diesel Generator load.

	1 Generator 241 Kw	2 Generators 121 Kw x 2 pcs	Difference
NOx (kg)	3.618	3.568	-0.05
CO_2 (kg)	271.856	316.804	44.948
CO (kg)	0.353	1.144	0.791
O_2 (kg)	269.164	790.698	521.534
HC (kg)	0.04	0.18	0.14

Emission comparison of one or two generators at 241 kW power during maneuvers in order to meet electrical power demand are seen in Table 4.13. Data used to calculate the emissions during maneuvers, taken from the Table 4.2. In Table 4.13, using one or two generators for maneuver is examined in terms of amount of emissions at the same electrical power output. It is clearly understood from the Table 4.14, one diesel generator should be run in terms of reducing emissions during operation. However, for safety of the ship, it is important and required to use two generators together at the appropriate time.

Table 4.14. Test Results Emission for gram per 1 kW for Diesel Generator

	2 Generators 121x kW	1 Generator 241 Kw
NOx (g per kW)	0.01474380	0.01501244
CO_2 (g per kW)	1.309074380	1.128033195
CO (g per kW)	0.004272727	0.001464730
O_2 (g per kW)	3.280904564	1.116863070
HC (g per kW)	0.000743801	0.000165975

Table 4.14 shows emissions produced while producing 1 Kw for Diesel generators at 121 kW and 241 kW power. Also the table 4.15 shows the emissions produced in 24 hours for Diesel generators at 121 kW and 241 kW power.

Usually there is more than one generator on the ships. According to the required loads, they are run in parallel. But, minimum number of generators to provide the use of maneuver requests are important in terms of emissions as seen figure 4.11.

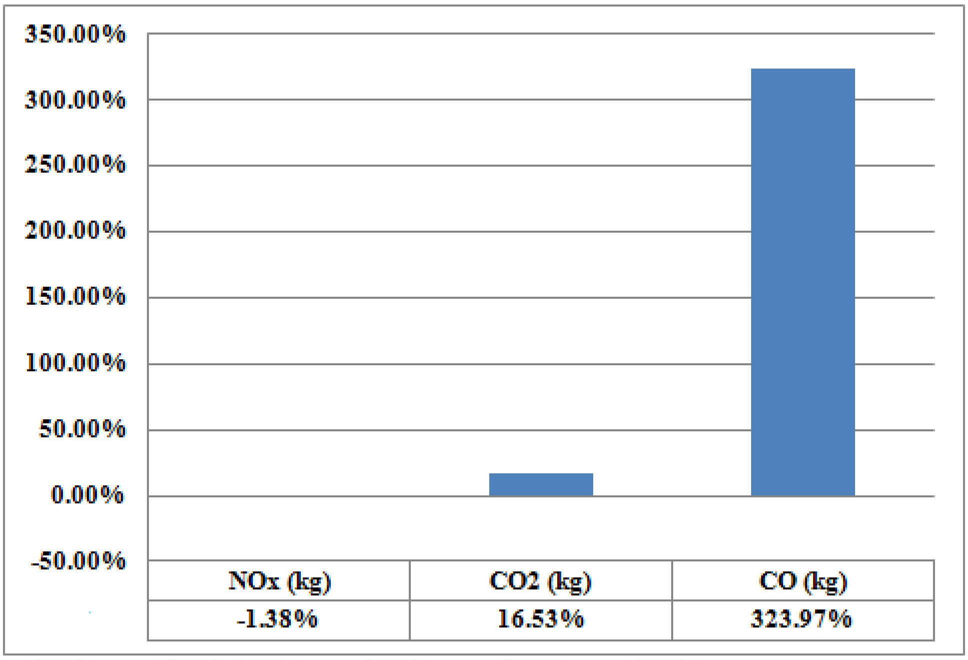

Figure 4.11. Percentage comparision of one or two generators' emissions at 241 kW.

Figure 4.1 shows the percentage emission of comparision of one or two generators emissions at 241 kW. During the manuvers and using two generators instead of one, CO_2 emission increases approximately 16.53%, CO increases approximately 323.97% but NOx degreases approximately -1.38% . This results show the importance of the selection of the number of the generators during maneuvering.

4.3. Total Emissions at Maneuvering

During the maneuvering, total emissions are calculated by using main engine and Diesel generators data. Table 4.15 shows the estimated emissions for three main emissions as NO_X, CO_2 and CO greenhouse effect gases.

Table 4.15. Total Emission Results for Maneuver

	Main Engine	Generator Diesel Engine(s)		TOTAL emission for one generator	TOTAL emission for two generators
		2 Diesel Engine (121 kW x 2)	1 Diesel Engine (241 kW)		
NOx (kg)	10.607	3.568	3.618	14.225	14.175
CO_2 (kg)	565.308	316.804	271.856	837.164	882.112
CO (kg)	5.626	1.144	0.353	5.979	6.77

In this study, calculations in two different scenarios were performed based on one or two generators to run. The amount of ship emissions during maneuvering are modeled as realistic as possible. Emissions will vary in different ship types and equipment features. The emissions for different ship's main engine and diesel generator can be calculated by using this basic practice. Also, the number of generators used at the port determined by this method. In this way, both fuel consumption and emissions are achieved.

DISCUSSION AND RESULT

Energy efficient shipping is a prerequisite for the reduction of the Green House Gas emissions to the levels anticipated within the next decades. Therefore, it is necessary to have technically high performance ships. High performance that release harmful gases into the atmosphere will be reduced by a ship.

A set of rules as a result of increased global warming in recent years has been come into force. In addition, tax treatment began on emissions. In this way, the ship owners were forced to pay according to their degree of polluting the air. At this point, it is required to measure of the air polluting level of the vessel. Various measuring methods have been developed related with the port, maneuvering and sailing modes of the ship.

In this study, unlike previous studies, estimations have been made for the overall emissions in the maneuvering. This sense, it aims to contribute to the existing literature. The results of Diesel engine performance measurement calculation is used to estimate produced power and emissions relations.

The supply of electricity by ports as well as ports of existing technology will completely eliminate emissions.

When the diesel engine is running, it produces more than 35 different gas emissions. Basic air pollutants and the terms of the international conventions as MARPOL Annex 6 are described. In particular, Diesel engines sourced pollutants have been identified as CO_2, CO, NO_X, PM, SO_X. Basic fuel standards have been compared with the announced rate on sulfur emissions.

Performance analysis of the Diesel engine is performed by the actual value measurement. Should any power loss ais found by comparing the values of the test data, operational checks and maintetence must be done.

Methodology using informations on primary and secondary sources is described in the test methods. A vessel is examined by performance of the total air pollution at maneuver by comparing different loads.

Results describe the concept as a precondition to calculate emissions and evaluate the performance. It describes how to evaluate the power of engine and relationship with emission gases by calculating results. The assessed value of main engine and generator are determined to find out specific and total emission at optimum working conditions. Considering the number of the operating diesel generators, it has been shown is necessary for the safety of the ship. This is a negative situation in terms of emissions, but is necessary for safety.

In maneuvering, main engine specific emission of carbon dioxide gas is more than 25%, 50%; 75% and 100% load conditions. During the manuvers, Main engine CO_2 emission is approximately 20%, CO is approximately 884% greater than the normal operating load. NOx for main engine is less than 25% during manuvers. Also using two generators instead of one, CO_2 emission increases approximately 17%, CO increases approximately 320% and NOx increases approximately -1.5% . This result show the importance of the maneuvering propulsion power and time and the effect on emissions.

The discussed concepts are instantly evaluated maneuver. These points are determined for different emissions. They are calculated at maneuvering position. Specific fuel consumption and pollutant emissions increase while maneuvering. Also, it has been found to be detrimental to the quantity of specific emissions while generators are operating low load.

Result of this study, maneuvers should be performed quickly and as soon as possible. This situation shows the captain's abilities come to the sceme. Emission gases can be calculated with the variety of different ship types and tonnage. Also according to the power and emissions, the number of the Diesel generators which might be used in the port identified as the most suitable options available.

Computing results identified instantly by maneuvering with more precision was generated by emission values. For any vessel, emissions can be calculated on different diesel engines depending on the performance and power by the same method. Ships should choose optimum routes for minimize fuel consumptions and emissions. Ships should also check the loaded and empty conditions with their emission and power performances.

Energy efficiency will be important in future studies to evaluate the emissions of different machines as pumps, boilers, cranes etc. at port and maneuvering conditions.

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

		Description: IMO Technical File	
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4	← Identification No. → 0 xx xx xx-x
Suppl. Drwg.:			Page No.: 2

Date	Des.	Chk.	Appd.	A.C.	Change/Replacement	C. No.
2004-06-15	SVH		SVH	–		1

Particulars of the engine

Two-stroke, uni-flow scavenged, turbo-charged, charge-air cooled, in-line, cross-head, water cooled, open-chamber, direct-injection diesel engine, with pump-line-nozzle fuel injection for each cylinder, and for operation on heavy fuel oil.

1 *Name and address of manufacturer* — MAN B&W Diesel A/S, Alpha Diesel, Niels Juels vej 15, 9900 Frederikshavn, Denmark

2 *Date of engine build and pre-certification survey* — 21 July 2005

3 *Parent engine responsible* — MAN B&W Diesel A/S, Copenhagen

4 *Built at manufacturer (name and address)* — MAN B&W Diesel A/S, Alpha Diesel, Niels Juels vej 15, 9900 Frederikshavn, Denmark

5 *Date of parent engine build and pre-certification survey* — 19. April 2004

6 *Engine type* — S35MC
Number of cyl. 6 *Bore (mm)* 350 *Stroke (mm)* 1400
Cooling system Central (fixed)

7 *Engine number* — *Parent* 37067 — *Member* 37075

8 *Plant spec. number* — 908863-9 — 908926-4

9 *If applicable, the engine is:* *an Individual engine* *a Parent engine* *a Member engine* X
of the following engine Group: ADF-S35MC-04-1
On-board survey code name ADF-S35MC-04-1
version(s) E2&E3, both TB and on-board MC, ver.5-3

10 *Test cycle(s) (see chapter 3 of the Technical Code)* — E2

11 *Rated MCR Power (kW) and Speed (r/min) *)* — 4440 kW at 173 r/min

12 *Layout MEP (bar) / max. cylinder pressure (barabs) *)* — 19.1 bar / 147 barabs

13 *Specification(s) of test fuel (and/or Certification no. of fuel sample analysis)* — ITS certificate 28398 (see Encl. 3)

14 *NOx reducing device designated approval number (if installed)* — Not applicable (N/A)

15 *Applicable NOx Emission Limit (g/kWh) (regulation 13 of Annex VI)* — 16.1

16 *Parent Engine's actual NOx Emission Value (g/kWh)* — E2: 14.2 E3: 14.6

17 *NOx Emission at maximum allowed tolerances (g/kWh)* — E2: 15.3 E3: 15.4

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

	Description: IMO Technical File						
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4				← Identification No. → 0 xx xx xx-x	
Suppl. Drwg.:						Page No.:	8
Date	Des.	Chk.	Appd.	A.C.	Change/Replacement		C. No.
2004-06-15	SVH		SVH	–			1

2. Engine group definition

Engine group designation	ADF-S35MC-04-1
Member engine(s)	6S35MC Plant specification(s): 908926-4, 0908863-9 All engines built to the specified plant specification(s) (i.e. through the technical data in the Tables 1.1 to 1.3) and within the following rated power/speed/ MEP ranges: 4440 kW / 173 r/min / 19.1 bar
Parent engine	Alpha 6S35MC, plant specification: 0908863-9 Power/speed/MEP rating: 4440 kW / 173 r/min / 19.1 bar Class approval: LR Engine no 37067 built at Alpha and tested: 2 December 2004
Confirmation of conformity *)	Product conformity through MAN B&W plant specification - licencees supplied drawings (with tolerances) and 'Conformity of Production' procedures

*) *documentation for group engines only to the Authorized Company*

3. On-board NOx verification procedure

3.1 Introduction

MAN B&W has defined a combination of performance parameter checks and, component and setting verification as the *on-board survey method*. Fig. 1 shows a flow chart of the on-board survey procedures, and Appendix B includes a detailed description of all survey procedures. MAN B&W recommends as a standard procedure to include the results of the on-board survey to the *'record book'* after any performance adjustment or IMO component changes to the engine to secure and document continuing compliance.

3.2 Performance parameter check

The parameter check can be performed using the manufacturer supplied *survey code* as an easy tool to calculate and present the ISO corrected reference values to verify compliance. The expected (simulated) NOx emission is added for additional benefit of the Owner. The survey code is supplied on a CD ROM and dedicated to a specific engine group. The code is based on EXCEL 2000. (If a computer is not available, also a manual check can be performed (see step-by-step procedures in Appendix B, Section B.3.2).)

Two options of the code exist on the CD. The *'on-board'* option to be used as the standard survey method on board and the *'test-bed'* (TB) option, a more detailed version, to be used to show compliance on test bed for member engines. The on-board option (for *initial* and *intermediate surveys*) surveys the performance at 75% load for MC engines without VIT, and at 75% load and a load point above the break point (to ensure checking of the maximum firing pressure) for engines with VIT. The TB option includes all the E3/E2 cycle load points.

The code is based on a 'standard MAN B&W performance check' (see necessary parameters in Appendix B, Table B.2.1 and the measurement positions in the schematic of the engine Fig. 2) and follows the described procedures and formulas in Appendix B. Enclosure 1 (at the end of the Technical File) shows input and output from the survey code based on the actual test-bed data for the parent engine (as documented in Chapter 4.) The

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

		Description: IMO Technical File				
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4			← Identification No. → 0 XX XX XX-X	
Suppl. Drwg.:					Page No.:	9
Date	Des.	Chk.	Appd.	A.C.	Change/Replacement	C. No.
2004-06-15	SVH		SVH	–		1

Compliance is confirmed for the actual setting values for the engine when the ISO-corrected performance parameters are within the specified tolerances as given in Table 1.3. *(In compliance with the 'NOx Technical Code' §2.4 and §6.2.2.)* A slightly more strict requirement than showing the simulated NOx value to be lower or equal the maximum tolerance value (item 17 in particulars of the engine.) The output Tables from the code (Enclosure 1) shall be added to the record book on board.

3.3 Components and settings verification

In order to physically verify the components and settings allowed within this certificate, a check of the actual NOx components is necessary. The allowed components are specified in Chapter 1.1 (or the last output page from the survey code in Enclosure 1,) and Appendix A specifies the necessary verification procedures.

Turbocharger, air cooler and auxiliary blower are verified through their nameplates. To verify the turbochargers internal parts (marked by the turbocharger manufacturer) dismantling is necessary (*procedures are not included.*)

To verify the setting values on board, a performance check has to be performed using the on-board survey code (as described in the previous Chapter 3.2.) When the required performance data, (see Appendix B, Table B.2.1 within the given tolerances) are entered, the code will verify compliance of the actual adjustments. Since the setting values may be changed in the future, a record of these changes shall be kept in the record book for future guidance.

When a performance check has been performed and no changes were entered in the record book, verification of the fuel nozzle on board is enough to show compliance (see comments in Appendix B.) *(However, other NOx components may be checked, as considered necessary and in compliance with the 'NOx Technical Code' §2.3.12 and §6.2.2.)*

The performance data to check the setting values for the survey can be based on data from either before or after the opening-up inspection of the engine (one cylinder unit, usually requested.) The engine must be assembled again using the last verified setting values. Since a performance check cannot be performed in dock, the 'missing' setting values are based on recorded data obtained within (a recommended) one-month period from a called (or anticipated) survey. However, it is strongly recommended to perform a performance check to verify the setting values soonest possible after docking (or adjustment service or repair on board) to ensure continuing compliance.

4. Test report

4.1 Review of engine performance and settings

A summary of the documentation from the engine test-bed report is included as Enclosure 2.

4.2 Emission characteristics for parent engine

The performed emission measurements follows the guidelines given in the MAN B&W procedures 'Emission Measurement Procedures for IMO Certification of MAN B&W Two-Stroke Engines on Test Bed'. The specific emission values are calculated using the MAN B&W code 'IMOCALC' version 3.0 in accordance with the 'NOx Technical Code'. Output from IMOCALC for the E3/E2 cycle load conditions during the official test is given in Enclosure 3.

A summary of the NOx emission corrected in steps from 'measured' to 'ISO ambient', to 'ISO ambient & performance reference' and finally to 'ISO ambient at max. tolerance' is given in Table 4.1 (the final data are also given in Enclosure 1). The corrections follow the procedures and equations described in Appendix B, Chapter B.2.4. *(For additional details or documentation of the emission measurements and the engine performance, reference is given to the supportive documentation submitted to the Authorized Company.)*

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

		Description: IMO Technical File					
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4				← Identification No. → 0 xx xx xx-x	
Suppl. Drwg.:						Page No.:	9
Date	Des.	Chk.	Appd.	A.C.	Change/Replacement		C. No.
2004-06-15	SVH		SVH	–			1

Compliance is confirmed for the actual setting values for the engine when the ISO-corrected performance parameters are within the specified tolerances as given in Table 1.3. *(In compliance with the 'NOx Technical Code' §2.4 and §6.2.2.)* A slightly more strict requirement than showing the simulated NOx value to be lower or equal the maximum tolerance value (item 17 in particulars of the engine.) The output Tables from the code (Enclosure 1) shall be added to the record book on board.

3.3 Components and settings verification

In order to physically verify the components and settings allowed within this certificate, a check of the actual NOx components is necessary. The allowed components are specified in Chapter 1.1 (or the last output page from the survey code in Enclosure 1,) and Appendix A specifies the necessary verification procedures.

Turbocharger, air cooler and auxiliary blower are verified through their nameplates. To verify the turbochargers internal parts (marked by the turbocharger manufacturer) dismantling is necessary (*procedures are not included.*)

To verify the setting values on board, a performance check has to be performed using the on-board survey code (as described in the previous Chapter 3.2.) When the required performance data, (see Appendix B, Table B.2.1 within the given tolerances) are entered, the code will verify compliance of the actual adjustments. Since the setting values may be changed in the future, a record of these changes shall be kept in the record book for future guidance.

When a performance check has been performed and no changes were entered in the record book, verification of the fuel nozzle on board is enough to show compliance (see comments in Appendix B.) *(However, other NOx components may be checked, as considered necessary and in compliance with the 'NOx Technical Code' §2.3.12 and §6.2.2.)*

The performance data to check the setting values for the survey can be based on data from either before or after the opening-up inspection of the engine (one cylinder unit, usually requested.) The engine must be assembled again using the last verified setting values. Since a performance check cannot be performed in dock, the 'missing' setting values are based on recorded data obtained within (a recommended) one-month period from a called (or anticipated) survey. However, it is strongly recommended to perform a performance check to verify the setting values soonest possible after docking (or adjustment service or repair on board) to ensure continuing compliance.

4. Test report

4.1 Review of engine performance and settings

A summary of the documentation from the engine test-bed report is included as Enclosure 2.

4.2 Emission characteristics for parent engine

The performed emission measurements follows the guidelines given in the MAN B&W procedures 'Emission Measurement Procedures for IMO Certification of MAN B&W Two-Stroke Engines on Test Bed'. The specific emission values are calculated using the MAN B&W code 'IMOCALC' version 3.0 in accordance with the 'NOx Technical Code'. Output from IMOCALC for the E3/E2 cycle load conditions during the official test is given in Enclosure 3.

A summary of the NOx emission corrected in steps from 'measured' to 'ISO ambient', to 'ISO ambient & performance reference' and finally to 'ISO ambient at max. tolerance' is given in Table 4.1 (the final data are also given in Enclosure 1). The corrections follow the procedures and equations described in Appendix B, Chapter B.2.4. *(For additional details or documentation of the emission measurements and the engine performance, reference is given to the supportive documentation submitted to the Authorized Company.)*

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

	Description: IMO Technical File	
MBD Info No. 3 00 044 / A 4	Engine Type 6S35MC, Plant spec 908926-4	← Identification No. → 0 xx xx xx-x
Suppl. Drwg.:		Page No.: 10

Date	Des.	Chk.	Appd.	A.C.	Change/Replacement	C. No.
2004-06-15	SVH		SVH	–		1

Table 4.1 E2: Corrections of measured NOx emission on test bed

Power (%)	Measured NOx (g/kWh)	ISO ambient and test-bed perf. NOx (g/kWh)	ISO amb. And reference perf. NOx (g/kWh)	ISO amb. NOx at max. perf. tolerances (g/kWh)
100	13.43	12.96	14.09	15.19
75	14.54	14.24	14.99	16.03
50	12.33	12.07	12.52	13.54
25	10.58	10.35	10.85	11.84
IMO NOx Cycle	13.76	13.42	14.24	15.29

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

E1-1

Engine description

Engine type:	6S35MC	**MCR Power**	4440 kW	**VIT:**	No	Engine no: ADF 37067
Test cycle:	E2	**MCR Speed**	173 r/min	**Cooling system:**		Fixed temperature (36°C)
Engine group:	ADF-S35-04-1	**Vessel name/data for:**	Delivery Test			Survey code ver. 5-3-3

Test bed survey

-Fill in yellow cells

Table 1: Input		Measured data			
		Load (%)			
Date: 2004-04-19		100	75	50	25
Ambient pressure	mbar	996	1000	1000	1000
Compression pressure	bar	120	93	62	42
Maximum pressure	bar	143	119	84	53
Compressor inlet temperature	°C	24,7	25,4	25,8	26
Scavenging air temperature	°C	42	35	30	37
Sea water inlet temperature	°C	25	25	25	25
Turbine back pressure	mmWC	270	180	85	10
Scavenging air pressure	bar	2,78	1,92	1,02	0,34
Power	kW	4440	3340	2220	1091
Engine speed	r/min	173	173	173	173
Turbocharger speed	r/min	19000	16600	13300	8100

Table 2: Output		Load (%)				E2 cycle value
Measured values		100	75	50	25	
Pscav @ ISO ambient	barabs	3,82	2,98	2,06	1,36	
Pmax @ ISO ambient	barabs	144,5	120,9	85,8	54,4	
Pcomp @ ISO ambient	barabs	121,9	95,3	64,0	43,5	
Tscav	°C	42,0	35,0	30,0	37,0	
Pback	mmWC	270	180	85	10	
ΔPower	%	0,0	0,2	0,0	-0,4	
Limit values						
Pmax, maximum	barabs	150,0	124,0	91,0	58,0	
Pcomp, minimum	barabs	116,0	90,0	62,0	40,0	
Tscav, maximum (at ISO ambient)	°C	54,0	46,0	42,0	47,0	
Pback, maximum	mmWC	450,0	340,0	225,0	115,0	
ΔPower, maximum	%	2,2	2,2	2,2	2,2	
Compliance						
Pmax		**yes**	**yes**	**yes**	**yes**	
Pcomp		**yes**	**yes**	**yes**	**yes**	
Tscav						
Pback		**yes**	**yes**	**yes**	**yes**	
Power deviation < 2.2%		**yes**	**yes**	**yes**	**yes**	
IMO NOx						**E2 cycle value**
Member engine site NOx	g/kWh	12,78	14,23	11,94	10,31	**13,35**
Parent engine ISO corr. NOx	g/kWh	14,09	14,99	12,52	10,85	**14,24**
ISO NOx at max tolerances	g/kWh	15,19	16,03	13,54	11,84	**15,29**

Approval:

Performed date	
Performed by	
Approval	

Survey code E2 cycle 6S35MC IMO 0908863-9 37067.xls 1

Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W	D.E.: S35MC	Water brake: Z14	No.: 2778		TEST BED
	No.: 37075	Yard:			
Layout kW: 4440	RPM: 173	Date: 21-07-2005		Sign: LWP	Test no: G1
Turbocharger(s): Nos.: 1	Serial No.	No. of cyl.: 6	Bore (m): 0,35	Stroke (m): 1,400	
Make: MAN	1	1192189	Cylinderconstant (kW,bar): 0,2245	TCS power (kW):	
Type: NA40/SO1077	2		Governor: Woodward	Type: PGA 58	
Max. RPM: 21.400	3		TC specification: AD=221,0cm^2 A_4K=168,3 cm^2		
Max. temp. °C: 620	4		MFP: 1,15	Compr. slip factor: 0,70	Compr. diameter: 0,4800
T/C lub. oil system (Tick box):	Internal system ■	External from M.E. syst. ☐	External from gravity tank ☐		
Humidity-rel % 47,6	at 28 °C			Brand	Type
Bunker station	Q8 Aalborg		Cylinder oil	BP	CL505
Oil brand Q8 Diesel	Heat value kCal/kg: 10224		Circulating oil	BP	Energol OE-HT30
Density at 15 °C: 0,8432	Sulphur %: 0,04		Turbo oil	BP	Energol OE-HT30

Date (yymmdd)	Hour (hh:mm)	Brake Load kNm	RPM	g/kWh indicated
05-07-21	08:51	245,7	173	169,00
η mech.		Speed setting bar	kW indicated	
0,92		4,60	4845	
Load %		Gov.nor index	kW eff.	g/kWh effective
100		6,5	4450	184,00
Barom. millibar				Fuel oil Cons. kg/h
996				819

Cyl.	Pi bar	Pmax bar	Pcomp bar	Fuel pump index
1	20,81	144	113	59
2	20,79	144	115	59
3	20,35	142	114	59
4	20,72	143	115	59
5	21,08	143	113	60
6	21,00	143	113	59
7				
8				
9				
10				
11				
12				
Average	20,79	143	114	59

Ref.Pmax: 144 (bar)

Cyl.	Pmax. adjustment shims	Exhaust gas temp. °C Exhaust valve
1	5	405
2	5	420
3	5	420
4	5	415
5	5	400
6	5	400
7		
8		
9		
10		
11		
12		
Average	5,0	410

	Turbine Inlet °C	Turbine Outlet °C	Exh. press Receiver bar	Turb. outlet mmWC	Turbocharger RPM	Scav. air Δp Filter mmWC	Scav. air Δp Cooler mmWC	Scav. air Receiver bar	Scav. air temp. Inlet Blower °C	Before Cooler °C	After Cooler °C
1	480	0	2,57	210	19430	0	225	2,81	32,6	195	38
2			mmHg 1928					mmHg 2108			
3								°C 46			
4											
Digi 1	458	285									
Digi 2 / Local			2,52					2,78			
Average	458	285	bar	210	19430	0	225	bar	32,6	195	38

Auxiliary blower: on ☐ off X

Cooling water Pressure [bar] LT	HT	Air cooler Inlet	Air cooler Outlet	Main engine Inlet	Outlet cyl. 1	2	3	Turb. Outlet
2,3	2,7	27	46	65	83	83	83	0
	ΔP 0,65				83 (4)	83 (5)	83 (6)	
Flow [m³/h] LT	HT				7	8	9	
89	48				10	11	12	
					Average		83	

Lubricating oil	Press. bar	°C Inlet	Outlet piston 1	2	3
System oil	2,1	engine 45	56	57	57
Cool. oil		Inlet camsh.	57	57	55
Exh.V oil		Outlet camsh.	10	11	12
			Average		57
Turb. oil	2,0	Thrust segm. 47	Flow [m³/h] 86,70		

Turbochargers	MAN inlet/ BBC blower inlet/	MAN outlet/ ABB turbine outlet/
1		57
2		
3		
4		

Fuel oil pressure bar	
Before filter	
After filter	7,8
Temp. °C Before pumps	34

Governor.	Temp.:	Oil.: OE-HT 30
Axial vibration monitor.:	0,62	

Remarks: Exhaust temp reciever: °C

Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W	D.E.: S35MC	Water brake: Z14	No.: 2778	TEST BED
	No.: 37075	Yard: Sonay 2		
Layout kW: 4440	RPM: 173	Date: 21-07-2005	Sign: LWP	Test no: G4
Turbocharger(s): Nos.: 1	Serial No.	No. of cyl.: 6	Bore (m): 0,35	Stroke (m): 1,400
Make: MAN 1	1192189	Cylinderconstant (kW,bar): 0,2245		TCS power (kW):
Type: NA40/SO1077 2		Governor: Woodward	Type: PGA 58	
Max. RPM: 21.400 3		TC specification: AD=221,0cm² A_dK=168,3 cm²		
Max. temp. °C: 620 4		MFP: 1,15	Compr. slip factor: 0,70	Compr. diameter: 0,4800
T/C lub. oil system (Tick box):	Internal system ■	External from M.E. syst. ☐	External from gravity tank ☐	
Humidity-rel % 43,6 at 28 °C			Brand	Type
Bunker station Q8 Aalborg		Cylinder oil	BP	CL505
Oil brand Q8 Diesel	Heat value kCal/kg: 10224	Circulating oil	BP	Energol OE-HT30
Density at 15 °C: 0,8432	Sulphur %: 0,04	Turbo oil	BP	Energol OE-HT30

Date (yymmdd)	Hour (hh:mm)	Brake Load kNm	RPM	g/kWh indicated	Pi bar			Pmax bar			Pcomp bar			Fuel pump index		
					1	2	3	1	2	3	1	2	3	1	2	3
05-07-21	11:03	184	173	168,36	15,44	15,54	15,22	117	118	115	86	87	86	45	45	44
η mech.		Speed setting bar	kW indicated		4	5	6	4	5	6	4	5	6	4	5	6
					15,36	15,71	15,57	116	116	115	87	86	85	45	45	45
					7	8	9	7	8	9	7	8	9	7	8	9
0,92		4,60	3606													
Load %		Gov.nor index	kW eff.	g/kWh effective	10	11	12	10	11	12	10	11	12	10	11	12
75		5,2	3330	182,30	Average		15,47	Average		116	Average		86	Average		45
Barom. millibar				Fuel oil Cons. kg/h				Ref.Pmax:	117	(bar)						
997				607												

Pmax. adjustment shims			Exhaust gas temp. °C: Exhaust valve			Turbine Inlet	Turbine Outlet	Exh.press Receiver	Turb. outlet mmWC	Turbocharger RPM	Scav. air pressure: Δp Filter mmWC	Δp Cooler mmWC	Receiver	Scav. air temp. °C: Inlet Blower	Before Cooler	After Cooler	Auxiliary blower
1	2	3	1	2	3	1	1	bar	1	1	1	1	bar	1	1	1	on
5	5	5	370	380	380	435	0	1,68	110	17100	0	190	1,90	36,0	160	32	
4	5	6	4	5	6	2	2	mmHg	2	2	2	2	mmHg	2	2	2	off
5	5	5	380	365	360			1260					1425				X
7	8	9	7	8	9	Digi 1	Digi 1		3	3	3	3	°C	3	3	3	
						414	279						42				
10	11	12	10	11	12	Digi 2	Digi 2	Local	4	4	4	4	Local	4	4	4	
								1,66					1,85				
Average		5,0	Average		373	414	279	bar	110	17100	0	190	bar	36,0	160	32	

Cooling water Pressure [bar] LT	HT	Cooling water temperature °C: Air cooler Inlet	Air cooler Outlet	Main engine Inlet	Outlet cylinders			Turb. Outlet	Lubricating oil: Press. bar	Temperature °C: Inlet	Outlet pistons			Turbochargers		Fuel oil pressure bar
LT	HT	1	1		1	2	3	1	System oil	Inlet engine	1	2	3	MAN inlet/ BBC blower inlet/	MAN outlet/ ABB turbine outlet/	Before filter
2,3	2,7	27	40	68	83	82	82	0	2,3	45	55	55	55			
	▲P	2	2		4	5	6	2			4	5	6			
	0,64				82	82	83		Cool. oil	Inlet camsh.	56	56	55			After filter
Flow [m³/h]		3	3		7	8	9	3			7	8	9			8,1
LT	HT															
88	48	4	4		10	11	12	4	Exh.V	Outlet camsh.	10	11	12	1	1	Temp. °C Before pumps
															52	
					Average		82				Average		55	2	2	38
									Turb. oil	Thrust segm.	Flow [m³/h]			3	3	
									2,0	46	87,00					
														4	4	

Governor.	Temp.:	Oil.: OE-HT 30

Axial vibration monitor.:	0,63

Remarks: Exhaust temp reciever: °C

Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W	D.E.: S35MC	Water brake: Z14	No.: 2778		TEST BED
	No.: 37075	Yard: Sonay 2			
Layout kW: 4440	RPM: 173	Date: 21-07-2005	Sign: LWP		Test no: G5
Turbocharger(s):	Nos.: 1 / Serial No.	No. of cyl.: 6	Bore (m): 0,35		Stroke (m): 1,400
Make: MAN	1 / 1192189	Cylinderconstant (kW,bar): 0,2245		TCS power (kW):	
Type: NA40/SO1077	2	Governor: Woodward		Type: PGA 58	
Max. RPM: 21.400	3	TC specification: AD=221,0cm² A_4K=168,3 cm²			
Max. temp. °C: 620	4	MFP: 1,15	Compr. slip factor: 0,70	Compr. diameter: 0,4800	
T/C lub. oil system (Tick box):	Internal system ■	External from M.E. syst. ☐	External from gravity tank ☐		
Humidity-rel % 47,6	at 27 °C			Brand	Type
Bunker station	Q8 Aalborg		Cylinder oil	BP	CL505
Oil brand Q8 Diesel	Heat value kCal/kg: 10224		Circulating oil	BP	Energol OE-HT30
Density at 15 °C: 0,8432	Sulphur %: 0,04		Turbo oil	BP	Energol OE-HT30

Date (yymmdd)	Hour (hh:mm)	Brake Load kNm	RPM	g/kWh indicated
05-07-21	12:02	121	173	171,23
η mech.		Speed setting bar	kW indicated	
0,90		4,60	2422	
Load %		Gov.nor index	kW eff.	g/kWh effective
49		3,9	2190	189,40
Barom. millibar				Fuel oil Cons. kg/h
998				415

Cyl.	Pi bar	Pmax bar	Pcomp bar	Fuel pump index
1	10,37	83	59	32
2	10,42	84	59	32
3	10,20	83	59	32
4	10,24	82	59	32
5	10,67	83	59	33
6	10,47	82	58	32
7				
8				
9				
10				
11				
12				
Average	10,40	83	59	32

Ref.Pmax: 84 (bar)

Cyl.	Pmax. adjustment shims	Exhaust gas temp. °C Exhaust valve
1	5	350
2	5	360
3	5	360
4	5	350
5	5	350
6	5	350
7–12		
Average	5,0	353

	Turbine Inlet °C	Turbine Outlet °C	Exh.press Receiver	Turb. outlet mmWC	Turbocharger RPM	Δp Filter mmWC	Δp Cooler mmWC	Scav. air pressure Receiver	Scav. air temp. Inlet Blower °C	Before Cooler °C	After Cooler °C	Auxiliary blower
1	415	0	bar 0,83	35	13426	0	105	bar 1,00	36,4	110	26	on
2			mmHg 623					mmHg 750				off X
3 / Digi 1	397	306						°C 33				
4 / Digi 2 / Local			0,82					0,98				
Average	397	306	bar	35	13426	0	105	bar	36,4	110	26	

Cooling water Pressure [bar] LT	HT	Air cooler Inlet	Air cooler Outlet	Main engine Inlet	Outlet cylinders	Turb. Outlet
2,3	2,7	1: 24	1: 30	70	1: 81, 2: 82, 3: 82	1: 0
	ΔP 0,64	2:	2:		4: 82, 5: 82, 6: 82	2:
Flow [m³/h] LT 84	HT 48	3: , 4:	3: , 4:		7–12:	3: , 4:
					Average 82	

Lubricating oil Press. bar		°C		Outlet pistons		Turbochargers MAN inlet/ BBC blower inlet/	MAN outlet/ ABB turbine outlet/
System oil	2,2	Inlet engine	45	1: 54, 2: 55, 3: 55		1:	1: 46
Cool. oil	2,2	Inlet camsh.	45	4: 55, 5: 55, 6: 54		2:	2:
Exh.V oil	2,2	Outlet camsh.		7–12:		3:	3:
Turb. oil	2,0	Thrust segm.	46	Flow [m³/h] 86,30	Average 55	4:	4:

Fuel oil pressure bar	
Before filter	
After filter	8,4
Temp. °C Before pumps	40

Governor.	Temp.:	Oil.: OE-HT 30
Axial vibration monitor.:	0,59	

Remarks: Exhaust temp reciever: °C

Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W	D.E.: S35MC	Water brake: Z14	No.: 2778	TEST BED
	No.: 37075	Yard: Sonay 2		
Layout kW: 4440	RPM: 173	Date: 21-07-2005	Sign: LWP	Test no: G6
Turbocharger(s): Nos.: 1	Serial No.	No. of cyl.: 6	Bore (m): 0,35	Stroke (m): 1,400
Make: MAN	1 1192189	Cylinderconstant (kW,bar): 0,2245		TCS power (kW):
Type: NA40/SO1077	2	Governor: Woodward	Type: PGA 58	
Max. RPM: 21.400	3	TC specification: AD=221,0cm² A_4K=168,3 cm²		
Max. temp. °C: 620	4	MFP: 1,15	Compr. slip factor: 0,70	Compr. diameter: 0,4800
T/C lub. oil system (Tick box):	Internal system ■	External from M.E. syst. ☐	External from gravity tank ☐	

			Brand	Type
Humidity-rel % 48,3	at 28 °C			
Bunker station	Q8 Aalborg	Cylinder oil	BP	CL505
Oil brand Q8 Diesel	Heat value kCal/kg: 10224	Circulating oil	BP	Energol OE-HT30
Density at 15 °C: 0,8432	Sulphur %: 0,04	Turbo oil	BP	Energol OE-HT30

Date (yymmdd)	Hour (hh:mm)	Brake Load kNm	RPM	g/kWh indicated
05-07-21	12:40	59,6	174	165,12
η mech.		Speed setting bar	kW indicated	
0,83		4,60	1307	
Load %		Gov.nor index	kW eff.	g/kWh effective
25		2,3	1090	198,00
Barom. milli-bar				Fuel oil Cons. kg/h
998				216

Cyl.	Pi bar	Pmax bar	Pcomp bar	Fuel pump index
1	5,58	52	39	18
2	5,53	52	40	18
3	5,54	52	39	18
4	5,49	52	39	18
5	5,68	52	39	19
6	5,64	51	39	18
7				
8				
9				
10				
11				
12				
Average	5,58	52	39	18

Ref.Pmax: 53 (bar)

Cyl.	Pmax. adjustment shims	Exhaust gas temp. °C Exhaust valve
1	5	335
2	5	330
3	5	320
4	5	310
5	5	330
6	5	320
7		
8		
9		
10		
11		
12		
Average	5,0	324

	Turbine Inlet	Turbine Outlet	Exh.press Receiver	Turb. outlet mmWC	Turbo-charger RPM	Scav. air Δp Filter mmWC	Scav. air Δp Cooler mmWC	Scav. air Receiver	Scav. air temp. Inlet Blower	Before Cooler	After Cooler	Auxiliary blower
1	380	0	bar 0,25	3	7900	0	40	bar 0,31	35,0	60	23	on X
2			mmHg 188					mmHg 233				off
Digi 1 / 3	365	318						°C 38				
Digi 2 / 4			Local 0,22					Local 0,3				
Average	365	318	bar	3	7900	0	40	bar	35,0	60	23	

Cooling water Pressure [bar] LT	HT	Air cooler Inlet	Air cooler Outlet	Main engine Inlet	Outlet cylinders	Turb. Outlet
2,3	2,7	1: 23	1: 25	72	1: 80, 2: 82, 3: 82	1: 0
	▲P 0,64	2	2		4: 81, 5: 82, 6: 82	2
Flow [m³/h] LT 84	HT 48	3	3		7, 8, 9	3
		4	4		10, 11, 12	4
					Average 82	

Lubricating oil	Press. bar	Temperature °C	Outlet pistons	Turbochargers MAN inlet/BBC blower inlet/	MAN outlet/ABB turbine outlet/
System oil	2,2	Inlet engine 44	1: 53, 2: 54, 3: 53		
Cool. oil		Inlet camsh.	4: 53, 5: 54, 6: 53		
Exh.V oil		Outlet camsh.	7, 8, 9	1	1: 44
			10, 11, 12	2	2
			Average 53	3	3
				4	4

Fuel oil pressure bar	
Before filter	
After filter	8,8
Temp. °C Before pumps	44

Governor.	Temp.:	Oil.: OE-HT 30

Axial vibration monitor.:	0,69

Turb. oil	Thrust segm.	Flow [m³/h]
2,0	46	87,00

Remarks: Exhaust temp reciever: °C

Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

		IMO Technical File	
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4	← Identification No. → 0 xx xx xx-x
Suppl. Drwg.:			Page No.: E3-1

Date	Des.	Chk.	Appd.	A.C.	Change/Replacement	C. No.
2004-06-15	SVH		SVH	–		1

Enclosure 3

E2 Cycle – Summary Emission Data (Parent engine)

Test no		**1P100**	**1G75**	**2G50**	**3G25**
Date		2004-04-19	2004-04-19	2004-04-19	2004-04-19
Load	%	**100**	**75**	**50**	**25**
Engine power	kW	4440	3340	2220	1091
Engine speed	r/min	173.0	173.0	173.0	173.0
Sample cooler temperature	°C	5.0	5.0	5.0	5.0
Gas sample temperature	°C	190	190	190	190
Ambient Condition					
Back ground CO2 (assumed)	%	0.04	0.04	0.04	0.04
Measured values					
O2 (dry)	%	14.20	14.90	14.90	15.50
CO2 (dry)	%	4.90	4.50	4.50	4.10
CO (dry)	ppm	76	83	102	114
NOx (wet)	ppm	1001	1000	828	609
HC (wet)	ppmC1	130	173	155	165
Corrected to dry 15%O2					
CO2	%	4.27	4.26	4.27	4.28
CO	ppm	67	80	98	121
NOx	ppm	922	1010	837	677
HC	ppmC1	119	175	157	183
SO2 (calculated)	ppm	9.2	9.2	9.2	9.3
H2O (calculated)	%	5.45	5.02	5.03	4.70
Specific emission					
O2	g/kWh	1245.6	1415.6	1450.6	1766.0
CO2	g/kWh	595.2	586.9	601.9	639.6
CO	g/kWh	0.594	0.705	0.883	1.154
NOx (as NO2)	g/kWh	13.43	14.54	12.33	10.58
HC (as CH4)	g/kWh	0.606	0.877	0.804	0.997
SO2 (calculated)	g/kWh	0.187	0.184	0.189	0.201
H2O (calculated)	g/kWh	286.1	285.9	293.3	319.5
Air amount					
Oxygen based	kg/kWh	8.24	9.06	9.27	10.87
Carbon based	kg/kWh	8.11	8.70	8.92	10.38
Used for calculation	kg/kWh	8.18	8.88	9.09	10.63
Exhaust gas amount	kg/h	37132	30271	20607	11813

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

		IMO Technical File				
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4				← Identification No. → 0 xx xx xx-x
Suppl. Drwg.:						Page No.: E3-1

Date	Des.	Chk.	Appd.	A.C.	Change/Replacement	C. No.
2004-06-15	SVH		SVH	–		1

Enclosure 3

E2 Cycle – Summary Emission Data (Parent engine)

Test no		**1P100**	**1G75**	**2G50**	**3G25**
Date		2004-04-19	2004-04-19	2004-04-19	2004-04-19
Load	%	**100**	**75**	**50**	**25**
Engine power	kW	4440	3340	2220	1091
Engine speed	r/min	173.0	173.0	173.0	173.0
Sample cooler temperature	°C	5.0	5.0	5.0	5.0
Gas sample temperature	°C	190	190	190	190
Ambient Condition					
Back ground CO2 (assumed)	%	0.04	0.04	0.04	0.04
Measured values					
O2 (dry)	%	14.20	14.90	14.90	15.50
CO2 (dry)	%	4.90	4.50	4.50	4.10
CO (dry)	ppm	76	83	102	114
NOx (wet)	ppm	1001	1000	828	609
HC (wet)	ppmC1	130	173	155	165
Corrected to dry 15%O2					
CO2	%	4.27	4.26	4.27	4.28
CO	ppm	67	80	98	121
NOx	ppm	922	1010	837	677
HC	ppmC1	119	175	157	183
SO2 (calculated)	ppm	9.2	9.2	9.2	9.3
H2O (calculated)	%	5.45	5.02	5.03	4.70
Specific emission					
O2	g/kWh	1245.6	1415.6	1450.6	1766.0
CO2	g/kWh	595.2	586.9	601.9	639.6
CO	g/kWh	0.594	0.705	0.883	1.154
NOx (as NO2)	g/kWh	13.43	14.54	12.33	10.58
HC (as CH4)	g/kWh	0.606	0.877	0.804	0.997
SO2 (calculated)	g/kWh	0.187	0.184	0.189	0.201
H2O (calculated)	g/kWh	286.1	285.9	293.3	319.5
Air amount					
Oxygen based	kg/kWh	8.24	9.06	9.27	10.87
Carbon based	kg/kWh	8.11	8.70	8.92	10.38
Used for calculation	kg/kWh	8.18	8.88	9.09	10.63
Exhaust gas amount	kg/h	37132	30271	20607	11813

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Appendix 1. M.A.N. B&W S35MC Model Main Engine Test Bench Report.

MAN B&W Diesel A/S

	IMO Technical File						
MBD Info No. 3 00 044	A 4	Engine Type 6S35MC, Plant spec 908926-4				← Identification No. → 0 XX XX XX-X	
Suppl. Drwg.:						Page No.: E3-2	
Date	Des.	Chk.	Appd.	A.C.	Change/Replacement		C. No.
2004-06-15	SVH		SVH	–			1

E2 Cycle – Summary Performance Data **(Parent engine)**

Test no		**1P100**	**1G75**	**2G50**	**3G25**
Date		2004-04-19	2004-04-19	2004-04-19	2004-04-19
Time		9:47	14:09	14:42	15:18
Load	%	**100**	**75**	**50**	**25**
Engine power	kW	4440	3340	2220	1091
Engine speed	r/min	173.0	173.0	173.0	173.0
Ambient pressure	mbar	996	1000	1000	1000
Ambient temperature	°C	24.0	26.0	26.2	27.0
Ambient relative humidity	%	36.7	31.8	31.4	30.6
Scavenge-air pressure	bara	3.78	2.92	2.02	1.34
Cylinder maximum pressure	bara	144.0	120.0	85.0	54.0
Cylinder compression press.	bara	121.0	94.0	63.0	43.0
MEP pressure	bar				
Exhaust gas pressure	bara	3.50	2.71	1.86	1.03
Turbine back pressure	mmWC	270	180	85	10
Central cooler, coolant inlet temp. (or sea-water temperature)	°C	25.0	25.0	25.0	25.0
Air cooler, coolant inlet temp	°C	25.0	25.0	25.0	25.0
Air cooler, coolant outlet temp.	°C	49.0	41.0	32.0	27.0
Compressor inlet temp.	°C	24.7	25.4	25.8	26.0
Scavenge-air temp. (receiver)	°C	42	35	30	37
Cylinder exhaust temp.	°C	412	373	359	320
Turbine inlet temp.	°C	451	399	389	348
Turbine outlet temp.	°C	284	276	303	302
Turbocharger speed	r/min	19000	16600	13300	8100
SFOC (actual)	g/kWh	187.09	184.67	189.40	201.33

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Appendix 2. M.A.N. B&W D 2876 Model Diesel Generator Test Bench Report.

MAN

Page 2 Work no. 5684708 / 3

1.) Technical data of engine:

Rated power	345	kW
Rated speed	1500	rpm
Compression ratio	15,5:1	-
Bore	128	mm
Stroke	166	mm
Mean effective pressure	21,5	bar
Start of delivery	13 Grad V.O.T.	Degree BTDC(±1°)
Specific fuel consumption	215	g/kWh
Exhaust-gas temperature	435	°C
Exhaust-gas mass flow	1735	kg/h
Actual NOx value of parent engine	8,9	g/kWh
Combustion cycle	4-stroke	-
Cooling medium	Water	-
Piston displacement	-	-
No. of cylinders	6	-
Cylinder configuration	Inline	-
Type of aspiration	Turbocharged intercooled	-
Type of fuel	Distillate ISO8217	-
Combustion chamber	Open	-
Valve	Cylinder head	-
Type of fuel system	Pump-line-injector	-
Other features	none	-

2.) Fuel injection system

2.1) Fuel injection nozzle

Type	MAN Identification no.	Identification procedure
ROBERT BOSCH GMBH	51.10100-7407	See item 6.5

2.2) Fuel injection pump

Type	MAN Identification no.	Identification procedure
BOSCH ROBERT GMBH	51.11103-7700	See item 6.2

Appendix 2. M.A.N. B&W D 2876 Model Diesel Generator Test Bench Report.

MAN

Page 15 Work no. 5684708 / 3

Emissions Test Report No. ..1...D 2.....

Ambient and Gaseous Emissions Data* **Sheet 4/5**

Mode		1	2	3	4	5	6	7	8	9	10
Power / Torque	%	100	75	50	25	10					
Speed	%	100	100	100	100	100					
Time at beginning of mode		8:30	8:55	9:15	9:30	9:45					
Ambient Data											
Atmosph. pressure	mbar	986	986	986	986	986					
Intake air temp.	°C	24,2	23,6	24,3	24,5	24,7					
Intake air humidity	g/kg %	28	28	28	28	28					
Atmospheric factor (fa)		1,004	1,004	1,004	1,004	1,004					
Gaseous Emissions Data											
NOx conc. dry/wet	ppm	1130	1088	895	502	238					
CO conc. dry/wet	ppm	385	250	135	252	328					
CO2 conc. dry/wet	%	8,3	7,7	6,6	4,4	2,9					
O2 conc. dry/wet	%	9,5	10,4	12	15,1	17,6					
HC conc. dry/wet	ppm	42,9	27	35	77	49					
NOx hum.corr.factor	KHDIS	0,94	0,94	0,94	0,94	0,94					
Fuel spec.factor (FFH)		1,85	1,85	1,86	1,88	1,89					
Dry/wet corr.factor	KWR	0,92	0,92	0,93	0,95	0,96					
NOx mass flow	kg/h	4,15	3,25	2,15	1,06	0,46					
CO mass flow	kg/h	0,92	0,48	0,21	0,34	0,41					
CO2 mass flow	kg/h	311,7	234,4	161,5	94,1	56,4					
O2 mass flow	kg/h	259,6	230,4	213,6	234,9	249,2					
HC mass flow	kg/h	0,055	0,028	0,028	0,054	0,076					
SO2 mass flow	kg/h	- - -	- - -	- - -	- - -	- - -					
NOx specific	g/kWh	8,64	9,00	8,91	8,73	9,33					

* If applicable

Appendix 2. M.A.N. B&W D 2876 Model Diesel Generator Test Bench Report.

MAN

Page 15 Work no. 5684708 / 3

Emissions Test Report No. ..1...D 2.....

Ambient and Gaseous Emissions Data* **Sheet 4/5**

Mode		1	2	3	4	5	6	7	8	9	10
Power / Torque	%	100	75	50	25	10					
Speed	%	100	100	100	100	100					
Time at beginning of mode		8:30	8:55	9:15	9:30	9:45					
Ambient Data											
Atmosph. pressure	mbar	986	986	986	986	986					
Intake air temp.	°C	24,2	23,6	24,3	24,5	24,7					
Intake air humidity	g/kg %	28	28	28	28	28					
Atmospheric factor (fa)		1,004	1,004	1,004	1,004	1,004					
Gaseous Emissions Data											
NOx conc. dry/wet	ppm	1130	1088	895	502	238					
CO conc. dry/wet	ppm	385	250	135	252	328					
CO2 conc. dry/wet	%	8,3	7,7	6,6	4,4	2,9					
O2 conc. dry/wet	%	9,5	10,4	12	15,1	17,6					
HC conc. dry/wet	ppm	42,9	27	35	77	49					
NOx hum.corr.factor	KHDIS	0,94	0,94	0,94	0,94	0,94					
Fuel spec.factor (FFH)		1,85	1,85	1,86	1,88	1,89					
Dry/wet corr.factor	KWR	0,92	0,92	0,93	0,95	0,96					
NOx mass flow	kg/h	4,15	3,25	2,15	1,06	0,46					
CO mass flow	kg/h	0,92	0,48	0,21	0,34	0,41					
CO2 mass flow	kg/h	311,7	234,4	161,5	94,1	56,4					
O2 mass flow	kg/h	259,6	230,4	213,6	234,9	249,2					
HC mass flow	kg/h	0,055	0,028	0,028	0,054	0,076					
SO2 mass flow	kg/h	- - -	- - -	- - -	- - -	- - -					
NOx specific	g/kWh	8,64	9,00	8,91	8,73	9,33					

* If applicable

Appendix 2. M.A.N. B&W D 2876 Model Diesel Generator Test Bench Report.

MAN

Page 16 Work no. 5684708 / 3

Emissions Test Report No. ..1...D 2....... **Engine Test Data*** **Sheet 5/5**

Mode		1	2	3	4	5	6	7	8	9	10
Power / Torque	%	100	75	50	25	10					
Speed	%	100	100	100	100	100					
Time at beginning of mode		8:30	8:55	9:15	9:30	9:45					
Engine Data											
Speed	rpm	1800	1800	1800	1800	1800					
Auxiliary power	kW	481	361	241	121	49					
Dyno setting	kW										
Power	kW										
Mean eff. pressure	bar	14,6	11,0	7,3	3,7	1,5					
Fuel rack	mm	---	---	---	---	---					
uncorr.spec.fuel cons.	g/kWh	207	207	213	249	371					
Fuel flow	kg/h	99,5	74,7	51,4	30,1	18,2					
Air flow GAIRD	kg/h	2571	2075	1658	1442	1314					
Exhaust flow (gexhw)	kg/h	2687,7	2167	1724,7	1478	1327					
Exhaust temp.	°C	396	360	307	227	172					
Exhaust backpress.	mbar	---	---	---	---	---					
Cyl.Coolant temp. out	°C	80,6	78,8	75,7	72,5	70,5					
Cyl.Coolant temp. in	°C	77,6	77,1	74,6	71,7	69,8					
Cyl.Coolant pressure	bar	---	---	---	---	---					
Temp. intercooled air	°C	50,4	45,3	40,8	37,6	33,9					
Charge air pressure	mbar	1,08	0,68	0,36	0,16	0,08					
Lubricant temp.	°C	80,4	80,4	80,4	80,4	80,4					
Lubricant pressure	bar	4,75	5,0	5,4	5,9	6,15					
Inlet depression	mbar	---	---	---	---	---					

* If applicable

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PUBLICATIONS/PRESENTATIONS ON THE THESIS

SCI / SCI-Expanded / SSCI / AHCI Scope Journal

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