UNIVERSITAS INDONESIA

HEAT EXCHANGER MODELING FOR CUMMINS ENGINE

(COIL COPPER TUBE)

SKRIPSI

TENGKU ADITYA PRIANDANA

0405820037

FAKULTAS TEKNIK

PROGRAM TEKNIK MESIN

DEPOK

NOVEMBER 2009

UNIVERSITAS INDONESIA

HEAT EXCHANGER MODELING FOR CUMMINS ENGINE

(COIL COPPER TUBE)

SKRIPSI

Diajukan sebagai salah satu syarat untuk memperoleh gelar Sarjana Teknik

TENGKU ADITYA PRIANDANA

0405820037

FAKULTAS TEKNIK

PROGRAM STUDI TEKNIK MESIN

KEKHUSUSAN PROGRAM INTERNASIONAL

DEPOK

NOVEMBER 2009

STATEMENT OF AUTHORSHIP

Name:

Tengku Aditya Priandana

Address:

1104/30 Tank Street, Brisbane, Queensland 4000

Title of Report:

Heat Exchanger Modeling for Cummins Engine (Coil Copper Tube)

Principal Supervisor:

Dr. Richard Brown

This report is submitted as required for the Project in accordance with the unit BEB801-BEB 802 rules laid down by the Faculty Advisory Committee and the University Academic Board of Queensland University of Technology as part of the requirements for the award of the degree of Bachelor of Engineering.

I declare that the work presented in this report is my own work except where due reference or acknowledgement is given to the work of others.

Signature

of Student: ____________________ Date: ________________

ABSTRACT

This report deals with the heat exchanger modeling for the Cummins engine. The engine is used in dual fuel project that ongoing at Queensland University of Technology, interested in developing and optimizing a dual fuel engine developed by Uli Kruger. The design being calculated and designed to achieved appropriate heat exchanger that will be used at the engine. The heat exchanger need to provide sufficient heat transfer energy that required to vaporize the ethanol. The limited space that available to install the heat exchanger also needs to be considered. To overcome the requirement, student tried to calculate and design a copper tube coil heat exchanger. Beside heat exchanger, this report also determines the hazard and safety issues not only during the dual fuel engine test campaign but also when services and modification are carry out

Keywords: Heat exchanger, copper coil tube, dual fuel engine, Cummins engine, safety, risk assessment

EXECUTIVE SUMMARY

Tugas akhir yang dikerjakan oleh penulis fokus pada eksperimen mesin dengan menggunakan dua jenis bahan bakar, yaitu diesel atau solar dan ethanol. Diesel atau solar digunakan sebagai bahan bakar utama sedangkan ethanol digunakan sebagai bahan bakar sekunder. Selain eksperimen tersebut penulis juga mendisain dan modeling untuk heat exchanger dan juga tentang hazard and risk assessment terhadap eksperimen yang dilakukan. Tugas akhir ini secara keseluruhan diawasi oleh Richard Brown.

Tujuan dan Objektif

Tujuan utama dari tugas akhir ini adalah untuk mendisain heat exchanger yang tepat dan cocok untuk digunakan pada mesin eksperimen, yaitu mesin diesel dengan merek Cummins. Heat exchanger yang didisain ini harus dapat bekerja efektif untuk memanaskan udara yang diperlukan untuk memanaskan ethanol menjadi uap secara keseluruhan. Spek data dan juga hasil eksperimen dari mesin Cummins digunakan untuk membantu perhitungan dalam mendisain heat exchanger yang tepat bagi mesin ini. Perhitungan yang digunakan untuk mendisain heat exchanger ini digunakan berdasarkan buku-buku dan sumber lain yang tepat untuk mendisain heat exchanger.

Objektif lain dari tugas akhir ini adalah untuk menentukan faktor bahaya dan keselamatan (hazard, risk, and safety assessment) selama eksperimen menggunakan mesin dual bahan bakar ini. Penulis harus mengamati dan menganalisa berbagai macam bahaya dan risiko yang dapat mungkin timbul dalam eksperimen. Hazard dan risk assessment harus dilakukan tidak hanya ketika mesin tersebut sedang digunakan dalam eksperimen tetapi juga ketika sedang diperbaiki maupun ketika sedang ada penambahan dan modifikasi yang dilakukan.

Objektif terakhir yang harus dilakukan penulis adalah untuk menganalisa dan menjelaskan secara keseluruhan data hasil dari eksperimen yang dilakukan pada saat eksperimen mesin diesel pada saat bulan oktober. Penulis juga harus menjelaskan masalah apa saja yang muncul pada saat eksperimen tersebut dilakukan.

Heat Exchanger Modelling

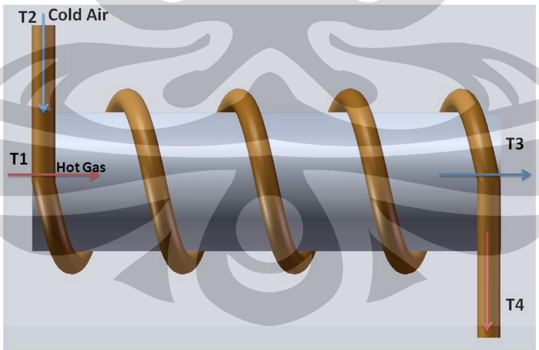
Heat Exchanger

Heat exchanger adalah alat yang digunakan untuk mempermudah perpindahan panas atau kalor antara dua jenis objek yang masing-masing memiliki suhu yang berbeda. Objek tersebut bisa saja udara, fluid, atau pun yang lainnya. Heat exchanger juga bertindak sebagai pembatas atau penghalang agar dua objek tersebut tidak bercampur satu denga yang lain. Perpindahan kalor dalam heat exchanger dapat secara konveksi maupun konduksi tergantung jenis objek apa yang digunakan. Objek yang digunakan dalam tugas akhir ini adalah udara bebas dengan suhu ruangan dan udara panas dari gas buang knalpot. Fungsi yang diharapkan dari heat exchanger ini adakah untuk memberikan panas yang sesuai sehingga cukup untuk memanaskan ethanol hingga mencapai titip penguapan dan dapat menguap sepenuhnya.

Disain Heat Exchanger

Coil Copper Tube

Disain yang digunakan dalam heat exchanger ini adalah pipa tembaga yang dililitkan mengelilingi pipa knalpot, didalam pipa tembaga mengalir udara dengan suhu ruangan yang dialirkan oleh kompresor sedangkan gas buang panas mengalir didalam pipa knalpot. Desain tersebut dapat dilihat pada gambar dibawah ini.



Keuntungan dari menggunakan disain ini adalah disain coil copper tube dapat digunakan ditempat yang memiliki luas terbatas. Heat exchanger ini dapat mencapai energi perpindahan kalor yang diperlukan untuk memanaskan ethanol tanpa menggunakan ruang yang besar. Ada beberapa parameter yang perlu dihitung dan ditentukan untuk menentukan energi perpindahan kalor yang diperlukan untuk menguapkan ethanol tersebut. Pertama kita harus menentukan ruang yang tersedia untuk instalasi heat exchanger tersebut dan dimensi yang tepat. Setelah itu kita harus menghitung kecepatan udara, Reynolds Number, Nusselts Number, koefisien perpindahan kalor, dan juga volume flow rate.

Karena heat exchanger ini terdiri dari dua pipa jadi harus dianggap sebagai dua buah pipa yang berbeda. Tiap pipa memiliki dimensi dan parameter yang berbeda yang harus dihitung masing-masing untuk mendisain heat exchanger ini.

Dimensi dan Parameter

Pipa Knalpot (Pipa Bagian Dalam)

$$D_i = Diameter\ bagian\ dalam = 0.0762\ metre$$

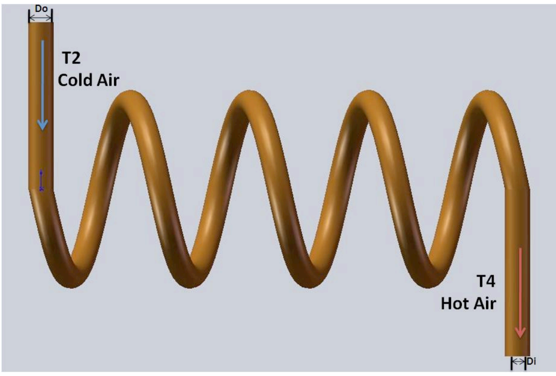
$$D_o = Diameter\ bagian\ luar = 0.0889\ metre$$

$$Temperature = 400°C\ (at\ 2500\ RPM)$$

$$= 525°C\ (at\ 1500\ RPM)$$

$$Tekanan = 2.5\ bar$$

Pipa Tembaga (Pipa Bagian Luar)



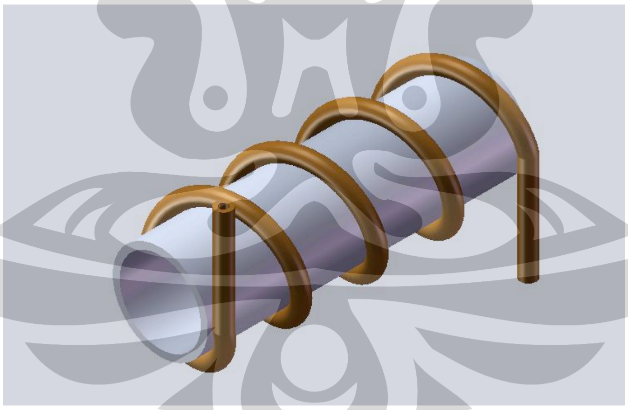
$$D_i = Diameter\ bagian\ dalam = 0.008\ metre$$

$$D_o = Diameter\ bagian\ dalam = 0.015\ metre$$

$$Inlet\ Temperature = 30°C$$

$$Tekanan = 1\ ATM$$

Disain secara keseluruhan



Kesimpulan

The objectified that need to be achieved could be attained. The copper tube coiled design could meet the required energy and temperature to heat and evaporate the ethanol. Each load at different speed required different wrapped of copper. Since the maximum wrapped need is 3.9, to make the fabrication and installation it rounded up to 4 wrapped. In general this copper tube coil could accomplish the requirement to gain sufficient energy to vaporize the ethanol in the limited available space.

Target objektif yang ditentukan berhasil dicapai, karena disain menggunakan pipa tembaga dapat mencapai energi perpindahan kalor yang diperlukan untuk memanaskan dan menguapkan ethanol. Tiap rpm pada mesin Cummins memerlukan jumlah lilitan pipa tembaga yang berbeda. Berdasarkan perhitungan yang dilakukan, yang dapat dilihat selengkapnya didalam laporan, jumlah lilitan terbanyak adalah 3,9 tetapi untuk memudahkan pemasangan makan dibulatkan menjadi 4 lilitan pipa tembaga. Secara perhitungan teoritis disain lilitan pipa tembaga ini dapat memenuhi kebutuhan energi perpindahan kalor yang diperlukan dalam ruang yang terbatas utuk pemasangan heat exchanger ini.

ACKNOWLEDGEMENT

To complete this thesis, student want to show appreciation goes to project supervisor Dr. Richard Brown who gave an opportunity to join his team and contribute to the project of Optimization of Dual Fuel Compression Ignition (Diesel) Engines with Respect to Heat Exchanger Modeling for Cummins Engine (Coil Copper Tube).

Furthermore, Student would like to thank Dr. Rong Situ for his inspirational advice, practical support and clear guidelines which directed to the right thinking pathway; Mr Tony Morris for his professional advice regarding the application of information and data from his past experiences; and Mr Glen Gerry for his generous assistance in conducting the risk assessment and also his help during the entire project. To Wirawan, Wendy Acno, Steven Herdy, and other colleagues also friends at the dual fuel engine team, student would like to show gratitude for their help and support during the project happened.

Last but not the least; a vote of thanks must be given to student family for the support throughout the time when working on the thesis with their patience and understanding.

Without all their patience and support, this thesis will not be as outstanding as it is.

Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION

The project that student done focused in dual-fuel engine experiment with diesel as the primary fuel and ethanol as the secondary fuel, modeling heat exchanger, and hazard and risk assessment. This project is supervised by Richard Brown.

1.1 Background

Biofuel is the name of a clean burning alternative fuel, produced from domestic, renewable resources. Biofuel contains no petroleum, but it can be blended at any level with petroleum fuel to create a biofuel blend. It can be used in compression-ignition engines with little or no modifications. Biofuel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics.

Biofuel carbon is better than fossil fuel carbon because in principle it does not lead to a net increase in atmospheric carbon concentrations. The biofuel carbon released to the atmosphere was originally derived though photosynthesis that used CO2 from today's atmospheric carbon sinks. Fossil fuels on the other hand increase atmospheric CO2 because the carbon is from prehistoric carbon matter that over time and under high pressures accumulated in the form of oil, coal, and natural gasoline. It can be said that the carbon of fossil fuels comes from a separate, older sink than the terrestrial and atmospheric sinks and therefore leads to net increases in the atmospheric sink.

1.2 Aims and Objectives

The main aim of this project is design an appropriate heat exchanger for Cummins engine. The heat exchanger should be work effectively to heat up the air that requires to vaporized the ethanol properly. The heat exchanger will be design with theoretical calculation that aid by the data that got from the engine baseline test. The modeling calculations will be derived theoretically according to the suitable books and other sources. The heat exchanger hopefully can work properly with the engine and can provide enough energy to heat up the ethanol into the required temperature.

Another objective is to determine the hazard and safety issues during the dual fuel engine test campaign. Student need to examine and analyze the various dangers and risk that could occur in testing an engine. The hazard and risk assessment need to be done not only when the engine run but also when services and modification are carry out.

The last objective is to show the result of October dual-fuel engine testing campaign. Student need to analyze data and explain clearly the result that achieve from the engine testing. Beside that the student need to identify any problem that encounter during that testing.

2.0 BACKGROUND AND LITERATURE REVIEW

2.1 Diesel Engine

The internal combustion engine that operates using diesel cycle is called diesel engine. Diesel engine known to have the highest thermal efficiency among any other internal and external engine due to their compression ratio. The defining feature of the diesel engine is the use of the heat of compression to initiate ignition to burn the fuel, which is injected into the combustion chamber during the final stage of compression. The diesel engine first founded by Rudolf Diesel in 1982. The diesel engine can be classified into two-stroke and four-stroke operating cycle. At the four-stroke engine, the four stages can be defined as intake, compression, power,and exhaust stroke. Diesel engine has been revolutionized in the last decade. Although the designs of the petrol and diesel engine are similar (both 2 strokes and 4 strokes design which use reciprocating piston driving a crankshaft), a diesel engine do not require spark plug. Instead, in a diesel engine the air just been compressed and when it closed to the Top Dead Centre, the fuel sprayed by an injector into the combustion chamber, where upon it mixed with the hot air and self-ignited.

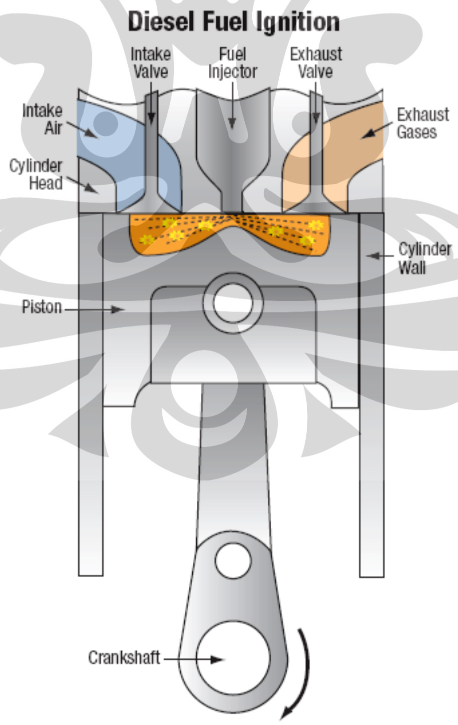


Figure 1- Diesel Fuel Ignition

The different between other engine, in diesel engine only air that introduced into combustion chamber. The air then compressed, because of this compression the air heated. When the air is being compressed, fuel was injected into the compressed air in the chamber. The fuel should be distributed as even as possible and broken down into small droplets, this condition can be achieved by the present of fuel injector. Then the heat from compressed air vaporised the fuel and then ignited it until all the droplets burnt. When the fuel droplets start to vaporise, it cause a delay periode during ignition. The characteristic diesel knocking sound as the vapour reaches ignition temperature and causes an abrupt increase in pressure above the piston. The expansion of the combustion gases then push the piston downward which provided power to the crankshaft. In diesel engine the combustion can happend without a separate ignition system because of the high level of compression. Since the compression is high the engine efficiency also high. This can obly happend in diesel engien because fuel not introduced into cylinder until shortly before TDC (top dead centre), so premature detonation is not an issue and compression ratios are much higher

2.1.1 Dual Fuel Technology

Dual fuel engine has been used since early 1930 (Hsu., 2002). The reason the dual fuel technologies not well-known earlier because the petroleum price is still low and affordable.

The term dual-fuel is generally associated with a compression ignition engine (Stewart et al., 2007). The dual fuel system must be at least as efficient as the diesel engine while its emissions must be reduced.

Dual fuel is usually associated with ignition engine (Stewart et al., 2007). Dual fuel engine uses two different fuel sources. The main fuel should be as the source of energy for the engine. Ideally this is injected into the engine as a homogenous gaseous mixture with the intake air. The secondary fuel is used to ignite the primary main fuel. The secondary fuel usually injected into the combustion chamber at the end of the compression stroke and helps to complete the engine's cycle. The secondary fuel is injected by using standard fuel injection equipment to minimize the engine modification that required to operated dual-fuel process. This usually called "late cycle gas injection". It make the compression ratio still at the same level as the ordinary diesel engine, and also the engine efficiency and power are similar with the ordinary diesel engine.

The event when alcohol introduced into the engine is called fumigation. The alcohol injected into the intake air stream by injector, this system is required a separate fuel tank for alcohol with own lines and controls. So it can make the alcohol fuel system is separated and independent from the diesel system which make the engine can run using single fuel sources or dual fuel sources. The fumigation also can help reduce the smoke from the emission, this is because the alcohol mixed well with the injected charge. Fumigation can substitute alcohol for diesel fuel, it can derived up to 50% of fuel energy from alcohol (Ecklund et al (1984)).

Uli Kruger has designed a system that has similar approach by put the fuel on separate tank. He designed an arrangement of injected secondary fuel into the compression internal combustion engine in which the air supply is first caused to pass through a vortex creator, and supply the secondary fuel into the low pressure area on the vortex mixer which can provided a constant ratio of secondary fuel to main fuel through varying load conditions. The Uli Kruger dual fuel system can be seen at the figure 2 below,

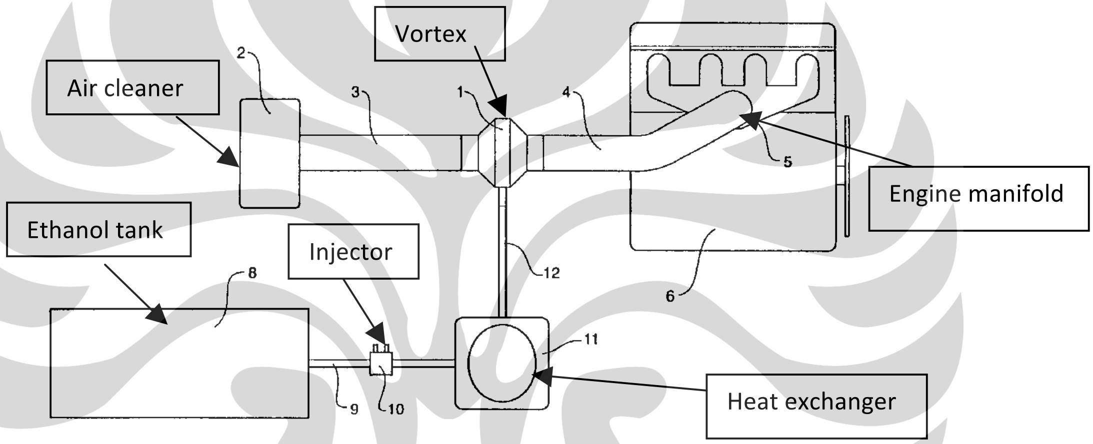


Figure 2 - Uli Kruger Dual Fuel System

To make the system work properly, the ethanol need to be heated into vaporization degree. So the ethanol need to passes through the heat exchanger that located between the vortex mixer an injector. The heat exchanger is water heated by engine water that approximately $85 - 100°C$. This change in state promotes better vaporization of the ethanol during the combustion process (Ajav et al., 1998) and provides a more consistent mass flow in each combustion chamber. The Uli Kruger system used a device that created a natural vortex inside the air stream. That is the difference between Uli Kruger's system and other dual system is in the way the ethanol introduced into the intake air stream.

2.1.2 Ethanol Fuel

Ethanol also called ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol. Ethanol is a flammable, colorless, and volatile liquid. It is best known as the type of alcohol that found in alcoholic beverages and in modern thermometers. Ethanol often referred as alcohol or spirits. Ethanol is a light alcohols (methanol, ethanol) which are readily produced from vegetable crops by distillation (Addison, 2000). Ethanol has widespread use as fuel for heat and light, and also as fuel for internal combustion engines and now receiving wide attention as alternative fuels for gasoline because of its high octane number (Kim & Choi, 2008). Ethanol can be mass-produced by fermentation of sugar or by hydration of ethylene from petroleum and other sources. Current interest in ethanol mainly lies in bio-ethanol, produced from the starch or sugar in a wide variety of crops, but there has been considerable debate about how useful bio-ethanol will be in replacing fossil fuels in vehicles. Concerns relate to the large amount of arable land required for crops, as well as the energy and pollution balance of the whole cycle of ethanol production. Recent developments with cellulosic ethanol production and commercialization may allay some of these concerns.

There are several problems that occurred to used ethanol in internal combustion engine according Lu et al (2004). First, the dynamic viscosity of ethanol is much lower than diesel fuel. It can bring up the engine wearing issues that will be big problem for dual fuel engine that used ethanol. Secondly, ethanol has limited solubility in diesel fuel. Third, ethanol has a low cetane number. Brown (1981) explained that cetane number is indicator of the self ignition ability of the fuel. The lower cetane number makes ethanol insufficient for direct substitution of diesel fuel, it may cause the ignition delay of ethanol inside the combustion chamber and the duration of combustion will become short. Since that the ethanol can give large ignition delay.

2.2 Heat Exchanger

Heat exchanger is a device to transfer heat from one medium to another, whether the media are separated by a solid wall so that they never mix, or the media are in direct contact. Heat exchanger is widely used in heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing. Common example of a heat exchanger is the radiator in a car. The function of the heat exchanger for the Cummins engine is to provide adequate heat so the ethanol reaches the evaporation temperature and can fully evaporate. To design and calculated heat exchanger, it applied the heat transfers law. So basic knowledge of heat transfers need to be familiarised first.

2.2.1 Heat Transfer

Heat transfer is the transition of thermal energy from a hotter object to a cooler object. When an object or fluid is at a different temperature than its surroundings or another object, transfer of thermal energy, also known as heat transfer, or heat exchange, occurs in such a way that the body and the surroundings reach thermal equilibrium. Heat transfer always occurs from a higher-temperature object to a cooler temperature one as described by the second law of thermodynamics or the Clausius statement. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed. There are three type of heat transfer.

- **Conduction**

Conduction is the transfer of thermal energy between neighbouring molecules in a substance due to a temperature gradient. It always takes place from a region of higher temperature to a region of lower temperature, and acts to equalize temperature differences. Conduction takes place in all forms of matter, viz. solids, liquids, gases and plasmas, but does not require any bulk motion of matter. In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.

- **Convection**

Convection is the transfer of heat energy between a solid surface and the nearby liquid or gas in motion. As fluid motion goes faster the convective heat transfer increases. The presence of bulk motion of fluid enhances the heat transfer between the solid surface and the fluid. There are two types of Convection Heat Transfer:

  - <u>Natural Convection</u>: Natural Convection is when the fluid motion is caused by forces that result from the density variations due to variations of temperature in the fluid. For example the hotter volume transfers heat towards the cooler volume of that fluid.
  - <u>Forced Convection</u>: Forced Convection is when the fluid is forced to flow over the surface by external source such as fans and pumps.

Internal and external flow can also classify convection. Internal flow occurs when the fluid is enclosed by a solid boundary such as a flow through a pipe. An external flow occurs when the fluid extends indefinitely without encountering a solid surface. Both these convections, either natural or forced, can be internal or external as they are independent of each other.

- **Radiation**

Radiation can be known as thermal radiation is electromagnetic radiation emitted from the surface of an object which is due to the object's temperature. An example of thermal radiation is the infrared radiation emitted by a common household radiator or electric heater. Thermal radiation is generated when heat from the movement of charged particles within atoms is converted to electromagnetic radiation. Solar radiation heats the earth during the day, while at night the earth re-radiates some heat back into space.

2.2.2 Heat Transfer Energy

- **Heat Transfer Energy $(\dot{Q})$**

Heat transfer energy is the energy that produces or occurs from the transfer of heat in the system .To calculates the heat transfer energy $(\dot{Q})$. It can be used this general heat transfer energy equation,

$$\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T$$

Where $\dot{m}$ is mass flow rate of the fluid, it can be found from the data specification or the engine testing data. C_p is specific heat of the fluid based on the temperature, it may vary between each temperature. Specific heat can be found from the air properties table. ΔT is the temperature difference between each part , it could be difference temperature at the outlet with the inlet or from the inlet of exhaust pipe with the inlet of the copper tube. Other than using the equation above, the heat transfer energy can be found by using this equation,

$$\dot{Q} = \frac{\Delta T}{R_{total}}$$

Where ΔT is the temperature difference between each part, it could be difference temperature at the outlet with the inlet or from the inlet of exhaust pipe with the inlet of the copper tube. R_{total} is total thermal resistance that occur that the system. It can be from the wall of type, the thermal resistance at the pipe, and any other thermal resistance that occur.

- **Total Thermal Resistance (R_{total})**

In this heat exchanger design, the heat transferred from one fluid to another that separated by pipe wall. The exhaust air moves the heat to the wall by convection then through the wall by conduction and at last from wall to the cold air by convection. The thermal resistance network can show in the figure below.

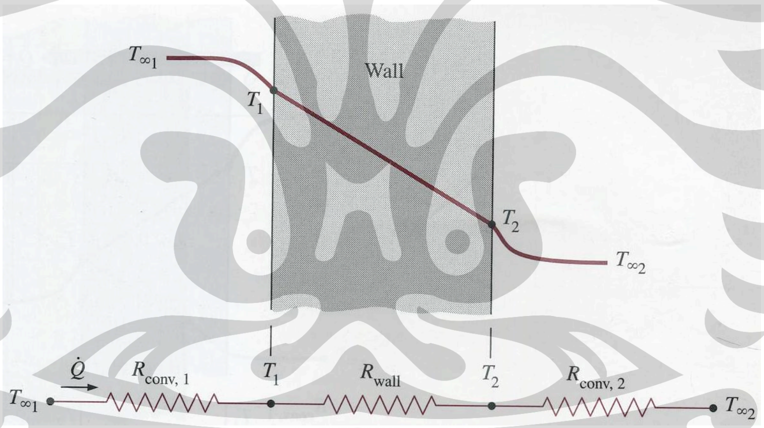


Figure 3 - Thermal Resistance Network

To calculate the heat transfer energy $(\dot{Q})$ the total thermal resistance need to be determined. The total thermal resistance can be calculated by sum all thermal resistance that occur at the heat exchanger system. The total thermal resistance can be calculated using equation below.

$$R_{total} = R_i + R_{wall\,inside} + R_{wall\,outside} + R_o$$

Where R_i is thermal resistance at the exhaust pipe, R_o is thermal resistance at the copper tube, $R_{wall\,inside}$ is thermal resistance of exhaust pipe wall, and $R_{wall\,outside}$ is thermal resistance of copper tube wall. To found the thermal resistance at the copper tube and exhaust pipe, it can be calculated using equation below,

$$R = \frac{1}{h \times A}$$

Where h is convecton heat transfer coefficient. A is contact surface area, the A can be found by multiply the $\pi, D_i, and L_x$. D_i is the inner diameter of the tube, meanwhile L_x is the length of the of the segment that will be calculated. The heat exchanger divided into several segments by L_x length to simplify and make easier the calculation.

To determine thermal resistance of exhaust pipe wall and thermal resistance of copper tube wall can be found by using equation below,

$$R_{wall} = \frac{\ln\left({}^{D_o}/_{D_i}\right)}{2\pi \times K_{material} \times L_x}$$

Where D_o is outer diameter and D_i is inner diameter of the pipe. L_x is the length of the of the segment that will be calculated and $K_{material}$ is thermal conductivity that can be vary for each material.

To find the thermal resistance there are several parameter that need to be find, there are volume flow rate, velocity, Reynolds Number, Nusselts Number, and heat transfer coefficient.

- **Volume Flow Rate $(\dot{v})$**

Volume flow rate is the volume of fluid which passes through a given surface per unit time. The volume flow rate at the cooper pipe can be found using the equation,

$$\dot{v} = \frac{\dot{m}_{air\,from\,turbo} \times 5\%}{\rho_{air}}$$

Where $\dot{m}_{air\,from\,turbo}$ is mass flow rate of air that flow from turbo. The data of $\dot{m}_{air\,from\,turbo}$ usually can be found from the engine spesification or from the engine data test. While ρ_{air} is density of air that can be get from air properties table. To find the volume flow rate, the mass flow rate of the air from turbo need to be multiply by five percent. So the mass flow rate of the cool air is assumed to be five percent from the air mass flow rate from turbo. The assumption made because the pump that flow the cool air to the copper tube doesn not have as much power as the turbo. So the power to push the air into the copper tube not as big as the suction of the turbo. Then after that it just divided by air density.

- **Velocity** $(\mathcal{V})$

Also known as upstream velocity, the velocity of the approaching fluid far ahead of the body. The upstream may vary with the location and the time, but usually at the analysis the upstream velocity is assumed to be uniform and steady form convience.

$$\mathcal{V} = \frac{\dot{v}}{A}$$

Where $\mathcal{V}$ is velocity, $\dot{v}$ is volume flow rate , and A is surface area of the tube. The volume flow rate can be calculated using the equation that already explain earlier or by get it from the engine spesification or from engine testing data. The surface area can be determine by applied into the surface area of a circular, for this type of heat exchanger.

- **Reynolds Number (Re)**

Reynolds Number is ratio of inertia forces to viscous forces in the fluid. The ratio is a dimensionless quantity. thus, it quantifies the relative importance of these two types of forces for given flow conditions. Reynolds numbers often arise when performing dimensional analysis of fluid dynamics and heat transfer problems. They are also used to characterize different flow regimes, such as laminar or turbulent flow. Laminar flow occurs at low Reynolds numbers, where viscous forces are dominant. Laminar flow is characterized by smooth and constant fluid motion, while turbulent flow occurs at high Reynolds numbers and is dominated by inertial forces, which tend to produce random eddies, vortices and other flow fluctuations. This number is one of the important parameter that needs to be calculated. The value of Reynolds Number is different for various geometry and flow condition. The equation to find Reynolds Number is:

$$Re = \frac{L_c \times \mathcal{V}}{v}$$

Where $\mathcal{V}$ is the upstream velocity that can calculated using the equation on the previous part, meanwhile L_c is the characteristic length of the geometry (in this case is inner diameter of the exhaust pipe), and v is kinematic viscosity of the fluid. The value of kinematic viscosity can be found at the air properties table. The value of ar viscosity may vary between different temperature, so it the value of kinematic viscosity that will be used at the exhaust pipe inlet and the copper tube inlet may vary depends on the temperature.

- **Nusselt Number (Nu)**

Nusselt number is the ratio of convective to conductive heat transfer across (normal to) the boundary. Nusselt Number is dimensionless temperature gradient at the surface. The conductive component is measured under the same conditions as the heat convection but with a stagnant fluid. A Nusselt number close to unity is characteristic of "slug flow" or laminar flow. A larger Nusselt number corresponds to more active convection, with turbulent flow typically in the 100-1000 range. There are several ways to find Nusselt Number. It depends on the Reynolds Number that will be get from the calculation, wether the flow is laminar or turbulent. The common equation to find Nusselt Number is shown below,

$$Nu = \frac{h.L_c}{k}$$

Where thermal conductivity for air, and L_c is characteristic length. L_c is equal to inner diameter since the geometry of the pipe is circular. If the the Reynolds Number is above 10000, according to Heat and Mass Transfer a Practical Approach by Yunus Cengel, it means the flow is fully developed turbulent flow. For the condition at the pipe or tube it can be assumed that it has a smooth surface, so The Colburn Equation can be used. The Colburn Equation was used because from the past calculation shows all the Reynolds number value are above 10000, if the Reynolds Number above 10000 it means the flow is fully developed turbulent flow and it happened in the smooth tubes the Colburn Equation can be applied. The Nusselts Number can be obtained using this equation:

$$Nu = 0.023 \times Re^{0.8} \times Pr^{1/3}$$

To improve the accuracy of the result, the calculation for such condition can modify it into Dittus-Boelter Equation. The Dittus-Boelter Equation is preferred to the Colburn Equation, it just change the value of 1/3 it another value depend on the purpose of the fluid that flow through the tube. The Dittus-Boelter Equation,

$$Nu = 0.023 \times Re^{0.8} \times Pr^{n}$$

Where Re is Reynolds number that can be determine using the equation from the earlier chapter, Pr is Prandtl number. The Prandtl number Pr is a dimensionless number approximating the ratio of momentum diffusivity (kinematic viscosity) and thermal diffusivity. The value may vary depends on the material, for air and gases the value is between 0.7 and 0.8. While n is just a coefficient that the value betwee 0.3and 0.4, based on the purpose of the fluid. 0.3 is for cooling system and 0.4 is for heating.

- **Prandtl Number (Pr)**

As already stated before Prandtl number or Pr is a dimensionless number approximating the ratio of momentum diffusivity (kinematic viscosity) and thermal diffusivity. It is can be defined as this equation,

$$Pr = \frac{v}{\alpha} = \frac{C_p \times \mu}{k}$$

Where v is kinematic viscosity and α is thermal diffusivity. There is another by multiply specific heat of the substance with it viscosity, then divided it with the thermal conductivity as shown at the equation above. The value of Pr may vary from 0.015 for mercury to 40000 for engine oil. The value for air and gases usually is in the range between 0.7 and 0.8.

- **Convection Heat Transfer Coefficient (h)**

Heat transfer coefficient is usually used in calculating the heat transfer, typically by convection or phase change between a fluid and a solid. There are numerous methods for calculating the heat transfer coefficient in different heat transfer modes, different fluids, flow regimes, and under different conditions. Often it can be estimated by dividing the thermal conductivity of the convection fluid by a length scale. The heat transfer coefficient is often calculated from the Nusselt number. The convection heat transfer coefficient be found rearranging the Nusselt Number general equation,

$$Nu = \frac{h \times K_{material}}{L_c}$$

Then it can be rearranged into,

$$h = \frac{Nu \times K}{L_c}$$

After rearranging the first into the second equation, the convection heat transfer coefficient can be calculated using this equation below, where Nusselt number can be found from previous calculation. K is thermal conductivity for air, and L_c is characteristic length. L_c is equal to inner diameter since the geometry of the pipe is circular.

3.0 HEAT EXCHANGER DESIGN

Heat exchanger work as an equipment that help the exchange of heat between two substances at different temperature, the substance could be air, fluid, or any other. Heat exchanger also acts as barrier so the two substances will not mix with each other. The heat transfer at the heat exchanger involves heat convection within the substance (i.e. Fluids) and conduction (i.e. the wall between two substances). The substance for this project is cooled bled air and hot exhaust gas from the engine. The function for the heat exchanger for the Cummins engine is to provide adequate heat so the ethanol reaches the evaporation temperature and can fully evaporate.

3.1 Coil Copper Tube

The heat exchanger is designed in such a way where coiled copper tubing (containing the bled air) is wrapped tangentially around the steel exhaust pipe. Therefore heat is transferred from the hot exhaust air to the cooler bled air as can be seen Figure 4.

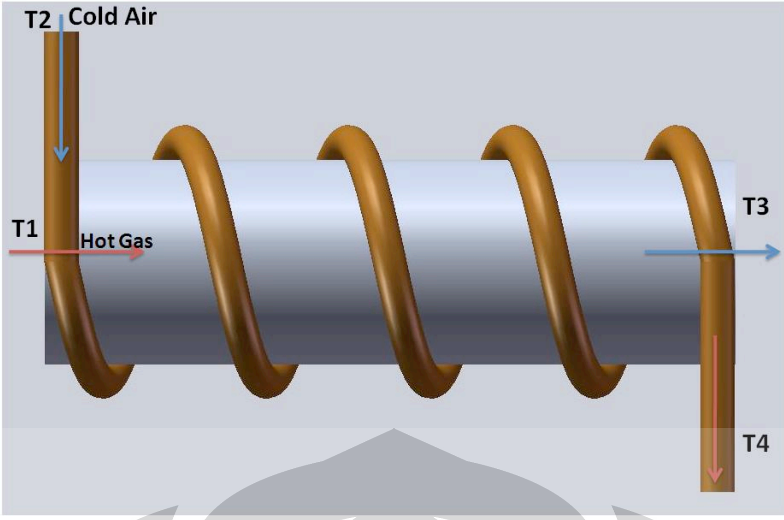


Figure 4 - Coil Copper Tube Design

The wrapped coil is making contact with the surface of the exhaust pipe, which successfully infers heat conduction as the primary means in which heat is exchanged by two liquids. Convection heat transfer also occurred in the system between cool air and exhaust gas.

The main benefit of using coiled cooper tubing heat exchanger is it can be used in the place with space limitation. It can reach the heat transfer energy that desired without using much space, because it can be wrapped around the exhaust pipe. Because the Cummins engine need quite high heat transfer energy to evaporate the ethanol but with small space available, it will be better to using this type of heat exchanger. The coil tube design is easy to install, clean, and flexible to use at different type of pipe.

3.1.1 Design and Calculation

- **Heat Transfer Energy Ethanol** $(\dot{Q}_{ethanol})$

After choosing the design that will be used, the desired heat transfer energy need to be calculated. The heat exchanger need to heat the cool air to the desired temperature, so the energy to heat the air is at least equal to the energy that required to evaporate the ethanol. So firstly the heats transfer energy to heat up the ethanol need to be calculated. It can be calculate using the equation below:

$$\dot{Q}_{ethanol} = \dot{m}_e \times ((C_{pe} \times \Delta T) + L)$$

Where,

$m_e = Ethanol\ Mass\ Flow\ Rate = 40\%\ from\ diesel\ mass\ flow rate$

$C_{pe} = Ethanol\ Specific\ Heat\ Capacity = 2.44\ {}^{kJ}/_{kg \cdot K}$

$L = Latent\ Heat\ Vaporation = 838\ {}^{kJ}/_{kg}$

$\Delta T = T2 - T1$

$T1 = Room\ Temperature = 30°C$

$T2 = Desired\ Temperature\ to\ Evaporate\ Ethanol = 78°C$

To calculate the heat transfer energy for ethanol, the diesel mass flow rate and the specific heat capacity need needs to be found. The diesel mass flow rate can be found from the engine baseline test data. Mass flow rate is the mass of substance which passes through a given surface per unit time. Its unit is mass divided by time, so kilogram per second. The value of diesel mass flow rate is shown at the table below.

RPM	Load	Mass Flow Rate (Kg/s)
2500	Full	0.009671667
	Three Quarter	0.007322833
	Half	0.005250333
	Quarter	0.003316
1500	Full	0.007461
	Three Quarter	0.005803
	Half	0.003868667
	Quarter	0.001934333

Table 1 - Diesel Mass Flow Rate

From the table 6 it can be seen the value of diesel mass flow rate for each load at different rpm. The ethanol mass flow rate can be calculated using this equation,

$$m_e = 40\%\ \times m_d$$

So the values for the ethanol mass flow rate are:

RPM	Load	Mass Flow Rate (Kg/s)
2500	Full	0.003868667
	Three Quarter	0.002929133
	Half	0.002100133
	Quarter	0.0013264
1500	Full	0.0029844
	Three Quarter	0.0023212
	Half	0.001547467
	Quarter	0.000773733

Table 2 - Ethanol Mass Flow Rate

Using the value from ethanol mass flow rate table, the heat transfer energy for ethanol at different load and speed can be found by calculated it by equation that already shown earlier.

RPM	Load	Energy That Required (kW)
2500	Full	3.666722
	Three Quarter	2.776233
	Half	1.99
	Quarter	1.257
1500	Full	2.8286
	Three Quarter	2.2
	Half	1.466
	Quarter	0.733344

Table 3 - Ethanol Heat Transfer Energy

- **Inside Pipe (Exhaust Pipe)**

Hence the heat exchangers consist of two pipes so it needs to be considered as two different pipes. Each part has a different dimensions and parameter that need be calculated that will be used at further calculation.

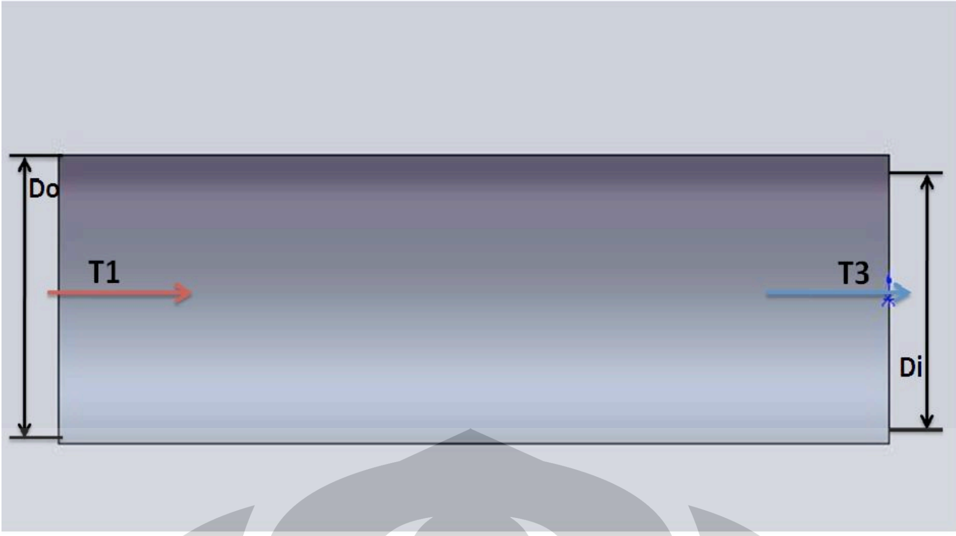


Figure 5 - Inside Pipe (Exhaust Pipe)

Exhaust Pipe Dimension and Parameter

$D_i = Inside\ Diameter = \ 0.0762\ metre$

$D_o = Outer\ Diameter = \ 0.0889\ metre$

$Temperature = \ 400°C\ (at\ 2500\ RPM)$

$= 525°C\ (at\ 1500\ RPM)$

$Pressure = 2.5\ bar$

- Volume flow rate $(\dot{v})$

First the volume flow rate at the exhaust pipe needs to be determined. The volume flow rate at the inside pipe is same with the exhaust flow rate, because the inside pipe is the exhaust pipe. The value for exhaust flow rate can be found from the baseline test data.

RPM	Load	Volume Flow Rate (m^3/s)
2500	Full	0.60448
	Three Quarter	0.58559

	Half	0.49114
	Quarter	0.39669
1500	Full	0.398232
	Three Quarter	0.33186
	Half	0.265488
	Quarter	0.22124

Table 4 - Air Volume Flow Rate at Inside Pipe

❖ Velocity ($\mathcal{V}$)

After the volume flow rate can be found, the velocity needs to be calculated. It can be determine using this equation,

$$\mathcal{V} = \frac{\dot{v}}{A}$$

Where,

$\mathcal{V} = Velocity\ ({}^{m}/{}_{s})$

$\dot{v} = volume\ flow\ rate\ \left({}^{m^3}/{}_{s}\right)$

$$A = Surface\ Area = \frac{(\pi \times {D_i}^2)}{4} = 0.00456\ m^2$$

By inputting the data that already got and known into the equation above, the velocity for each load and speed can be found.

RPM	Load	Velocity (m/s)
2500	Full	132.5437095
	Three Quarter	128.4017185
	Half	107.6917639
	Quarter	86.98180933
1500	Full	87.32454488
	Three Quarter	72.77045407
	Half	58.21636325
	Quarter	48.51363605

Table 5 - Velocity at Inside Pipe

❖ Reynolds Number (Re)

Reynolds Number is ratio of inertia forces to viscous forces in the fluid. This number is one of the important parameter that needs to be calculated. The value of Reynolds Number is different for various geometry and flow condition. The equation to find Reynolds Number is:

$$Re = \frac{L_c \times \mathcal{V}}{v}$$

Where,

$L_c = Characteristic\ Length = D_i = 0.0762\ metre$

$\mathcal{V} = Velocity\ (m/s)$

$v = air\ viscosity = 62.53 \times 10^{-6}\ m^2/s\ (at\ 400°C)$

$\mathcal{V}$ is the upstream velocity that already calculated before, L_c is the characteristic length of the geometry (in this case is inner diameter of the exhaust pipe), and v is kinematic viscosity of the fluid. The values of air kinematic viscosity get from air properties table at Appendix A. By inputting the data that already got and known into the Reynolds number equation, The Reynolds Number for every load and speed can be determine. The result shown at table below,

RPM	Load	Re
2500	Full	161519.7611
	Three Quarter	156472.2686
	Half	131234.8059
	Quarter	105997.3432
1500	Full	106415.0059
	Three Quarter	88679.1716
	Half	70943.33728
	Quarter	59119.44773

Table 6 - Reynolds Numbers at Inside Pipe

❖ Nusselt Number (Nu)

According the result of Reynolds Number from calculation before the Nusselt Number can be found using Colburn Equation. The Colburn Equation was used because from the past calculation shows all the Reynolds number value are above 10000, according to Heat and Mass Transfer a Practical Approach by Yunus Cengel if the Reynolds Number above 10000 it means the flow is fully developed turbulent flow and it happened in the smooth tubes the Colburn Equation can be applied. The Nusselts Number can be obtained using this equation:

$$Nu = 0.023 \times Re^{0.8} \times Pr^{1/3}$$

To improve the accuracy of the result, the calculation for such condition can modify it into Dittus-Boelter Equation. The Dittus-Boelter Equation is preferred to the Colburn Equation, it just change the value of 1/3 it another value depend on the purpose of the fluid that flow through the tube. The Dittus-Boelter Equation,

$$Nu = 0.023 \times Re^{0.8} \times Pr^{n}$$

Where,

$Re = Reynolds\ Number$

$Pr = Prandtl\ Number = 0.7\ (gases)$

$n = coefficient = 0.3\ (for\ cooling)$

$= 0.4\ (for\ heating)$

$\therefore since\ it\ is\ for\ heating\ so\ the\ n\ value\ that\ used\ is\ 0.4$

The value of Nusselt Number can be found by input that Reynolds Number that already find in last calculation and Prandtl number of air into the Dittus-Boelter Equation. Prandtl number of air is taken from Appendix A. The result of the calculation can be seen at the Nusselt Number table below,

RPM	Load	Nu
2500	Full	292.6493628
	Three Quarter	285.3099747
	Half	247.8599048
	Quarter	208.9310736
1500	Full	209.5894176
	Three Quarter	181.144167

	Half	151.5292046
	Quarter	130.9638238

Table 7 - Nusselt Number at Inside Pipe

❖ Convection Heat Transfer Coefficient (h_i)

Convection Heat Transfer Coefficient (h_i) need to be calculated to find the wall resistance for the exhaust pipe, since the exhaust gas was blockade from outside atmosphere by the pipe wall. The convection coefficient for this type of heat exchanger can be found rearranging the Nusselt Number equation,

$$Nu = \frac{h \times K_{material}}{L_c}$$

Rearranging,

$$h = \frac{Nu \times K}{L_c}$$

After rearranging the first into the second equation, the convection heat transfer coefficient can be calculated using this equation below, where Nusselt number can be found from previous calculation. K_{air} is thermal conductivity for air which is 0.0515 $W/_{m \cdot K}$ at 673 K, and L_c is characteristic length. The thermal conductivity for air is get from air properties table at Appendix A. L_c is equal to inner diameter since the geometry of the pipe is circular.

$$h_i = \frac{Nu \times K_{air}}{L_c}$$

Where,

$Nu = Nusselt\ Number$

$K_{air} = Air\ Thermal\ Conductivity = 0.0515\ W/_{m \cdot K}\ (at\ 673K)$

$L_c = Characteristic\ Length = D_i = 0.0762\ metre$

By inputting the data that already got and known into the Convection Heat Transfer Coefficient equation, The Convection Heat Transfer Coefficient for every load and speed can be determine. The result shown at table below,

RPM	Load	$h_i\ \left(W/_{m^2 \cdot K}\right)$
2500	Full	197.7879552
	Three Quarter	192.8276076
	Half	167.5168648
	Quarter	141.2066967
1500	Full	141.6516405
	Three Quarter	122.426832
	Half	102.4114703
	Quarter	88.51229559

Table 8 - Convection Heat Transfer Coefficient at Inside Pipe

❖ Thermal Resistance (R_i)

The exhaust gases were flow inside the pipe, so the thermal resistance can be calculate using the equation below:

$$R_i = \frac{1}{h_i \times A_i}$$

Where,

$h_i = \text{Convection Heat Transfer Coefficient}\ \left(\text{W}/_{\text{m}^2 \cdot \text{K}}\right)$

$A_i = Contact\ Surface\ Inner\ Area\ (m^2) = \pi \times D_i \times L_x = 23.927 \times 10^{-5}\ m^2$

$L_x = Length = 0.001\ m$

The value of thermal resistance (R_i) can be found by input the value of heat transfer coefficient that already calculated before and the contact surface inner area into the equation. The result can be seen in the table below.

RPM	Load	$R_i\ (K/W)$
2500	Full	21.13078056
	Three Quarter	21.67435427
	Half	24.94921263
	Quarter	29.59784469
1500	Full	29.50487452
	Three Quarter	34.13805462
	Half	40.81001734
	Quarter	47.21845537

Table 9 - Thermal Resistance at Inside Pipe

- **Outside Pipe (Cooper tube Pipe)**

Hence the heat exchangers consist of two pipes so it needs to be considered as two different pipes. Each part has a different dimensions and parameter that need be calculated that will be used at further calculation.

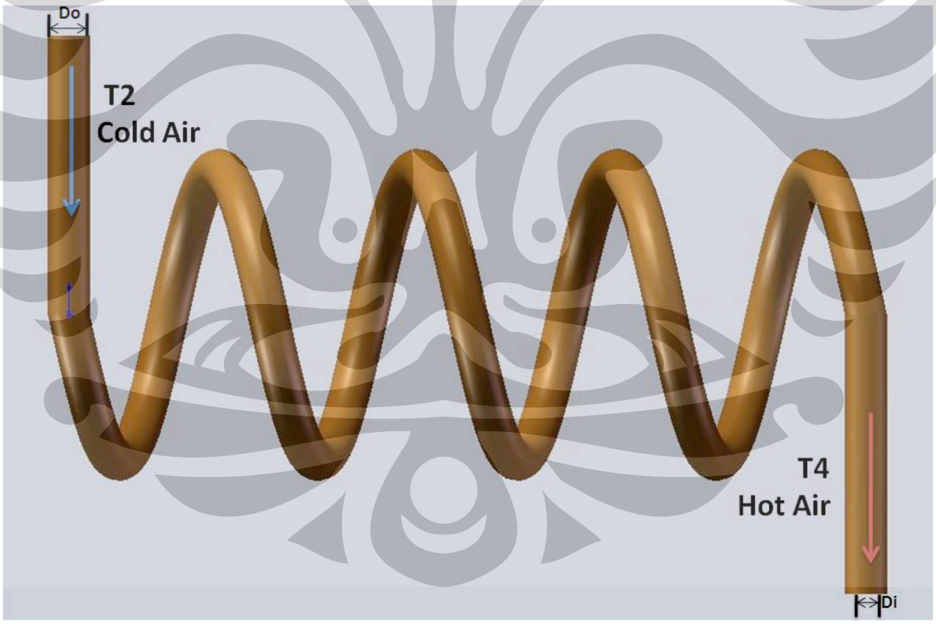


Figure 6 - Copper Coil Tube

Copper Pipe Dimension and Parameter

$D_i = Inside\ Diameter = \ 0.008\ metre$

$D_o = Outer\ Diameter = 0.015\ metre$

$Inlet\ Temperature = 30°C$

$Pressure = 1\ ATM$

❖ Volume flow rate $(\dot{v})$

The volume flow rate at the cooper pipe needs to be determined. Volume flow rate is the volume of fluid which passes through a given surface per unit time. The volume flow rate at the cooper pipe can be found using the equation,

$$\dot{v} = \frac{\dot{m}_{air\ from\ turbo} \times 5\%}{\rho_{air}}$$

Where,

$\dot{m}_{air\ from\ turbo} = air\ mass\ flow\ rate\ from\ turbo\ \left({Kg}/{s}\right)$

$\rho_{air} = air\ density = 1.168\ {Kg}/{m^3}$

The mass flow rate from turbo can be found from engine baseline test and the density can be found from Appendix B, the values are:

RPM	Load	Mass Flow Rate (Kg/s)
2500	Full	0.32
	Three Quarter	0.31
	Half	0.26
	Quarter	0.21
1500	Full	0.18
	Three Quarter	0.15
	Half	0.12
	Quarter	0.1

Table 10 - Air Mass Flow Rate from Turbo

Then the volume flow rate can be calculated using the data above and input it into the volume flow rate equation.

RPM	Load	$\dot{v}\ (m^3/s)$
2500	Full	0.01369863
	Three Quarter	0.013270548
	Half	0.011130137
	Quarter	0.008989726
1500	Full	0.007705479
	Three Quarter	0.006421233
	Half	0.005136986
	Quarter	0.004280822

Table 11 – Air Volume Flow Rate at Copper Tube

❖ Velocity ($\mathcal{V}$)

After the volume flow rate can be found, the velocity needs to be calculated. It can be determine using the equation that already used and explained at the inner tube section:

$$\mathcal{V} = \frac{\dot{v}}{A}$$

Where,

$\mathcal{V} = Velocity\ (m/s)$

$\dot{v} = volume\ flow\ rate\ (m^3/s)$

$$A = Surface\ Area = \frac{(\pi \times D_{i-cooper}{}^2)}{4} = 5.027 \times 10^{-5}\ m^2$$

By inputting the data that already got and known into the equation above, the velocity for each load and speed can be found.

RPM	Load	Velocity (m/s)
2500	Full	272.5255875
	Three Quarter	264.0091629
	Half	221.4270398
	Quarter	178.8449168
1500	Full	153.295643
	Three Quarter	127.7463691

	Half	102.1970953
	Quarter	85.16424609

Table 12 - Velocity at Copper Tube

❖ Reynolds Number (Re)

Reynolds Number is ratio of inertia forces to viscous forces in the fluid. This number is one of the important parameter that needs to be calculated. The equation to find Reynolds Number is:

$$Re = \frac{D_{i-cooper} \times V}{v}$$

Where,

$D_i = Inside\ Diameter = 0.008\ metre$

$V = Velocity\ (^{m}/_{s})$

$v = air\ viscosity = 16.04 \times 10^{-6}\ ^{m^2}/_{s}\ (at\ 30°C)$

The values of air kinematic viscosity get from air properties table at Appendix A and the velocity can be found from the previous calculation. By inputting the data that already got and known into the Reynolds number equation, The Reynolds Number for every load and speed can be determine. The result shown at table below,

RPM	Load	Re
2500	Full	135922.9863
	Three Quarter	131675.393
	Half	110437.4264
	Quarter	89199.45974
1500	Full	76456.67978
	Three Quarter	63713.89982
	Half	50971.11985
	Quarter	42475.93321

Table 13 - Reynolds Number at Copper Tube

❖ Nusselt Number (Nu)

Then the Nusselt Number can be found using Dittus-Boelter Equation as already explained before. The Dittus-Boelter Equation,

$$Nu = 0.023 \times Re^{0.8} \times Pr^{n}$$

Where,

$Re = Reynolds\ Number$

$Pr = Prandtl\ Number = 0.7\ (gases)$

$n = coefficient = 0.3\ (for\ cooling)$

$= 0.4\ (for\ heating)$

$\therefore since\ it\ is\ for\ cooling\ so\ the\ n\ value\ that\ used\ is\ 0.3$

The value of Nusselt Number can be found by input that Reynolds Number that already find and Prandtl number of air into the Dittus-Boelter Equation. Prandtl number of air is taken from Appendix A. The result of the calculation can be seen at the Nusselt Number table below,

RPM	Load	Nu
2500	Full	264.1749136
	Three Quarter	257.5496396
	Half	223.7434188
	Quarter	188.6023185
1500	Full	166.720727
	Three Quarter	144.0935691
	Half	120.5359481
	Quarter	104.1769387

Table 14 - Nusselt Number at Copper Tube

❖ Convection Heat Transfer Coefficient (h_o)

Convection Heat Transfer Coefficient (h_o) needs to be calculated to find the wall resistance for the exhaust pipe, since the exhaust gas was blockade from outside atmosphere by the pipe wall. The convection coefficient for this type of heat exchanger can be found rearranging the Nusselt Number equation. It already arranged and used before at the h_i calculation. Where Nusselt number can be found from previous calculation. K_{air} is thermal conductivity for air which is $0.0264\ {}^{W}/_{m \cdot K}$ at 303 K, and L_c is characteristic length. The thermal conductivity for air is get from air properties table at Appendix A. L_c is equal to inner diameter since the geometry of the pipe is circular.

$$h_o = \frac{Nu \times K_{air}}{L_c}$$

Where,

$Nu = Nusselt\ Number$

$K_{air} = Air\ Thermal\ Conductivity = 0.0264\ {}^{W}/_{m \cdot K}\ (at\ 673)$

$L_c = Characteristic\ Length = D_i = 0.008\ metre$

By inputting the data that already got and known into the Convection Heat Transfer Coefficient equation, The Convection Heat Transfer Coefficient for every load and speed can be determine. The result shown at table below,

RPM	Load	$h_o\ \left({}^{W}/_{m^2 \cdot K}\right)$
2500	Full	871.7772149
	Three Quarter	849.9138107
	Half	738.353282
	Quarter	622.387651
1500	Full	550.1783992
	Three Quarter	475.508778
	Half	397.7686287
	Quarter	343.7838978

Table 15 - Convection Heat Transfer Coefficient at Copper Tube

❖ Thermal Resistance (R_o)

The exhaust gases were flow inside the pipe, so the thermal resistance can be calculate using the equation below:

$$R_o = \frac{1}{h_o \times A_o}$$

Where,

h_o = Convection Heat Transfer Coefficient $\left(\mathrm{W}/_{\mathrm{m^2 \cdot K}}\right)$

$A_o = Contact\ Surface\ Outer\ Area\ (m^2) = \pi \times D_{i-cooper} \times L_x = 2.51327 \times 10^{-5}\ m^2$

$L_x = Length = 0.001\ m$

The value of thermal resistance (R_o) can be found by input the value of heat transfer coefficient that already calculated before and the contact surface outer area into the equation. The result can be seen in the table below.

RPM	Load	$R_o\ \left(K/_W\right)$
2500	Full	45.64094483
	Three Quarter	46.81502439
	Half	53.8884796
	Quarter	63.92918579
1500	Full	72.31969817
	Three Quarter	83.67613304
	Half	100.0298488
	Quarter	115.7376364

Table 16 - Thermal Resistance at Copper Tube

- **Total Thermal Resistance** (R_{total})

Total thermal resistance can be calculated by sum all thermal resistance that occur at the heat exchanger system. The total thermal resistance can be calculated using equation below.

$$R_{total} = R_i + R_{wall\ inside} + R_{wall\ outside} + R_o$$

Where,

$R_i = Thermal\ Resistance\ at\ the\ exhaust\ pipe$

$R_{wall\ inside} = Thermal\ Resistance\ at\ wall\ of\ the\ exhaust\ pipe$

$R_{wall\ outside} = Thermal\ Resistance\ at\ wall\ of\ the\ cooper\ pipe$

$R_o = Thermal\ Resistance\ at\ the\ cooper\ pipe$

Since the R_i and R_o already found, just $R_{wall\,inside}$ and $R_{wall\,outside}$ that needs to be calculated. Both $R_{wall\,inside}$ and $R_{wall\,outside}$ can be determine using equation below. The $K_{material}$ or thermal conductivity for the material.

$$R_{wall} = \frac{\ln\left(D_o/D_i\right)}{2\pi \times K_{material} \times L_x}$$

Where,

$D_o = Outer\ Diameter\ (m)$

$D_i = Inner\ Diameter$ (m)

$K_{material} = Thermal\ Conductivity\ \left(W/_{m \cdot K}\right)$

$L_x = Length = 0.001\ m$

Wall Thermal Resistance Inside

Known,

$D_i = Inside\ Diameter = 0.0762\ metre$

$D_o = Outer\ Diameter = 0.0889\ metre$

$K_{stainless\,steel} = Thermal\ Conductivity = 14.9\ W/_{m \cdot K}$

$L_x = Length = 0.001\ m$

$$R_{wall\,inside} = \frac{\ln\left(D_o/D_i\right)}{2\pi \times K_{stainless\,steel} \times L_x}$$

$$= \frac{\ln\left(0.0889/_{0.0762}\right)}{2\pi \times 14.9 \times 0.001}$$

$$= 1.647402\ K/_{W}$$

Wall Thermal Resistance Outside

Known,

$D_i = Inside\ Diameter = 0.008\ metre$

$D_o = Outer\ Diameter = 0.015\ metre$

$K_{cooper} = Thermal\ Conductivity = 400\ {}^{W}/_{m \cdot K}$

$L_x = Length = 0.001\ m$

$$R_{wall\ outside} = \frac{\ln\left({}^{D_o}/_{D_i}\right)}{2\pi \times K_{cooper} \times L_x}$$

$$= \frac{\ln\left({}^{0.015}/_{0.008}\right)}{2\pi \times 400 \times 0.001}$$

$$= 0.25024\ {}^{K}/_{W}$$

After all data that required already gather, total thermal resistance can be calculated using this equation,

$$R_{total} = R_i + R_{wall\ inside} + R_{wall\ outside} + R_o$$

The result of the calculation can be found at the table below.

RPM	Load	R_i	$R_{wall\ inside}$	$R_{wall\ outside}$	R_o	R_{total}
2500	Full	21.13078	1.647402	0.25024	45.64094	68.66937
	Three Quarter	21.67435	1.647402	0.25024	46.81502	70.38702
	Half	24.94921	1.647402	0.25024	53.88848	80.73533
	Quarter	29.59784	1.647402	0.25024	63.92919	95.42467

1500	Full	29.50487	1.647402	0.25024	72.3197	103.7222
	Three Quarter	34.13805	1.647402	0.25024	83.67613	119.7118
	Half	40.81002	1.647402	0.25024	100.0298	142.7375
	Quarter	47.21846	1.647402	0.25024	115.7376	164.8537

Table 17 - Total Thermal Resistance

- **Heat Transfer Energy $(\dot{Q})$**

To calculate the heat transfer energy $(\dot{Q})$, this equation below that can be used:

$$\dot{Q} = \frac{\Delta T}{R_{total}}$$

For this heat exchanger calculation, the heat exchanger divided into several segments by L_x length to simplify and make easier the calculation, it also can shows the required length needed to achieved the desired heat transfer energy. The value of L_x for this calculation is 1 mm. The calculation to find heat transfer energy will be calculated for every section.

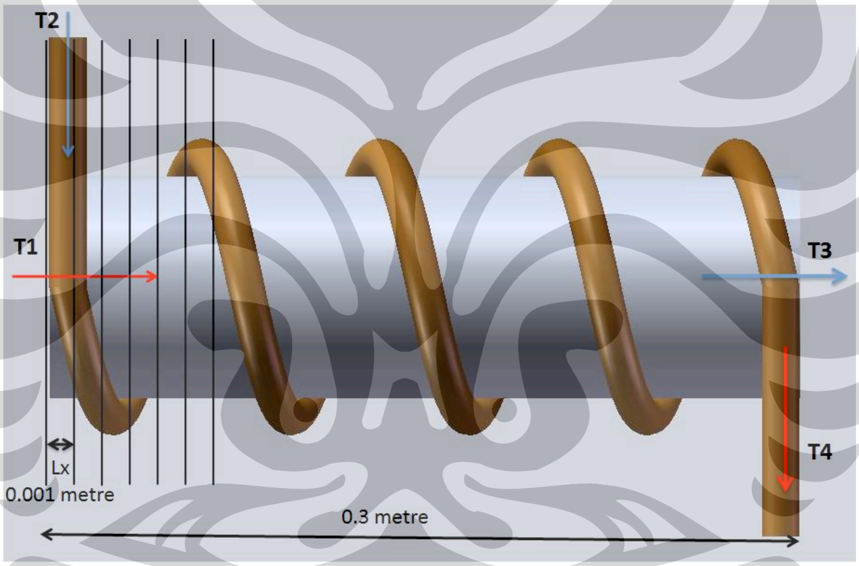


Figure 7 - Coil Copper Tube Diagram

By applying the heat transfer energy $(\dot{Q})$ equation, the initial heat transfer energy between hot gases in the exhaust pipe and the cool air in the copper tube can be calculated. The temperature difference may vary between each speed, $370K\ at\ 2500\ RPM\ and\ 495K\ at\ 1500\ RPM$.

$$\dot{Q}_o = \frac{\Delta T}{R_{total}}$$

Where,

$T_1 = Temperature\ at\ exhaust\ pipe\ inlet = 673\ K$

$T_2 = Temperature\ at\ copper\ tube\ inlet = 303\ K$

$\Delta T\ (T_1 - T_2) = Temperature\ Difference = 370K\ (at\ 2500\ RPM)$

$= 495°K\ (at\ 1500\ RPM)$

$R_{total} = Total\ of\ Thermal\ Resistance\ of\ the\ System\ (^K/_W)$

All the calculation below will show the calculation at 2500 RPM that running full load to clarify the step that used. All other result for the calculation from different speed and load will be shown in the table 19 at result chapter. The ΔT is 370 K and R_{total} is$68.66937\ ^K/_W$. The R_{total} is get from the previous calculation, the result can be seen at table 22- R_{total}. Then input all the value into the equation.

$$\dot{Q}_o = \frac{\Delta T}{R_{total}}$$

Where,

$\Delta T\ (T_1 - T_2) = 370K\ (at\ 2500\ RPM)$

$R_{total} = 68.66937\ ^K/_W$

$$\dot{Q}_o = \frac{370K}{68.66937\ ^K/_W}$$

$$= 5.38814\ W$$

So the initial heat transfer energy at the inlet section of exhaust pipe is 5.38814 W.

There are temperature differences on every segment that will be used to determine the heat transfer energy and different segments and length.

- **Temperature at exhaust pipe outlet (T_3)**

After the heat transfer rate at the first segment already found, then the T_3 or the outlet exhaust gas temperature after the first segment can be found. It can be found by using the heat transfer energy equation that shown below.

$$\dot{Q} = \dot{m} \cdot C_p \cdot \Delta T$$

The $\dot{m}$ is mass flow rate, C_p is specific heat of the fluid based on the temperature, and ΔT is the temperature difference. For the calculation for 2500 RPM that running at full load the mass flow rate that will be used is exhaust gas mass flow rate at 2.5 bar. The pressure 2.5 bar because the pressure of after turbo according to the engine data is 2.5 bar, the value can be seen at table 18.

RPM	Load	Mass Flow Rate (Kg/s)
2500	Full	0.32
	Three Quarter	0.31
	Half	0.26
	Quarter	0.21
1500	Full	0.18
	Three Quarter	0.15
	Half	0.12
	Quarter	0.1

Table 18 - Air Mass Flow Rate from Turbo

The specific heat is specific heat of air at 673 K and temperature difference is the difference between the inlet and outlet temperature of exhaust gas. The specific heat is specific heat of air at 673 K shown at air properties table at Appendix A.Then input all the value into the heat transfer energy equation.

$$\dot{Q}_o = \dot{m}_{exhaust\ gas} \cdot C_{p-air} \cdot \Delta T$$

Then rearranging it into,

$$\Delta T = \frac{\dot{Q}_o}{\dot{m}_{exhaust\ gas} \cdot C_{p-air}}$$

Where,

$\dot{Q}_o = Initial\ heat\ transfer\ energy = 5.38814\ W = 5.38814\ {}^{J}/_{s}$

$\dot{m}_{exhaust\ gas} = 1.6456768\ {}^{Kg}/_{s}\ (at\ 2.5\ bar)$

$C_{p-air} = 1068\ {}^{J}/_{Kg \cdot K}\ (at\ 673K)$

$\Delta T = T_1 - T_3$

Then input all the value that already know into the equation below,

$$\Delta T = \frac{\dot{Q}_o}{\dot{m}_{exhaust\ gas} \cdot C_{p-air}}$$

$$= \frac{5.38814\ {}^{J}/_{s}}{1.6456768\ {}^{Kg}/_{s} \cdot 1068\ {}^{J}/_{Kg \cdot K}}$$

$= 0.003066\ K$

$\Delta T = T_1 - T_3 = 0.003066\ K$

$673\ K - T_3 = 0.003066\ K$

$T_3 = 673\ K - 0.003066\ K$

$= 672.997\ K = 399.997\ {}^{\circ}C$

The temperature of the exhaust gas at outlet is$672.997\ K\ or\ 399.997\ {}^{\circ}C$.

- **Temperature at copper tube outlet (T_4)**

Then the T_4 or the temperature at copper tube outlet needs to be calculated. It can be found using the similar step and calculation that used to find theT_3. To find T_4 the equation that will be used is,

$$\Delta T = \frac{\dot{Q}_o}{\dot{m}_{cold\,air} \cdot C_{p-air}}$$

Where $\dot{Q}_o$ is heat transfer energy that already being calculated earlier. $\dot{m}_{cold\,air}$ is mass flow rate of the cold air inside the copper pipe. The value of the cold water mass flow rate is assumed to be 5% from the air flow rate from the turbo. The air mass flow rate from the turbo can be found from Cummins engine baseline test data that shown at table 23-turbo air mass flow rate. Then input all the data that needed into the equation.

$$\Delta T = \frac{\dot{Q}_o}{\dot{m}_{cold\,air} \cdot C_{p-air}}$$

Where,

$\dot{Q}_o = Initial\ heat\ transfer\ energy = 5.38814\ W = 5.38814\ {}^{J}/_{s}$

$\dot{m}_{cold\,air} = 0.016\ {}^{Kg}/_{s}$

$C_{p-air} = 1005.6\ {}^{J}/_{Kg \cdot K}\ (at\ 303K)$

$\Delta T = T_4 - T_2$

Then input all the value that already know into the equation below,

$$\Delta T = \frac{\dot{Q}_o}{\dot{m}_{cold\,air} \cdot C_{p-air}}$$

$$= \frac{5.38814\ {}^{J}/_{s}}{0.016\ {}^{Kg}/_{s} \cdot 1005.6\ {}^{J}/_{Kg \cdot K}}$$

$$= 0.334883\ K$$

$\Delta T = T_4 - T_2 = 0.334883\ K$

$T_4 - 303\ K = 0.334883\ \ K$

$T_4 = 303\ K + 0.334883\ \ K$

$= 303.334883\ K = 30.334883\ °C$

The temperature at the copper tube outlet is $303.334883\ K\ or\ 30.334883\ °C$

- **Heat transfer energy at the end of segment $(\dot{Q}_i)$**

To calculate the heat transfer energy$(\dot{Q}_i)$, this equation is used.

$$\dot{Q} = \frac{\Delta T}{R_{total}}$$

Since the overall calculation divide into several segment, the heat transfers energy at the end of segment also need to be found. To find the heat transfer energy$(\dot{Q}_i)$ at the end of each segment, the calculation can use the heat transfer energy equation that already modify. The equation is,

$$\dot{Q}_i = \frac{\Delta T_i}{R_{total}}$$

Where ΔT_i is temperature difference between the temperatures at the outlet of exhaust pipe and the copper tube, for the 2500 RPM and full load is$369.6621\ K$. The R_{total} is total thermal resistance at the segment, it is already calculated before which is $68.66937\ {}^{K}/_{W}$. The R_{total} is get from the previous calculation, the resul can be seen at table 17- R_{total} Then input all the parameter that needed into the equation.

$$\dot{Q}_i = \frac{\Delta T_i}{R_{total}}$$

Where,

$T_3 = Temperature\ at\ exhaust\ pipe\ outlet = 672.997\ K = 399.997\ °C$

$T_4 = Temperature\ at\ copper\ tube\ outlet = 303.334883\ K = 30.334883\ °C$

$\Delta T_i = (T_3 - T_4) = 369.6621\ K$

$R_{total} = 68.66937\ {}^{K}/_{W}$

$$\dot{Q}_i = \frac{369.6621\ K}{68.66937\ {}^{K}/_{W}}$$

$= 5.383216\ W$

So the value of heat transfer energy at the end of the segment is equal to $5.383216\ W$.

Hence, the overall calculation divided into several segment then the calculation step above need to be redone for other segment until the total heat transfers energy at the end of segment $(\dot{Q}_i)$ reach the required energy that needed to evaporate the ethanol. The different is that the heat transfers energy at the end of segment $(\dot{Q}_i)$ become the initial heat transfer energy $(\dot{Q}_o)$ and the temperature at end of the exhaust pipe (T_3) become the temperature at inlet exhaust pipe (T_1) also temperature at outlet of coil tube (T_4) become the temperature at inlet coil tube (T_2). The step will be repeated again for the segment after this until the desired total heat transfer energy at the outlet $(\dot{Q}_i)$ can be fulfil.

3.1.2 Result

As already stated before the overall heat transfer coefficient result will be shown at this chapter. The overall result of the calculation can be seen below,

RPM	Load	Q Ethanol / Required (kW)	Q tot (kW)	Copper Tube Length (m)	Coil Wrapped
2500	Full	3.666722	3.9269	1.1	3.9
	Three Quarter	2.776233	3.2178	0.8	2.9
	Half	1.99	2.3396	0.6	2.2
	Quarter	1.257	1.5265	0.4	1.5
1500	Full	2.8286	3.0758	1	3.6
	Three Quarter	2.2	2.4875	0.9	3.2
	Half	1.466	1.6558	0.6	2.3

	Quarter	0.733344	0.9517	0.3	1.1

Table 19 - Calculation Result

From the table it can be seen the desired total heat transfer energy $(\dot{Q}_i)$ that need to be reached for each speed and load so it can evaporate the ethanol properly. It also had shown the required copper tube length to reached total heat transfer energy$(\dot{Q}_i)$. After the length known, the coil wrapped that needed for the heat exchanger can be calculated. To calculated that it can used this equation,

$$Coil\ Wrapped = \frac{Cooper\ Tube\ Length}{The\ Exhaust\ Pipe\ Circumference} = \frac{Cooper\ Tube\ Length}{\pi \times Exhaust\ Pipe\ Outer\ Diameter}$$

Since the maximum coil wrap needed was 3.9, to make the fabrication and installation easier it will be better to round up the coil wrap needed into four wrap. If the coil wrap become bigger the total heat transfer energy also become bigger, it is good to prevent the heat lose that could happened. The heat exchanger installation is limited to 0.3 meter at the exhaust pipe due to the space limitation, for that available space the coil wrap can go up to approximately 12 wrap. So if the higher total heat transfer energy required, the user can add the wrap until 12 coil wrap.

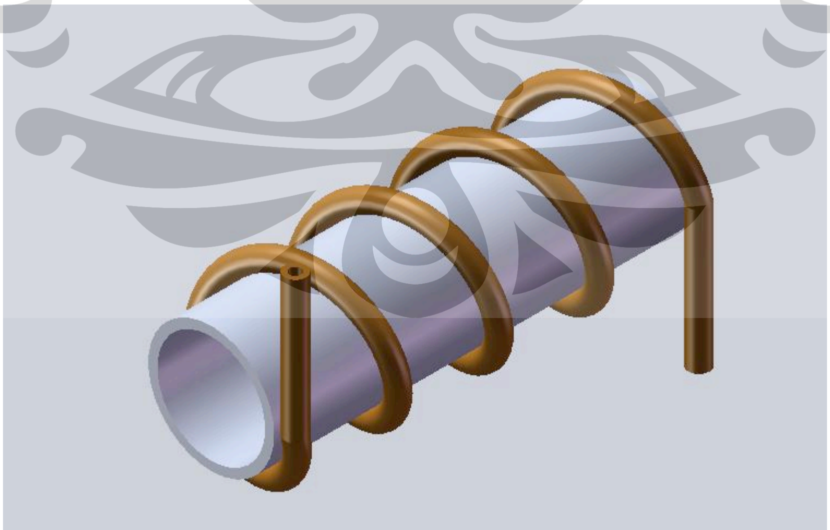


Figure 8 - Solid Modeling Image

4.0 HAZARD AND RISK ASSESSMENT

4.1 Scope

This chapter focused mostly on safety information and identification of safety issues for using equipments and tools to carry out the dual fuel test experiment in the engine laboratory room O122 at Queensland University of Technology (QUT). The procedure of the risk management is based on The Risk Management Guide (CP097) that provided from Faculty of Built Environment and Engineering (BEE).

Risk Management Code of Practice, (2007) assured the risk management process is to avoid a person's injury, illness, or death caused by a workplace; a related workplace area; work activities; or plant or substances that use at a workplace.

4.2 Definitions

According to Risk Management Code of Practice (2007), the meaning of Hazard and Risk are:

- Hazard is the materials (both hazardous and dangerous), plant, work processes, and other part of the work environment with the possibility to cause injury.
- Risk is the possibility of something happening that will affect the objectives. It is considered in terms of the likelihood of occurrence of the hazard and the severity of the consequences of the damage the harm could cause. The amount of risk is affected by the likelihood of that particular consequence and the severity of the consequence that may occur.

- Risk assessment is the procedure of evaluating the severity of a risk, for the purposes of prioritizing and taking action to control the risk. The processes consider the likelihood of harm arising from a hazard and the severity of the consequences that could result. This process may also be known as risk profiling

4.3 Risk Assessment Approach

There are five step risk assessment and control process according to the guidelines in (CP097) Risk Management Guide for the Faculty of Built Environment and Engineering. The steps are:

1. Determine Relevant Personnel
2. Identify Hazards within the project or task
3. Assess the risks existing for each Hazard
4. Determine and Implement Control Measures
5. Review effectiveness of Control Measure

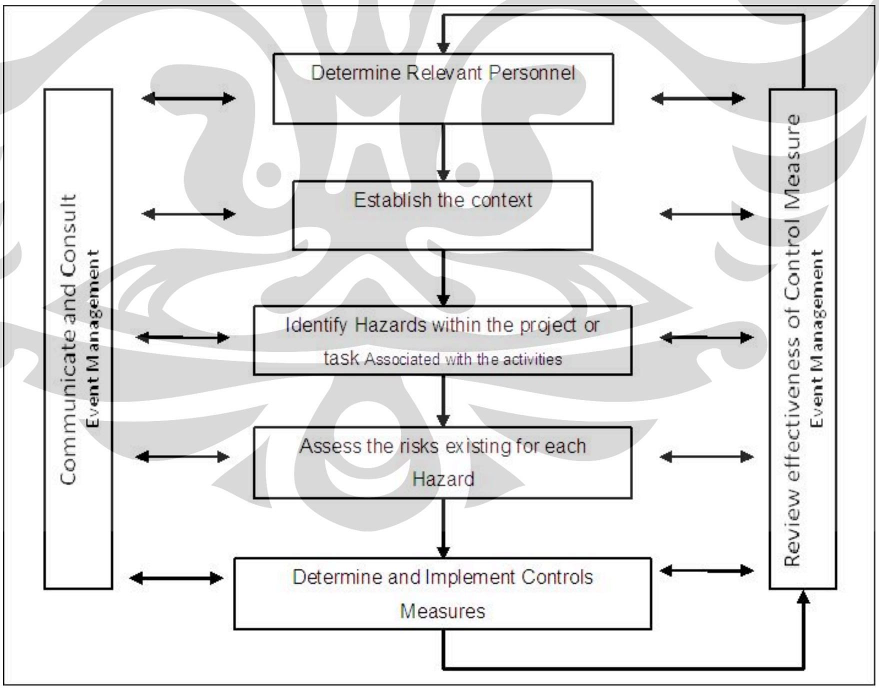


Figure 9 - Flowchart of the Risk Management Process

4.3.1 Determine Relevant Personnel

Risk management is a joint practice, because the responsibility for undertaking and carrying out risk management is shared between many persons.

The first step in the risk management process is to identify briefly the persons that will be involved in the project. The entire people that take part at the testing or service need to identify and put the name on the Risk Management Plan, Risk Management Plan can be seen at the Appendix F.

4.3.2 Identify Hazards within the Project or Task

The risk management was using the Hazard Identification & Risk Register Form (CF104) that published by Queensland University of Technology. First fill in the project details part then identify all Hazards that could be a source of potential harm or a situation that possible to cause harm. Hazards can occur from:

- The workplace environment
- Poor design or practices
- Inappropriate management system and procedures
- Human behavior
- The use of plant and substance

Hazard identification Supplement 1 (2007) stated the hazards can be recognized by visual inspection and observation and consultation.

- **Visual inspection and observation**

  The hazards are simply identified by conduct visual inspection of the laboratory. Look at each section in the laboratory to identify if any hazards could present.

- **Consultation**

Consulting from technicians that have knowledge work at the laboratory might assist identify hazards that have occurred in their experience.

4.3.3 Assess the Risk Existing for Each Hazard

The point of assess the risk that occur for each hazard is to decide if there is any possibility of a potentially dangerous condition that can cause injury, illness, death, or disease to persons in the workplace and the risk that require to be controlled and the urgently level (Risk assessment Supplement 2, 2007)

It is very important to evaluate the identified risks with the tools that show below. It will help to determine which ones are the most serious and arrange the actions needed to control the risks in order of priority, from the most to the least serious that can risks health and safety.

- **Likelihood Determination:** The following governing factors were considered when calculating the likelihood that a potential vulnerability might be exploited in the context of the associated threat environment:

The following table defines the likelihood determinations.

Level	Likelihood Definition
Almost Certain	The event is expected to occur in most circumstances
Likely	The event will probably occur in most circumstances
Moderate	The event should occur at some time
Unlikely	The event could occur at some time
Rare	The event may occur only in exceptional circumstances

Table 20 - Likelihood Definition

- **Impact Analysis:** The next major step in measuring level of risk was to determine the adverse impact resulting from successful exploitation of vulnerability. The adverse impact of a security event can be described in terms of loss or degradation of any, or a combination of any, of the following three security goals:

- Loss of Confidentiality – Impact of unauthorized disclosure of sensitive information (e.g., Privacy Act).
- Loss of Integrity – Impact if system or data integrity is lost by unauthorized changes to the data or system.
- Loss of Availability – Impact to system functionality and operational effectiveness.

Magnitude of Impact	Impact Definition
Catastrophic	Exercise of the vulnerability (1) may result in the highly costly loss of major tangible assets or resources; (2) may significantly violate, harm, or impede an organization's mission, reputation, or interest; or (3) may result in human death or serious injury.
Major	Exercise of the vulnerability (1) may result in the costly loss of tangible assets or resources; (2) may violate, harm or impeded an organization's mission, reputation, or interest; or (3) may result in human injury.
Moderate	Exercise of the vulnerability (1) may result in the loss of some tangible assets or resources; (2) may noticeably affect an organization's mission, reputation, or interest.
Minor	Exercise of the vulnerability (1) may result in the loss of some tangible assets or resources; (2) may noticeably affect an organization's mission, reputation, or interest.
Insignificant	Exercise of the vulnerability (1) may result in the loss of some tangible assets or resources; (2) may not cause injuries

Table 21 - Impact Definition

- **Risk Determination:** The following were used to assess the level of risk to the IT system:
  - The likelihood of a given threat source's attempting to exercise a given vulnerability.
  - The magnitude of the impact should a threat-source successfully exercise the vulnerability.
  - The adequacy of planned or existing security controls for reducing or eliminating risk.

The following table provides a definition for the risk levels. These levels represent the degree or level of risk to which an IT system, facility, or procedure might be exposed if a given vulnerability were exercised.

Magnitude of Impact	Risk Level Definition
Extreme	There is a strong need for corrective measures. Existing activities have to stop and the respective action a corrective action plan must be applied immediately.
High	There is a need for corrective measures. An existing system cannot operate and the corrective action plan must be put in place as soon as possible.
Moderate	Corrective actions are needed and a plan must be developed to incorporate these actions within a reasonable period of time.
Low	The system's Authorizing Official must determine whether corrective actions are still required or decide to accept the risk.

Table 22 - Risk Level Definition

RISK CALCULATOR (see guide for explanation on use)					
	CONSEQUENCES				
LIKELIHOOD	INSIGNIFICANT	MINOR	MODERATE	MAJOR	CATASTROPHIC
ALMOST CERTAIN	MODERATE	HIGH	EXTREME	EXTREME	EXTREME
LIKELY	MODERATE	HIGH	HIGH	EXTREME	EXTREME
MODERATE	LOW	MODERATE	HIGH	EXTREME	EXTREME
UNLIKELY	LOW	LOW	MODERATE	HIGH	EXTREME
RARE	LOW	LOW	MODERATE	HIGH	HIGH

Table 23 - Risk Matrix

(Source: Faculty of Built Environment and Engineering (2008))

4.3.4 Determine and implement control measures

Control Measures are based on a Control Hierarchy. The control hierarchy can be used to eliminate or minimize exposure to hazards. There are six level of control hierarchy. The six levels are shows below:

1. Eliminate

Eliminating the hazard completely is the most effective control and must always be attempted first when deciding on control measures.

2. Substitute

The less hazardous material, equipment and process can be used alternatively.

3. Engineer

Supplementary equipments should be used in order to prevent the injuries from the hazards. Additional machinery and laboratory setup should be installed to provide a safety working environment.

4. Isolate

The warning sign has been used and the potential hazardous area should be separated from people by the use of barriers, enclosures or distance.

5. Administrate

In the administrative level, the procedural instructions can be created and the training section should be provided to everyone involve in the operation. Alternatively, the procedures should be changed to reduce exposure to a hazard.

6. Personal Protective Equipment

Personal Protective Equipment (PPE) is gloves, hats, boots, goggles, masks and clothing designed to be worn in order to protect someone from risks of injury or illness. PPE will be used after the previous measures have been tried and found to be ineffective in controlling the risk to a reasonably practicable level.

4.3.5 Review the effectiveness of the Control Measure

Regular reviews need to be completed to make sure that the control measures gave the wanted level of the risk mitigation and the hazard that identified recently are managed effectively during the experiment.

Control, Implement, Monitor and Review Supplement 3 (2007) indicated the monitoring and reviewing procedure should consider all conditions of the particular case before getting a decision that include a review of previous records of risk assessments. All situations could indicate for a particular risk or for the entire risk management procedure.

4.4 Consultation

Risk Management Code of Practice (2007) recommended the consultation should happen at every stage of the risk management procedure as well as:

- Establishing priorities for the assessment of problem jobs and during the risk assessment process;
- Identifying problem jobs which require assessment;
- Reviewing the effectiveness of implemented control measures and identifying whether further risks of injury have been created by the chosen controls;
- New work processes, equipment or tools are being designed, purchased or modified;
- Deciding on control measures to manage exposure to risk factors; and
- Deciding the contents of procedural documents, as experienced workers can help make sure they are as relevant as possible to the actual work situation.

There are some benefits to the consultation during the risk management process because it can:

- Contributes to developing a positive safety culture in the laboratory, by increasing team commitment to workplace health and safety;
- Brings together different areas of expertise to identify and analyze risks and allows those with day to day experience of the hazards to provide valuable input;
- Improves trust, communication and teamwork; and
- Increases the likelihood that workers will be committed to implementing the control measures because they understand why they are being imposed

4.5 Record Keeping

The record keeping is an important thing in the risk management. It can maximize the effectiveness of the procedure and assists when undertaking following risk assessments (Risk Management Code of Practice, 2007). The information that needs to be recorded includes:

- The risk assessment date, identified hazards, assessed risks and chosen control measures;
- How the control measures were implemented, monitored and reviewed;
- The consultation undertaken and who was involved; and
- Relevant related training records.

Risk Management Code of Practice (2007) stated everyone in the workplace must aware of record keeping requirements, including records accessibility and storages.

5.0 DUAL FUEL ENGINE TESTING

5.1 Engine Description

A Ford 2701C 4 cylinder naturally aspirated direct injection diesel engine was used throughout the entirety of the engine performance analysis tests.

The dual fuel engine project used Ford 2701C 4 cylinder naturally aspirated direct injection diesel engine to do the testing. The engine specifications are shown below:

Engine Specifications	
Make	Ford
Model	2710C
Rated Horsepower (kW)	64
Rated Speed (rpm)	2500
No of Cylinders	4
Bore x Stroke (mm)	108.2 x 115
Displacement Volume	1057 cm^3
Compression Ratio	15.5:1

Table 24 - Ford Diesel Engine Specifications

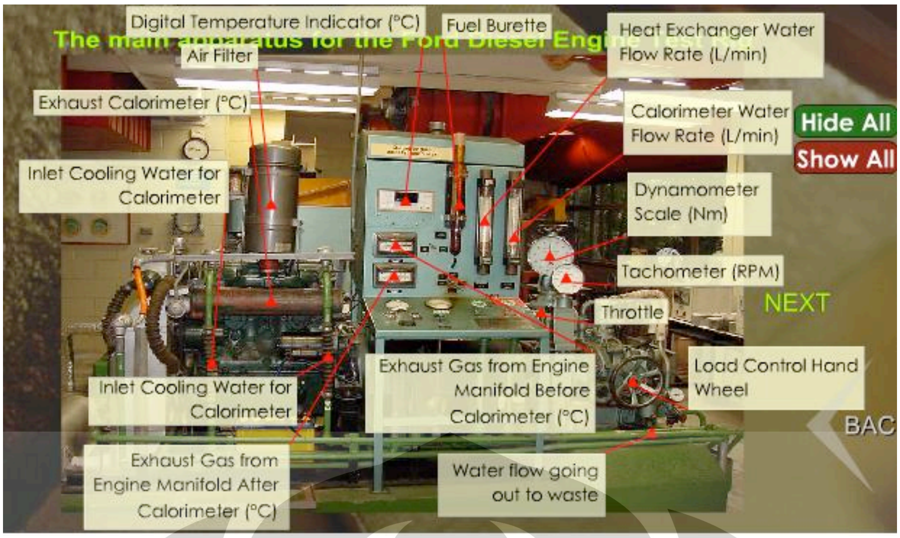


Figure 10 - Ford Diesel Engine Test Rig

The Ford engine is connected to Froude D.P.X Type Hydraulic Dynamometer, the load of the dynamometer can be applied by increase the water flow rate inside the dynamometer housing. The measurements that can be read from the dynamometer were RPM and torque. To improve the reading at dynamometers RPM dial, external portable digital tachometer was used. The engine used the fuel injection pump that has a mechanically controlled spring balance fuel governing system. The engine also can be used to calculate the fuel consumption, it can be calculated by measured the time that required to consumed 400ml of diesel. To assist the engine fuel consumption calculation, the engine provided with a glass burette. Before the project started, the engine was inspected and review was carried out to determine the general condition and suitability for the project.

There are some modifications needed to make the Ford engine suitable to conduct the performance test. A vortex mixer and ethanol injection system need to be installed. Vortex mixer used to provide a constant ratio of secondary fuel to main fuel through varying load conditions. To assembly an ethanol injector there are several parts needed, such as: injector controller, ethanol injector, ethanol pump, pressure regulator, filter, and heat exchanger. Heat exchanger used to raise the ethanol temperature to evaporation point, and promotes better vaporization of the ethanol during the combustion process (Ajav et al., 1998). It also can provide a more consistent mass flow in each combustion chamber.

The engine testing can begin after the repairs and service that needed already fulfilled. The purpose of the testing is to found the torque, power, and fuel consumption data from the current condition then the data from current condition will be compared with the engine specification from company that make the engine. All the engine parameter, such as:

pressures and temperature, monitored closely to make sure it still in the tolerable standards. The data that get from the engine test showed that the engine at 1700 rpm can produce 236 Nm of torque, this value is higher than the value at engine specification that get from the manufacturer. The max fuel setting was adjusted bringing the engines power/torque back within specifications (208 Nm at 1700 rpm).

5.2 Engine Testing (October Campaign)

5.2.1 Test Procedure

During the October test campaign there were twenty five engine performances testing that conducted. Besides test the engine performance using dual fuel system, emission testing also carried out. Since the student only in charge with the engine performance test then this report only discuss about the data from engine performance test.

The entire test was run at full load at 2000 RPM. The fuel injection was set at the rated according to the engine manual specification, which is 209 Nm at 1700 RPM for the entire test that carried out in October. The data that collected and gathered from the testing campaign then being calculated and analyzed. From the data that composed the energy balance, thermal efficiency, and break specific fuel consumption can be determine and calculate. Another test campaign will be conducted during December, but this report only discuss about the engine performance test during October campaign. At the December campaign the test will be conducted at the different and load.

The data that collected divided into three sections which are emissions data, performance and fuel consumption, and pressure volume diagrams. To conduct this test efficiently and smoothly at least five people needed to take part, so each people have their own job.

There are several procedures that need to be taken to make sure the test was run properly. There are:

- After the engine started give some time to allowed the engine for warm up;
- Take it to the rated RPM and torque;
- Then reduce the load to a torque that corresponded to a known diesel flow rate, add a known flow rate of ethanol to the engine;

- Use the throttle to bring the engine RPM/ torque back to rated values;
- Make sure the engine is running acceptably (eg. The engine run in stable temperature, ethanol fully vaporizes.);
- Collect and record the data that needed.

The data that already been collected then being compiled together at excel spread sheet, after the all data completed then analysis was conducted. The analysis was carried out to determine any peculiarity and to find out if re-testing is needed.

5.2.2 Problem Encountered

There are some difficulty that occured during the engine testing campaign. First, the heat exchanger didn't fully heat the ethanol into the evaporation point. This was a big problem because if the ethanol didn't evaporate, it could damage the engine. Air heater 1000 W was installed directly after the heat exchanger to solved heat exchanger problem. The heater can help keep the minimum temperature of vapour when entered the engine. Beside installed a heater, a low pressured compressed air also being injected into the ethanol flow system. The purpose of this compressed air was to make sure that the vapour noth reached it saturation level. After the modification applied, the ethanol can fully vaporized. The new modification that recently applied also give diadvantages, beside benefits. Since the a heater was installed, process to controlled regulator of the air heater was not steady. If the operation of regulator that control the heater not stable, it could affected the final result. This condition can affected the test result of thermal efficiency badly, because of the inlet air temperature changing that entered the engine.

Beside the problem with heat exchanger, another problem that occured is with the ethanol injector. The ethanol injector that used was too large, becuase it too large the precise control of ethanol flow rates became a problem. To overcome that problem the injector was operated at lower pressure from it supposed. By make the ethanol injector operated at lower pressure, it can make the injector attained the flow that required for the test. Meanwhile the software that used to supplied the ethanol just can afford 5% duty cycle steps. The injector could not achived the flow rate that required, if only run at one pressure. So the injector need to run at different pressure to gain the required ethanol flow rate since the software just only provided 5% duty cycle.

5.3 Result

To collect the data, there were three spread sheets that used. First were the engine performance sheet, then the fuel consumption, and the emission. All the data then inputted into Microsoft Excel to be analyzed and calculated. The aim of carried the analysis is to determine whether the team already satisfied with the data or the test need to be re-run.

All the data then plotted into matrix to make the analysis easier. The matrix data that gathered from the October campaign can be seen below,

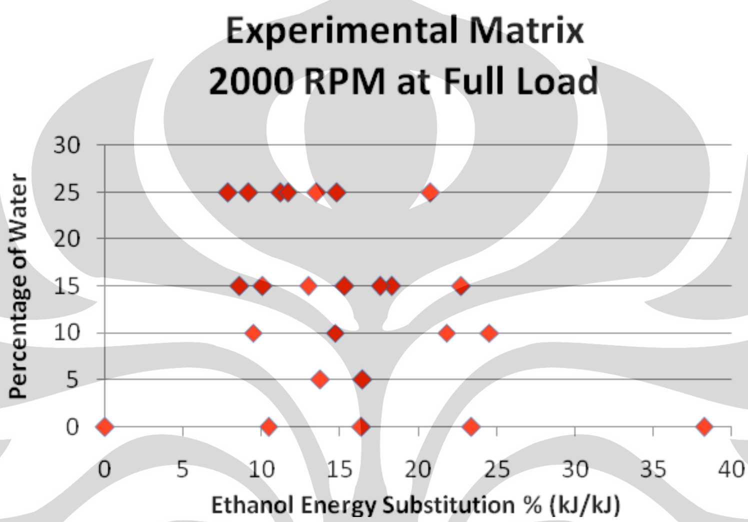


Figure 11 - Data Matrix of 2000 RPM at Full Load

The X axis at the matrix represent the total energy that supplied by ethanol, while the Y axis represent the percentage of water mass in ethanol. The data points were spread at not evenly along the X axis, this happened because there were some difficulties to adjust the ethanol and diesel mass flow during the entire test.

From the data that collected by testing team, the thermal efficiency can be calculated and analyses. The thermal efficiency matrix shown below,

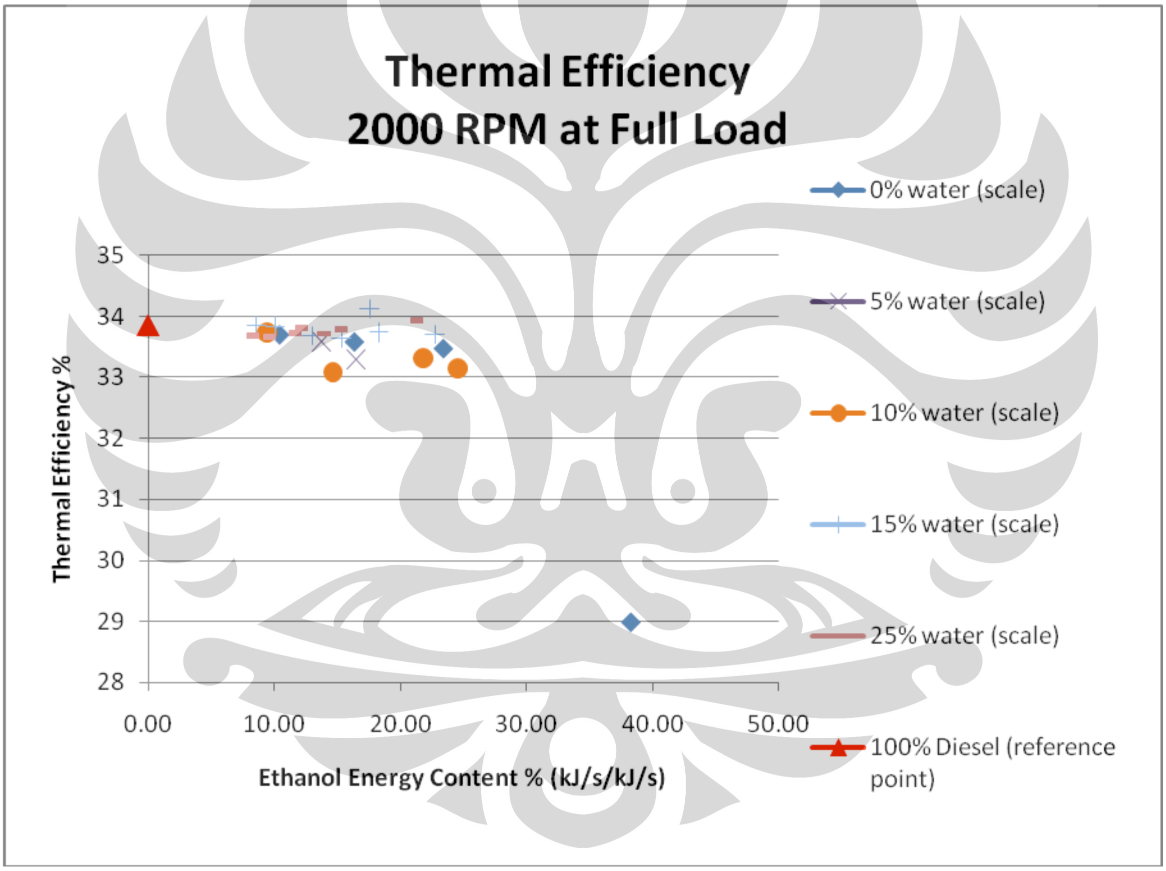


Figure 12 - Thermal Efficiency on 2000 RPM at Full Load

The X axis is the percentage of ethanol energy content, while Y axis represents the thermal efficiency percentage. There were several different marks at the matrix, each mark represent different water percentage and one point is 100 % diesel act as the reference point. There were small drops at the thermal efficiency at 0%, 5%, and 10% water percentage, however the 15% and 25% water concentration deviate less if compare with other. The general deviation approximately 1% but no trend was occurred since the introduction of water. This data were different with the Abu-Qudais's results. The results that Abu-Qudais get show the rise in thermal efficiency (Abu-Qudais *et al.*, 2000). During the campaign there were two test that the percentage of ethanol/diesel proportion near 50%, the data that gathered shown that the drop was pretty big. The condition need confirmation to make sure the validity, so the next test will run at vary water concentration to confirms it validity.

Another analysis that carried out was the brake specific fuel consumption. The graph below will shown the data that achieved from the testing,

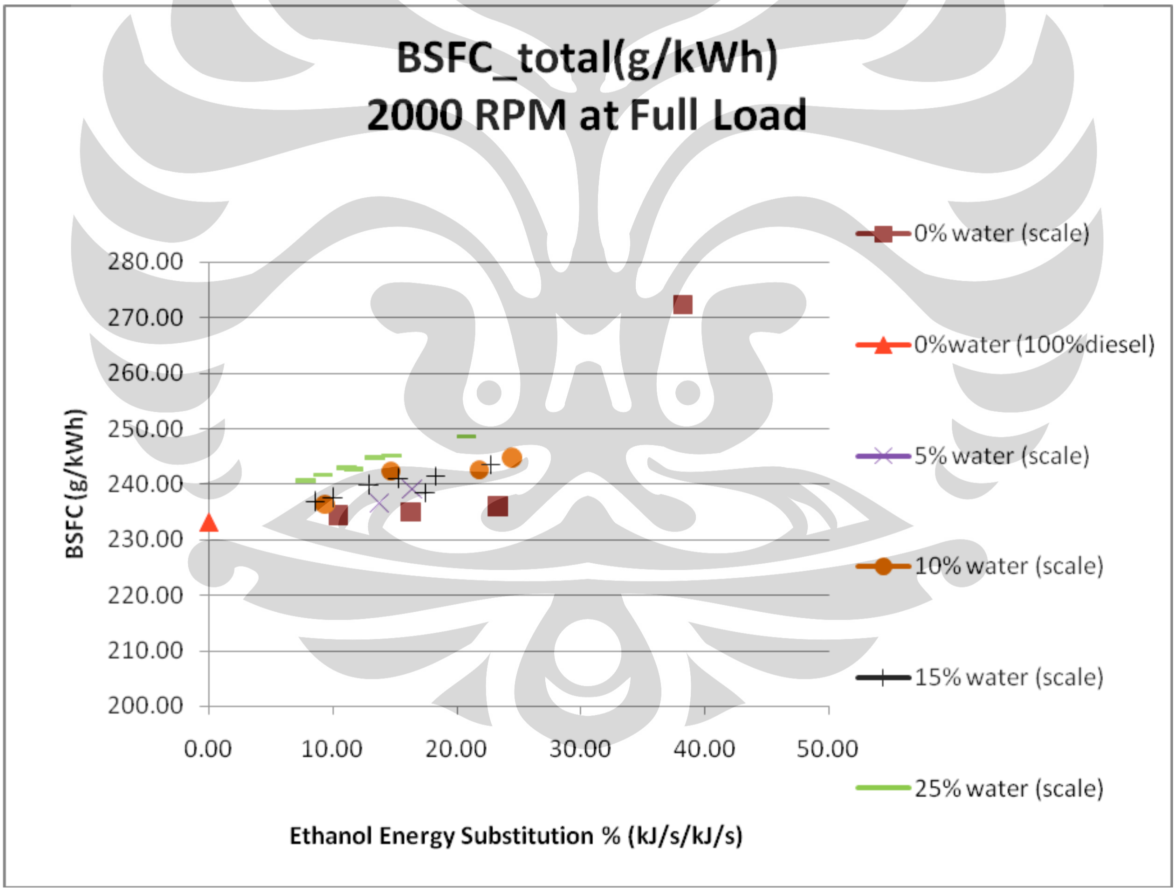


Figure 13 - BSFC on 2000 RPM at Full Load

The X axis is the percentage of ethanol energy content, meanwhile Y axis represents the brake specific fuel consumption (BSFC). There were several different dots at the graph, each dot stand for different water percentage but one point act as the reference point which is 100 % diesel. According to the graph, there were gradual rise during the increase of ethanol percentage. So the trend for the BSFC is increase and proportional between the BSFC and the ethanol percentage. The condition was same with research that conducted by Yukel, Yukel stated that the data which he got is shown the increase of BSFC proportionally with the ethanol percentage (Yuksel *et al.*, 2004).

6.0 Conclusion and Future work

6.1 Conclusion

The objectified that need to be achieved could be attained. The copper tube coiled design could meet the required energy and temperature to heat and evaporate the ethanol. Each load at different speed required different wrapped of copper. Since the maximum wrapped need is 3.9, to make the fabrication and installation it rounded up to 4 wrapped. In general this copper tube coil could accomplish the requirement to gain sufficient energy to vaporize the ethanol in the limited available space.

Risk assessment is a simple document to record the potential hazards and the safety execution when the experiment is conduct in the laboratory. Safety at workplace could be enhanced by implementing the plan accordingly. Workplace safety is an important part for the experiment and by followed the plans one can try to avoid injuries and harm to equipments and also life.

Data that attained from the engine testing campaign shows the thermal efficiency tend to decrease while the ethanol percentage increased. Although the thermal efficiency did not shows any trend but there were slight drops of thermal efficiency at the beginning when ethanol was being introduced. Meanwhile the brake specific fuel consumption data had an increase trend that proportionally with the ethanol substitution. The result that achieved from October test campaign cannot completely represent the affects of introducing ethanol into the intake air system of naturally aspirated direct injection diesel engine, since the test campaign only run at a single load on single RPM.

6.2 Future work

The dual fuel project that student involved is a project that optimize and apply Uli Kruger's design of dual-fuel engine system. The heat exchanger design and calculation of copper tube coil hopefully could be apply at the Cummins engine and make contribution for the dual fuel project. In the future, the calculation and design which student already done can be improved by add another modification. There could be another option of heat exchanger that available, the team could try to design and calculated a double pipe heat exchanger. The double pipe heat exchanger could use two different fluids in that flow in opposite direction. It may achieve the energy and temperature that required heating up the ethanol into the evaporation point.

REFERENCES

Cengel, Y.2007. *Heat and Mass Transfer a Practical Approach*, Third Edition. New Youk: McGraw Hill Companies.

Eastop, T. D., & McConkey, A.1993. *Applied Thermodynamics for Engineering Technologists* (5th ed.). Essex: Longman.

Heywood, J. B.1988. *Internal Combustion Engine Fundamentals*, New York: McGraw-Hill.

Abu-Qudais, M. Haddad, O. & Qudaisat, M.2000. *"The Effect of Alcohol Fumigation on Diesel Engine Performance and Emissions"*, Energy Conversion and Management, vol. 41, no. 4, pp. 389-399.

Brown, W. A.1981. *Fuel Ethanol: A Guide for the Small Scale Producer*, Bio-Energy Developments, Christchurch.

Lu, X. C. Yang, J. G. & Zhang, W. G.2004. *Effect of Cetane Number Improver on Heat Release Rate and Emissions of High Speed Diesel Engine Fueled with Ethanol–Diesel Blend Fuel*. FUEL, 83 (14-15), 2013-2020

Majewski, W. & Khair, K. 2006. *Diesel Emissions and Their Control*. Warrendale, Pa: SAE International.

Risk Management Code of Practice.2007. *Risk management*, Available from: Queensland Government, Web site: http://www.deir.qld.gov.au/pdf/whs/riskman_code2007.pdf [Accessed: June 25, 2009].

Risk assessment Supplement 2.2007. *Workplace Health and Safety Queensland*, Available from: Queensland Government, Web site: http://www.deir.qld.gov.au/pdf/whs/riskman_07supp2.pdf [Accessed: June 12, 2009].

Control, Implement, Monitor and Review Supplement 3.2007. *Workplace Health and Safety Queensland*, Available from: Queensland Government, Web site: http://www.deir.qld.gov.au/pdf/whs/riskman_07supp3.pdf [Accessed: June 12, 2009].

Faculty of Built Environment and Engineering 2008. *Project Safety Plan*, Available from: Queensland University of Technology, Web site: http://www.deir.qld.gov.au/workplace/subjects/riskman/index.htm [Accessed: Accessed: June 15, 2009].

Hazard identification Supplement 1.2007. *Workplace Health and Safety Queensland*, Available from: Queensland Government, Web site: http://www.deir.qld.gov.au/pdf/whs/riskman_07supp1.pdf [Accessed: June 12, 2009].

Despiau, Y. 2009. Engine Performance and Gaseous Emissions of a Natural Aspirated Dual Fuel Engine. Under graduate thesis. Queensland University of Technology. http://blackboard.qut.edu.au/webapps/portal/frameset.jsp?tab_tab_group_id=_5_1&url=%2Fwebapps%2Fblackboard%2Fexecute%2FcourseMain%3Fcourse_id%3D_47026_1 (accessed June 25, 2009).

APPENDIX A: Air Properties

Air Properties Table

Temperature - t - (^oC)	Density - ρ - (kg/m^3)	Specific heat capacity - c_p - ($kJ/kg\ K$)	Thermal conductivity - l - ($W/m\ K$)	Kinematic viscosity - ν - (m^2/s) x 10^{-6}	Expansion coefficient - b - ($1/K$) x 10^{-3}	Prandtl's number - P_r -
-150	2.793	1.026	0.0116	3.08	8.21	0.76
-100	1.980	1.009	0.0160	5.95	5.82	0.74
-50	1.534	1.005	0.0204	9.55	4.51	0.725
0	1.293	1.005	0.0243	13.30	3.67	0.715
20	1.205	1.005	0.0257	15.11	3.43	0.713
40	1.127	1.005	0.0271	16.97	3.20	0.711
60	1.067	1.009	0.0285	18.90	3.00	0.709
80	1.000	1.009	0.0299	20.94	2.83	0.708
100	0.946	1.009	0.0314	23.06	2.68	0.703
120	0.898	1.013	0.0328	25.23	2.55	0.70
140	0.854	1.013	0.0343	27.55	2.43	0.695
160	0.815	1.017	0.0358	29.85	2.32	0.69
180	0.779	1.022	0.0372	32.29	2.21	0.69
200	0.746	1.026	0.0386	34.63	2.11	0.685
250	0.675	1.034	0.0421	41.17	1.91	0.68
300	0.616	1.047	0.0454	47.85	1.75	0.68
350	0.566	1.055	0.0485	55.05	1.61	0.68
400	0.524	1.068	0.0515	62.53	1.49	0.68

Air Density Table

Density of air 1) (lb/ft³)

Air temperature (°F)	Gauge Pressure (psi)											
	0	5	10	20	30	40	50	60	70	80	90	100
30	0.081	0.109	0.136	0.192	0.247	0.302	0.357	0.412	0.467	0.522	0.578	0.633
40	0.080	0.107	0.134	0.188	0.242	0.295	0.350	0.404	0.458	0.512	0.566	0.620
50	0.078	0.105	0.131	0.185	0.238	0.291	0.344	0.397	0.451	0.504	0.557	0.610
60	0.076	0.102	0.128	0.180	0.232	0.284	0.336	0.388	0.440	0.492	0.544	0.596
70	0.075	0.101	0.126	0.177	0.228	0.279	0.330	0.381	0.432	0.483	0.534	0.585
80	0.074	0.099	0.124	0.174	0.224	0.274	0.324	0.374	0.424	0.474	0.524	0.574
90	0.072	0.097	0.121	0.171	0.220	0.269	0.318	0.367	0.416	0.465	0.515	0.564
100	0.071	0.095	0.119	0.168	0.216	0.264	0.312	0.361	0.409	0.457	0.505	0.554
120	0.069	0.092	0.115	0.162	0.208	0.255	0.302	0.348	0.395	0.441	0.488	0.535
140	0.066	0.089	0.111	0.156	0.201	0.246	0.291	0.337	0.382	0.427	0.472	0.517
150	0.065	0.087	0.109	0.154	0.198	0.242	0.287	0.331	0.375	0.420	0.464	0.508
200	0.060	0.081	0.101	0.142	0.183	0.244	0.265	0.306	0.347	0.388	0.429	0.470
250	0.056	0.075	0.094	0.132	0.170	0.208	0.246	0.284	0.322	0.361	0.399	0.437
300	0.052	0.070	0.088	0.123	0.159	0.195	0.230	0.266	0.301	0.337	0.372	0.408
400	0.046	0.062	0.078	0.109	0.141	0.172	0.203	0.235	0.266	0.298	0.329	0.360
500	0.041	0.056	0.070	0.098	0.126	0.154	0.182	0.210	0.238	0.267	0.295	0.323
600	0.038	0.050	0.063	0.089	0.114	0.140	0.165	0.190	0.216	0.241	0.267	0.292

Density of air 1) (lb/ft³)

Air temperature (°F)	Gauge Pressure (psi)											
	120	140	150	200	250	300	400	500	700	800	900	1000
30	0.743	0.853	0.909	1.185	1.460	1.736	2.29	1.84	3.94	4.49	5.05	5.60
40	0.728	0.836	0.890	1.161	1.431	1.702	2.24	2.78	3.86	4.40	4.95	5.49
50	0.717	0.823	0.876	1.142	1.408	1.674	2.21	2.74	3.80	4.33	4.87	5.40
60	0.700	0.804	0.856	1.116	1.376	1.636	2.16	2.68	3.72	4.24	4.76	5.28
70	0.687	0.789	0.840	1.095	1.350	1.605	2.12	2.63	3.65	4.16	4.67	5.18
80	0.674	0.774	0.824	1.075	1.325	1.575	2.08	2.58	3.58	4.08	4.58	5.08
90	0.662	0.760	0.809	1.055	1.301	1.547	2.04	2.53	3.51	4.00	4.50	4.99
100	0.650	0.747	0.795	1.036	1.278	1.519	2.00	2.48	3.45	3.93	4.42	4.90
120	0.628	0.721	0.768	1.001	1.234	1.467	1.933	2.40	3.33	3.80	4.26	4.73
140	0.607	0.697	0.742	0.967	1.193	1.418	1.868	2.32	3.22	3.67	4.12	4.57
150	0.597	0.686	0.730	0.951	1.173	1.395	1.838	2.28	3.17	3.61	4.05	4.50
200	0.552	0.634	0.675	0.879	1.084	1.289	1.698	2.11	2.93	3.34	3.75	4.16
250	0.513	0.589	0.627	0.817	1.088	1.198	1.579	1.959	2.72	3.10	3.48	3.86
300	0.479	0.550	0.586	0.764	0.941	1.119	1.475	1.830	2.54	2.90	3.25	3.61
400	0.423	0.486	0.518	0.675	0.832	0.989	1.303	1.618	2.25	2.56	2.87	3.19
500	0.379	0.436	0.464	0.604	0.745	0.886	1.167	1.449	2.01	2.29	2.58	2.86
600	0.343	0.394	0.420	0.547	0.675	0.802	1.057	1.312	1.822	2.08	2.33	2.59

APPENDIX B: Cummins Engine Specifications

CUMMINS ENGINE COMPANY LIMITED

Automotive Engine Data Sheet FR91210 Date of Issue 31/10/03

Engine Model: ISBe220 31 CPL: 2925 Certification: Euro 3
Advertised Power: 162kW @ 2500rpm, 217BHP @ 2500rpm
Peak Torque: 820Nm @ 1500rpm, 605lbft @ 1500rpm

General

Certification:	ECE R24.03. 2001/27/EC (88/77/EEC)
Data on this sheet refers to Installation Diagram:	3170502
Weight Dry: kg (with flywheel [FW9461], No Compressor, alternator or starter).	470
Weight Wet: kg	498
Compression Ratio:	17.3:1
C.G. Distance from F.F.O.B: mm	400
C.G. Distance above crank centre line: mm	150
Maximum bending moment at R.F.O.B: Nm	1360
Thrust bearing load limit	
Maximum intermittent: N	5670
Maximum continuous: N	xxxx

Performance Data

Idle Speed: rpm	600 - 800
Maximum no load governed speed: rpm	2850
Maximum overspeed capability: rpm (15secs max.)	4200
Maximum altitude for continuous operation: m	2000
Clutch engagement torque at 800rpm: Nm	500
Maximum Torque from Front Power Take off in a Straight Torque Drive: Nm	475
When using exhaust brakes:	
Exhaust pressure, at 3100rpm, at turbocharger outlet, must not exceed: bar	4.3
Brake blade must have orifice to control exhaust pressure: dia mm	8.5
Approximate engine retardation: kW @ 2500rpm	97

RPM	Oil Pressure	Air to Turbo	Air From Turbo		Exhaust Flow	Exhaust Temp	Fuel Flow	Coolant Flow #	Heat Rejection		Friction Power
	kPa	m³/min	Flow kg/min	Pressure kPa	m³/min	°C	l/hr	l/m	Coolant kW	Air kW	kW
2500	355	10.2, [illegible]	18.0 [illegible]	180	34.0	400	95.0	215	85.0	33.0	34.0
• 2200	350	14.8	17.6	170	35.0	470	95.0	195	88.0	33.0	28.0
1500	290	9.6	11.3	145	25.0	525	78.0	136	71.0	21.0	13.0

• Cooling System check speed.

Radiator coolant flow is approximately 5% less with a continuous deaerating system.
Coolant : 50/50 - Ethylene Glycol / Water by Volume.

All values within ± 5%

Updated Data Since Previous Issue

Correct at Date of Issue

CUMMINS ENGINE COMPANY LIMITED

Automotive Engine Data Sheet FR91210 Date of Issue :31/10/03

Engine Model: ISBe220 31 CPL: 2925 Certification: Euro 3

Advertised Power: 162kW @ 2500rpm, 217BHP @ 2500rpm

Peak Torque: 820Nm @ 1500rpm, 605lbft @ 1500rpm

Lubrication System

Oil pan capacity (OP9298)	
High: litre	17.5
Low: litre	15.0
Total capacity: litre	19.5

Angularity (OP9298) low oil level: Front up 22°, Rear up 50°, F/P side up 43°, Exh side up 45°

Air Intake System

Max. temp. rise between ambient air and turbo air inlet: °C	15
Max. intake restriction with dry type air cleaner, with clean filter	
Medium Duty: kPa	2.9
Heavy Duty: kPa	3.7
Max. intake restriction with dirty filter: kPa	6.2

Charge Air Cooling

Max. temp. rise between ambient air and intake manifold: °C	30.0
Max. ΔP between turbo outmanifold in: kPa	13.5
Intake pipe size normally acceptable: mm dia	65

Exhaust System

Maximum bending moment on the turbo exhaust outlet flange Nm	15
Max. back pressure imposed by piping and silencer: kPa	10.0
Exhaust pipe size normally acceptable: mm dia	75

Fuel System

Max. restriction at inlet to ECM cooler with clean pre-filter: kPA	30
Max. return line restriction: kPa	20
Min. fuel tank vent capacity: m^3/hr	0.2
Max fuel temperature at lift pump inlet: °C	70
Min. seperation of free and emulsified water (chassis pre-filter) at 2% solution in fuel %	90

Cooling System

Engine coolant capacity: litre	10
Standard modulating thermostat (range): °C	83 - 95
Block coolant pressure (no pressure cap and thermostat closed): kPa @ 2800 rpm	280
Max. coolant temperature (engine out): °C	100
Max. deaeration time: mins	25
Max. coolant flow to accessories: litre/min	27
Min. coolant temperature: °C	70
Min. fill rate: litre/min	19
Min. coolant expansion space % of system capacity	6
Min. drawdown (excluding expansion space) % of total system:	11
Min. allowable pressure cap: kPa	50
Coolant alarm activation temperature: °C	104
Air on fan, typical operating temperature range: °C	93
Shutter opening temperature: °C	Do Not Use
Min. cooling capability at normal fuel rate:	See AEB 21.42

Electrical System 24Volt

Max. resistance of starting circuit: ohms	0.004
Min. recommended battery capacity for -18 °C and above (SAE J537)	
Engine only with de-clutched load cold cranking amperes:	550

Starting System

Min. unaided cold start temperature -15 °C @ 120 average rpm.
Min. aided cold start temperature -30 °C @ 100 average rpm.

Correct at Date of Issue

All data subject to change without notice. Cummins Engine Co. Ltd European Technical Operations, Yarm Road, Darlington, DL1 4PW, England. Tel 01325 556005 Fax 01325 359363

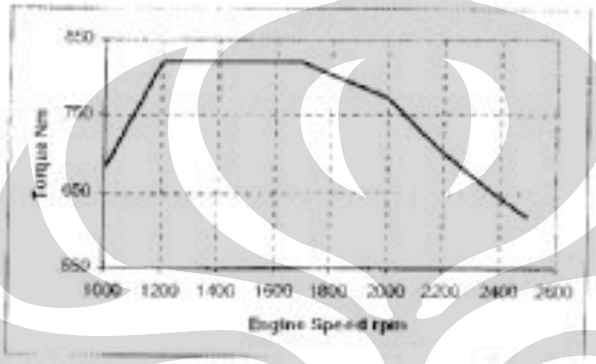
CUMMINS ENGINE COMPANY LIMITED

Automotive Engine Data Sheet FR91210 Date of Issue 31/10/03

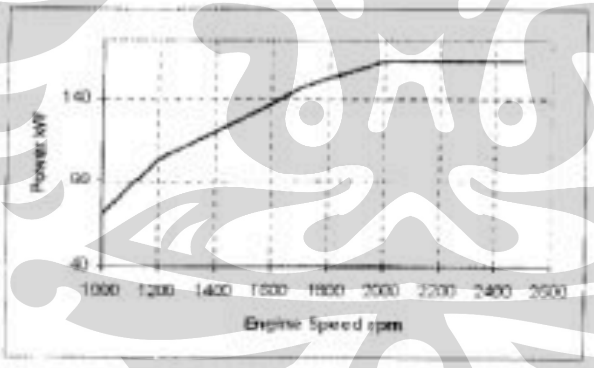
EURO 3

Engine Model: ISBe220 31	CPL: 2925
Advertised Power: 162kW @ 2500rpm 217BHP @ 2500rpm	Peak Torque: 820Nm @ 1500rpm 605lbft @ 1500rpm

Displacement: 5.9Litre	Bore: 102mm	Aspiration: Turbochargered & Aftercooled
Configuration: 6 cylinder in-line	Stroke: 120mm	Fuel System: Bosch HPCR



	Torque	
rpm	Nm	lb-ft
1000	680	502
1200	820	605
1400	820	605
1600	820	605
1700	820	605
1800	804	593
2000	773	570
2200	703	519
2400	644	475
2500	618	456



	Power	
rpm	kW	bhp
1000	71	95
1200	103	138
1400	120	161
1600	137	184
1700	146	196
1800	152	204
2000	162	217
2200	162	217
2400	162	217
2500	162	217

Correct at Date of Issue

Performance data shown is nominal, and is to 80/1269/EEC (as amended) conditions of 990mbar barometric pressure and 25 °C air intake temperature. Not included are Compressor, Fan and Alternator