Sudan University of Science and Technology

College of Graduate Study

School of Mechanical Engineering

Study of Internal Combustion Engines Waste Heat Recovery Using Turbocharger Compounding

دراسة استرداد الطاقة الحرارية المهدرة في محركات الاحتراق الداخلي باستخدام المضاعف الشاحن التوربيني

A thesis Submitted to the Sudan University of Science and Technology in Partial fulfilment of the Requirements for the degree of Master of Science in Mechanical Engineering

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Dedications

I would like to take this opportunity to finally give back a small something to my parents whose support and unconditional love are the reason for my being here today. They have supported me through the peaks and troughs of life and refused to give up on me at times when I almost gave up on myself. They gave me the power to push through university and get gave me the head start in life what I need to make something of myself, I also dedicate this for my wife which encourages me to do good things.

Acknowledgements

This research project was a draining yet educationally rewarding journey, with the laboratory proving to be a second home.

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I also thankful to Sudan University,

Finally, I owe a special thanks to my family and friends for their continuing encouragement and confidence in me.

I deeply grateful to you all, and forever in your debt.

Abstract

The purpose of this project is to study the effects of turbocharger technology in a diesel engine. The Perkins diesel six cylinders 4 stroke Stationary CI Engine (case study) comes without a turbocharger. The Study is based on predict the effects of using this technology in the performance of engine, air pollution and global warming by calculations and simulation.

After the calculations and simulation found that Recovering technology is decreasing the temperature of exhaust gas from 570˚C to 150˚C which decrease the pollution and save 76.62 kW of heat which reduce the global warming. The simulation is done by Diesel RK software to study the effect of using turbocharger in the emissions of the engine. The Curves have been drawn by MATLAB software.

ملخص الدراسة

الغرض من الدراسة هو دراسة تأثير تقنية الشاحن التوربيني في محرك الديزل. محرك الديزل الثابت ذو الست اسطوانات و اربعة اشواط من شركة بيركينز (موضوع الدراسة) يأتي من غير شاحن توربيني. الدراسة قائمة علي توقع تأثير استخدام هذه التقنية علي اداء المحرك, تلوث الهواء والاحتباس الحراري بالحسابات و المحاكاة.

بعد اجراء الحسابات و المحاكاة وُجد ان تقنية الشاحن التوربيني يخفض درجة حرارة غازات العادم من 570 درجة مئوية الي 150 درجة مئوية والتي بدورها تقلل تلوث الهواء ويوفر 76.62 كيلووات من الحرارة والتي تقلل من الاحتباس الحراري. المحاكاة تمت بواسطة برنامج ديزل ر.ك لدراسة تأثير استخدام المضاعف التوربيني علي الانبعاثات من المحرك. المنحيات رُسمت ببرنامج ماتلاب.

Content

List of Tables

List of Figures

List of Symbols

n	number of cylinders
D	Bore diameter, mm
L	Stroke length, mm
V_r	Compression Ratio
V_s	Swept Volume, L
V_c	Clearance volume, L
ρ_f	Fuel Density, kg/$\boldsymbol{m^3}$
ρ_a	Air Density, kg/$\boldsymbol{m^3}$

N	Engine speed, RPM
$\dot{V}$	Volume Rate, $\boldsymbol{m^3/min}$
$\dot{m}_a$	Air mass flow rate, kg/s
$\dot{m}_f$	Fuel mass flow rate, kg/s
$\dot{m}_e$	Exhaust gas mass flow rate, kg/s
$\dot{Q}_e$	Heat loss due to exhaust gases, kW
C_{p_e}	Exhaust gases heat at constant pressure, kJ/kg/.K
CV	Value, kW/kg
ΔT	Temperature deference between exhaust gases and ambient,
η_v	Volumetric Efficiency
η_{isen}	Isentropic Efficiency
η_{mech}	Mechanical Efficiency
η_{th}	Thermal Efficiency
PM	Specific Particulate Matter, g/kWh
SE	Summery Emission of PM and NO_x
IC	Internal Combustion
CI	Compression Ignition
ICE	Internal Combustion Engine

1.1 Background

Recent trend about the best ways of using the deployable sources of energy in to useful work in order to reduce the rate of consumption of fossil fuel as well as pollution.

Out of all the available sources, the internal combustion engines are the major consumer of fossil fuel around the globe.

Out of the total heat supplied to the engine in the form of fuel, approximately, 30 to 40% is converted into useful mechanical work.

The remaining heat is expelled to the environment through exhaust gases and engine cooling systems, resulting in to entropy rise and serious environmental pollution, so it is required to utilized waste heat into useful work [1, 2].

The recovery and utilization of waste heat not only conserves fuel, usually fossil fuel but also reduces the amount of waste heat and greenhouse gases damped to environment.

It is imperative that serious and concrete effort should be launched for conserving this energy through exhaust heat recovery techniques; however, around 60-70% of the fuel energy is still lost as waste heat through the coolant or the exhaust.

Moreover, increasingly stringent emissions regulations are causing engine manufacturers to limit combustion temperatures and pressures lowering potential efficiency gains [3].

1.2 The Objectives

- Improve engine’s thermal efficiency.
- Increase the output power.
- Improve the volumetric efficiency.
- Reduce the global warming and pollution.

1.3 Scope of Study

The study is done in stationary diesel fuelled internal combustion engine.

1.4 Methodology

- Theoretical study.
- Engine calculations.
- Turbocharger calculations.
- Simulation.

1.5 Importance of the Study

The importance of the study lies in the important subject that it addresses and its impact on the lives of people and on the environment, it is important to carry out scientific and environmental studies in the use of exhaust gases

1.6 Research Problem

The research problem lies in the amount of exhaust gases that rise in the air without benefiting from them, and the danger to the people environment, the study is based on the use of the turbocharger compounding to take advantage of exhaust gases**.**

Chapter

2

Literature

Review

2.1Introduction

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber. In an internal combustion engine, the expansion of the high-temperature and high -pressure gases produced by combustion apply direct force to some components of the engine. This force is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy.

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines, along with variants, such as the six-stroke piston engine and the Wankel rotary engine. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described [4].

The internal combustion engine (or ICE) is quite different from external combustion engines, such as steam or Stirling engines, in which the energy is delivered to a working fluid not consisting of, mixed with, or contaminated by combustion products. Working fluids can be air, hot water, pressurized water or even liquid sodium, heated in some kind of boiler.

The large number of different designs for ICEs have been developed and built, with a variety of different strengths and weaknesses. Powered by an energy-dense fuel (which is very frequently gasoline, a liquid derived from fossil fuels). While there have been and still are many stationary applications, the real strength of internal combustion engines is in mobile applications and they dominate as a power supply for cars, aircraft, and boats [1].

2.2 Combustion

All internal combustion engines depend on the combustion of a chemical fuel, typically with oxygen from the air (though it is possible to inject nitrous oxide in order to do more of the same thing and gain a power boost). The combustion process typically results in the production of a great quantity of heat, as well as the production of steam and carbon dioxide and other chemicals at very high temperature; the temperature reached is determined by the chemical makeup of the fuel and oxidizers, as well as by the compression and other factors [2].

The most common modern fuels are made up of hydrocarbons and are derived mostly from fossil fuels (petroleum). Fossil fuels include diesel fuel, gasoline and petroleum gas, and the rarer use of propane. Except for the fuel delivery components, most internal combustion engines that are designed for gasoline use can run on natural gas or liquefied petroleum gases without major modifications. Large diesels can run with air mixed with gases and a pilot diesel fuel ignition injection. Liquid and gaseous biofuels, such as ethanol and biodiesel (a form of diesel fuel that is produced from crops that yield triglycerides such as soybean oil), can also be used. Engines with appropriate modifications can also run on hydrogen gas, wood gas, or charcoal gas, as well as from so-called producer gas made from other convenient biomass. Recently, experiments have been made with using powdered solid fuels, such as the magnesium injection cycle.

Internal combustion engines require ignition of the mixture, either by spark ignition (SI) or compression ignition (CI). Before the invention of reliable electrical methods, hot tube and flame methods were used. Experimental engines with laser ignition have been built [3].

2.3 Gasoline Ignition Process

Gasoline engine ignition systems generally rely on a combination of a lead–acid battery and an induction coil to provide a high-voltage electric spark to ignite the air-fuel mix in the engine's cylinders. This battery is recharged during operation using an electricity-generating device such as an alternator or generator driven by the engine. Gasoline engines take in a mixture of air and gasoline and compress it to not more than 12.8 bar (1.28 MPa), then use a spark plug to ignite the mixture when it is compressed by the piston head in each cylinder [4].

2.4 Diesel Ignition Process

Diesel engines and HCCI (Homogeneous charge compression ignition) engines rely solely on heat and pressure created by the engine in its compression process for ignition. The compression level that occurs is usually twice or more than in gasoline engine. Diesel engines will take in air only, and shortly before peak compression, a small quantity of diesel fuel is sprayed into the cylinder via a fuel injector that allows the fuel to instantly ignite. HCCI type engines will take in both air and fuel but continue to rely on an unaided auto-combustion process, due to higher pressures and heat. This is also why diesel and HCCI engines are more susceptible to cold-starting issues, although they will run just as well in cold weather once started. Light duty diesel engines with indirect injection in automobiles and light trucks employ glow plugs that pre-heat the combustion chamber just before starting to reduce no-start conditions in cold weather. Most diesels also have a battery and charging system; nevertheless, this system is secondary and is added by manufacturers as a luxury for the ease of starting, turning fuel on and off (which can also be done via a switch or mechanical apparatus), and for running auxiliary electrical components and accessories. Most new engines rely on electrical and electronic engine control units (ECU) that also adjust the combustion process to increase efficiency and reduce emissions [5].

2.5 Major Advantages of Diesel Engine

Diesel engines have several advantages over other internal combustion engines:

They burn less fuel than a petrol engine performing the same work, due to the engine's higher temperature of combustion and greater expansion ratio. Gasoline engines are typically 30 percent efficient while diesel engines can convert over 45 percent of the fuel energy into mechanical energy [5].

They have no high voltage electrical ignition system, resulting in high reliability and easy adaptation to damp environments. The absence of coils, spark plug wires, etc., also eliminates a source of radio frequency emissions which can interfere with navigation and communication equipment, which is especially important in marine and aircraft applications.

The life of a diesel engine is generally about twice as long as that of a petrol engine due to the increased strength of parts used. Diesel fuel has better lubrication properties than petrol as well [6].

Diesel fuel is distilled directly from petroleum. Distillation yields some gasoline, but the yield would be inadequate without catalytic reforming, which is a more costly process.

Diesel fuel is considered safer than petrol in many applications. Although diesel fuel will burn in open air using a wick, it will not explode and does not release a large amount of flammable vapor. The low vapor pressure of diesel is especially advantageous in marine applications, where the accumulation of explosive fuel-air mixtures is a particular hazard. For the same reason, diesel engines are immune to vapor lock.

For any given partial load the fuel efficiency (mass burned per energy produced) of a diesel engine remains nearly constant, as opposed to petrol and turbine engines which use proportionally more fuel with partial power outputs [7].

Diesel engines can accept super- or turbo-charging pressure without any natural limit, constrained only by the strength of engine components. This is unlike petrol engines, which inevitably suffer detonation at higher pressure.

The carbon monoxide content of the exhaust is minimal; therefore diesel engines are used in underground mines [8].

Biodiesel is an easily synthesized, non-petroleum-based fuel (through trans esterification) which can run directly in many diesel engines, while gasoline engines either need adaptation to run synthetic fuels or else use them as an additive to gasoline e.g., ethanol added to gasohol.

2.6 Application

Internal combustion engines are most commonly used for mobile propulsion in vehicles and portable machinery. In mobile equipment, internal combustion is advantageous since it can provide high power-to-weight ratios together with excellent fuel energy density. Generally using fossil fuel (mainly petroleum), these engines have appeared in transport in almost all vehicles (automobiles, trucks, motorcycles, boats, and in a wide variety of aircraft and locomotives).

Where very high power-to-weight ratios are required, internal combustion engines appear in the form of gas turbines. These applications include jet aircraft, helicopters, large ships and electric generators [8].

2.7 Types of internal combustion engine

Engines can be classified in many different ways: By the engine cycle used, the layout of the engine, source of energy, the use of the engine, or by the cooling system employed.

Internal combustion engines can be classified by their configuration.

Common layouts of engines are:

2.7.1 Rotary

2.7.1.1 Wankel Engine

The shaft turns three times for each rotation of the rotor around the lobe and once for each orbital revolution around the eccentric shaft.

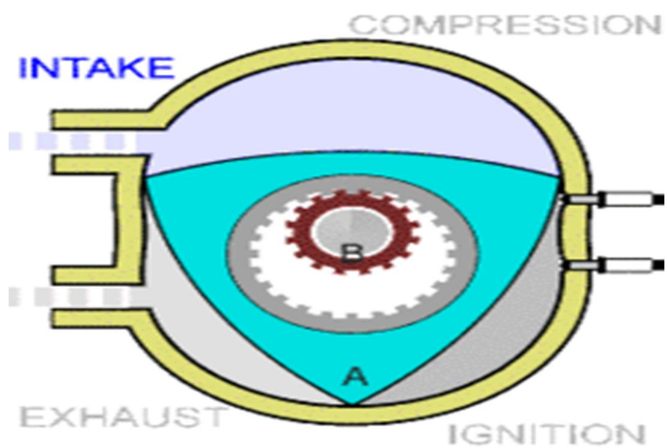

Figure (2.1) Wankel engine

The Wankel engine (rotary engine) does not have piston strokes. It operates with the same separation of phases as the four-stroke engine with the phases taking place in separate locations in the engine. In thermodynamic terms it follows the Otto engine cycle, so may be thought of as a "four-phase" engine. While it is true that three power strokes typically occur per rotor revolution due to the 3:1 revolution ratio of the rotor to the eccentric shaft, only one power stroke per shaft revolution actually occurs; this engine provides three power 'strokes' per revolution per rotor giving it a greater power-to-weight ratio than piston engines.

This type of engine is most notably used in the current Mazda RX-8, the earlier RX-7, and other models [9].

2.7.2 Reciprocation

- Two-stroke engine
- Four-stroke engine
- Six-stroke engine
- Diesel engine
- Atkinson cycle
- Miller cycle

2.7.3 Continuous Combustion

- Gas turbine
- Jet engine (including turbojet, turbofan, ramjet, Rocket, etc.)

2.8 Two Stroke Engines

2.8.1 Introduction

Is a diesel engine that works in two strokes? A diesel engine is an internal combustion engine which operates using the Diesel cycle. Invented in 1892 by German engineer Rudolf Diesel, it was based on the hot bulb engine design and patented on February 23, 1893. During the period of 1900 to 1930, four-stroke diesel engines enjoyed a relative dominance in practical diesel applications. Charles F. Kettering and colleagues, working at the various incarnations of Electro-Motive and at the General Motors Research Corporation during the 1930s, advanced the art and science of two-stroke diesel technology to yield engines with much higher power-to-weight ratios than the two-stroke diesels of old This work was instrumental in bringing about the dieselization of railroads in the 1940s and 1950s .

All diesel engines use compression ignition, a process by which fuel is injected after the air is compressed in the combustion chamber causing the fuel to self-ignite. By contrast, gasoline engines utilize the Otto cycle, in which fuel and air are mixed before entering the combustion chamber and then ignited by a spark plug [7].

2.8.2 Two Stroke Engine Defined

The stroke is the term used to describe an up or down piston movement. A two-stroke engine requires only an up/down movement from the piston to operate. Fuel compression and exhaust occur on the same stroke. A four-stroke engine requires two up/down movements: a compression stroke, exhaust stroke and two return strokes.

This system manages to pack one power stroke into every two strokes of the piston (up-down). This is achieved by exhausting and recharging the cylinder simultaneously.

The steps involved here are:

- Intake and exhaust occur at bottom dead center. Some form of pressure is needed, either crankcase compression or super-charging.
- Compression stroke: Fuel-air mix is compressed and ignited. In case of diesel: Air is compressed, fuel is injected and self-ignited.

- Power stroke: Piston is pushed downward by the hot exhaust gases [10].

2.8.3 Two Stroke Compression Ignition (CI) Engines

Intake begins when the piston is near the bottom dead center. Air is admitted to the cylinder through ports in the cylinder wall (there are no intake valves). All two-stroke Diesel engines require artificial aspiration to operate, and will either use a mechanically-driven blower or a hybrid turbo-supercharger to charge the cylinder with air. In the early phase of intake, the air charge is also used to force out any remaining combustion gases from the preceding power stroke, a process referred to as scavenging.

As the piston rises, the intake charge of air is compressed. Near top dead center, fuel is injected, resulting in combustion due to the extremely high pressure and heat created by compression, which drives the piston downward. As the piston moves downward in the cylinder it will reach a point where the exhaust port is opened to expel the high-pressure combustion gasses. However, most current two-stroke diesel engines use top-mounted poppet valves and uniflow scavenging. Continued downward movement of the piston will expose the air intake ports in the cylinder wall, and the cycle will start again [7].

2.8.4 Two Stroke Cycle Diesel Engine

The pump scavenge two stroke diesel engine designed by Sir Dugald Clerk in 1879 was the first successful two-stroke engine; thus the two-stroke-cycle engine is sometimes called the Clerk engine. Uniflow scavenging took place - fresh charge entering the combustion chamber above the piston while the exhaust outflow occurred through ports uncovered by the piston at its outermost position. Low- and medium-speed two-stroke marine diesels engines still use this system, but high-speed two-stroke diesel engines reverse the scavenging flow by blowing fresh charge through the bottom inlet ports, sweeping up through the cylinder and out of the exhaust ports in the cylinder head Figure.(2.2)

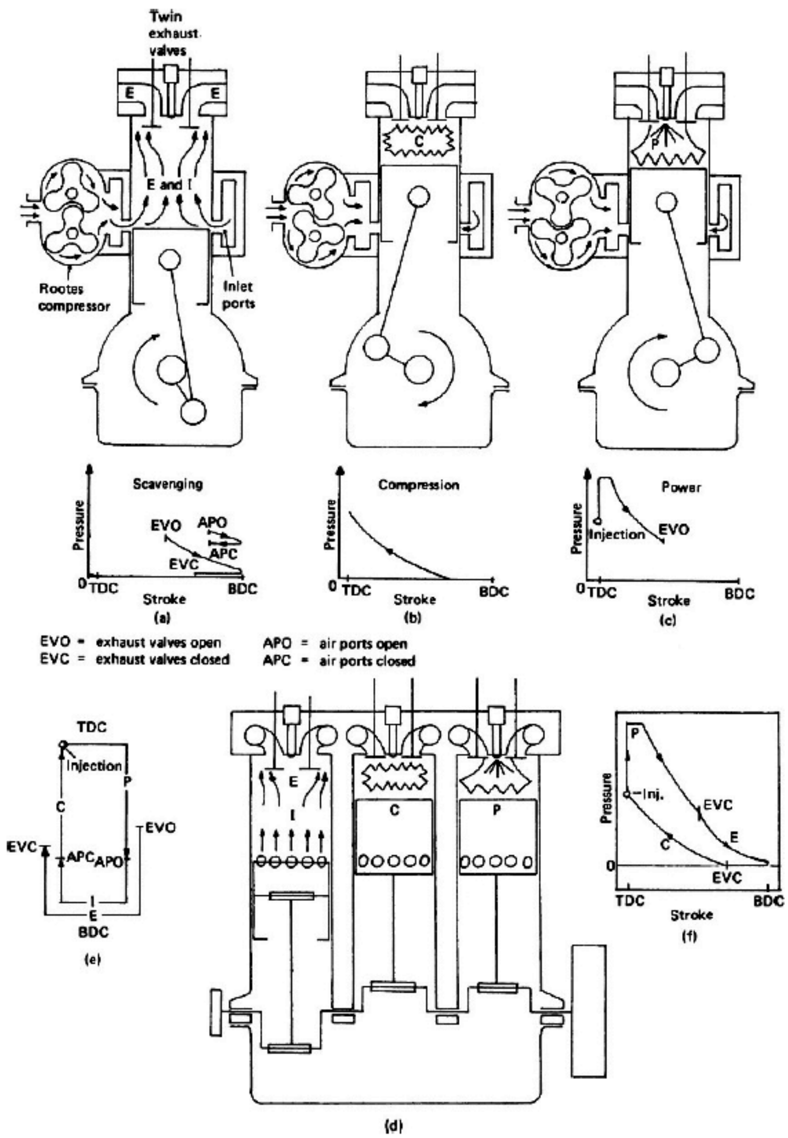

Figure (2.2) Two Stroke Cycle Diesel Engine

With the two-stroke diesel engine, intake and exhaust phases take place during part of the compression and power stroke respectively, so that a cycle of operation is completed in one crankshaft revolution or two piston strokes. Since there are no separate intake and exhaust strokes, a blower is necessary to pump air into the cylinder for expelling the exhaust gases and to supply the cylinder with fresh air for combustion.

Scavenging (induction and exhaust) phase Figure (2.2 a) the piston moves away from the cylinder head and, when it is about half-way down its stroke, the exhaust valves open. This allows the burnt gases to escape into the atmosphere. Near the end of the power stroke, a horizontal row of inlet air ports is uncovered by the piston lands Figure (2.2 a). These ports admit pressurized air from the blower into the cylinder. The space above the piston is immediately filled with air, which now blows up the cylinder towards the exhaust valves in the cylinder head. The last remaining exhaust gases will thus be forced out of the cylinder into the exhaust system. This process of fresh air coming into the cylinder and pushing out unwanted burnt gas is known as scavenging.

Compression phase Figure (2.2 b) towards the end of the power stroke, the inlet ports will be uncovered. The piston then reaches its outermost position and reverses its direction of motion. The piston now moves upwards so that the piston seals and closes the inlet air ports, and just a little later the exhaust valves close. Any further upward movement will now compress the trapped air Fig (2.2 b). This air charge is now reduced to about 1:15 to 1:18 of its original volume as the piston reaches the innermost position. This change in volume corresponds to a maximum cylinder pressure of about 30-40 bar. Power phase Fig (2.2 c) shortly before the piston reaches the innermost position to the cylinder head on its upward compression stroke, highly pressurized liquid fuel is sprayed into the dense intensely heated air charge Figure (2.2 c). Within a very short period of time, the injected fuel droplets will vaporize and ignite, and rapid burning will be established by the time the piston is at the top of its stroke. The heat liberated from the charge will be converted mainly into gas-pressure energy which will expand the gas and so do useful work in driving the piston outwards.

An overall view of the various phases of operation in a two-stroke-cycle three-cylinder diesel engine is shown in Figure (2.2 d), and Figure (2.2 e and f) show the cycle of events in one crankshaft revolution expressed in terms of piston displacement and cylinder pressure [7].

2.8.5 The Major Component of Two Stroke Engine

- Cylinder: a cylindrical vessel in which a piston makes an up and down motion.
- Combustion chamber: a portion above the cylinder in which the combustion of the fuel-air mixture takes place.
- Intake and exhaust ports: an intake port allows the fresh fuel-air mixture to enter the combustion chamber and an exhaust port discharges the products of combustion.
- Crankshaft: the crankshaft in a two-stroke engine rotates, moving the piston by means of the connecting rod. These three parts are the only moving parts in a two-stroke engine. All power produced is a direct result of the action of these three moving parts.
- Connecting Rod: the connecting rod is connected to the crankshaft at one end, and to the piston at the other. It translates the movement of the crankshaft so that the piston is moved up and down.
- Piston: the piston is moved up and down inside the cylinder by the crankshaft, which is connected to it via the connecting rod. A vacuum

is formed as it takes its upward stroke, drawing air down through the reed valve. When the piston reaches the top, the fuel Injected, burning it and sending the piston back down. On the downward stroke, the reed valve gets closed because of the increased pressure, which is being compressed. New air travel via the intake port into the cylinder, ready to be burnt. The exhaust is expelled through the exhaust port, and an unpleasant side effect is that it usually takes some of the unburned fuel mixture with it [7].

2.8.6 Advantages of Two Stroke Engine

• It has no valves or camshaft mechanism, hence simplifying its mechanism and construction.

• For one complete revolution of the crankshaft, the engine executes one cycle—the 4-stroke executes one cycle per two crankshafts revolutions.

• Less weight and easier to manufacture.

• High power to weight ratio.

2.8.7 Disadvantages of Two Stroke Engine

• The lack of lubrication system that protects the engine parts from wear. Accordingly, the 2-stroke engines have a shorter life.

• 2-stroke engines do not consume fuel efficiently.

• 2-stroke engines produce lots of pollution.

• Sometimes part of the fuel leaks to the exhaust with the exhaust gases. In conclusion, based on the above advantages and disadvantages, the 2-stroke engines are supposed to operate in vehicles where the weight of the engine is required to be small, and it is not used continuously for long periods of time.

We found some problem of two stroke engine; actually the two-stroke engine should perform twice the performance of a four-stroke engine with the same cubic capacity. Though it is just possible to gain a performance that is about 50% better. The reasons are obvious: The cylinder can't be filled up with the same amount of fuel as in the four-stroke engine, because the individual strokes are separated not so clearly. If more fuel is induced, it leaves the combustion chamber through the ejection pipe without being burnt. Many concepts were developed to provide a better expulsion of the exhaust in way that the fresh gas doesn't leave the combustion chamber. Though all these inventions, the filling of the two-stroke engine is always worse than in the four-stroke engine, which loses fresh fuel only because of the "overlap" of the valve times (both valves are open for an instant). Beside these performance-technical problems, there are also increasing difficulties with the environment. The fuel mixture of the two-stroke engine often gets shifted with a certain quantity of oil because of the necessary lubrication. Unfortunately the oil gets burnt partly, too, and harmful gases are expulsed by the engine [7].

2.8.8 Two Stroke Engine Configuration

Engines based on the two-stroke cycle use two strokes (one up, one down) for every power stroke. Since there are no dedicated intake or exhaust strokes, alternative methods must be used to scavenge the cylinders. The most common method in spark-ignition two-strokes is to use the downward motion of the piston to pressurize fresh charge in the crankcase, which is then blown through the cylinder through ports in the cylinder walls.

Spark-ignition two-strokes are small and light for their power output and mechanically very simple; however, they are also generally less efficient and more polluting than their four-stroke counterparts. In terms of power per cm^3, a two-stroke engine produces comparable power to an equivalent four-stroke engine. The advantage of having one power stroke for every 360° of crankshaft rotation (compared to 720° in a 4-stroke motor) is balanced by the less complete intake and exhaust and the shorter effective compression and power strokes. It may be possible for a two-stroke to produce more power than an equivalent four-stroke, over a narrow range of engine speeds, at the expense of less power at other speeds.

Small displacement, crankcase-scavenged two-stroke engines have been less fuel-efficient than other types of engines when the fuel is mixed with the air prior to scavenging allowing some of it to escape out of the exhaust port. Modern designs (Sarich and Paggio) use air-assisted fuel injection which avoids this loss, and are more efficient than comparably sized four-stroke engines. Fuel injection is essential for a modern two-stroke engine in order to meet ever more stringent emission standards.

Research continues into improving many aspects of two-stroke motors including direct fuel injection, amongst other things. The initial results have produced motors that are much cleaner burning than their traditional counterparts. Two-stroke engines are widely used in snowmobiles, lawnmowers, string trimmers, chain saws, jet skis, mopeds, outboard motors, and many motorcycles. Two-stroke engines have the advantage of an increased specific power ratio (i.e. power to volume ratio), typically around 1.5 times that of a typical four-stroke engine.

The largest internal combustion engines in the world are two-stroke diesels, used in some locomotives and large ships. They use forced induction (similar to super-charging, or turbo charging) to scavenge the cylinders; an example of this type of motor is the Wartsila-Sulzer turbocharged two-stroke diesel as used in large container ships. It is the most efficient and powerful internal combustion engine in the world with over 50% thermal efficiency For comparison, the most efficient small four-stroke motors are around 43% thermal efficiency (SAE 900648); size is an advantage for efficiency due to the increase in the ratio of volume to surface area.

Common cylinder configurations include the straight or inline configuration, the more compact V configuration, and the wider but smoother flat or boxer configuration. Aircraft engines can also adopt a radial configuration which allows more effective cooling. More unusual configurations such as the H, U, X, and W have also been used.

Multiple crankshaft configurations do not necessarily need a cylinder head at all because they can instead have a piston at each end of the cylinder called an opposed piston design. Because here gas in- and outlets are positioned at opposed ends of the cylinder, one can achieve uniflow scavenging, which is, like in the four-stroke engine, efficient over a wide range of revolution numbers. Also the thermal efficiency is improved because of lack of cylinder heads. This design was used in the Junkers Jumo 205 diesel aircraft engine, using at either end of a single bank of cylinders with two crankshafts, and most remarkably in the Napier Deltic diesel engines. These used three crankshafts to serve three banks of double-ended cylinders arranged in an equilateral triangle with the crankshafts at the corners. It was also used in single-bank locomotive engines, and continues to be used for marine engines, both for propulsion and for auxiliary generators [10].

2.8.9 Uses

Two-stroke engines are most commonly found in lawn and garden tools such as chainsaws, weed trimmers and some lawnmowers. Two-stroke engines can also be used to power go-carts, outboard motors, scooters and smaller motorcycles. Two-stroke diesel engines are capable of powering large marine vessels and industrial engines [10].

2.9 Four Stroke Engine

2.9.1 Introduction

The diesel engine is a technical refinement of the 1876 Otto Cycle engine. Where Otto had realized in 1861 that the efficiency of the engine could be increased by first compressing the fuel mixture prior to its ignition, Rudolph Diesel wanted to develop a more efficient type of engine that could run on much heavier fuel. The Lenoir, Otto Atmospheric, and Otto Compression engines (both 1861 and 1876) were designed to run on Illuminating Gas (coal gas). With the same motivation as Otto, Diesel wanted to create an engine that would give small industrial concerns their own power source to enable them to compete against larger companies, and like Otto to get away from the requirement to be tied to a municipal fuel supply. Like Otto, it took more than a decade to produce the high compression engine that could self-ignite fuel sprayed into the cylinder. Diesel used an air spray combined with fuel in his first engine.

During initial development, one of the engines burst nearly killing Diesel. He persisted and finally created an engine in 1893. The high compression engine, which ignites its fuel by the heat of compression is now called the Diesel engine whether a four-stroke or two-stroke design.

The four-stroke diesel engine has been used in the majority of heavy duty applications for many decades. Chief among the reasons for this is that it uses a heavy fuel that contains more energy, requires less refinement, and is cheaper to make (although in some areas of the world diesel fuel costs more than gasoline). The most efficient Otto Cycle engines run near 30% efficiency. The Volkswagen Jetta TDI 1.9 liter engine achieves 46%. It uses an advanced design with turbocharging and direct fuel injection. Some BMW ships Diesels with ceramic insulation have exceeded 60% efficiency.

Both Audi and Peugeot compete in the endurance races of the Le Mans Series with race cars having diesel engines. These are four-stroke, four-valve and high revving, turbocharged diesels that dominate largely due to fuel economy and having to make fewer stops [11].

2.9.2 Four Stroke Diesel Cycle

Compression-ignition (C.I) engines burn fuel oil which is injected into the combustion chamber when the air charge is fully compressed. Burning occurs when the compression temperature of the air is high enough to spontaneously ignite the finely atomized liquid fuel. In other words, burning is initiated by the self-generated heat of compression Fig (2-3). Compression-ignition (C.I) engines are also referred to as 'oil engines', due to the class of fuel burnt, or as 'diesel engines' after Rudolf Diesel, one of the many inventors and pioneers of the early C.I. engine.

Note: in the United Kingdom fuel oil is known as 'DERV', which is the abbreviation of 'diesel-engine road vehicle'.

Just like the four-stroke-cycle petrol engine, the Compression-ignition (C.I.) engine completes one cycle of events in two crankshaft revolutions or four piston strokes. The four phases of these strokes are (i) induction of fresh air, (ii) compression and heating of this air, (iii) injection of fuel and its burning and expansion, and (iv) expulsion of the products of combustion. Induction stroke Figure (2.3 a)with the inlet valve open and the exhaust valve closed, the piston moves away from the cylinder head.

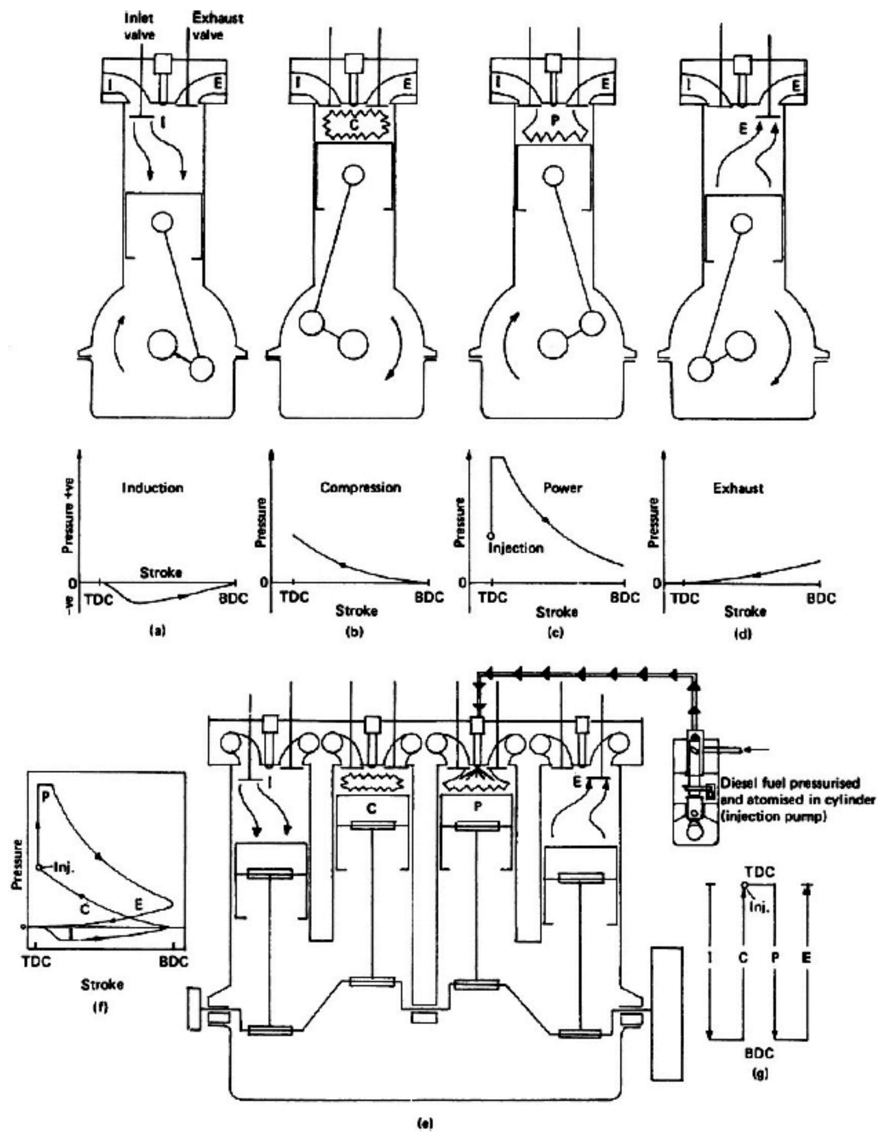

Figure (2.3) Four Stroke Diesel Cycle

The outward movement of the piston will establish a depression in the cylinder, its magnitude depending on the ratio of the cross-sectional areas of the cylinder and the inlet port and on the speed at which the piston is moving. The pressure difference established between the inside and outside of the cylinder will induce air at atmospheric pressure to enter and fill up the cylinder. Unlike the petrol engine, which requires a charge of air-and-petrol mixture to be drawn past a throttle valve, in the diesel-engine inlet system no restriction is necessary and only pure air is induced into the cylinder. A maximum depression of maybe 0.15 bar below atmospheric pressure will occur at about one-third of the distance along the piston's outward stroke, while the overall average pressure in the cylinder might be 0.1 bar or even less.

Compression stroke Figure (2.3 b)) with both the inlet and the exhaust valves closed, the piston moves towards the cylinder head Figure (2.3 b).

The air enclosed in the cylinder will be compressed into a much smaller space of anything from 1:12 to 1:24 of its original volume. A typical ratio of maximum to minimum air-charge volume in the cylinder would be 16:1, but this largely depends on engine size and designed speed range.

During the compression stroke, the air charge initially at atmospheric pressure and temperature is reduced in volume until the cylinder pressure is raised to between 30 and 50 bar. This compression of the air generates heat which will increase the charge temperature to at least 600 °C under normal running conditions.

Power stroke Figure (2.3 c) with the inlet and the exhaust valves closed and the piston almost at the end of the compression stroke Figure (2.3 c), diesel fuel oil is injected into the dense and heated air as a high-pressure spray of fine particles. Provided that they are properly atomized and distributed throughout the air charge, the heat of compression will then quickly vaporize and ignite the tiny droplets of liquid fuel. Within a very short time, the piston will have reached its innermost position and extensive burning then releases heat energy which is rapidly converted into pressure energy. Expansion then follows, pushing the piston away from the cylinder head, and the linear thrust acting on the piston end of the connecting-rod will then be changed to rotary movement of the crankshaft.

Exhaust stroke when the burning of the charge is near completion and the piston has reached the outermost position, the exhaust valve is opened. The piston then reverses its direction of motion and moves towards the cylinder head Figure (2.3 d).

The sudden opening of the exhaust valve towards the end of the power stroke will release the still burning products of combustion to the atmosphere. The pressure energy of the gases at this point will accelerate their expulsion from the cylinder, and only towards the end of the piston's return stroke will the piston actually catch up with the tail-end of the outgoing gases.

Figure (2.3 e) illustrates the sequence of the four operating strokes as applied to a four-cylinder engine, and the combined operating events expressed in terms of cylinder pressure and piston displacement are shown in Figures (2.3 f and g) [11].

2.9.3 The Major Component of Four Stroke Diesel Engine

- **Cylinder:** it is a cylindrical vessel in which a piston makes up and down motion.
- **Piston:** it is a cylindrical component making up and down movement in the cylinder.
- **Combustion Chamber**: it is the portion above the cylinder in which the combustion of the Fuel-air mixture takes place.
- **Cylinder Head:** also referred to as the top end, the cylinder head houses the pistons, valves, rocker arms and camshafts.

- **Valves:** a pair of valves, used for controlling fuel intake and exhaust, is controlled by a set of fingers on the camshaft called lobes. As the intake valve opens, a mixture of fuel and air from the carburetor is pulled into the cylinder. The exhaust valve expels the spent air/fuel mixture after combustion.
- **Camshaft :** usually chain or gear-driven, the camshaft spins, using its lobes to actuate the rocker arms. These open the intake and exhaust valves at preset intervals.
- **The crankshaft**: crankshaft is made up of a left and right flywheel connected to the piston's connecting rod by a crank pin, which rotates to create the piston's up-and-down motion. The cam chain sprocket is mounted on the crankshaft, which controls the chain that drives the camshaft.
- **Connecting Rod:** the connecting rod connects the Piston with the crankshaft.
- **Fuel Injector:** it is located at the cylinder head. It is used to admit the fuel into the combustion chamber.

2.9.4 Four Stroke Compression Ignition (CI) Engine

The diesel internal combustion engine differs from the gasoline powered Otto cycle by using highly compressed hot air to ignite the fuel rather than using a spark plug (compression ignition rather than spark ignition).

In the true diesel engine, only air is initially introduced into the combustion chamber. The air is then compressed with a compression ratio typically between 15:1 and 22:1 resulting in 40-bar (4.0 MPA; 580 psi) pressure compared to 8 to 14 bars (0.80 to 1.4 MPA) (about 200 psi) in the petrol engine. This high compression heats the air to 550 °C

(1,022 °F). At about the top of the compression stroke, fuel is injected directly into the compressed air in the combustion chamber. This may be into a (typically toroidal) void in the top of the piston or a pre-chamber depending upon the design of the engine. The fuel injector ensures that the fuel is broken down into small droplets, and that the fuel is distributed evenly. The heat of the compressed air vaporizes fuel from the surface of the droplets. The vapor is then ignited by the heat from the compressed air in the combustion chamber, the droplets continue to vaporize from their surfaces and burn, getting smaller, until all the fuel in the droplets has been burnt. The start of vaporization causes a delay period during ignition and the characteristic diesel knocking sound as the vapor reaches ignition temperature and causes an abrupt increase in pressure above the piston. The rapid expansion of combustion gases then drives the piston downward, supplying power to the crankshaft. Engines for scale-model aero planes use a variant of the Diesel principle but premix fuel and air via a carburation system external to the combustion chambers.

As well as the high level of compression allowing combustion to take place without a separate ignition system, a high compression ratio greatly increases the engine's efficiency. Increasing the compression ratio in a spark-ignition engine where fuel and air are mixed before entry to the cylinder is limited by the need to prevent damaging pre-ignition. Since only air is compressed in a diesel engine, and fuel is not introduced into the cylinder until shortly before top dead center (TDC), premature detonation is not an issue and compression ratios are much higher [12].

2.9.5 Configurations

Many configurations of fuel injection have been used over the past century (1901–2000).Most present day (2008) diesel engines make use of a camshaft, rotating at half crankshaft speed, lifted mechanical single plunger high-pressure fuel pump driven by the engine crankshaft. For each engine cylinder, the corresponding plunger in the fuel pumps measures out the correct amount of fuel and determines the timing of each injection. These engines use injectors that are very precise spring-loaded valves that open and close at a specific fuel pressure. Separate high-pressure fuel lines connect the fuel pump with each cylinder. Fuel volume for each single combustion is controlled by a slanted groove in the plunger which rotates only a few degrees releasing the pressure and is controlled by a mechanical governor, consisting of weights rotating at engine speed constrained by springs and a lever. The injectors are held open by the fuel pressure. On high-speed engines the plunger pumps are together in one unit. The length of fuel lines from the pump to each injector is normally the same for each cylinder in order to obtain the same pressure delay.

A cheaper configuration on high-speed engines with fewer than six cylinders is to use an axial-piston distributor pump, consisting of one rotating pump plunger delivering fuel to a valve and line for each cylinder (functionally analogous to points and distributor cap on an Otto engine).

Many modern systems have a single fuel pump which supplies fuel constantly at high pressure with a common rail (single fuel line common) to each injector. Each injector has a solenoid operated by an electronic control unit, resulting in more accurate control of injector opening times that depend on other control conditions, such as engine speed and loading, and providing better engine performance and fuel economy. This system does have the drawback of requiring a reliable electrical system for operation. [Citation needed]

Both mechanical and electronic injection systems can be used in either direct or indirect injection configurations.

Older diesel engines with mechanical injection pumps could be inadvertently run in reverse, albeit very inefficiently. When this occurs, massive amounts of soot are ejected from the air intake. This was often a consequence of push starting a vehicle using the wrong gear. Large ship diesels are capable of running either direction [12].

2.9.6 Advantages of Four Stroke Engines

The two-stroke vs. four-stroke argument has been going on ever since Dugals Clarks patented the design in 1881; exactly 20 years after Alphonse Beau de Rochas patented the four stroke in 1861. Though 2-strokes are undoubtedly lighted and produce more power per revolution than four strokes, they do have a number of disadvantages. While modern technology has narrowed the gap between these two engine designs, the fact is that 4-stroke engines are preferred for almost every road-going vehicle on the planet.

1. Fuel Economy

The primary reason that 2-strokes tend to get worse fuel economy than four strokes is that they pull air in through the intake port while simultaneously pushing used gases out through the exhaust port. Along with other factors, this crossover often results in fuel being expelled from the exhaust before it has the opportunity to burn. 4-Stroke engines have a dedicated intake, power and exhaust stroke, which keeps fuel-to-exhaust crossover to a minimum. All else being equal, a 4-stroke engine with the same type of direct injection system used by modern 2-strokes will still get better fuel economy.

2. More Torque

In general, 4-stroke engines almost always make more torque at low RPM than 2-strokes. This extra torque has a lot to do with the efficiency of the fuel burn; a 4-stroke uses almost all of its fuel to impart power to the crankshaft, whereas fuel crossover in a 2-stroke means that it will produce less power per RPM. 2-strokes do enjoy an advantage in high-RPM power output, but simply don't produce the torque of a 4-stroke.

3. More Durability

Because 2-strokes must rev to very high RPM to make any power, most applications using them are geared toward maintaining that RPM. Any engine designer will tell you that the more times an engine goes around, the quicker it will wear out. It's pretty simple math; if an engine can go through ten million RPMs before it wears out, then one that revolves at 5,000 revolutions per minute will go 2000 minutes between rebuilds. The same engine running at 10,000 RPM will only last 1,000 minutes.

4. Cleaner Emissions

Above all else, the primary reason that 2-strokes aren't more popular in mass-vehicle applications is that they tend to run very dirty. 2-stroke engines require that oil be injected with the fuel in order to lubricate the crankcase; that oil gets burned along with the gasoline, which drastically increases emissions and soot. 4-Stroke engines have a dedicated oiling system that's kept largely separate from the combustion chamber, which help to ensure that the only thing burning in the engine is gasoline. If you've ever seen an old car blowing huge plumes of blue smoke from its tailpipe, then you've witnessed the effect that oil burning can have on emissions.

2.9.7 Disadvantages of Four stroke

- Low power to weight ratio.
- More moving parts, not suitable for high speed.
- More number of stroke per circle.
- High service and overhaul cost due to more parts [12].

2.10 Energy distribution in IC engines

This part examines the heat distribution occurs within an IC engine, this being extremely important for proper operation.

About 35% percent of the total chemical energy that enters an engine in the fuel is converted to useful crankshaft work, and about 30% of the fuel energy is carried away from the engine in the exhaust flow in the form of enthalpy and chemical energy. This leaves about one-third of the total energy that must be dissipated to the surroundings by some mode of heat transfer.

Temperatures within the combustion chamber of an engine reach values on the order of 2700º K and up. Materials in the engine cannot tolerate this kind of temperature and would quickly fail if proper heat transfer did not occur. Removing heat is highly critical in keeping an engine and engine lubricant from thermal failure. On the other hand, it is desirable to operate an engine as hot as possible to maximize thermal efficiency [13].

$$power\ genetrated = W_{shaft} + Q_{losses} + Q_{exhaust}$$

W_{shaft} = Brake power for Engine and its accessories.
$Q_{exhaust}$ = Heat loss in Exhaust gas flow.
Q_{losses} = all other losses to surrounding.

2.11 Waste heat and waste heat recovery

Waste heat is energy that is rejected to the environment. It arises from equipment and operating inefficiencies, as well as from thermodynamic limitations on equipment and processes. Often, part of waste heat could potentially be used for some useful purpose. At present, about 20 to 40% of energy used in IC Engine is rejected as waste heat. A significant part of this wasted energy is low-temperature heat that is sent to the atmosphere mainly from fluegases. Usually, distillation column overhead streams at temperatures of 100–200ºC reject heat by fluegases. WHR can be defined as the process of capturing some portion of the heat that normally would be wasted, and delivering it to a device or process where it can be used as an effective, economical and environmentally friendly way to save energy. Large investments are presently incurred to exhaust waste heat to the atmosphere in the form of c fluegases.

WHR has the potential to minimize these costs, and to reduce environmental impact along with several other benefits [14].

2.12 Possibility and Availability of waste heat from IC engines

2.12.1 Possibility of waste heat from IC engine

Today's modern life is greatly depends on automobile engine, i.e. Internal Combustion engines. The majority of vehicles are still powered by either spark ignition (SI) or compression ignition (CI) engines. CI engines also known as diesel engines have a wide field of applications and as energy converters they are characterized by their high efficiency.

Table (2.1) Shows that various engine and there power ranges. In general, diesel engines have an efficiency of about 35% and thus the rest of the input energy is wasted [3].

Table (2.1) Various engines and there outputs

Sr. No.	Engine Type	Power Output KW	Waste Heat
1	Small air cooled Diesel Engines	35	30-40% of Energy Waste Loss from IC Engine
2	Small Agricultural Tractors and Construction machines	150	
3	Water air cooled Engine	35-150	
4	Earth moving machineries	520-720	
5	Marine Application	150-220	
6	Trucks and Road Engines	220	

2.12.2 Availability of waste heat from IC engine

The quantity of waste heat contained in an exhaust gas is a function of both the temperature and the mass flow rate of the exhaust gas:

$$Q = \dot{m} \times Cp \times \Delta T$$

Q = exhaust gas Heat.

$\dot{m}$ = exhaust gas mass flow rate.

Cp = Specific heat capacity.

ΔT = temperature difference between exhaust gas and ambient.

Moreover, the magnitude of the temperature difference between the heat source and sink is an important determinant of waste heat's utility or "quality".

The source and sink temperature difference influences the rate at which heat is transferred per unit surface area of recovery system, and the maximum theoretical efficiency of converting thermal from the heat

The temperature range has important function for the selection of waste heat recovery system designs [4, 5].

Table (2.2) Temperature range in some IC engines

Sr. No.	Engine	Temperature In ^{o} C
1	Single cylinder four strokes Diesel Engine	456
2	Four cylinder four strokes Diesel Engine (TATA Indica)	448
3	Four cylinder four strokes Diesel Engine(Mahindra arjun 605DI)	310
4	Genset (Kirloskar) at power 198hp	383

5	Genset (Cummins) at power 200hp	396

2.13 Previous Studies

Electrical Turbocompound Caterpillar Setup 2005

(Hybrid power-train vehicle)

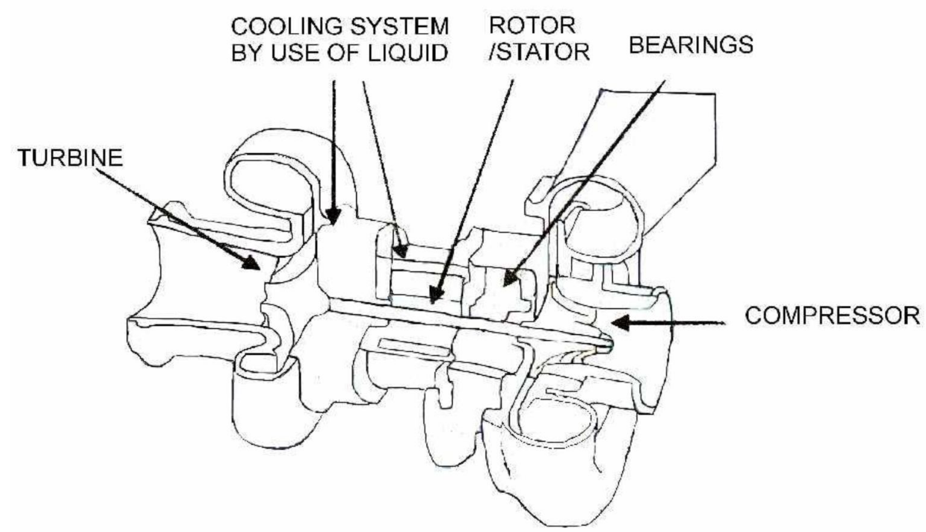

Figure (2.4) Caterpillar 2005 Turbo-compound

Show results in achieving overall engine efficiency in the range of 3-5% [15].

BMW Turbosteamer, BMW 2011

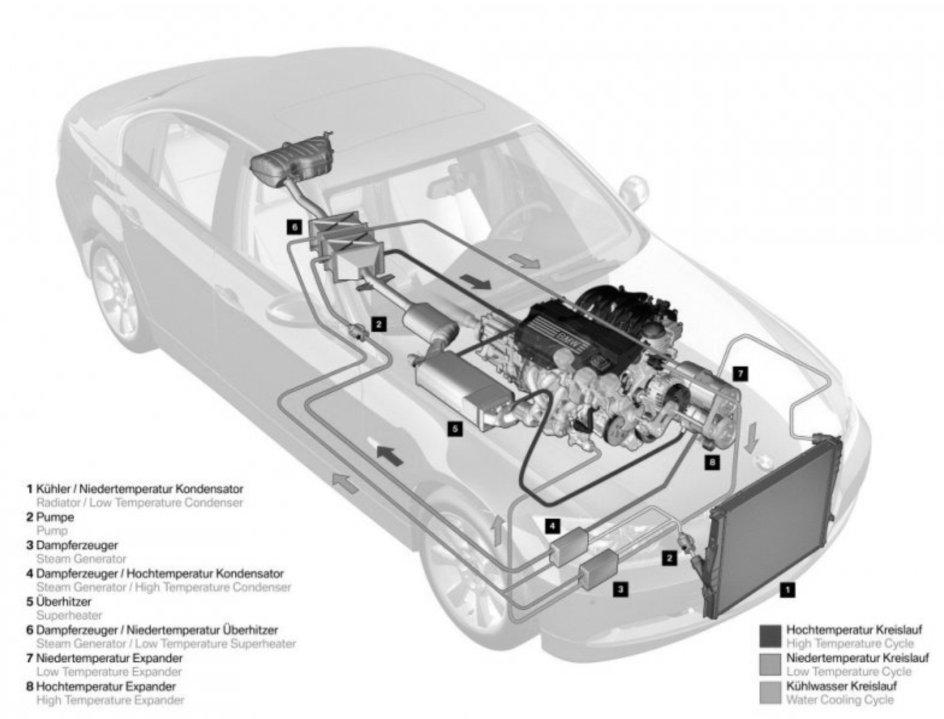

Figure (2.5) BMW Turbo-Steamer

BMW claimed that the system produces 10 kW power and 20 Nm of torque at peak, yielding an estimated 15% gain in fuel efficiency [16].

Honda Rankine Cycle Engine, Rosebro (2008)

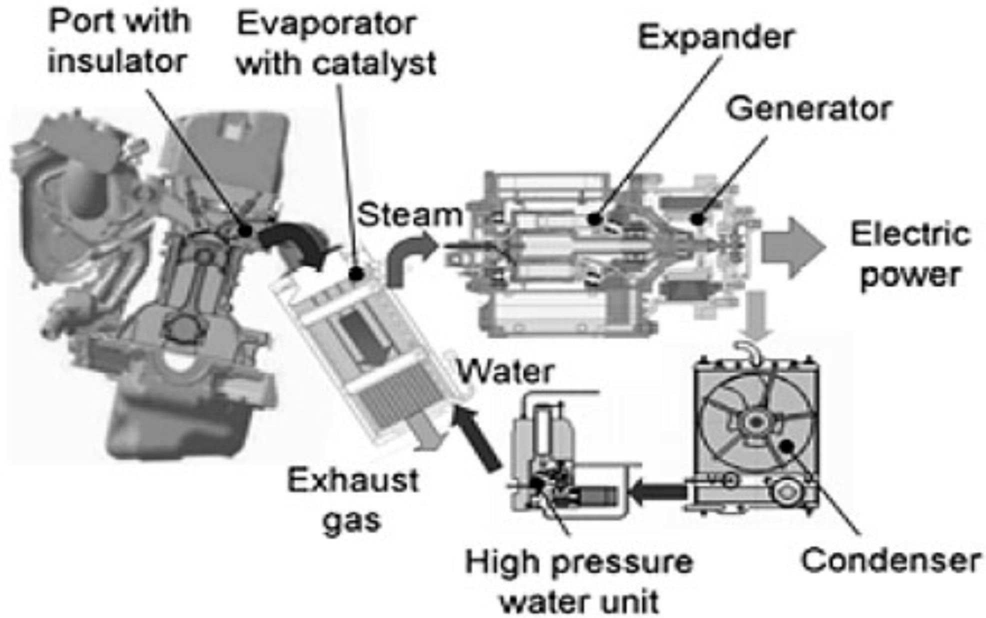

Figure (2.6) Honda Robsebero 2008 EGR

The improvement is 4% in overall vehicle efficiency [15].

- Brands, achieved WHR in a six cylinder, 14.5 L, Cummins NTC-400 diesel engine rated at 298 kW at 2100 RPM by turbo-compounding. This involved the use of a power turbine to recover energy from the exhaust gas. The authors demonstrated a 12.5% improvement in power and 14.8% net improvement in fuel economy due to WHR by Rankine cycle turbo-compounding [16].
- Teng, analyzed a supercritical ORC system of WHR from heavy duty diesel engines. The exhaust WHR was analyzed from the perspectives of the first and second law of thermodynamics. They

predicted up to a 20% improvement in engine power using a supercritical ORC [17].

- Stationary IC engines were investigated by Vaja, for WHR using a thermodynamic analysis. They predicted a 12% improvement in thermal efficiency. Various working fluids were tested and benzene showed the highest improvement. A critical heat exchanger was needed to be designed in their analysis to achieve the predicted results [18].

Chapter 3

Theoretical Study & Calculations

3.1 Turbocharger

3.1.1 Definition.

Briefly it is an air pump designed to operate on the normally wasted energy.

In engine exhaust gas. These gases drive the turbine wheel and shaft which is coupled to a compressor wheel which when rotating provides high volume of air to the engine combustion chambers. Turbocharger systems are measured by the amount of pressure the compressor can output above ambient

Although precision built, is basically a very simple but durable machine, however, require maintenance and care as any other piece of working machinery. Mainly a positive head and flow of clean lubricating oil.

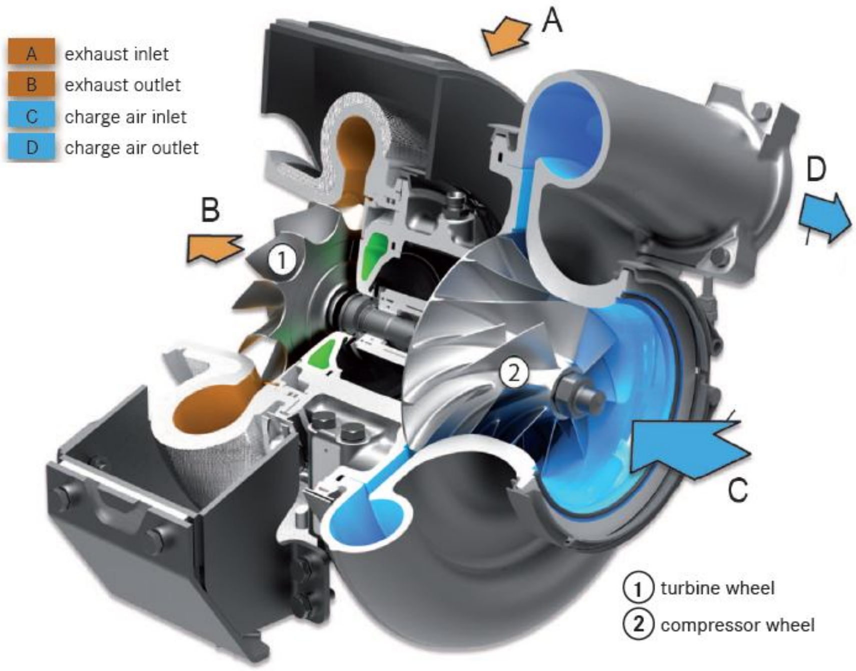

Figure (3.1) turbocharger section

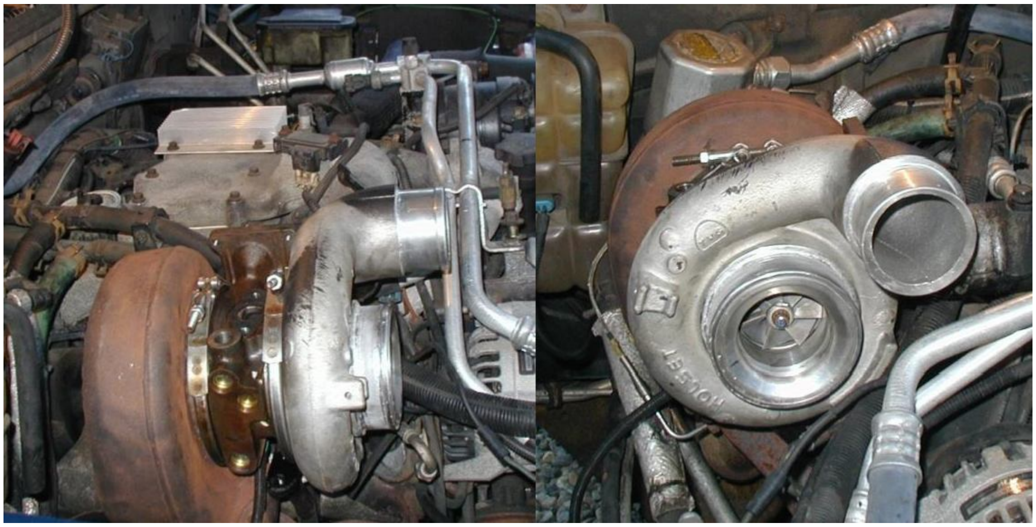

Figure (3.2) Turbocharger

3.1.2 The Principle

The heat energy and pressures in the engine exhaust gas is utilized to drive the turbine wheel.

The speed of the rotating assembly and output of the compressor wheel is controlled by the design and sizing of the turbine wheel and turbine housing. The housing acts as a nozzle to direct the exhaust gas flow to the turbine wheel blades, which drives the shaft wheel assembly.

Since the compressor wheel is directly coupled to the shaft, it rotates at the same speed as the turbine wheel. Clean air from the air cleaner is drawn into the compressor housing and wheel where it is compressed and delivered through a crossover pipe to the engine air intake manifold. The amount of air pressure rise and air volume delivered to the engine from the compressor outlet is determined by wheel size, housing size, and performance matching of the turbocharger to a given engine. Each engine size must be properly matched [19].

There are quite a number of benefits to be gained by turbo charging a diesel engine. Combustion of the fuel is more complete, cleaner, and takes place within the engine cylinders where its work is accomplished, because the turbocharger delivers an abundance of compressed air to the engine. The positive air pressure head (above atmospheric pressure) that is maintained in the engine intake manifold benefits the engine in several ways. During engine valve overlap (before intake stroke starts) clean air is pushed across the combustion chamber scavenging all remaining burned gases, cools cylinder heads, pistons, valves and the exhaust gas. The cleaner burning of the fuel plus the engine cooling which results helps to extend engine life.

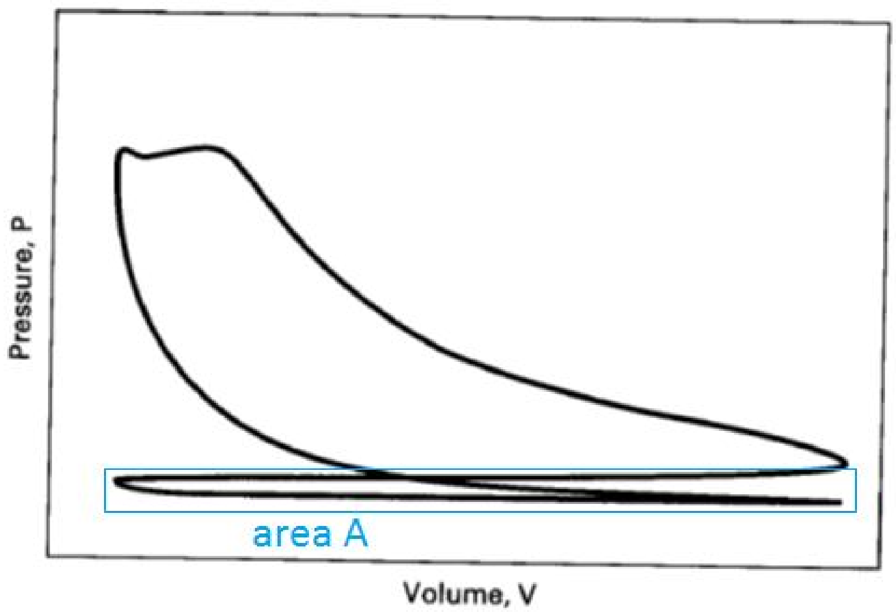

Figure (3.3) Real Diesel cycle P, V diagram

As shown in Figure (3.3) area (A) and it represents the energy lost by exhaust gas, an area in which it operates by turbo.

3.1.3 Maintaining

Good maintenance practices should be observed, particularly with regard to air and oil filtration, to maintain service life and performance. Years of experience have shown that the largest percentages of device failures are caused by oil lag, lack of oil flow and dirt in the oil. Foreign objects entering the compressor and turbine wheels cause second largest percentage.

- Dust or sand entering the compressor housing from a leaky air inlet system can seriously erode the compressor wheel blades and will result in the deterioration of device and engine performance. The wearing away of the blades, if uneven, can induce a shaft motion, which will pound out, and eventually fail the main shaft bearings.

- Plugged or restricted air cleaner systems, resulting from poor maintenance procedures, will reduce air pressure and volume at the compressor air inlet and cause losses of performance. Restricting the air inlet reduces airflow to the engine and over fueled condition results causing excessive engine and exhaust temperatures and black smoke. The restricted air cleaner and the resultant air pressure drop between cleaner and the can, during engine idle periods, cause oil pullover at the compressor end of the device.

- Nearly all of the present day devices operate at shaft speeds in excess of 60,000 rpm and utilize full floating bearings, which have correspondingly high rotational speeds. Adequate clean oil supply is required for cooling and lubrication to maintain the bearing system.

- Dirt or foreign material when introduced into the bearing system by the lube oil creates wear primarily on the center housing bearing bores surfaces. Contaminants both imbed in the bearing surfaces and act as an abrasive cutting tool or cut and wear both bearings and bearing bores as it washes through. The shaft hub and either or both wheels will start to rub the housings causing the rotating assembly to turn slower when bearing and bore wear becomes excessive [20].

3.1.4 Failure

Preventive maintenance must be practiced to achieve maximum performance and a full service from a device. An Electric Turbo Compounding is in a very vulnerable position and many kinds of engine.

Failures will also damage of it. Most failures are secondary failures following primary failures of the engine and its accessories and not the result of normal wear.

The things, which can cause a fail, are many and vary, but they can all be grouped into four general categories:

- Lack of lubricating oil.
- Foreign material or dirt in the lubrication system.
- Foreign material in either the exhaust or air induction systems.
- Defective material or workmanship [20].

3.2 Engine Specifications

Table (3.1) Engine Specifications

Manufacture	Perkins Diesel Engines
Engine	Six cylinders 4 stroke Stationary CI Engine
Bore	131 mm
Stroke	158 mm
Comp. Ratio	18:1
Capacity	12.78 L
Sp. Fuel Consumption @100% load	91.80 LPH
RPM	1500
BHP@1500	400 KW
Cooling System	Water Cooled
Exhaust temperature	570˚C

3.3 Calculations

Capacity

$=\frac{\pi D^2 L * n}{4}$

$= \frac{6*\pi*158*131^2}{4}$ =12.78 L

$V_r = \frac{V_s + V_c}{V_c}$

18=$\frac{12.78*10^{-3} + V_c}{V_c}$

V_c= 0.752 L

Total Volume = $V_s + V_c$

Total Volume = 13.532 L

$\dot{m}_f = \ = \frac{\rho_f * 91.8*10^{-3}}{3600}$

$\dot{m}_f = 835 * \frac{91.8*10^{-3}}{3600} = 0.0213\ Kg/s$

s.f.c $= \frac{\dot{m}_f}{power}$

s.f.c $= \frac{0.0213}{400}$

s.f.c = 0.1917 $Kg/KW.h$

$\dot{V} = V_s * \frac{N}{2}$

$\dot{V} = \frac{12.78*10^{-3}*1500}{2} = 9.585\ m^3/min$

$\eta_v = \frac{\dot{m}_a}{\dot{V}*\rho_a}$

$0.90 = \frac{\dot{m}_a}{\frac{9.585*1.181}{60}}$

$\dot{m}_a = 0.17\ Kg/s$

$\dot{m}_e = \dot{m}_f + \dot{m}_a$

$\dot{m}_e = 0.1913 Kg/s$

$\dot{Q}_e = \dot{m}_e * C_{p_e} * \Delta T$

$\dot{Q}_e$ = 0.1913*1.1*(570-30)

$\dot{Q}_e$ = 113.63 KW

Assume

η_v = 90%

η_{isen} = 75%

η_{mech} = 80%

P_2/P_1 =1.35

P_2 = 1.35*1.013 =1.367 bar

$\dot{V}_{act}$ = 8.63 m^3/min

The Engine developed $\frac{400}{8.63}$ = 46.35 $KW/m^3/min$

Temperature after Isentropic Compression

$$T_{2s} = T_1 \left(P_2/P_1\right)^{\gamma-1/\gamma}$$

$$T_{2s} = 303 \left(1.367/1.013\right)^{0.4/1.4}$$

$$T_{2s} = 330K$$

$$\eta_{isen} = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$0.75 = \frac{330-303}{T_2-303}$$

$$T_2 = 339K$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{8.63*1.367}{339} = \frac{1.013*V_2}{303}$$

V_2= 10.4 m^3/min

Increase in Indicated Power

$$\frac{\Delta P*V_S}{60} = \frac{(1.367-1.013)*9.585}{60}$$

= 5.65 KW

Increase in Indicated Volume

= (10.4-8.63) = 1.77 m^3/min

Increase in Power from air Induced
1.77*46.35 = 82 KW

Mass of air delivered by the Turbo

$$\frac{1.367*10.4*100}{339*0287} = 14.6\ Kg/min$$

Power required to drive the Turbo

$$\frac{\dot{m}_a * C_{p_a} * T_1}{60}[({}^{P_2}/{}_{P_1})^{\gamma-1/\gamma} - 1]\frac{1}{\eta_{isen}}$$

$$\frac{14.6*1.005*339*0.089527}{60*0.75} = 9.9KW$$

Total Increase Power
82 + (0.8*5.65) = 86.52 KW

Net Increase Power
= 86.52 – 9.9 =76.62 KW

Heat loss due to Exhaust gases (after Recovery)
$\dot{Q}_e = \dot{m}_e * C_{p_e} * \Delta T$
$\dot{Q}_e$ = 0.1913*1.1*(150-30)
$\dot{Q}_e$ = 25.25 KW

Heat loss due to Heat Transfer & Uncountable losses
113.63 – 25.25 – 76.62 = 11.76 KW

Percentage of Recovered Power

$$\frac{76.62}{113.63} = 67.43\%$$

New Volumetric Efficiency

$$\eta_v = \frac{14.6}{11.319885} = 129\%$$

$$\eta_{th} = \frac{\dot{Q}_{out}}{\dot{Q}_{in}}$$

$$\eta_{th} = \frac{\mathrm{BHP}}{\dot{m}_f * CV}$$

$$\eta_{th} = \frac{400}{0.0213*44000} = 0.4268 = 42.68\%$$

Thermal Efficiency after Recovering

$$\eta_{th} = \frac{476.62}{0.0213*44000} = 0.5085 = 50.85\%$$

3.4 Turbocharger and Global Warming

Until the middle of the 20th century the number of IC engines in the world was small enough that the pollution they emitted was tolerable, and the environment, with the help of sunlight, stayed relatively clean. As world population grew.

This chapter explores the undesirable emissions generated in the combustion process of IC engines.

These emissions pollute the environment and contribute to global warming, acid rain, smog, odours, and respiratory and other health problems. The major causes of these emissions are non-stoichiometric combustion, dissociation of nitrogen, and impurities in the fuel and air. The emissions of concern are hydrocarbons (He), carbon monoxide (CO), oxides of nitrogen (NOx), Sulphur, and solid carbon particulates. Ideally, engines and fuels could be developed such that very few harmful emissions are generated, and these could be exhausted to the surroundings without a major impact on the environment. With present technology this is not possible, and after treatment of the exhaust gases to reduce emissions is very important. This consists mainly of the use of thermal or catalytic converters and particulate traps [21].

3.5 Negative Effects of Combustion Products

- Unburned hydrocarbons and soot cause respiratory problems and are known to be carcinogenic.
- Carbon monoxide fixes to hemoglobin in the blood so that the blood loses its ability to carry oxygen.
- NO fixes to hemoglobin in the blood and threatens life if inhaled in excess.
- NOx is the main cause of smog and acid rain.
- Acid rain is mostly caused by emissions of sulfur and nitrogen compounds (Sox and NOx) that form acids when they react with water in the atmosphere.
- Carbon dioxide is considered a major contributor to global warming through its role in the greenhouse effect.
- Carbon dioxide absorbs and reemits the thermal-infrared radiation emitted by the earth [22].

3.6 Simulation

3.6.1 Introduction

This experiment could have been done in one of two ways:

1. as a lab experiment: running the experiment empirically would yield more accurate and practical results but this was not the case in this research for the following reasons:

- It is difficult to apply different pressure ratios on the same engine.

- The results would be prone to human mistakes.
- The results would be prone to natural conditions.
- The results would depend on the efficiency of the engine being used.
- The experiment would be time-consuming.
- The expenses would be very high due to the need of various expensive equipment.

2. Using a simulation program: and this is the case in this research. The simulation program chosen for this experiment is "Diesel-RK". There are certain advantages and disadvantages of using a simulation program and here are a few:

3.6.2 Advantages of using a Simulation Program

- Ability to provide practical feedback.
- Ability to change design and input data.
- Ability to compare alternatives.
- Ability to test the system at different levels.
- Ability to test complex systems.
- Ability to evaluate performance.

3.6.3 Disadvantages of using a Simulation Program:-

- Some simulations need large computational power.
- Compromised accuracy.
- Results may differ from empirical experiments.

3.6.4 Diesel – RK Software

DIESEL-RK is an engine simulation tool, is designed for simulating and optimizing working processes of two- and four-stroke internal combustion engines with all types of boosting. The program can be used for modeling the following types of engines:

- DI Diesel engines.
- SI petrol engines.
- SI gas engines including prechamber systems.
- Two-stroke engines with uniflow and loop scavenging, opposed piston engines (Junkers engines) and OPOC engines.

The DIESEL-RK is thermodynamic software and has been designed since 1981 - 1982. In those years it was applied in researches of many engines with different sizes, speed and application. All these years the software is improving to grow efficiency and field of application. Results of simulation in every research are compared with experimental data obtained by various authors, mainly obtained by diesels manufacturers. Main features of program DIESEL-RK are similar to known thermodynamic programs. However, together with conventional features, the DIESEL-RK has new advanced applications which are absent in other programs. DIESEL-RK is oriented on diesel combustion optimization and ICE analysis and optimization. The assumption about identical work of all engine cylinders allows considerably increase operating speed and one makes it possible to resolve multi- parametrical optimization tasks. The Main Applications of the DIESEL-RK are:-

- Torque curve and other engine performances prediction.
- Fuel consumption prediction and optimization.

- Combustion and emission analysis and optimization.
- Knock prediction.
- Valve timing optimization.
- EGR system analysis and optimization.
- Turbocharger and bypasses matching and optimization.
- Research and optimization of fuel injection profile including multiple injection, sprayer design and location as well as piston bowl shape optimization.
- Convert of diesel engines into gas engines.

3.6.5 Test Conditions

The main interest of this study is the comparison between Turbocharged and non-Turbocharged engine. Tests are performed on a thermodynamic software: "DIESEL-RK" and are intended for calculation and optimization of Exhaust Products at different conditions, which are:

- Constant pressure ratio (18).
- Engine speeds (1000, 1100, 1200, 1300, 1400 and 1500 rpm).

The main characteristics of the engine subjected to the simulation of the Diesel – RK are:

- Engine type: Perkins Stationary Diesel Engine.
- Turbocharged diesel engine comp ratio (1.35).
- Intercooler system.
- In - line engine design.
- 6 cylinders – 24 valves.
- Cylinder bore 131 mm.
- Stroke 158 mm.
- Water cooling.
- Ambient parameters:
    1. Pressure 1.013 bars.
    2. Temperature 303K.

The specifications of the fuel used are:

- Composition mass fraction (C = 0.87and H = 0.13).
- Chemical composition of the fuel $C_{15}H_{28}$
- Sulfur fraction in fuel = 0.00606 (%).
- Low heating value of fuel = 43.45 (MJ/Kg).
- Cetane number = 56.5.
- Density of fuel at 323 K = 930 (Kg/m^3).
- Surface tension factor of fuel at 323 K = 0.031 (N/m).
- Dynamic viscosity coefficient of fuel at 323 K = 0.035 (PA.s).
- Specific vaporization heat = 250 (KJ/Kg).
- Molecular mass of fuel = 208.

3.6.6 Preprocessor of Diesel - RK

The diesel – RK software prepares a numbers of windows, these windows used for entry the data and all specifications and characteristics of the engine under, using the most known technical decisions accepted in area of propulsion engineering. Thus it is becomes simpler not only a process of input data entering but also the most difficult stage of computational research: calibration of engine models. The last is especially important for the engineers who are not having enough time and experimental data for customizing of the program on object of research, and also for researchers who makes express engine analysis. The Wizard selects prototype data file from internal data base, adjusts main dimensions of the engine parts corresponding with assigned cylinder bore and nominal RPM, builds piston bowl shape and injector design being more character for current kind of the engine as well assigns empirical coefficients being character for the engine. User just has to answer the questions listed below:

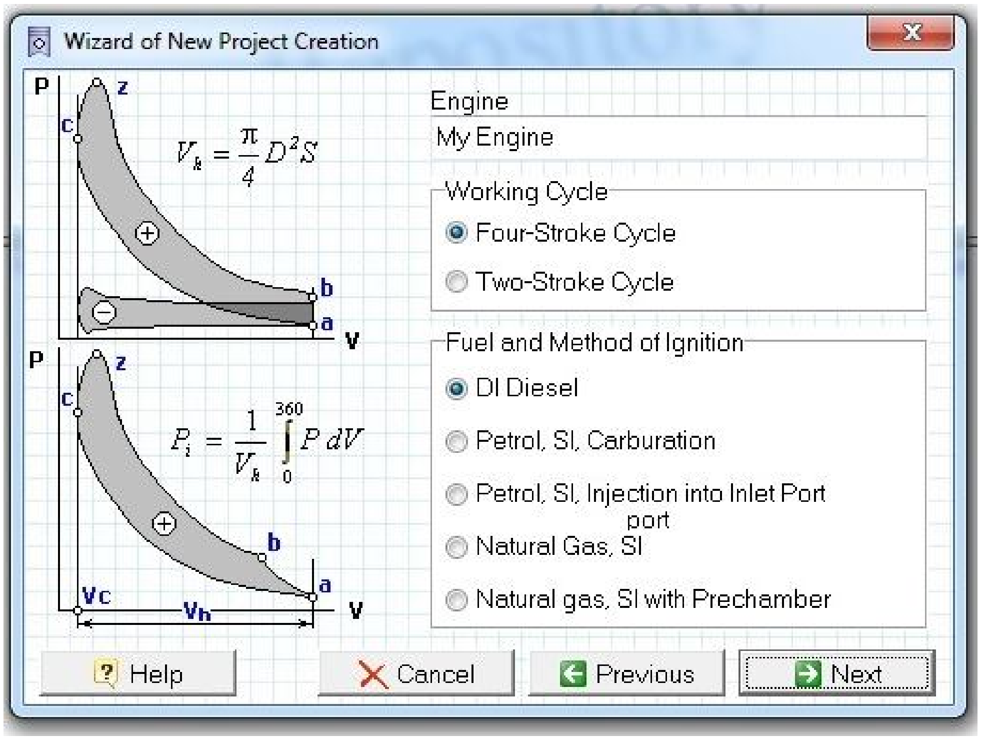

Figure (3.4) Window with questions about the engine cycle and fuel

Figure (3.4) shows the type of working cycle of the engine, four – stroke cycle or two – stroke cycle, and also the first window ask the type of fuel used and methods of injection, direct ignition diesel, spark ignition petrol with carburetion, spark ignition petrol with injection into inlet port, spark ignition with natural gas, or spark ignition natural gas with prechamber.

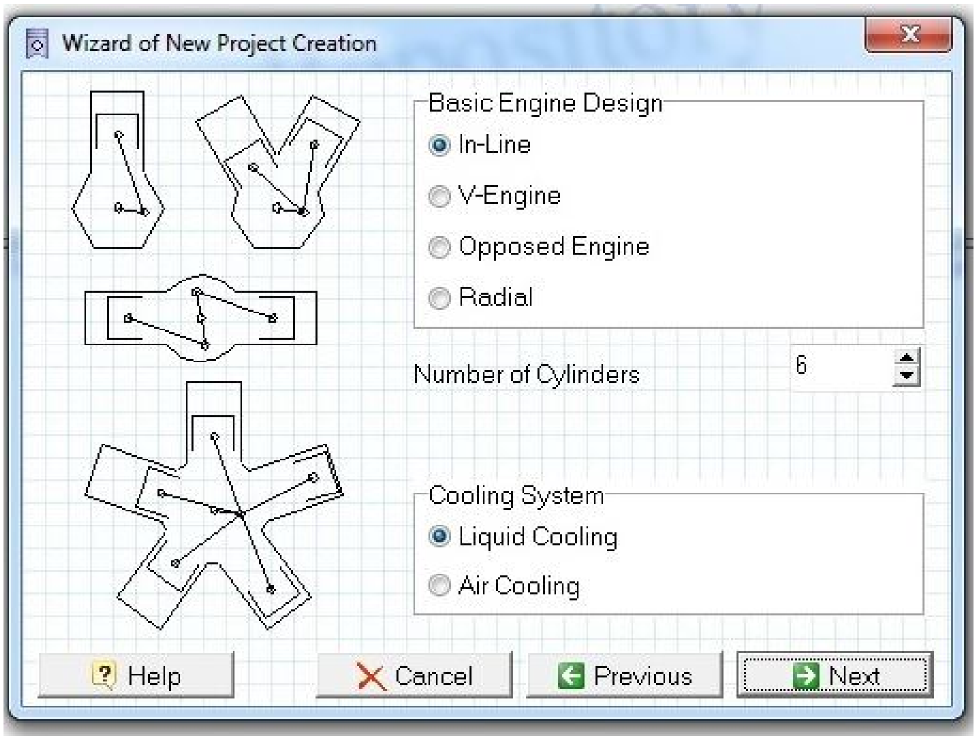

Figure (3.5) Window with questions about the engine design and cooling system

The next window shown in figure (3.5), which explains the selection of the type of the basic engine design: In – line, V – engine, opposed engine, or radial engine. Also the window helps the user to define

- The number of cylinders in the engine where the combustion take place and.
- The cooling system used: liquid or air.

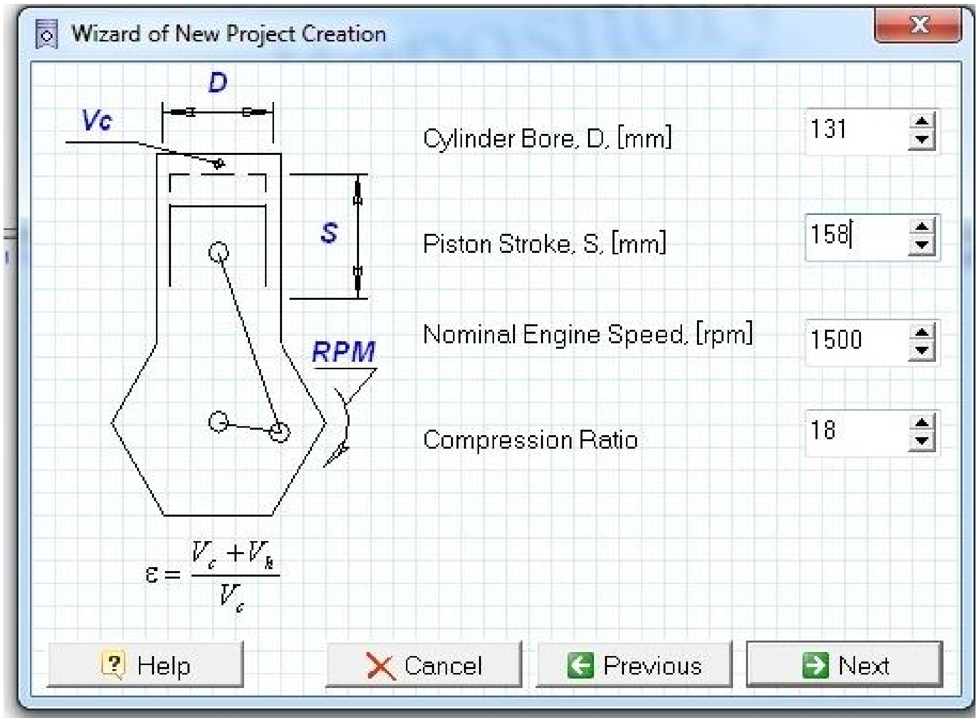

Figure (3.6) Window with main engine dimensions and speed

Figure (3.6), shows the third window which concerns the geometrical properties of the engine

- **Cylinder Bore**, mm. It is assumed all engine cylinders have same Diameter.
- **Piston Stroke**, mm. It is assumed all engine cylinders have same Piston Stroke.
- **Compression Ratio**. It is assumed all engine cylinders have same CR.

Also the nominal engine speed in revolution per minute will be defined in this window.

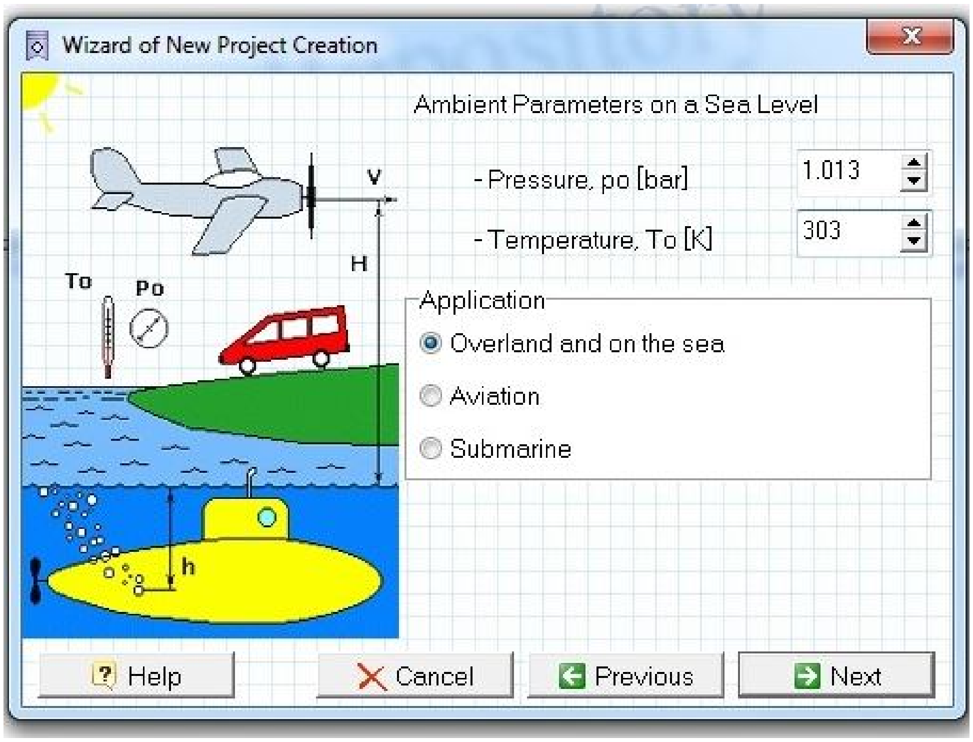

Figure (3.7) Questions about the engine application and environment.

Window shown in figure (3.7) concern with ambient parameters on a sea level, both pressure (po) in bar and temperature (To) in Kelvin, also the application of the engine must be defined

- Overland and on the sea.
- Aviation OR.
- Submarine.

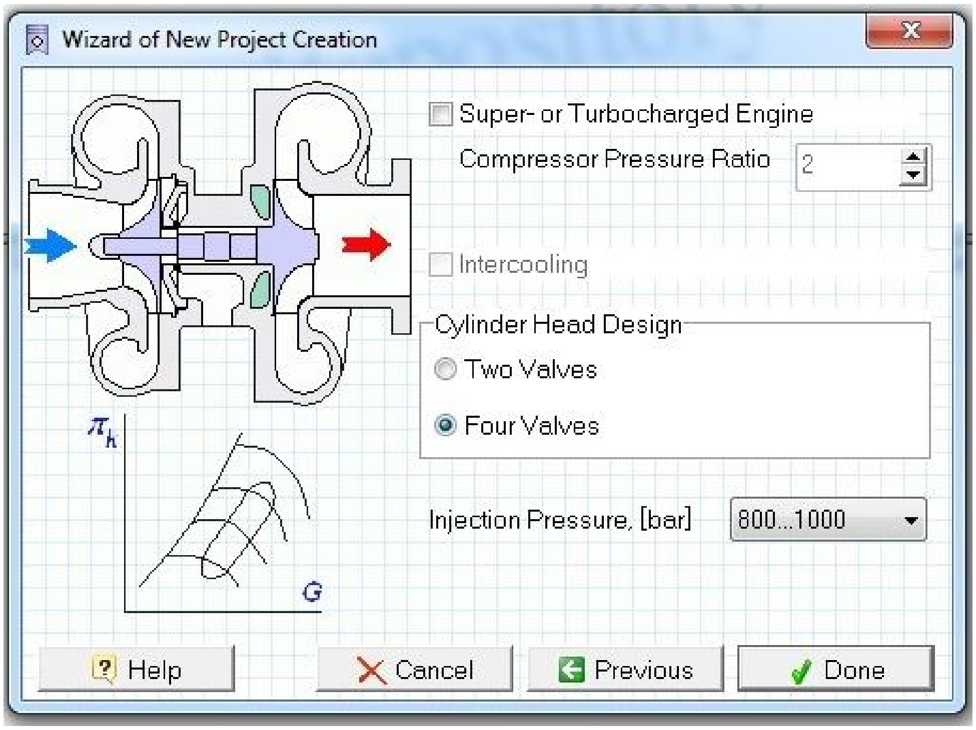

Figure (3.8 a) Window with questions about the engine boost, etc

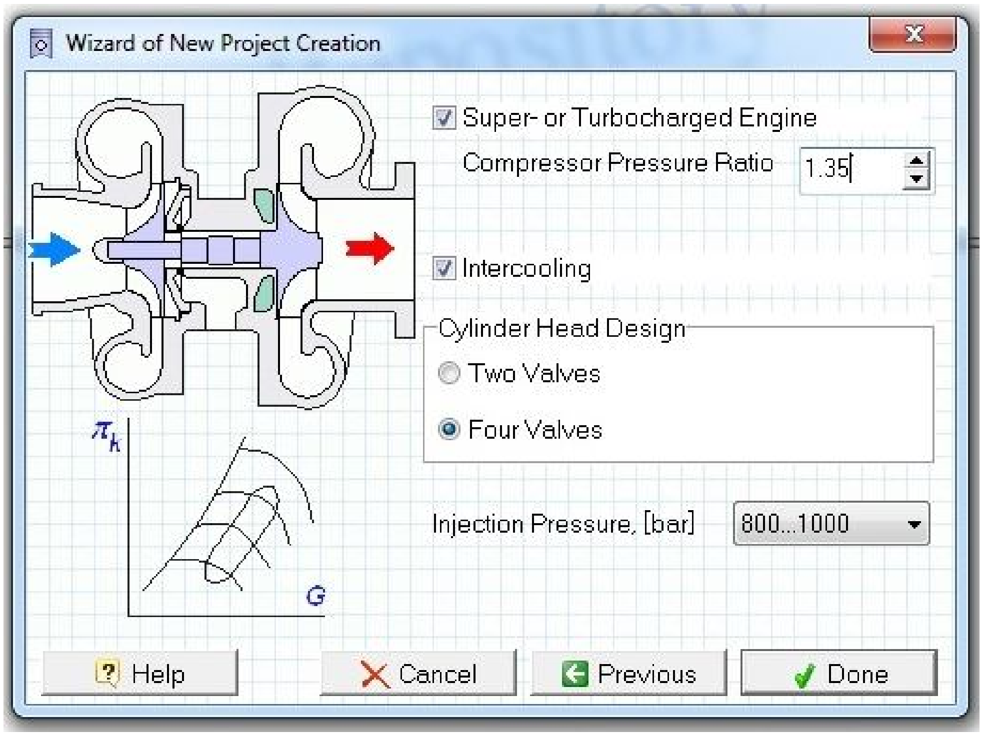

Figure (3.8 b) Window with questions about the engine boost, etc

Figure (3.8 a & b), shows the fifth window in the engine simulation, and it interesting in the information listed below.

- Type of charging air (with OR without turbocharger).
- Type of forcing air (turbocharger or supercharger).
- The values of compressor pressure ratio.
- With or without intercooling.
- Number of valves per cylinder (inlet and exhaust).
- Injection pressure of the fuel into the cylinder.

Chapter 4 Simulation Results & Discussions

4.1 Simulation Results

4.1.1 Results with Using Turbocharger

```
 ------------------------ ECOLOGICAL PARAMETERS ----------------------
0.70463     - Hartridge- Hartridge Smoke Level
0.07717     - Bosch     - Bosch Smoke Number
0.01678     - K,m-1     - Factor of Absolute Light Absorption, 1/m
0.00865     - PM        - Specific Particulate Matter, g/kWh
 731.98     - CO2       - Specific Carbon dioxide emission, g/kWh
 2151.9     - NOx,ppm   - Fraction of wet NOx in exh. gas, ppm
 13.464     - NO,g/kWh  - Specif. NOx emiss. reduc. to NO, g/kWh    (Zeldovich)
 1.9523     - SE        - Summary emission of PM and NOx
 0.0000     - SO2       - Specific SO2 emission, g/kWh
```

Figure (4.1) Ecological Parameters at 1100 RPM

Figure (4.1) shows the amount of some Combustion Products at Specific Engine speed (1100 RPM)

```
 ------------------------ ECOLOGICAL PARAMETERS ----------------------
0.97169     - Hartridge- Hartridge Smoke Level
0.10642     - Bosch     - Bosch Smoke Number
0.02314     - K,m-1     - Factor of Absolute Light Absorption, 1/m
0.01278     - PM        - Specific Particulate Matter, g/kWh
 732.34     - CO2       - Specific Carbon dioxide emission, g/kWh
 2170.4     - NOx,ppm   - Fraction of wet NOx in exh. gas, ppm
 13.587     - NO,g/kWh  - Specif. NOx emiss. reduc. to NO, g/kWh    (Zeldovich)
 1.9836     - SE        - Summary emission of PM and NOx
 0.0000     - SO2       - Specific SO2 emission, g/kWh
```

Figure (4.2) Ecological Parameters at 1200 RPM

Figure (4.2) shows the amount of some Combustion Products at Specific Engine speed (1200 RPM)

```
 ------------------------ ECOLOGICAL PARAMETERS ----------------------
 1.2784     - Hartridge- Hartridge Smoke Level
0.14001     - Bosch     - Bosch Smoke Number
0.03044     - K,m-1     - Factor of Absolute Light Absorption, 1/m
0.01783     - PM        - Specific Particulate Matter, g/kWh
 732.45     - CO2       - Specific Carbon dioxide emission, g/kWh
 2187.9     - NOx,ppm   - Fraction of wet NOx in exh. gas, ppm
 13.699     - NO,g/kWh  - Specif. NOx emiss. reduc. to NO, g/kWh    (Zeldovich)
 2.0164     - SE        - Summary emission of PM and NOx
 0.0000     - SO2       - Specific SO2 emission, g/kWh
```

Figure (4.3) Ecological Parameters at 1300 RPM

Figure (4.3) shows the amount of some Combustion Products at Specific Engine speed (1300 RPM)

```
 ------------------------ ECOLOGICAL PARAMETERS ----------------------
 1.6684     - Hartridge- Hartridge Smoke Level
0.18273     - Bosch    - Bosch Smoke Number
0.03972     - K,m-1    - Factor of Absolute Light Absorption, 1/m
0.02467     - PM       - Specific Particulate Matter, g/kWh
 733.16     - CO2      - Specific Carbon dioxide emission, g/kWh
 2205.7     - NOx,ppm  - Fraction of wet NOx in exh. gas, ppm
 13.823     - NO,g/kWh - Specif. NOx emiss. reduc. to NO, g/kWh    (Zeldovich)
 2.0570     - SE       - Summary emission of PM and NOx
 0.0000     - SO2      - Specific SO2 emission, g/kWh
```

Figure (4.4) Ecological Parameters at 1400 RPM

Figure (4.4) shows the amount of some Combustion Products at Specific Engine speed (1400 RPM)

```
 ------------------------ ECOLOGICAL PARAMETERS ----------------------
 2.1280     - Hartridge- Hartridge Smoke Level
0.23307     - Bosch    - Bosch Smoke Number
0.05067     - K,m-1    - Factor of Absolute Light Absorption, 1/m
0.03320     - PM       - Specific Particulate Matter, g/kWh
 733.60     - CO2      - Specific Carbon dioxide emission, g/kWh
 2221.8     - NOx,ppm  - Fraction of wet NOx in exh. gas, ppm
 13.933     - NO,g/kWh - Specif. NOx emiss. reduc. to NO, g/kWh    (Zeldovich)
 2.1011     - SE       - Summary emission of PM and NOx
 0.0000     - SO2      - Specific SO2 emission, g/kWh
```

Figure (4.5) Ecological Parameters at 1500 RPM

Figure (4.5) shows the amount of some Combustion Products at Specific Engine speed (1500 RPM)

4.1.2 Results without Using Turbocharger

```
------------------------ ECOLOGICAL PARAMETERS ----------------------
 1.7857      - Hartridge- Hartridge Smoke Level
0.19558      - Bosch     - Bosch Smoke Number
0.04252      - K,m-1     - Factor of Absolute Light Absorption, 1/m
0.02725      - PM        - Specific Particulate Matter, g/kWh
 747.98      - CO2       - Specific Carbon dioxide emission, g/kWh
 1801.9      - NOx,ppm   - Fraction of wet NOx in exh. gas, ppm
 17.734      - NO2,g/kWh- Specif. NOx emis. reduc. to NO2, g/kWh    (Zeldovich)
 2.6243      - SE        - Summary emission of PM and NOx
 0.0000      - SO2       - Specific SO2 emission, g/kWh
```

Figure (4.6) Ecological Parameters at 1100 RPM

Figure (4.6) shows the amount of some Combustion Products at Specific Engine speed (1100 RPM)

```
------------------------ ECOLOGICAL PARAMETERS ----------------------
 2.3502      - Hartridge- Hartridge Smoke Level
0.25741      - Bosch     - Bosch Smoke Number
0.05596      - K,m-1     - Factor of Absolute Light Absorption, 1/m
0.03812      - PM        - Specific Particulate Matter, g/kWh
 748.34      - CO2       - Specific Carbon dioxide emission, g/kWh
 1829.2      - NOx,ppm   - Fraction of wet NOx in exh. gas, ppm
 18.012      - NO2,g/kWh- Specif. NOx emis. reduc. to NO2, g/kWh    (Zeldovich)
 2.7003      - SE        - Summary emission of PM and NOx
 0.0000      - SO2       - Specific SO2 emission, g/kWh
```

Figure (4.7) Ecological Parameters at 1200 RPM

Figure (4.7) shows the amount of some Combustion Products at Specific Engine speed (1200 RPM)

```
------------------------ ECOLOGICAL PARAMETERS ----------------------
 3.2007      - Hartridge- Hartridge Smoke Level
0.35055      - Bosch     - Bosch Smoke Number
0.07621      - K,m-1     - Factor of Absolute Light Absorption, 1/m
0.05565      - PM        - Specific Particulate Matter, g/kWh
 748.82      - CO2       - Specific Carbon dioxide emission, g/kWh
 1827.7      - NOx,ppm   - Fraction of wet NOx in exh. gas, ppm
 18.009      - NO2,g/kWh- Specif. NOx emis. reduc. to NO2, g/kWh    (Zeldovich)
 2.7582      - SE        - Summary emission of PM and NOx
 0.0000      - SO2       - Specific SO2 emission, g/kWh
```

Figure (4.8) Ecological Parameters at 1300 RPM

Figure (4.8) shows the amount of some Combustion Products at Specific Engine speed (1300 RPM)

```
------------------------ ECOLOGICAL PARAMETERS ----------------------
 4.4217     - Hartridge- Hartridge Smoke Level
0.48438     - Bosch    - Bosch Smoke Number
0.10554     - K,m-1    - Factor of Absolute Light Absorption, 1/m
0.08292     - PM       - Specific Particulate Matter, g/kWh
 749.58     - CO2      - Specific Carbon dioxide emission, g/kWh
 1814.7     - NOx,ppm  - Fraction of wet NOx in exh. gas, ppm
 17.899     - NO2,g/kWh- Specif. NOx emis. reduc. to NO2, g/kWh    (Zeldovich)
 2.8334     - SE       - Summary emission of PM and NOx
 0.0000     - SO2      - Specific SO2 emission, g/kWh
```

Figure (4.9) Ecological Parameters at 1400 RPM

Figure (4.9) shows the amount of some Combustion Products at Specific Engine speed (1400 RPM)

```
------------------------ ECOLOGICAL PARAMETERS ----------------------
 5.9554     - Hartridge- Hartridge Smoke Level
0.65310     - Bosch    - Bosch Smoke Number
0.14389     - K,m-1    - Factor of Absolute Light Absorption, 1/m
0.12021     - PM       - Specific Particulate Matter, g/kWh
 750.30     - CO2      - Specific Carbon dioxide emission, g/kWh
 1800.4     - NOx,ppm  - Fraction of wet NOx in exh. gas, ppm
 17.775     - NO2,g/kWh- Specif. NOx emis. reduc. to NO2, g/kWh    (Zeldovich)
 2.9400     - SE       - Summary emission of PM and NOx
 0.0000     - SO2      - Specific SO2 emission, g/kWh
```

Figure (4.10) Ecological Parameters at 1500 RPM

Figure (4.10) shows the amount of some Combustion Products at Specific Engine speed (1500 RPM)

4.2 Result's Tables and Graphs

Table (4.1) PM in different speeds, with and without turbo

	With Turbo	Without Turbo
Engine Speed	PM g/KW.hr	PM
1100	0.00865	0.02725
1200	0.01278	0.03812
1300	0.01783	0.05565
1400	0.02467	0.08292
1500	0.0332	0.12021

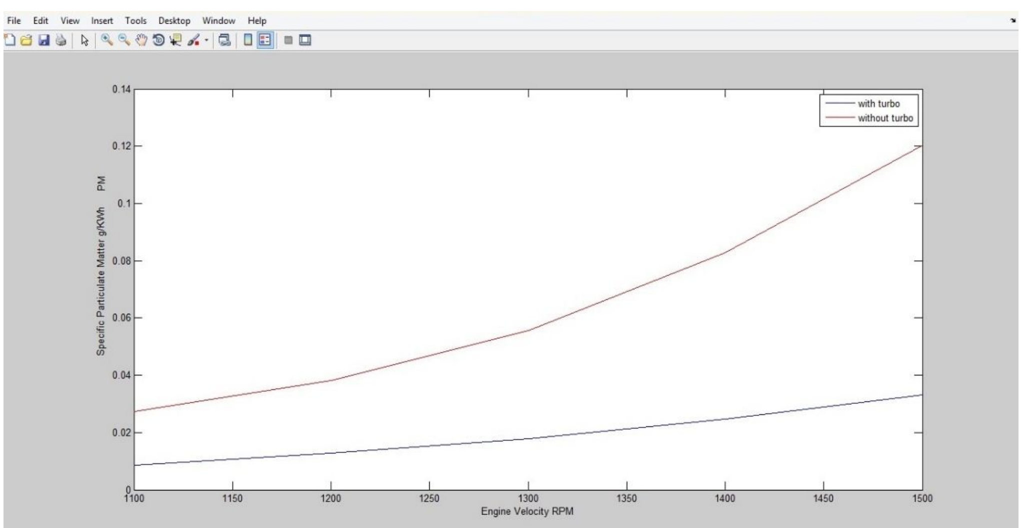

Figure (4.11) Engine speed versus Particulate Matter

From the graph (4.11) and table (4.1) note that the mass of Particulate Matter emerging with exhaust gases per kilowatt hour increases with the speed of engine and it increases in the case of non-using turbo compared to the mass when using turbo, especially in the operating speed 1500 rev / min.

Table (4.2) CO_2 emission in different speeds, with and without turbo

	With Turbo	Without Turbo
Engine Speed	CO_2 g/KW.hr	CO_2 g/KW.hr
1100	731.980	747.98
1200	732.340	748.34
1300	732.55	748.82
1400	733.28	749.58
1500	733.80	750.30

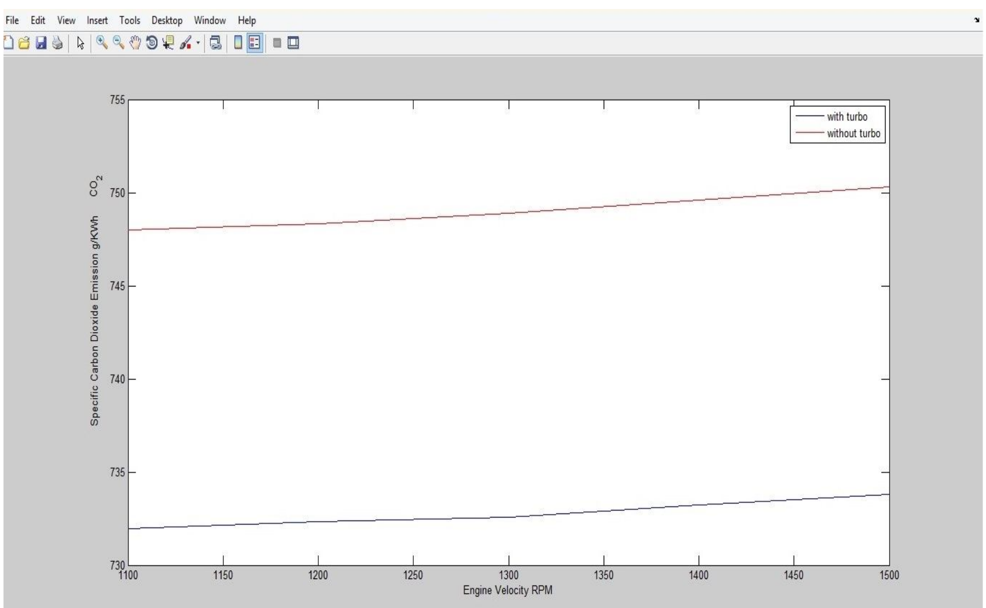

Figure (4.12) Engine speed versus CO_2 emission

From the graph (4.12) and table (4.2) note that the mass of carbon dioxide gas emerging with the exhaust gases per kilowatt hour is increases within increases in speed of engine and it is in the case of non-using turbo is relatively large compared to the mass when using turbo.

Table (4.3) NO_x emission in different speeds, with and without turbo

	With Turbo	Without Turbo
Engine Speed	NO_x PPM	NO_x PPM
1100	2151.90	1801.90
1200	2170.40	1892.20
1300	2187.9	1827.20
1400	2205.7	1814.70
1500	2221.8	1800.4

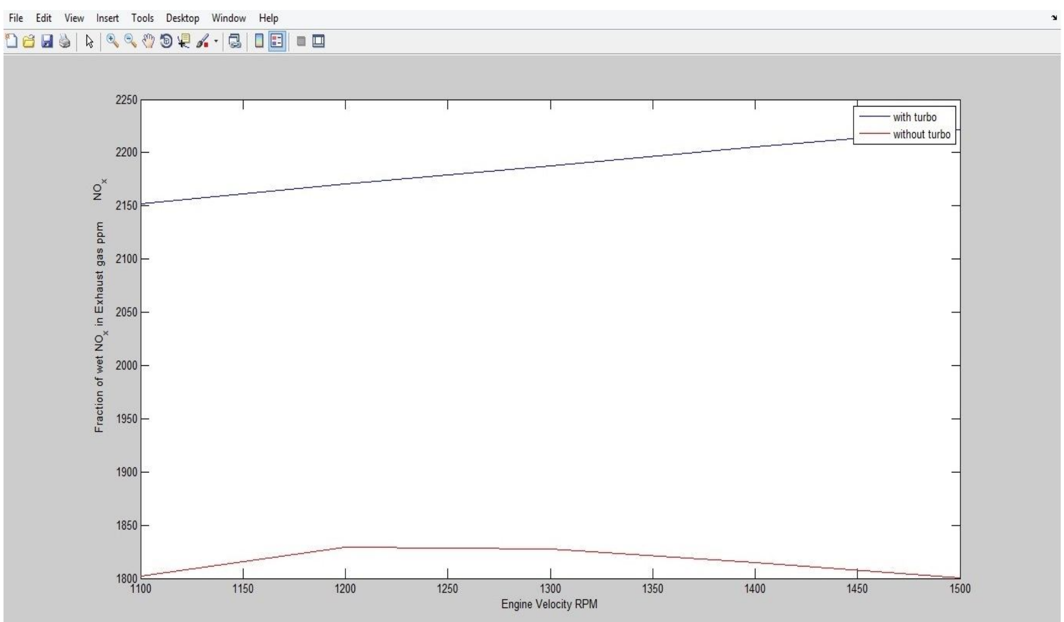

Figure (4.13) Engine speed versus NO_X emission

From the graph (4.13) and table (4.3) note that the number of molecules of nitrogen oxides emerging with the exhaust gases are increase within speed of engine when using turbo and there double in the case of the using turbo compared to the number of molecules when non-using turbo because of the amount of excess air. That's not a big problem cause of using technologies specially (turbo-charger, turbo-compounding…etc) the temperature of exhaust gases decreased which decreased the amount of NO_x.

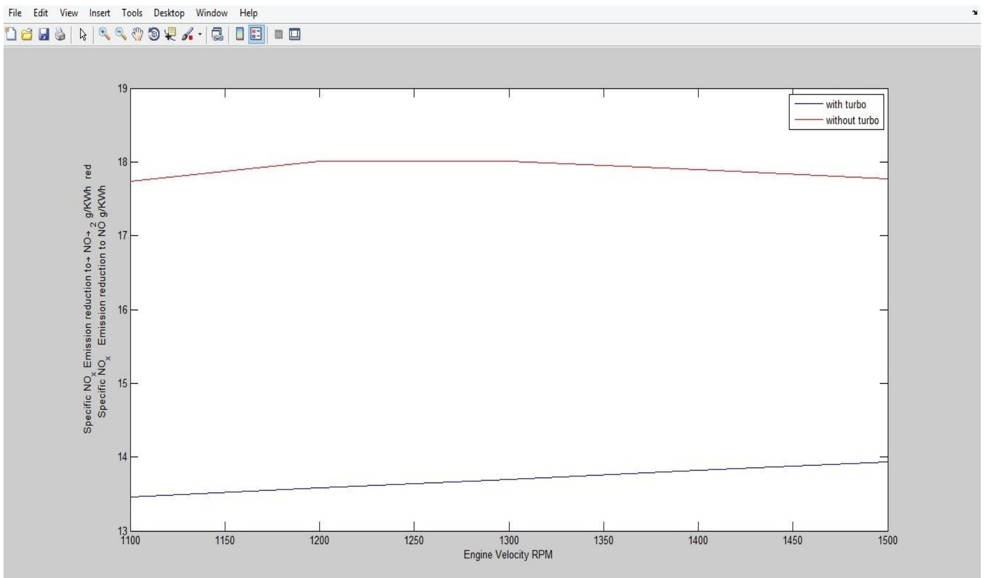

Figure (4.14) Engine speed versus NO_X reduction

From the graph (4.14) describes the amount of nitrogen oxides, which turn out to nitrogen dioxide in the case of non-using turbo and the other that turn into nitrogen monoxide in the case of the using turbo because of the amount of excess air is decreased the temperature inside the combustion chamber and it has relations with enthalpy of formation and some chemical issues.

Table (4.4) SE in different speeds, with and without turbo

	With Turbo	Without Turbo
Engine Speed	SE	SE
1100	1.9523	2.6243
1200	1.9836	2.7003
1300	2.0164	2.7582
1400	2.0570	2.8334
1500	2.1011	2.9400

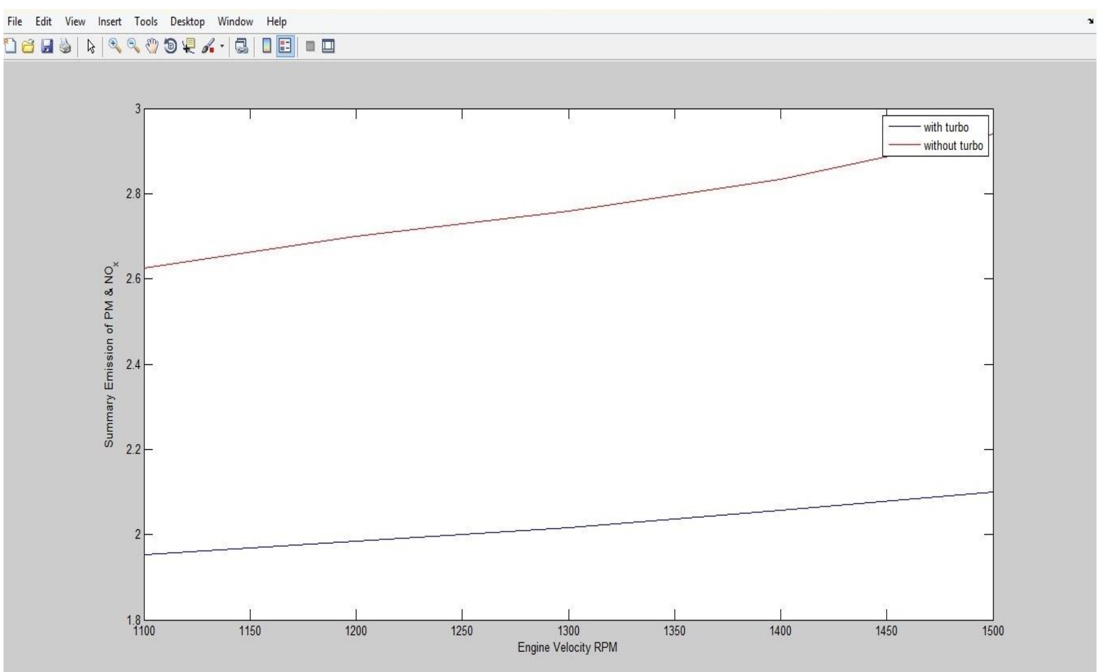

Figure (4.15) Engine speed versus Particulate Matter & NO_X

From the graph (4.15) note the summary emission of Particulate Matter and carbon dioxide, it is relatively larger in the case of non-using turbo compared when using turbo.

Chapter 5 Conclusion & Recommendations

5.1 Conclusion

After it recovers 76.62 kW of heat with percentage 67.43% of the exhaust losses due to recovers technology, decreases the exhaust temperature from 570ºC to 150ºC Turbocharger contributes in reduce the air pollution, and it's also raises the thermal efficiency from 42.68% to 50.85% and raises the volumetric efficiency from 90% to 129%. Turbocharger contributes in saving world from Global Warming by saving this amount of heat.

5.2 Recommendations

Keep going in calculation of this technology in other kinds of engines with different specifications in deferent ranges of speeds and compared it with each other, or compared with other technologies of heat recovery e.g. Electrical Turbo-Compounding.

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