Car Engine Simulation Tool

Final Bachelor Thesis

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INDEX

I. Introduction

Nowadays the most common engines that we have on our lives are the internal combustion ones. This kind of engines can be recognized because they obtain mechanical energy directly from chemical processes related with a fuel that burns into the combustion chamber. The name of these engines means that this combustion is made inside the engine and not out as in the steam machine.

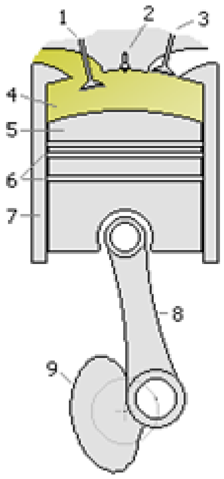
II. History

The first engine prototypes of this type had not the compression phase, the intake step finished with the closing of the injection valve when the piston was more or less in the middle of the cylinder so the spark that generated the internal combustion was not enough. When the compression phase was included this kind of engines started to replace the steam engines as they can produce a equal or greater power in lower dimensions.

In 1886 the internal combustion engine as it is know now a days was developed by Nikolaus Otto, who patent a four stroke engine based on the studies of Alphonse Beau de Rochas in 1862 that at the same time were based on the internal combustion studies of Barsanti and Matteucci (1853).

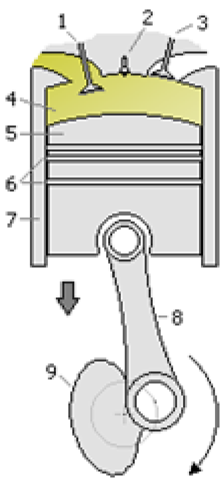
III. Four Stroke working procedure

A four stroke engine is the one that needs four runs of the piston, two completed turns of the crankshaft, to complete the thermodynamic combustion cycle.



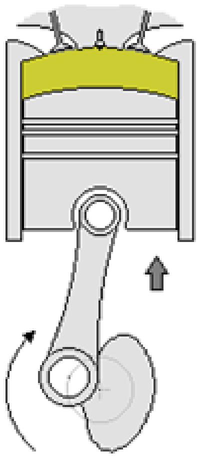
1. Injection Valve
2. Spark plug
3. Exhaust Valve
4. Combustion Chamber
5. Piston
6. Segments
7. Cylinder
8. Connecting rod
9. Crankshaft

The four steps are explained bellow:

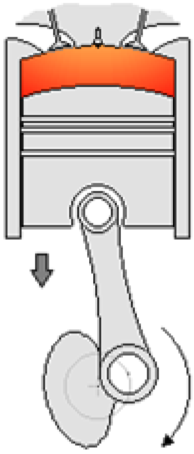


First Step or intake: in this step when the piston goes down allow the new combustion gas to get into by the injection valve. While this valve is opened the exhaust one keeps closed. This valve is opened before the process starts to give enough space to the fuel.

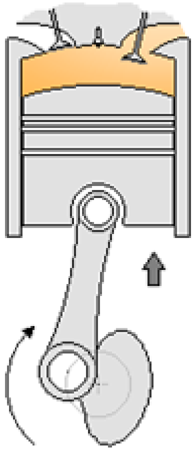
In this step the crankshaft makes a turn of 180 degrees.



Second Step or compression: At the end of the previous run the gas inside the cylinders gets compressed by means of the piston upper movement, so the injection valve gets closed by the pressure. Now the crankshaft has made 360 degrees from the initial position.



Third Step or explosion/expansion: After the compression time, when the piston comes back to the upper position, the maximum pressure inside the cylinder is obtained. In our case we have a Diesel engine so the fuel is injected sprayed and it gets burnt by means of the pressure and temperature inside the cylinder. Then the gas expansion makes the piston to move down again, is then when the work of the whole process is created. The expansion work obtained is more or less five times the needed compression work. During this process the crankshaft turns 180 degrees around, both valves are closed and the movement of the piston is down.



Fourth Step or exhaust: in this last step the upper movement of the piston makes the combustion gases to go out through the exhaust valve. When the piston is in the upper part, the exhaust valve gets closed and the injection one opened so the whole process starts again.

In this step the crankshaft has turned 180 degrees.

The aim of this report is thatknowing the data of a specified car engine and usingsimulation software, obtain a simulated data of the engine analyze it and try to improve the efficiency of the engine or give a range of engine speed in which the analyzed variables have the best values for a better road and more durability of this engine. Is also going to be explained which this affect each variable and why the values of it varies depending on the elements of our engine.

IV. Chosen Engine

In June of 2015 the ten cars most sold were:

Units sold	model
49555	Volkswagen Golf
33646	Ford Fiesta
31063	Volkswagen Polo
30821	Renault Clio
27133	Opel Corsa
25031	Ford Focus
23942	Renault Captur
23092	Peugeot 208
22899	Nissan Qashqai
21689	Volkswagen Passat

Looking on this table we decide to study the Ford Fiesta engine, with 33646 sells, because looking some years before this one is also in the top 10 of most sold cars list.

Getting focus on this engine it was searched for some data of it using some links, included on the bibliography, and the obtained information about it was:

-**Ford Fiesta 5d Trend 1.5 TDCi 75 CV**

-Diesel four stroke cycle engine

-4 in line cylinders

-2 valves per cylinder

-Manual 5 speeds

-41 liters of fuel capacity

-Max speed 167 km/h

-Compression ratio 16.0-1

-Cylinder Bore 73.5 mm

-Piston Stroke 88.3 mm

-Turbocharged engine with intercooler

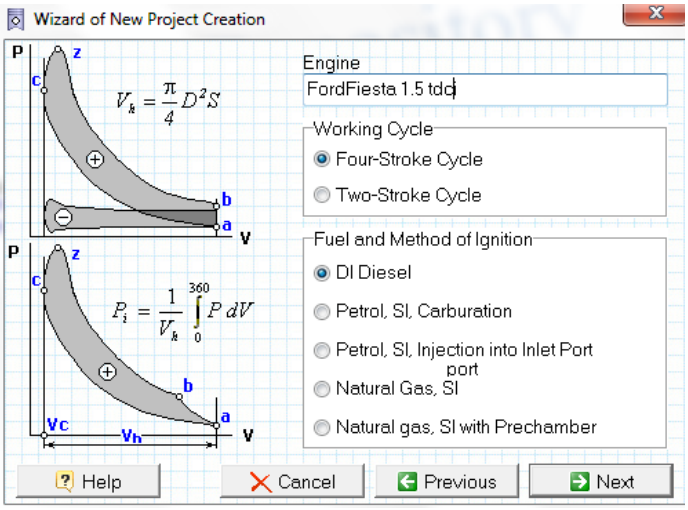
All this information is going to be used in the simulation of the engine so the trust of the data is assumed.

V. Simulation Software

The name of the software that is going to be used is Diesel-RK Net; it is a professional thermodynamic full-cycle engine simulation software and is focused on advanced diesel combustion simulation and emission formation simulation. It allows the user to obtain, with the use of the minimum empirical coefficients, high accuracy predictions of the simulation of any type of internal combustion engines working process.

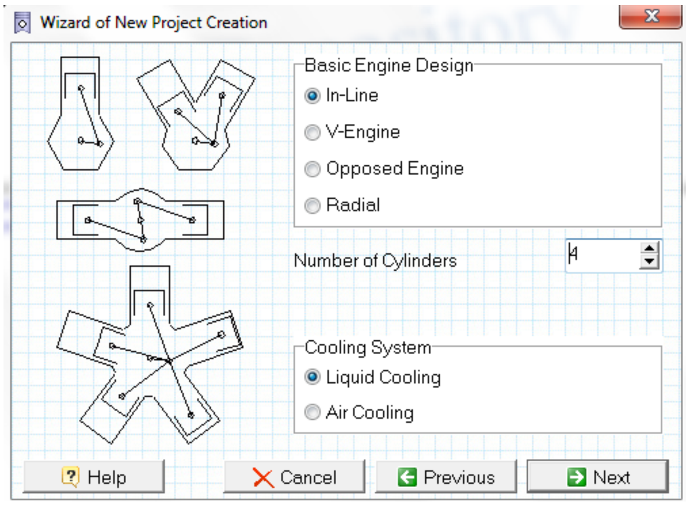
i. <u>Introducing the engine data on the software</u>

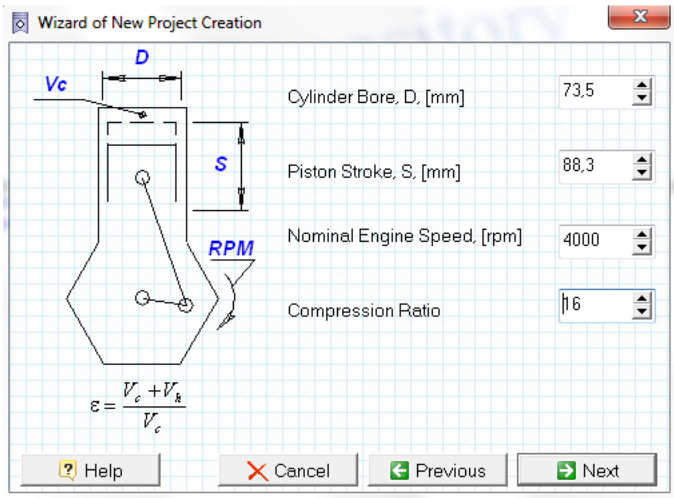
When we play the program it starts to ask us for some data of the engine whose working procedure is going to be simulated.



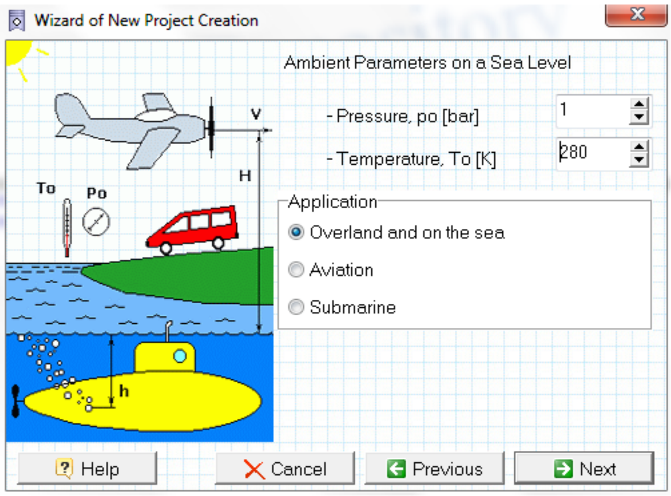
We start calling the engine as the chosen one and looking on its mechanical characteristics is found that the working cycle corresponds with a Four-Stroke one and working with DI Diesel as fuel.

In the next step is needed to check the Basic Engine Design, in this case we have an In-line engine, the number of cylinders, four in the studying case, and the cooling system, the chosen one has a Liquid Cooling system.





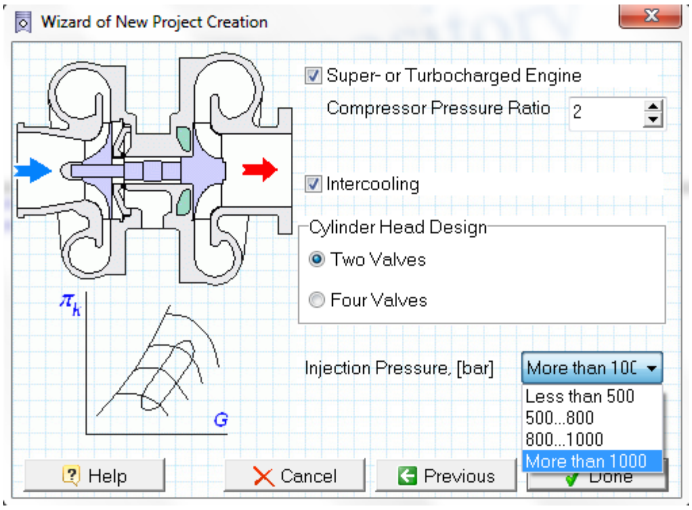
Using some data obtained by internet in some links about technical characteristics of car engines was obtained that the cylinder bore measures 73.5 mm and the piston stroke length is 88.3 mm. The nominal engine speed was decided to be established on 4000 rpm and the obtained compression ratio was 16.0-1.



As this study is being made in Poland it was decided to use the data of Gdansk that is more or less on the sea level and the temperature data is easier to obtain.

It was obtained that the mean temperature there is about 7ºC (280 K), at 1 bar and as is been studied a car engine, is chosen the "Overland and on the sea" option.

For completing this step it was found that the chosen engine is turbocharged, with intercooler and with two valves per cylinder, but the values for the compressor pressure ratio and injection pressure was not found so it was asked for help to a teacher specialized on this topics and knower of the software used and was decided to use the value of 2 for the compressor pressure ratio and "more than 1000" for the injection pressure value.

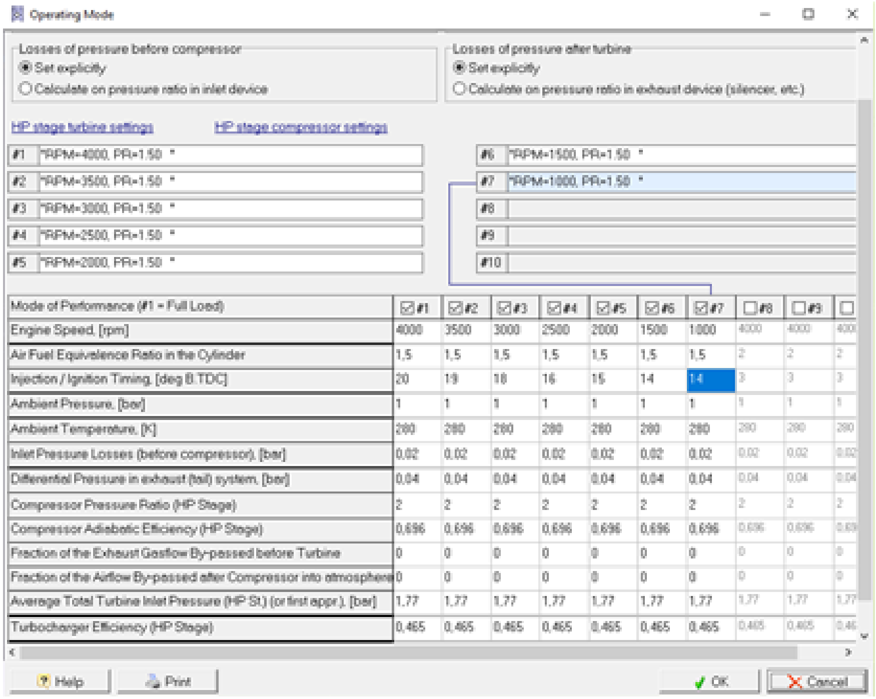


Once the entire required data is introduced the "new project" is created on the program and it is ready to be run and studied.

ii. Running the simulation

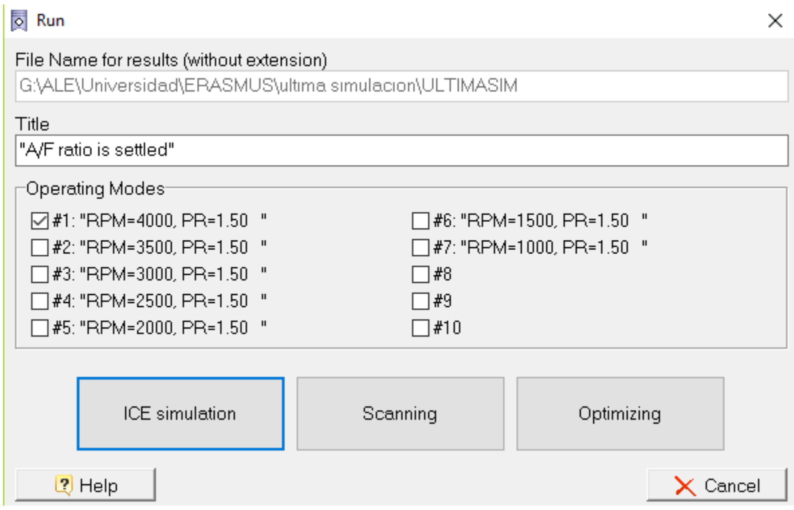
In the analysis of this engine two different types of running are used; the first one is only analyzing one point of the engine speed range, it means analyzing only one speed point. The second type consist on checking the hole acceleration time, in this way we obtain graphs that represents the evolution of some variables during this acceleration period.

The first thing that must be done is introduce the points in which we are interested. This is shown in the next picture.



Once the checking points are introduced we can run the simulation.

a. Simulation of only one point



It was taken the eight first points and was simulated one by one obtaining the exact values of the different variables. In the next table are included the obtained values:

Brake Torque (Nm)	Specific Fuel Consumption(kg/kWh)	Volumetric Efficiency	Piston Engine Power(kW)	NOx (ppm)	Specific Particulate Matter (g/kWh)
140.65	0.27214	0.87983	14.728	71.343	0.04165
162.21	0.24131	0.89977	25.478	57.318	0.02728
171.40	0.23195	0.91379	35.896	52.738	0.02728
173.68	0.22905	0.91441	45.466	50.996	0.03054
173.5	0.2308	0.9205	54.503	77.487	0.01754
171.82	0.23322	0.92113	62.971	92.167	0.0158
156.58	0.24355	0.87663	65.583	36.006	0.199

b. Simulation of the whole process

Here all the points are taken for the simulation and the results obtained are represented in graphs. These graphs have in the X axis the Engine Speed (rpm) as variable. We are going to get focus on checking the variables named on the table presented previously.

i. Analyzing the Graphs

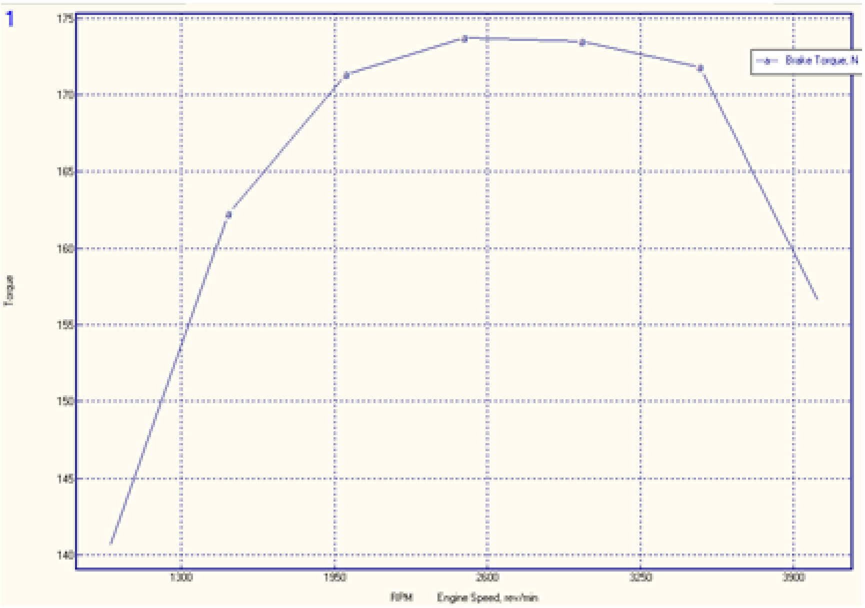
At this point the obtained graphs will be presented and analyzed, trying to determine the best engine speed in each case and giving some explanations about each variable.

Graph 1: Brake Torque

The torque is the ability of the engine to produce work. It is known that diesel engines can deliver too much more than gas ones. This is because in the gas process fuel-air mixture is compressed in the cylinder but in the diesel process only air is compressed. When the engine is working with gas the fuel is injected with air in the cylinder and then compressed but in the diesel process, the air is compressed until a determinate pressure and then the fuel is injected, because the higher temperature inside it ignites. Compressing the air alone means that the piston has to travel further; it means a longer piston stroke and a longer piston stroke means a larger crankshaft diameter.

If it is assumed that the force coming from diesel piston and from gas piston are the same; the diesel engine, as it has a larger stroke, is moving the crankshaft with a greater torque than the gas one. If the gas engine has to deliver the same power than the diesel one, it has to do it with more revolutions per minute in the crankshaft and less torque.

In the next graph is presented the evolution of the torque depending on the engine speed.

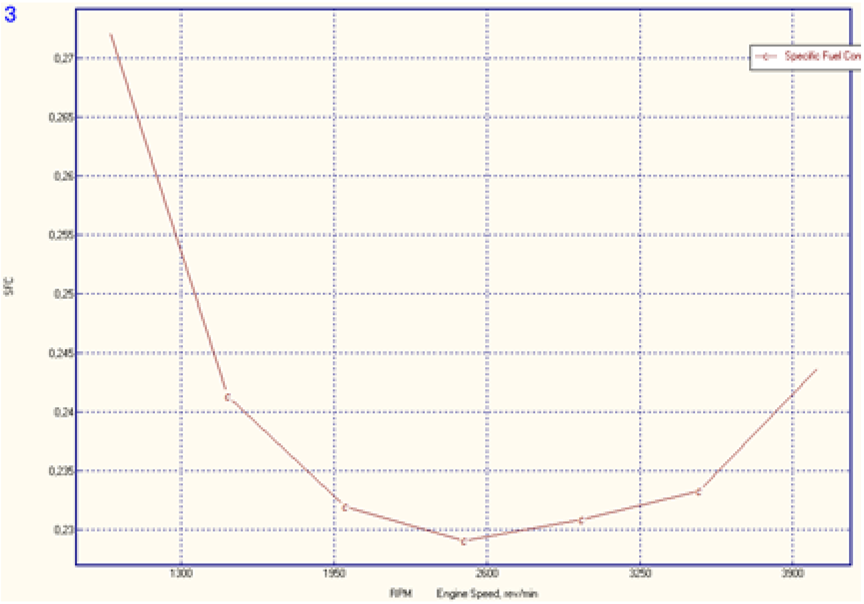


Engine Spee	Brake Torque (Nm)
1000 rpm	140.65
1500 rpm	162.21
2000 rpm	171.40
2500 rpm	173.68
3000 rpm	173.5
3500 rpm	171.82
4000 rpm	156.58

As we can see the higher obtained value of the brake torque is 173.68 Nm at 2500 rpm, it means that is with this engine speed when the maximum torque is produced 173.68 Nm. The best speed work range for the engine is between 1500 and 3000 rpm because is there where the engine produces its higher torque values. The real maximum obtained by ınternet ıs 185 Nm.

Graph 2: Specific Fuel Consumption

In the next graph is represented the evolution of the consumption depending on the value of the engine speed.



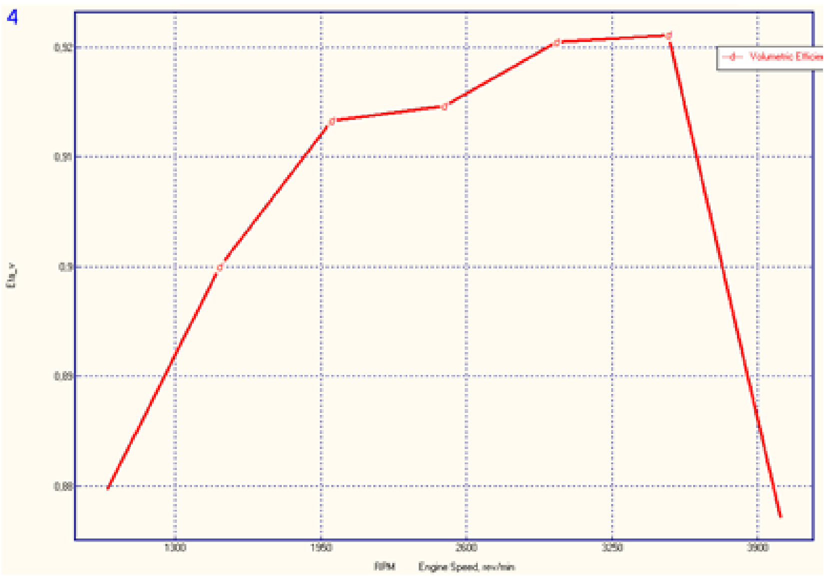
Engine Speed	Specific Fuel Consumption(kg/kWh)
1000 rpm	0.27214
1500 rpm	0.24131
2000 rpm	0.23195
2500 rpm	0.22905
3000 rpm	0.2308
3500 rpm	0.23322
4000 rpm	0.24355

In the graph is shown that when the engine reaches the 3500 rpm point it consumption grows up a lot. This is because in a diesel engine when the revolutions per minute increasesthe consumption of all the fuel gets harder for the engine as the quantity of oxygen for the ignition is lower and the compression gets uncontrolled. The fuel not burnt goes out by the same way as the exhaust gases.

The lowest consumption is obtained when the engine is working between 2000-2500 rpm and checking the graph it can be said that if its speed is between 1500-3000 rpm it will be working efficiently.

Graph 3: Volumetric Efficiency

The volumetric efficiency is defined as the ratio of mass fuel and air drawn in cylinder to its swept volume, it is also explained as the efficiency of the engine to move in and out of the cylinder fuel and air charged.



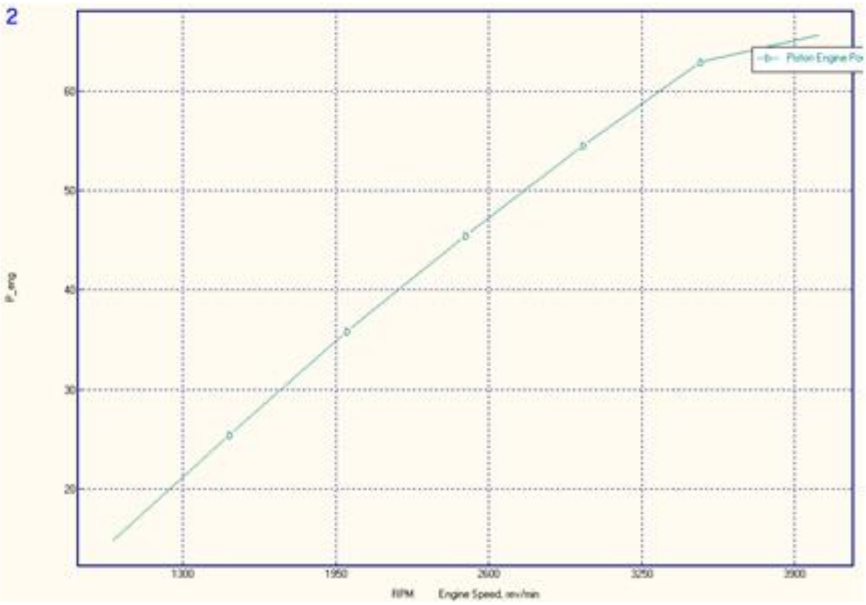
Engine Speed	Volumetric Efficiency
1000 rpm	0.87983
1500 rpm	0.89977
2000 rpm	0.91379
2500 rpm	0.91441
3000 rpm	0.9205
3500 rpm	0.92113
4000 rpm	0.87663

In technical words the volumetric efficiency is the ratio (or percentage) of the mass of air and fuel that during the intake step is taken divided by the mass of air that would occupy the displaced volume in a pressure equal to the one inside the cylinder.

It can be checked on the graph that the higher value of the volumetric efficiency is obtained around a speed of 3000 rpm. It can also be observed that before 1000 rpm and after 3500 rpm the volumetric efficiency value starts to decrease without control, when the volumetric efficiency is lower means that the engine is burning less amount of fuel than the last stroke and it is translated in a lower torque.

Graph 4: Piston Engine Power

The piston engine power is defined as the amount of work that can be done in a specified time. In vehicles having more power is traduced as arranging a higher velocity in a lower period of time.



Engine Speed	Piston Engine Power(kW)
1000 rpm	14.728
1500 rpm	25.478
2000 rpm	35.896
2500 rpm	45.466
3000 rpm	54.503
3500 rpm	62.971
4000 rpm	65.583

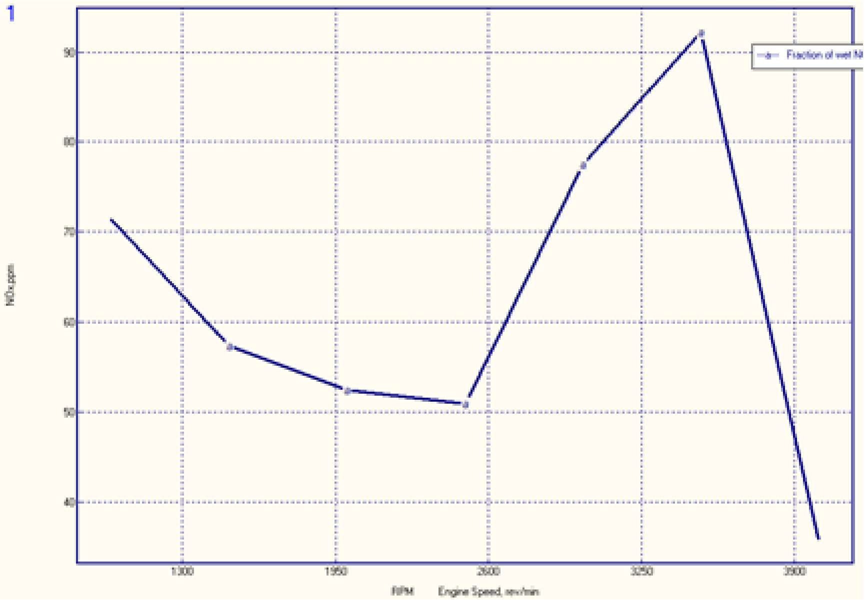
In the graph is clearly showed that the piston engine power is directly related with the engine speed, when the last one reaches its maximum also the power reaches its greater value obtaining 65.583 kW at 4000 rpm.

Until the speed 3500 is reached the engine power increases with a big slope but when this speed is exceed the slope gets lower, so working in with speeds greater than this limit means that the difference between piston engine powers will be invaluable. Looking for the real data of this engine was obtained a theoretıcal value of 55 kW for 3750 rpm.

Graph 5: NOx ppm

In this graph will be shown the emissions of NOx for our engine case, it refers to nitrogen oxides.

It is said that this group is composed by Nitric Oxide (NO) and Nitrogen Dioxide (NO_2)also, but is known that also includes nitrous oxide(N_2O). These emissions are obtained because air is a mixture of nitrogen and oxygen in the most part. When the ignition is produced on the engine there are some areas with enough temperature to produce the oxidation of some nitrogen to NOx gases; the quantity only depends on the volume and duration of the hottest part of the flame.



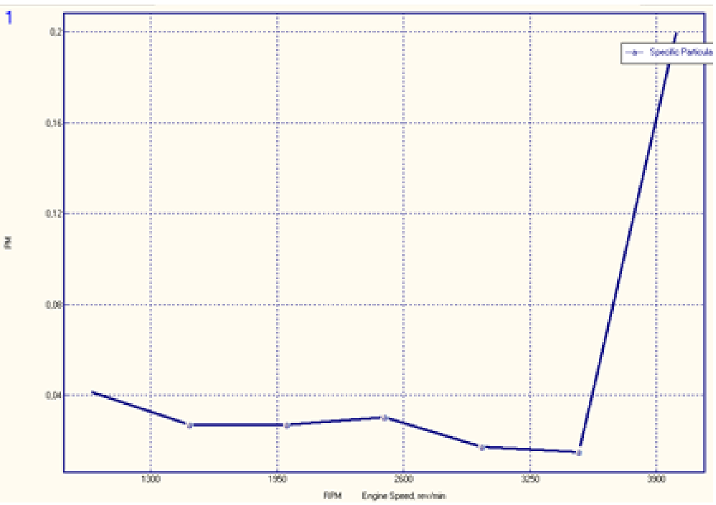
Engine Speed	NOx (ppm)
1000 rpm	71.343
1500 rpm	57.318
2000 rpm	52.738
2500 rpm	50.996
3000 rpm	77.487
3500 rpm	92.167
4000 rpm	36.006

In the graph can be appreciated that the emissions starts in a decline way but reaching 2500 rpm it starts to grew, this is because the hottest temperatures are reached at this speeds.

The greater emissions are obtained at 3500 rpm more or less and then it decreases without control as the engine starts its uncontrolled step

Graph 6: DPM for diesel engines

The most complex of diesel emissions is the Diesel Particulate Matter (DPM). These kinds of emissions are sampled from diluted and cooled exhaust gases in which are includes both solids and liquid material which condenses in the dilution process.



Engine Speed	Specific Particulate Matter (g/kWh)
1000 rpm	0.04165
1500 rpm	0.02728
2000 rpm	0.02728
2500 rpm	0.03054
3000 rpm	0.01754
3500 rpm	0.0158
4000 rpm	0.199

The DPM are mostly composed by carbon, heavy hydrocarbons from the fuel and lubricating oil, and hydrated sulfuric acid derived from the fuel sulfur. Small nuclei mode particles of diameters bellow 0,04µm can be found in diesel particles.

Analyzing the graph is observed that working on higher revolutions means higher emissions, this happen because the emissions are related with the amount of fuel that is wasted without being burnt, when we are working on lower speeds the engine introduce the needed fuel but when it is working with higher speeds and the uncontrolled situation starts, the engine can´t burn the hole injected fuel so a percentage of it is expulsed.

The minimum amount of emission is obtained around 3000 rpm, so if the engine works between 1500 and 3500 revolutions per minute it would be having the lower emissions.

In the graph can be appreciated the start of the uncontrolled situation at 3500 rpm where the graph start to increase until maximums.

ii. The influence of turbocharger and intercooler

In this part is going to be showed and explained the influence of the turbocharger and intercooler, it is going to be simulated the same engine but in this case is not going to be included the intercooler and turbocharger option.

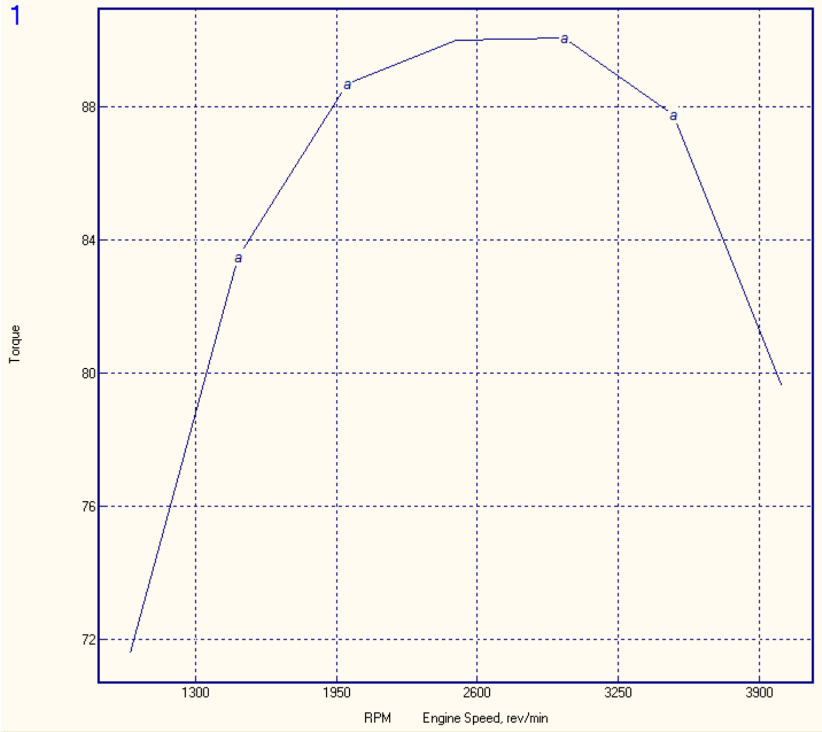
The turbocharger is composed by a turbine and a compressor jointed by the same rotational shaft , it can increase the engine combustion efficiency and also the power delivered by means of forcing some extra amount of air in the combustion chamber. It can be done as the compressor is working with different pressure value than the atmospheric one so the amount of taken fuel/air is higher. This compressor is activated by means of exhaust gases movement.

When the intake air pressure is increased, also temperaturegets higher inside the turbocharger because the thermal transference between exhaust gases activating the compressor and the intake gases. This heating makes gases to reduce it densities so the amount of oxygen per volume unit decreases. This lost of oxygen means a lower volumetric efficiency and engine power because there is less oxygen to the combustion.

The function of the intercooler is reducing the temperature around 60ºC to increase the power and engine volumetric efficiency.

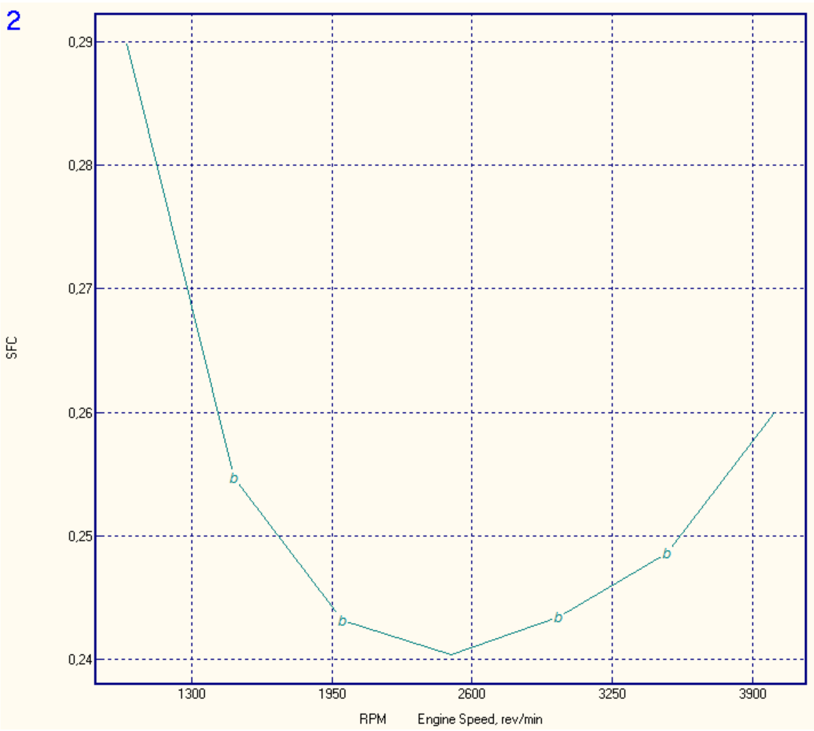
Now the Diesel-RK will be used to simulate a new motor engine with the same data as the previous one but in thiscase without intercooler neither turbocharged, the obtained data will be compared with the obtained for the first engine to see the influence of these elements in each variable.

Graph 1:Brake Torque (Nm)



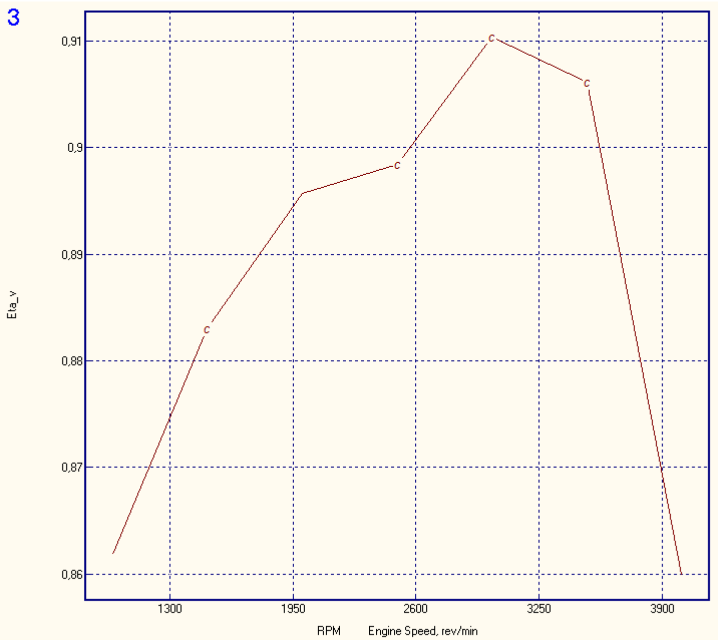
Engine Speed	Brake Torque (Nm)
1000 rpm	71.295
1500 rpm	83.479
2000 rpm	88.705
2500 rpm	90.022
3000 rpm	90.066
3500 rpm	87.827
4000 rpm	79.682

Graph 2: Specific Fuel Consumption



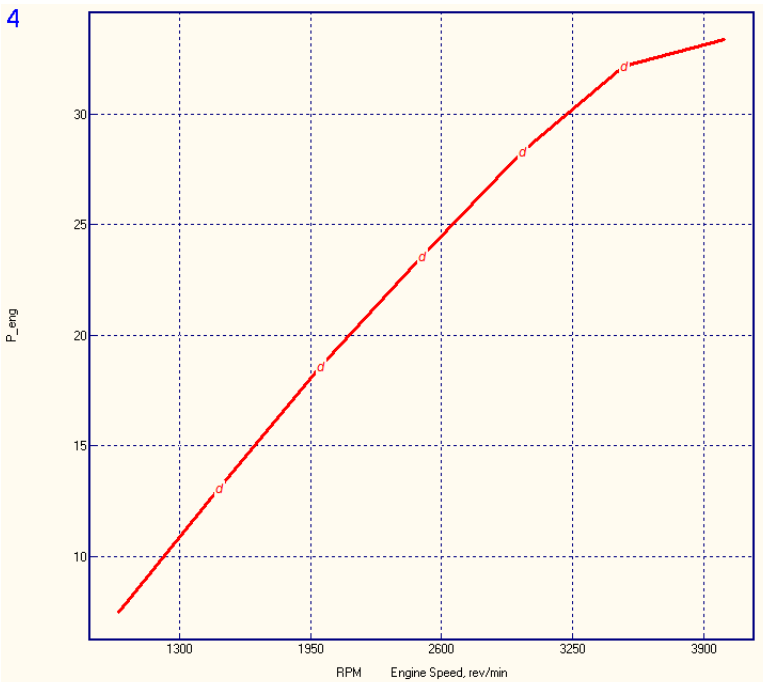
Engine Speed	Specific Fuel Consumption(kg/kWh)
1000 rpm	0.29068
1500 rpm	0.25468
2000 rpm	0.24316
2500 rpm	0.24037
3000 rpm	0.24344
3500 rpm	0.24855
4000 rpm	0.25993

Graph 3: Volumetric efficiency



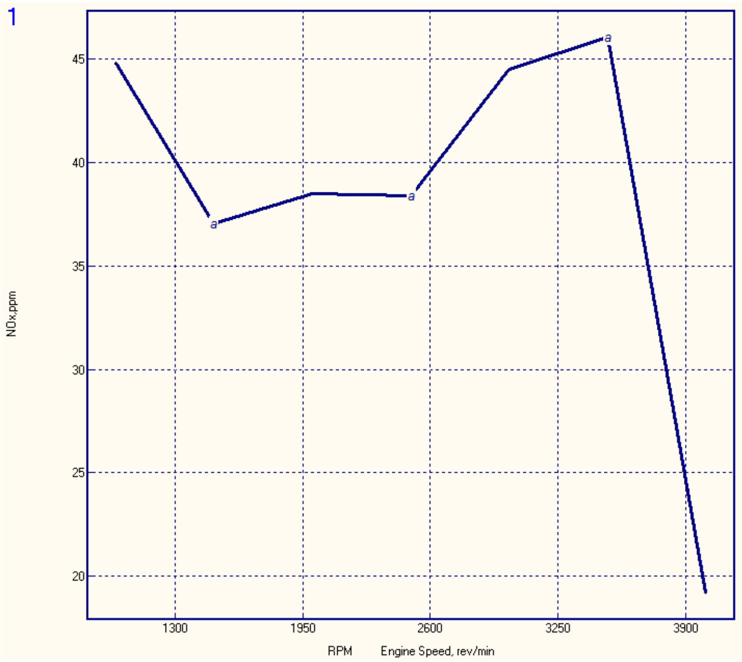
Engine Speed	Volumetric Efficiency
1000 rpm	0.86065
1500 rpm	0.88302
2000 rpm	0.89586
2500 rpm	0.8987
3000 rpm	0.91065
3500 rpm	0.90665
4000 rpm	0.86024

Graph 4: Piston Engine Power



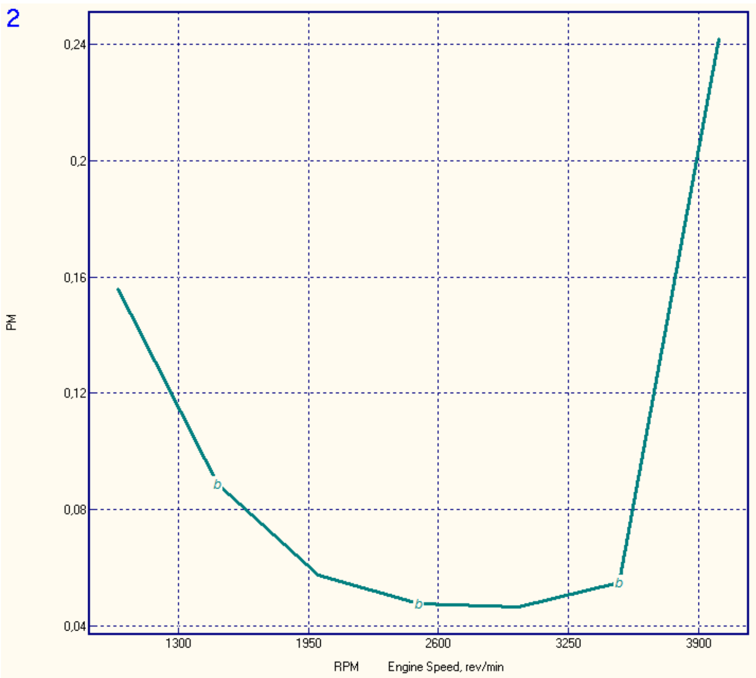
Engine Speed	Piston Engine Power(kW)
1000 rpm	7.465
1500 rpm	13.122
2000 rpm	18.577
2500 rpm	23.566
3000 rpm	28.293
3500 rpm	32.188
4000 rpm	33.375

Graph 5: NOx ppm



Engine Speed	NOx (ppm)
1000 rpm	46.851
1500 rpm	37.101
2000 rpm	38.495
2500 rpm	38.224
3000 rpm	44.455
3500 rpm	45.96
4000 rpm	19.204

Graph 6: DPM of diesel engine



Engine Speed	Specific Particulate Matter (g/kWh)
1000 rpm	0.1489
1500 rpm	0.08861
2000 rpm	0.05727
2500 rpm	0.04762
3000 rpm	0.04651
3500 rpm	0.05450
4000 rpm	0.24206

The easiest way to see the differences between the first engine simulation and the one without turbocharger and intercooler is comparing the obtained numerical values, showed in the next tables.

Eng.Speed	BT(Nm)	BT(Nm)	SFC(kg/kWh)	SFC(kg/kWh)	Vol.Eff	Vol.Eff	PEP(kW)	PEP(kW)	NOx (ppm)	NOx (ppm)	SPM(g/kWh)	SPM(g/kWh)
1000 rpm	140.65	71.295	0.27214	0.29068	0.87983	0.86065	14.728	7.465	71.343	46.851	0.04165	0.1489
1500 rpm	162.21	83.479	0.24131	0.25468	0.89977	0.88302	25.478	13.122	57.318	37.101	0.02728	0.08861
2000 rpm	171.40	88.705	0.23195	0.24316	0.91379	0.89586	35.896	18.577	52.738	38.495	0.02728	0.05727
2500 rpm	173.68	90.022	0.22905	0.24037	0.91441	0.8987	45.466	23.566	50.996	38.224	0.03054	0.04762
3000 rpm	173.5	90.066	0.2308	0.24344	0.9205	0.91065	54.503	28.293	77.487	44.455	0.01754	0.04651
3500 rpm	171.82	87.827	0.23322	0.24855	0.92113	0.90665	62.971	32.188	92.167	45.96	0.0158	0.05450
4000 rpm	156.58	79.682	0.24355	0.25993	0.87663	0.86024	65.583	33.375	36.006	19.204	0.199	0.24206

On the first row of the previous table, on blue, are included the obtained data for the first simulation of the real engine and on red the values for the engine without turbocharged and intercooler. It can be appreciated that the first engine produces more brake torque; it also has less specific fuel consumption, the volumetric efficiency of the engine working without turbocharger is less because it is introducing less amount of air inside the cylinder so the burnt fuel is also less. The piston engine power is reduced to the half more or less quitting the turbocharger and the intercooler and on the last columns are included the emissions of the engines, in case of the particulate matter is the first engine the one that has lower emissionsbut ın case of nitrogen emissions the second engine results are lower than on the first case, this is because as in the first one we are introducing more air means more pressure so higher temperatures and greater NOx emıssıons.

VI. Conclusions

Analyzing the whole project it can be said that if the engine is working between 2000 and 3000 revolutions per minute all the analyzed variables would give good results. The needed of the turbocharger and the intercooler can also be confirmed but in the emissions step it can be said that diesel engines produces less amount of NOx but more specific particulate matter that are worst for people as it are concentrated on the breaths and can create a lot of respiratory diseases.

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