Palestine Polytechnic University

College of Engineering

THE EFFECT OF INJECTING WATER TO THE AIR FUEL MIXTURE IN A SPARK IGNITION ENGINE

By

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الإهداء

إلى من هم أكرم منا جميعا ... الشهداء

إلى من ضحوا بحريتهم من أجل حرية غيرهم .... من علمونا معنا الكرامة .... ألأسرى الكرام

إلى كل من أضاء بعلمه عقل غيره

أو هدى بالجواب الصحيح حيرة سائليه

فأظهر بسماحته تواضع العلماء

وبرحابته سماحة العارفين

إلى ينبوع العطاء الذي زرع في نفسي الطموح والمثابرة ..... والدي العزيز

إلى نبع الحنان الذي لا ينضب .... أمي الغالية

إلى من يحملون في عيونهم ذكريات طفولتي وشبابي ... أخوتي وأخواتي

إلى من ضاقت السطور من ذكرهم فوسعهم قلبي .... أصدقائي

إلى زملائي وزميلاتي في جامعة بوليتكنك فلسطين

إلى كل من ساهم في إنجاح هذا المشروع

الشكر والعرفان

في البداية , الشكر والحمد لله جل في علاه. فإليه ينسب الفضل كله في إكمال هذا العمل والكمال يبقى لله وحده

وبعد الحمد لله , فأنني أتوجه إلى الدكتور ضياء عرفه بالشكر والتقدير الذي لن تفيه أي كلمات حقه فلولا مثابرته ودعمه المستمر ما تم هذا العمل.

وكذلك الدكتور جلال السلايمة على دعمه وإرشاده لنا في مسيرتنا .

وبعدها فالشكر موصول لكل أساتذتي اللذين تتلمذت على أياديهم في كل مراحل دراستي

كما نشكر كل من ساعدنا من قريب أو بعيد ولو بكلمة أو دعوة صادقة من القلب.

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Abstract:

It is known that the development and improvement of the Internal Combustion Engines are rapidly and continuously. The main concerns of the developers are to reduce the fuel consumption as well as to increase engine performance and efficiency. Many methods can be used to achieve these goals such as (Turbo charging, Exhaust Gas Recirculation EGR), But recently another method of injection water into ICE is getting more attraction.

Water injection into the ICE engine can be done by many methods. It may be a spray inside the cylinder or at the intake manifold. These methods lead to cool the combustion chamber, and achieve greater compression ratio and hugely eliminate the problem of Knock “detonation” in the engine. On the other hand, many other benefits will be obtained especially for the environment by reducing the emissions of Carbon Monoxide and Nitrogen Oxides.

In the present study, Water injection system for gasoline engine (SI) will be designed and the water will be injected into the intake manifold. The work will be divided into two stages; the first one is to design the Water Injection System (WIS)while in the second stage the (WIS) will be built and tested by experiments. In the experiments engine operating conditions will be measured with and without (WIS), and then results will be compared to investigate the effect of (WIS).

ملخص المشروع

حقن الماء هي عبارة عن تقنيه يتم فيها إدخال رذاذ الماء داخل غرفه الاحتراق في محرك الاحتراق الداخلي إما عن طريق حقن الماء مباشرة داخل غرفه الاحتراق او عن طريق حقن الماء في مجاري سحب الهواء للمحرك الأمر الذي يؤدي إلى

1-زيادة كفاءة المحرك
2-تقليل انبعاث أول أكسيد الكربون
3-تقليل انبعاث أكسيد النيتروجين
4-تقليل استهلاك الوقود
5-الحد من ظاهره الطرق في المحرك عند ارتفاع درجه حرارة المحرك

حيث يقوم رذاذ الماء بتبريد درجه حرارة غرفه الاحتراق وزيادة الكفاءة ألحجميه للمحرك

الهدف من هذا المشروع هو بناء نظام حقن ماء على محرك بنزين رباعي الأشواط ذات الأربع اسطوانات حيث سيتم حقن الماء في مجاري سحب الهواء للمحرك والتحكم في هذا النظام لإثبات فاعليه حقن رذاذ الماء إلى داخل غرفة الاحتراق على أداء المحرك وأيضا فاعليته في تقليل الانبعاث الناتج منه.

بعد بناء النظام وتشغيله يتم اخذ قراءات فعلية من المحرك لإثبات نجاح النظام حيث سيتم دراسة الغازات العادمة ونسبها عند تشغيل المحرك بدون حقن الماء ومقارنتها على نفس فتحة صمام الخانق مع وجود حقن الماء إضافة إلى مقارنة كفاءة وعزم المحرك في كلتا الحالتين حيث أن جميع الدراسات السابقة أثبتت فاعلية هذا النظام وان بعض الشركات قد أدخلت هذا النظام إلى المركبات التي تقوم بصناعتها فهذا النظام كان له تأثير فعال في محركات الطائرات و المركبات ذات السرعة العالية.

Chapter One (1)
Introduction

1.Introduction

1.1 Internal Combustion Engine

The Internal Combustion Engine (ICE) is an engine where the Combustion occurs in the combustion chamber.

Internal combustion engine (IC-Engines) transfer the chemical energy stored in fuel into mechanical energy by combustion process. The chemical energy is fist converted into thermal energy that leads to pressure rise inside the combustion chamber then the pressure will act on a crack slide mechanism which produce mechanical energy (rotation).

The first internal combustion Engine was built in 1859 by Etienne Lenoir, which was two strokes single cylinder engine. Unfortunately, it was not very powerful because the fuel and the air were not compressed so it did not burn fast enough.

The development of engine was kept going in recent year with the large improvement and modification with modern technology as we looked at modern vehicle now. Some engines are classified as reciprocating or rotary, spark ignition (SI) or compression ignition (CI), and two strokes or four strokes. The most familiar combination, used from automobiles to lawn mowers is the reciprocating, spark ignited, four stroke gasoline engine. Other type of internal combustion engines which could be gas turbine. [1]

1.1.1 Spark Ignition Engine (SI) and Compression Ignition engine (CI)

The term (spark ignition) is due to describes that the Air-fuel mixture inside the combustion chamber of the internal combustion engine is ignited by a spark comes from spark plug that connected into an electrical circuit of a lot of thousands of voltages.

The term (compression ignition) is due to describes that the Air-fuel mixture inside the combustion chamber of the internal combustion engine is ignited as a result of temperature rise that occurs inside the combustion chamber due to the high pressure inside it.

- **Comparison between SI and CI:**

✓ In **SI** engines Petrol or gasoline is used as a fuel. But the fuel used in **CI** is diesel.

✓ The compression ratio is much higher in **CI** than **SI**.

- ✓ The cycle used in **SI engines** is Otto cycle in which the additional heat in this cycle occurs at constant volume, In **CI engines** the cycle used is Diesel cycle in which the additional of heat occurs at constant pressure.
- ✓ In **SI engines**, the mixture of air-fuel is ignited in the head portion of the cylinder. While the Diesel is ignited from the bottom (towards the end stroke) in **CI engines.**
- ✓ The compression ratio of **CI engines** is greater so these engines are much heavier than **SI engines.**
- ✓ Gasoline or petrol is lighter than Diesel and burns more homogeneously so the speed achieved by **SI engines** is more than the speed achieved by **CI engines.**
- ✓ Higher compression ratio in **CI engines** gives it the potential to have better thermal efficiency than **SI engines**.

1.2 History and Background

In the 20^{th} century, the use of internal combustion engines becomes widely. A lot of applications depend on it to produce motive power. These applications include Automobiles, aircrafts, industrial engines and electrical generators. The injection of water date back to the $1930_s$when the manufacturers had to find a solution for engine's Knocking for the aircraft engines at a high power.

The first choice of the manufacturers was to lower the compression ratio to repression the pressure in the cylinder. But, they noticed after that the reduction in compression ratio leads to suppression in thermal efficiency of the cycle. So, water injection was the second choice which solves the problem of knock and keeps the thermal efficiency unchanged. In the world war two, the use of water injection becomes greater especially in the aircrafts which all powered by piston engines.

In cars:

In 1983 Renault started using water injection on their ~550hp turbocharged 1.5-litre F1 engine. The system used a 12-litre tank and a dedicated control unit. An electric pump, pressure regulator and pressure sensor were used. The system was triggered into action when manifold pressure exceeded 2.5 bar (36 psi).

In 1983 Ferrari also adopted water injection on their F1 engines. However, the water was added in a unique manner, being emulsified within the fuel itself before the fuel/water combination was injected.

Up until a few years ago (when it was banned), most World Rally Championship cars used water injection systems.

1.3 **Project importance**

In fact, there are many benefits for the use of water injection system. The main reason is to solve the problem of Knock “detonation” in the engines especially for engines working at high compression ratio and also to get more efficiency and fuel economy which leads to greater output power obtained.

Another benefit represents in cooling the engine, while the water has a very high vaporization temperature, the water injected into the intake of air-fuel mixture at temperature near to ambient then the heat is transferred from the hot cylinder into the water makes it to evaporate and then cooling the intake charge which makes it more volumetric efficient and reduce possibility to knock.

After a lot of experiments done by big known companies as said before, many environmental benefits were also discovered and represented in the reduction of NOx, CO_2 and soot emissions. So, this project is important in two ways, the first one is to develop performance and efficiency of the SIE. The second one is to reduce the harmful emissions in the environments.

As a result, the advantages of water injection system can be illustrated as follow:

- ✓ Water injection leads to reduction in NOx emissions
- ✓ Water injection leads to reduction in CO emissions
- ✓ Water addition leads to better output power and total efficiency
- ✓ Water injection gives good cooling for the engine which allows higher octane rating.
- ✓ Higher octane rate allows higher compression ratio

- ❖ **The main <u>disadvantage</u> of water injection system is the increasing of hydrocarbons (HC) emissions**

1.4 **Why this project?**

There are many reasons motivated the researchers to choose this project. The first important one is to develop engines (its performance and efficiency) and the second one is to solve the environmental problems from emissions that flow out the typical petrol engines (engines without water injection system).Also, Due to the rapid increasing in the petrol price in world, the developing in engine efficiency and performance leads to solving another problem which is economic one. So, the challenge is to solve these problems by using Water Injection System.

1.5 The aim of project

In this work, there are many goals that must be achieved. First of all is building the Water Injection System. After of that, many practical experiments on the system will be done to insure that the job attains the aims of project. Which are the improvement on the engine efficiency and its performance. Then, it is necessary to check the amount of NOx and CO emissions in the outlet port of the engine to insure that they are lower than usual in typical engines.

1.6 Budget and cost of the project

The cost of the project is shown in the following table as we detailed each part with its price.

Table 1.1: The estimated budget of the project

Project parts	Cost,(USD)($)
1- Petrol engine	300
2- Cooling	50
3- Spark plugs	20
4- Control unit	100
5- Battery	100
6- Frame materials	300
7- Water pumps	100
8- Injectors	100
9- Pipes and connections	90
10- Miscellaneous	150
Total cost	**1310**

1.7 Time Table for the first semester:

We have divided the duties among the semester as shown in the following table

.

Week number / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
abstract	x	x														
introduction			x	x	x	x										
Literature review							x	x	x	x	x	x				
System design												x	x	x	x	x

1.8 Time table for second semester

The hard work of the project were achieved as follow:

Week number / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Frame structure	x	x	x	x	x	x										
Engine configuration	x	x	x	x	x	x	x	x								
First WIS						x	x	x	x	x						
Second WIS											x	x	x			
testing														x	x	
analysis															x	x
conclusion																x

Chapter Two (2)
Literature review

2. Literature review

The use of water injection system in internal combustion engine is not new; it backs to the beginnings of the 20th century. Many researchers and engineers made a lot of studies in this field to improve the performance and efficiency of the engines.

2.1 History of water injection system

The first people used the (WIS) were Germans in the world war two. At that time, the Germans had a big problem because they didn't have a fuel with enough high octane number for their aviation which was 87 compared with octane number that allied had which were 100. The Germans tried to solve this problem by putting largest engine in smallest possible airframe. In the first part of the war, this gave them a similar performance compared with British have. But this had many disadvantages and problems present in the small plane couldn't hold a lot of fuel and the engine itself consume a lot of fuel?

Two years after, Germans had 96 octane's number, but the Allies still more advanced with octane fuel 130 and 150 which was a big difference between them!

The Germans were desperate, but they still trying to solve the problem. The most successful solution was the using of water or water/methanol injection. This method enabled them to add enough boost to get their engines from 1455 to 1973 horsepower.

The following Figure (2.1) is for The 109's engine, the DB605. It a 35.7 liter inverted V-12 with a supercharger, water injection, 4 valves per cylinder, and fuel injection. Notice the unusual placement of the supercharger. The Germans loved to drive superchargers at a 90 degree angle to the crankshaft, but that's a story for another time.

Figure(2.1): 109 engine with water injection system [1]

2.2 Water injection system development along the history

LEONARD C. NELSON 1949[1], made his own trying using 1949 automotive engine with 6 cylinders, 6.8-1 compression ratio, $\mathbf{3\frac{1}{4} * 4}$-3/8 bore and stroke, valve-in-block as head design and 91 rated power at 3800 rpm. This engine is shown in the following figure (2.2).

The engine was directly connected to dynamometer, and a scaled beam was used to measure the force exerted into the stator of the dynamometer. Also, there was an electrical tachometer used to measure rpm. The horsepower calculated as follow [2]:

B.H.P = KFN…………………………………………………………………[1.1]

B.H.P is Brake Horse Power

K is dynamometer constant = 1/3000

F is the measured force

N is the rpm

Figure(2.2): water injection system 1949 [2]

A balanced scale connected to revolution counter was used to measure fuel consumed. The revolution counter measure the number of revolutions needed to burn one pound of fuel then the following equation used to calculate brake specific fuel consumption [2].

$$\boldsymbol{B.S.F.C} = \frac{K'}{F*R} \ldots\ldots\ldots\ldots\ldots [1.2]$$

B.S.F.C is brake specific fuel consumption

K' is weighing device constant = 180,000

F is force on the scale

R is number of revolutions

The water injection system used was a commercial device. It was to inject water into the engine and it was placed between the intake air strainer and the carburetor.

The main results <u>NELSON</u> obtained are summarized as follow:

- The increasing of output power and efficiency of the engine can be realized if the octane rating is high enough to allow the spark to be advanced.

- The effects of water injection on the operation of a spark ignition engine are mainly due to the coolant properties *o*f the water.

- The lead acts chemically with the fuel to change the self-ignition temperature by the water which acts as a coolant lowers the temperature of the combustion chamber then self-ignition temperature is not reached.

- For best results of water injection system the fuel used should have octane rating lower than required by the engine.

- The mixture used has to be at best power ration of fuel and air.

Ricardo, 1953 [3], his test was at motor vehicle. The results of his experiments showed that water injection system represents a real method to avoid detonation and reduction in NOx emissions.

Nicholls [4], worked on finding the method to control NOx by using water-fuel emulsion emission. It was found that 10% water in gasoline caused10-20%reductions in nitrogen oxides.

For performance analysis was described by Tsao [5], he described that the power output was increased in the order of 3.8% to 14% when the based fuel containing 5% to 15% water was used by these preliminary performance data conducted with a single cylinder engine.

From German research, Tschalamoff and Laab [6],had reported the effects of water presence in fuel on SI engines. They indicated that the NOx content in the exhaust gas dropped by 1.3 % for 1 % additional of water to emulsified fuel.

Water injection effects in a single cylinder CFR engine was described by Lanzafame [7]. His results had shown that Nitrogen oxide (NOx) reductions of over 50% with water injection/fuel ratio in the range of 1 to 1.25.

PARAMUST JUNTARAKOD 2008 [8], used the following engine specifications in his study.

Table 2.1: engine specifications

Engine bore (m)	0.1
Engine stroke (m)	0.08
Half stroke to rod ratio (s/2l)	0.25
Start of burning angle (θ_S)	-35 (BTDC)

Burn duration angle (Burn timing) (θ	60
Engine surface temperature (K)	420
Piston blow-by constant (s^{-1})	0.8
Residual fraction	0.1
Start of compression angle	-pi (BDC)
Initial pressure (Pa)	100000
Initial temperature (K)	350
Initial volume	V_{BDC}
Fuel type	Gasoline
Air data	JANAF

The main results of this work:

- The pressure increasing rate with the molar water injection-fuel ratio and water injection duration angle increases gradually.
- The temperature decreasing rate with the molar water injection-fuel ratio and water injection duration angle increases significantly as expected.
- The indicated mean effective pressure (IMEP) and thermal efficiency (η) increased as the molar water injection-fuel ratio increased.
- water injection duration angle increased by 10-30 CAs

J. Parley Wilson 2011[9], A single cylinder, four stroke, gasoline, spark ignition engine was modified to test the effects of water injection in combination with an increased compression ratio in an engine. Three air/fuel ratios (13.7, 14.7 and 15.7), six water/fuel mass ratios (from 0 to .75) and two different compression ratios (6:1 and 7:1) were tested. It was found that water injection in combination with an increased compression ratio can increase torque output (up to 65%), reduce brake specific fuel consumption (up to 39%), lower exhaust temperature (up to 10%), lower BSNO emissions (by up to 78%) and lower BSCO emissions (by up to78%) but may increase BSHC emissions (up to 45%).

Torque, BSFC, exhaust temperature, as well as emission levels of NO, CO and HC were collected and reported.

Results:

Water injection may increase the torque output of the engine in multiple ways: by reducing compression work, by increasing the work done during the power stroke, by reducing temperature which reduces heat loss, and by increasing the burn rate. Increased compression ratio also increases torque. [9]

Water injection may reduce compression work and increase work out. When the water is injected into the intake manifold and drawn into the engine it is still a liquid, though it is in very small droplets. When the air-fuel-water mixture (the charge) is compressed, its temperature increases. However, the water droplets absorb some of this heat and are evaporated. Because some of the heat produced by compression goes to heating and evaporating the water, the charge is cooler and the pressure the charge reaches is reduced. This reduced pressure during the compression stroke reduces the work the engine must do to compress the charge. Steam expands more than air when heated. Thus, when heat is released in the charge during combustion the increase in pressure is greater due to the water vapor in the charge. The difference in pressure during the compression stroke and the power stroke is greater, which increases the torque and power output of the engine [9].

The purpose of the present study was to show the trends of multiple important effects of water injection in combination with an increased compression ratio in a gasoline SI engine. The engine was modified to have manifold fuel injection and manifold water injection. Water/fuel mass ratio was varied between 0 and 0.75. Compression ratio was varied from 6:1 to 7:1. Testing was done at three air/fuel ratios. Based on the experimental data it is concluded that water injection may: [9]

- ✓ Increase the torque and power output of the engine
- ✓ Decrease brake specific fuel consumption and thus improve efficiency
- ✓ Reduce exhaust temperature of the engine
- ✓ Lower NO emissions
- ✓ Lower CO emissions, at rich and stoichiometric conditions
- ✓ Increase HC emissions

It is also concluded that increasing the compression ratio may:

- ➢ Increase the torque and power output of the engine
- ➢ Decrease brake specific fuel consumption and thus improve efficiency
- ➢ Reduce exhaust temperature of the engine
- ➢ Increase NO emissions
- ➢ Increase CO emissions, at rich conditions

➢ Have an inconclusive effect on HC emissions

Furthermore it is concluded that water injection in combination with an increase in compression ratio may result in the follow benefits "Increase in the torque (and power output) of the engine, (up to 65%)". [9]

The following figures **(2.3, 2.4, and 2.5)** show the comparison between corrected torques versus water-fuel mass ratio at Lean mixture (0.94ϕ), Stoichiometric (1.0ϕ), and Rich mixture (1.07ϕ).

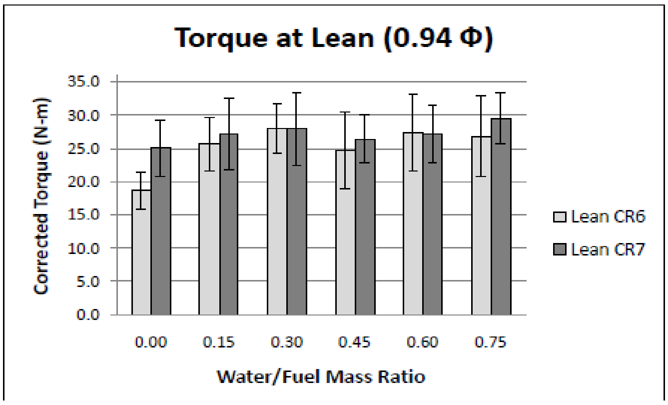
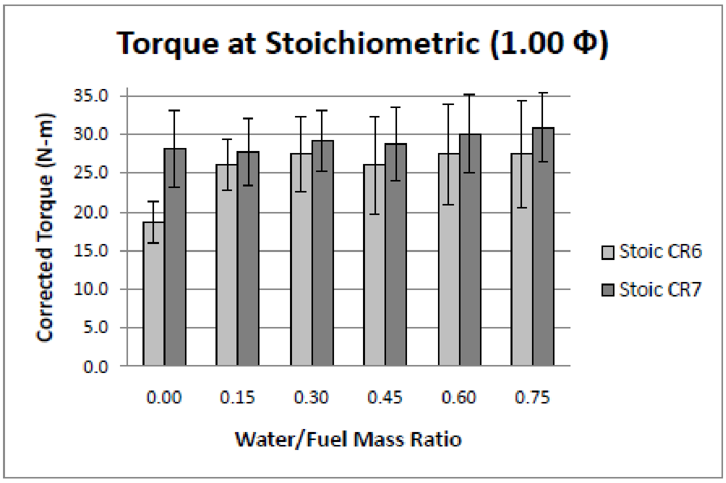
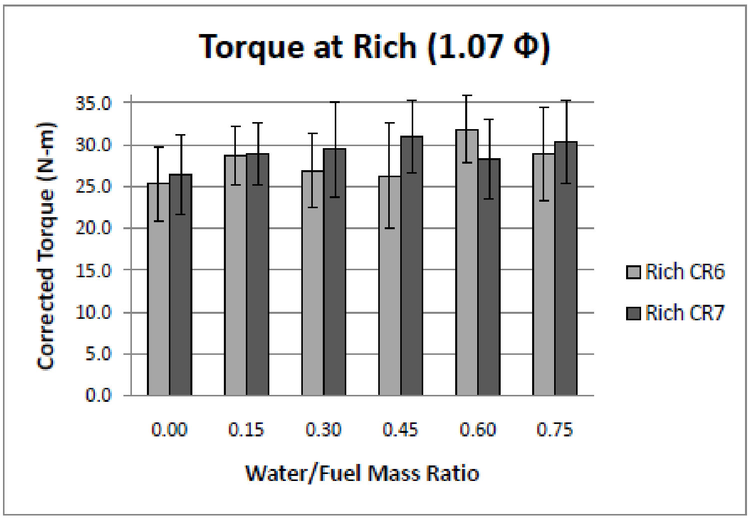


Figure (2.3): Torque at lean mixture condition [9]



Figure(2.4): Torque at Stoichiometric conditions [9]



Figure(2.5): Torque at Rich conditions [9]

- ✓ Decrease in brake specific fuel consumption (up to 39%) and thus improve efficiency
- ✓ Reduction of exhaust temperature of the engine (up to 10%)
- ✓ Lower NO emissions (up to 78%)

Lower CO emissions, at rich and stoichiometric conditions (up to 89%)
However, there is also a detriment to water addition in combination with an increase in compression ratio:

Increase in HC emissions (up to 45%)

It is concluded that water injection in combination with an increase in compression ratio may represents a means to significantly improve the torque, decrease BSFC, reduce temperature, lower NO and CO emissions, while increasing HC emissions. Note that emissions are prior to a catalytic converter. Naturally, in order to gain the greatest benefit of water injection with an increase in compression ratio, the engine would require some fine tuning. For a mobile use of this engine, it is recommended to use a 0.15 WFR and a 7:1 compression ratio and lean operating conditions. This amount of water would not significantly increase the mass of the vehicle, but provides significant improvement in torque and BSFC, less NO, already low CO and marginal increase in HC. Fine tuning would allow for the overall benefit of water injection with an increase in compression ratio to be maximized. [9]

Jaeheun Kim, Hyunwook Park 2015 [10],studied the Effects of water direct injection on the torque enhancement and fuel consumption reduction of a gasoline engine under high-load conditions and they did their job using: Water which was directly injected into the cylinder with an injection pressure of 5 MPa to investigate its effect on engine performance and emissions in a gasoline engine.

The test engine was a 1.6-L naturally aspirated prototype engine consisted of water direct injection and port fuel injection systems. The engine featured a compression ratio of 13.5. Commercial gasoline direct injection injectors were used to inject the water.

The water was injected at a fixed timing of −120 crank angle degrees after top dead center. The addition of water showed potential to mitigate the knock occurrence at part-load condition where the knock initially started to occur due to the high compression ratio. It allowed a further advance of spark timing; thus, the brake-specific fuel consumption was improved. The effects of water injection were further investigated under full-load condition within the engine speed range of 1500–3000 r/min.

The water effectively reduced the in-cylinder temperature and the exhaust gas temperature; therefore, charge cooling through over-fueling (fuel enrichment) was eliminated with reduced brake-specific fuel consumption. Increase in the injected water mass resulted in further spark advance without the knock occurrence and provided room for further brake-specific fuel consumption reduction.

An optimum water mass existed because too much water deteriorated the combustion efficiency, burn duration, and cycle efficiency. The positive effects of water injection were dulled with increased engine speed because the knocking resistance was already high intrinsically with the higher engine speed.

2.2.10 K Pradeep and G. Radha Krishna 2016[11], they used an electrical fuel injector which was consists of pump, microcontroller, tank, engine and fuel injector. Each device had a certain function as follow:

- The microcontroller unit was to setting the fuel injection period.
- The fuel pump was to suction the fuel into the injector from the tank.
- The fuel injector was to inject the fuel into the cylinder

The researchers made a comparison experiments between normal petrol engine and petrol engine with water injection system and they took many readings and calculations then put them in tables as follow:

Table 2.2: Readings for engine without WIS [11]

Speed	Time	Mass flow rate of fuel	BP	FP	IP	Mechanical efficiency	B_{the}	I_{the}	BSFC	ISFC	Heat flow rate
RPM	Sec	kg/sec	Kw	kW	kW	%	%	%	kg/kW -h	kg/kW -h	kW
3000	115	0.000125	1.21	1.2	2.41	50.3	20.21	40.25	0.37	0.186	0.068
3500	104	0.000138	1.42	1.2	2.62	54.19	21.37	39.55	0.35	0.19	0.075
4000	99	0.000145	1.62	1.2	2.82	57.49	23.25	40.56	0.32	0.185	0.079
4500	91	0.000158	1.82	1.2	3.02	60.26	23.96	39.77	0.31	0.188	0.086
5000	78	0.000185	2.04	1.2	3.24	62.96	23.02	36.56	0.32	0.205	0.099

Table 2.3: Readings for engine with WIS [11]

Speed	Time	Mass flow rate of fuel	BP	FP	IP	Mechanical efficiency	B_{the}	I_{the}	BSFC	ISFC	Heat flow rate
RPM	Sec	kg/sec	kW	kW	kW	%	%	%	kg/kW -h	kg/k-Wh	kW
3000	140	0.000102	1.21	0.9	2.11	57.34	24.52	42.76	0.30	0.175	0.055
3500	132	0.000109	1.42	0.9	2.32	61.20	27.14	44.34	0.27	0.169	0.058
4000	125	0.000115	1.62	0.9	2.52	64.28	29.29	45.57	0.256	0.164	0.063
4500	117	0.000123	1.82	0.9	2.72	66.91	30.82	46.07	0.24	0.162	0.066
5000	103	0.000139	2.04	0.9	2.94	69.38	30.57	44.06	0.24	0.170	0.072

The following charts explain the previous tables and the differences between the two engines in engine efficiencies and BSFC:

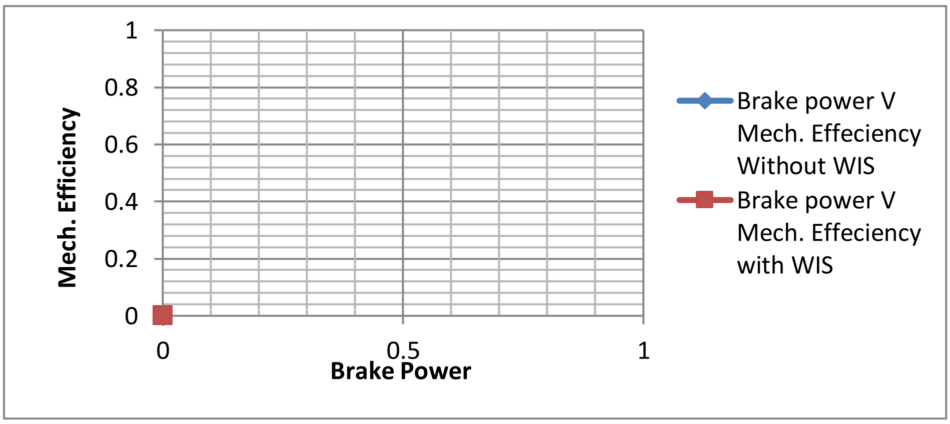


Figure (2.6): BP Vs Mech. Eff. of engine with WIS and without WIS.

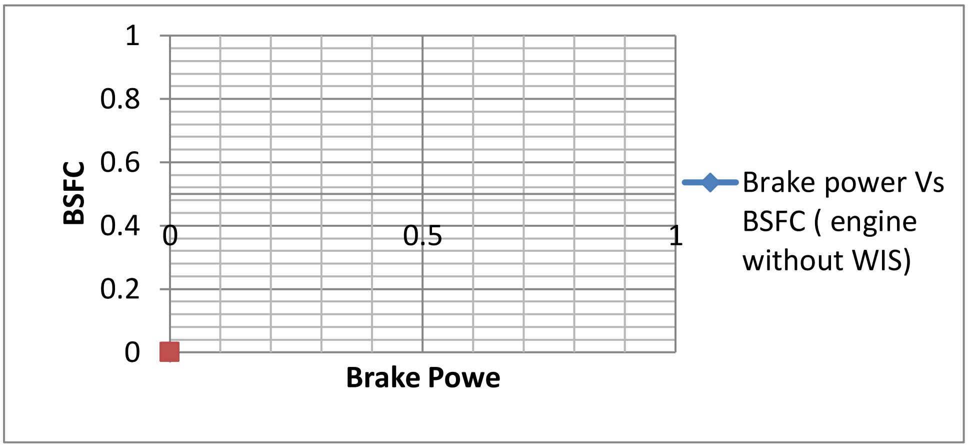


Figure (2.7): Brake power Vs BSFC

2.3 Conclusion and Discussion

After all these studies and experiments during this long time on water injection system especially in spark ignition engines any one can consider that this system is great discover not for anything but because it solved a lot of problems that is relative to the engine itself (its performance, efficiency, increasing of air-fuel ratio and octane rating) and also the environment benefits that can be illustrated in the reduction of NOx and CO emissions and output temperature.

In fact, these advantages of water injection system lead to other benefits, for example higher compression ratio gives a higher torque which results in higher output power obtained in addition to reduce brake specific fuel consumption. And also the reduction in brake fuel consumption leads to better engine efficiency.

Chapter Three (3)
System Design

3. Proposed System Design

3.1 System setup

Water injection system consists of many important components which works together to achieve the purpose of using this system.

The main components of the system are:

a) Water tank
b) Water Pump
c) Water injector
d) Pipe Fittings
e) Rail
f) Water Filter

g) Check valve between the tank and the pump

Figure (3.1) shows the block diagram of the system parts as they will be connected together.

b

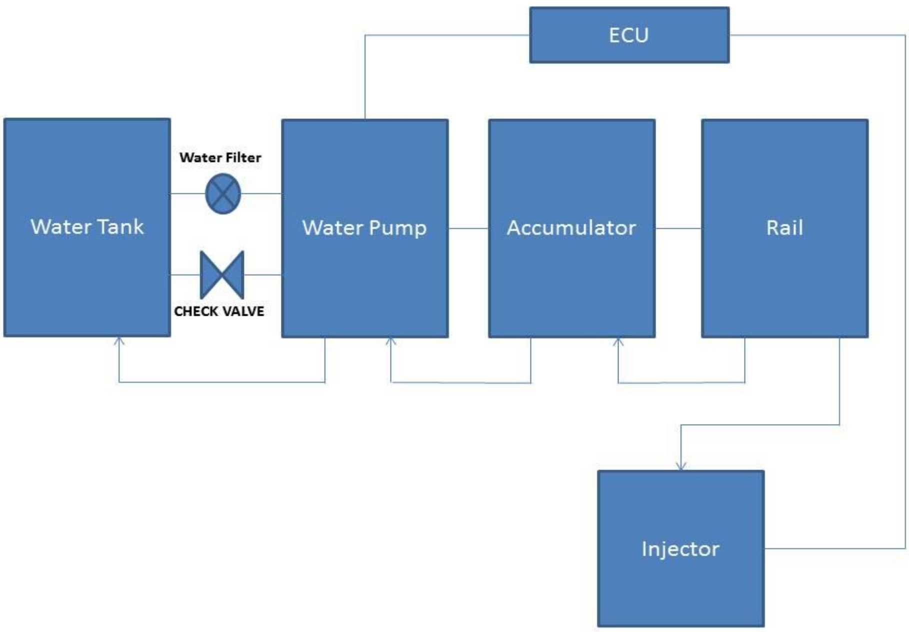


Figure (3.1): WIS Block Diagram

Water tank will be filled with water that will be delivered into the intake manifold by pump and then the water will be injected in the manifold by the injector.

The present study will inject water at the intake manifold as shown in figure (3.2).

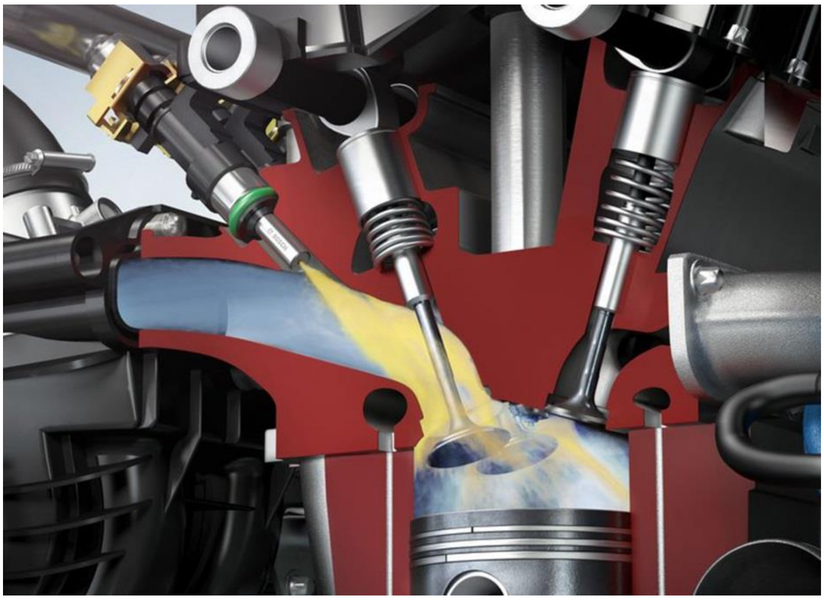


Figure (3.2): Intake manifold WIS.[12]

The main components of WIS are explained in the following subsections:

3.1.1 Water tank

It is a device like fuel tank. The water tank must be anti-corrosion, (so it has to be galvanized metal or made of plastic). The tank contains amount of water inside which is may be opened to the atmosphere or sometimes be pressurized. It is directly connected to the water pump. Figure (3.3) shows an example of water tank that may be used in the system.

Water tank specifications:

1. 4.2 gallon
2. Made of cross linked polyethylene that is suitable for water usage.
3. 8 inches round with 20 inches long
4. Steel chrome plated brackets with mounting hardware and rubber bushings

Figure (3.3): water tank [13]

3.1.2 Water Filter

The main function of the water filter is to clean the water from micro-particles so that increasing the water pump life and prevent it from clogging or damaging. The filter is connected between the water tank and the water pump. Figure (3.4) shows the filter which will be used in this study.

Filter specifications:

1. It filters particulates as small as 40 microns
2. Polypropylene housing.
3. Stainless steel mesh strainer
4. Large filtering area (long service life without reduce the flow)

Figure (3.4): Water Filter [14]

3.1.3 Water pump

The main function of the water pump is to pressurize the filtered water and provide it to the accumulator.

In fact, the water injection pump is the heart of the system and there are two types of water pumps.

a) Mechanical Pumps
b) Electrical Pumps

In this study, an electrical pump will be used as shown in figure (3.5).

With the following specifications:

a) Pressurized Up to 200 psi
b) 12 Volts DC
c) Flow rate up to 2 GPM
d) Recirculation style-pump
e) AEM brand

Figure (3.5): Water Pump [15]

The reason of choosing this type is the higher pressure (about 5 bar or more) that electrical pumps can provide compared with mechanical type. The higher pressure gives more distribution of the water inside the manifold and leads to better spray out of the injector.

The location of the water pump will be close to the intake manifold depending on the engine component space available.

3.1.4 Accumulator

The main function of the accumulator in the water injection system is to maintain full operating pressure. But also, the use of accumulator is useful to increase the life of the water pump if it acts as a buffer. Figure (3.6) shows the Accumulator that will be used in this study.

Accumulator specifications:

1. Maximum working pressure (125 Psi or 25 bar)
2. Pre-charged pressure (30 psi)
3. Total volume (24 oz or 709 ml)
4. Temperature range (1-49 C°)
5. Diameter 3 3/4" [95 mm]

Figure (3.6): Accumulator [16]

3.1.5 Water injector

The water injector is a part of water injection system. It controls the water flow, velocity and spray by means of a needle lift mechanism in the injector that operates electrically.

The water injector is mounted on the intake manifold and close to the cylinder ports. The main parameters in the injector include its internal balance, spray angle and uniformity of spray. Figure (3.7) shows the injector (solenoid valve injector) that will be used in this study.

Injector specifications:

The injector specifications depend mainly on the flow rate of spray water and also about the pressure.

The mass flow rate of the water depends on the mass flow rate of the air entered to the cylinders.

Figure (3.7): Water Injector [17]

3.1.6 Pipe Fittings

The connection system (pipe fittings) means the pipes used to connect the parts of the system with each other in order to make the system work. These pipes can be galvanized metal or plastic as shown in figure (3.8) to avoid corrosion and make it easy to connect without the need of cutting or using welding. In the present project the pipe fittings will be used between Tank, filter, pump, accumulator and injectors.

a) Metal Pipe b) Flexible plastic Pipe

Figure (3.8): Pipe Fittings [18]

3.1.7 Rail

The main function of the rail is to provide high pressure injection to the injector. The rail will be used in this work depends on the number of fuel injectors which will be equals to the number of water injectors. Figure (3.9) shows 4-injectors common rail.

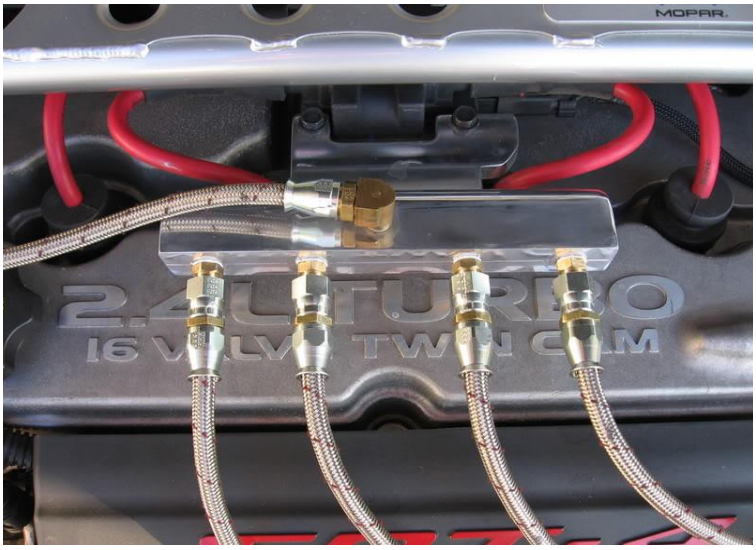


Figure (3.9): Common Rail 4-injectors [19]

3.1.8 Check Valve

The main function of the check valve is to prevent water to drain from the tank into the pump while the pump is OFF.

The check valve is a device that opens in one direction (one-way valve) and needs very high pressure to work. So, it is very useful in this system because we can insure that the valve will not be opened when the pump is off.

The location of the check valve is between the water tank and the water pump.

3.1.9 Water Injectors Locations

The location of the nozzle is very important to prevent the engine from damage that can be occurred if the nozzle is located at any wrong place. Figure (3.10) shows the most common locations of the nozzle and the best place [15] which is place number 7 as will be used in this project, the description of each location is given below:

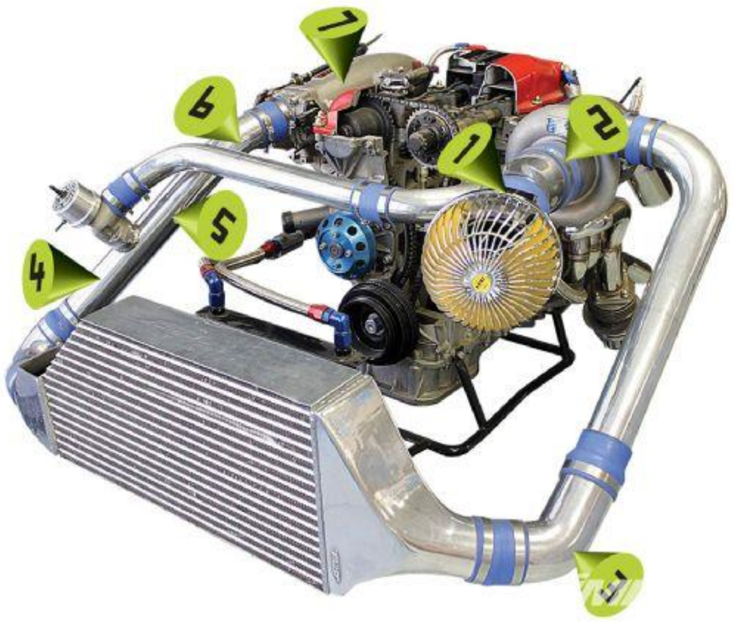


Fig (6): Nozzle locations

Figure (3.10): Water Injector Locations [15]

1. MAF Sensor

The injector must not be placed in front of the Mass Air-Flow sensor (MAF). Injecting water through the MAF sensor will likely cause it to short out.

2. Pre-Turbo

locating the injector in front of the turbo chemically alters the turbo compressor map, causing a change in the engine's air/fuel ratios. Injecting water directly into the turbo can also damage the compressor blade.

3. Pre-Intercooler

installing the injector before the intercooler might seem like the perfect location to aid in pre-cooling, but it does have its drawbacks. If the injector doesn't emit a fine enough mist, water can condense and collect in the bottom of an intercooler core. In colder climates, the overcooling effect can cause the water to freeze inside an intercooler, causing a blockage of airflow. On the other side, hot air from the turbo can prematurely vaporize the water by the time it reaches the intake, rendering the system ineffective.

4. Post-Intercooler

Most water installers prefer placing the injector before the intake air temperature (IAT) sensor typically found on newer vehicles. IAT sensors monitor the temperature of air going into an engine, and can automatically advance ignition timing and lean out air/fuel ratios due to cooler intake temps of water injection. This cause-and-effect scenario can create more horsepower, but may also damage an engine. Another problem we found was placing the injector before the blow-off valve, which causes an unwanted release of water vapors at throttle let-off.

5. Charge Pipe

placing the injector as far from the cylinders as possible on the intake charge pipe allows for the water to be better absorbed into the intake air charge. This allows for greater distribution into to each cylinder, creating the coolest possible air charge.

6. Throttle Body

The most common location to place the injector three to six inches from the throttle body. The injector should spray directly into the throttle body and should never be placed right before a tight-radius bend. Positioning the injector directly in front of an angled pipe can cause the liquid to adhere to the walls of the pipe before dribbling ineffectively into the intake manifold.

7. Intake manifold

Installing water injectors into each intake runner will deliver equal amounts of water to each cylinder. The only downside to installing the injectors into the manifold is the additional labor and parts costs.

3.2 System operation

Water Injection System like any other systems has determinants and signals to operate. Not only to get the maximum possible benefits of the system but also to avoid its damage or harmful effects that may be caused if the system operates in wrong time or condition. So, the water injection system must operate whenever there is need for that.

In this study, the indicative signal for WIS to start is when the engine is in worm up. And that means that the temperature of the engine is in the range of [85-105 C°]. This temperature is obtained from coolant temperature sensor.

This temperature is obtained from coolant temperature sensor. Figure (3.11) shows the flow chart of WIS operation.

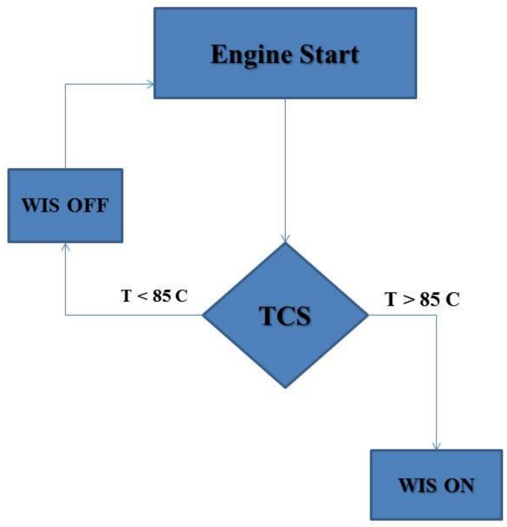


Figure (3.11): Logic Operation Algorithm

So, the state transition of the system can be shows in Figure (3.12) as follow:

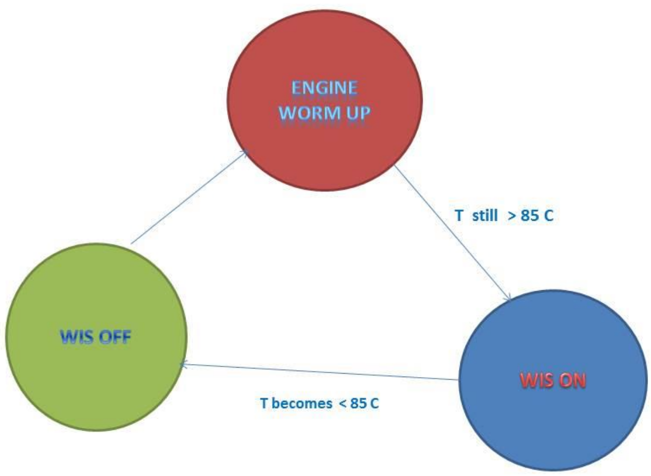


Figure (3.12): State Transition

That means, if the engine is already worm up (its temperature is more than 85 C) then the Water injection system will operate and keeps running till the temperature becomes lower than 85 C, then the WIS will be OFF.

The operation of the Water Injection System must be controlled in order to give its benefits and run correctly, the system control is described below.

3.3 System Control

The water injection pump (the modified pump) is fitted to the engine block. This pump takes the rotation motion from the pulley fitted on the crank shaft by using timing belt.

The pump is supplied with water from water tank to the inlet port of water pump. The outlet port is the water pressure line that is connected to the injector

If temperature of the engine is under the warm up temperature the clutch will not engage the pulley that is rotates freely. At time when engine temperature reaches warm up the clutch will engage and transmit the rotation motion into the pump and it will works and pumping the pressurized water to the injector.

The pump takes its rotational motion from the engine and its flow rate depends on the number of cycle. So, as a result any increasing at engine speed causes an increasing in the pump water flaw rate. This flow rate is controlled by water air ratio. And the injector works by tapping the fuel injector.

Chapter Four (4)

Experimental work

5. Experimental work

4.1 Testing frame

The frame of the project is one of the important parts on which the project will be built. The engine, its cooling system, wiring, control units and water and fuel tanks will be installed on it.

- ✓ Initially it was in the work of a engine base which included the lower part of the project and the engine was installed on it

- ✓ The second step was to install the engine's cooling system
- ✓ The frame was then completed and the exhaust barrel was installed and the place of the fuel and water tanks was placed and the space containing the control units
- ✓ After the frame was ready, all the components on it were removed and processed for the paint process and then re-assembled.

4.1.1 Engine

Table 4.1 shows the specifications of the engine which has been used in the experiments. The building of engine test rig is described below:

Table 4.1 Engine Specifications

Engine Specifications	
Engine type	Naturally Aspirated Petrol
Engine manufacturer	**Mitsubishi**
Engine code	4G18
Cylinders	**Straight 4**
Capacity	1.6 liter **1584 cc** (96.662 cu in)
Bore × Stroke	76 × 87.3 mm 2.99 × 3.44 in
Bore/stroke ratio	0.87

Valve gear	**single overhead camshaft** (SOHC) 4 valves per cylinder 16 valves in total
maximum power output	**97 PS (96 bhp) (72 kW)** at 5000 rpm
Specific output	60.6 bhp/liter 0.99 bhp/cu in
maximum torque	**150 Nm (111 ft.lb) (15.3 kg.m)** at 4000 rpm
Specific torque	94.7 Nm/liter 1.14 ft.lb/cu^3
Engine construction	
sump	wet sump
compression ratio	10:1
Fuel system	MPFi
bmep (brake mean effective pressure)	1190 kPa (172.6 psi)
Maximum RPM	
crankshaft bearings	
Engine coolant	Water
Unitary capacity	396 cc
Aspiration	Normal
Compressor	N/A
Intercooler	None
Catalytic converter	Y
Weight-to-power ratio	17.88 kg/kW 29.87 lb/bhp

Figure (4.1) the engine used in this project

4.1.2 Water cooler (radiator)

The purpose of water cooler in vehicles in general is to set or control the operation temperature in range when it exceeds its limit. Figure 4.2 shows the radiator selected in this work to be added into the system to achieve its goal.

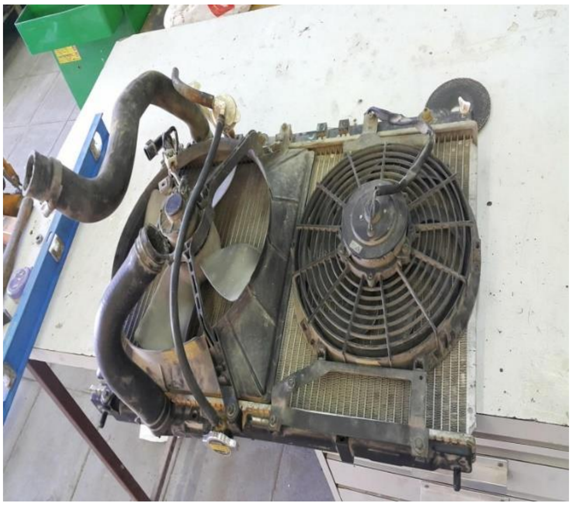


Figure (4.2): Radiator

4.1.3 Water and fuel tanks

These tanks are filled in water and fuel respectively to supply the engine with fuel and water injection system by water. figure 4.3 shows the tanks selected

Figure (4.3): Water and Fuel Tanks

4.1.4 Metallic frame

Project frame was designed carefully so that it can carry the engine and whole system together. It made from steel and wood as shown in Figure (4.4)

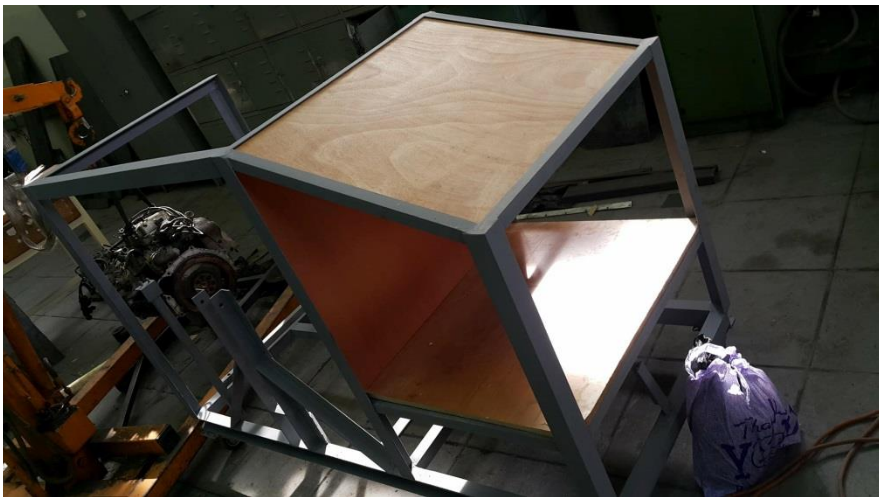


Figure (4.4): Frame of System (engine and all additional parts)

4.1.5 Engine rubber seats

The main idea of adding these parts to the system (see Figure 4.5) is to absorb the shocks resulted from engine vibration and damping them.

Figure (4.5): Rubber seats

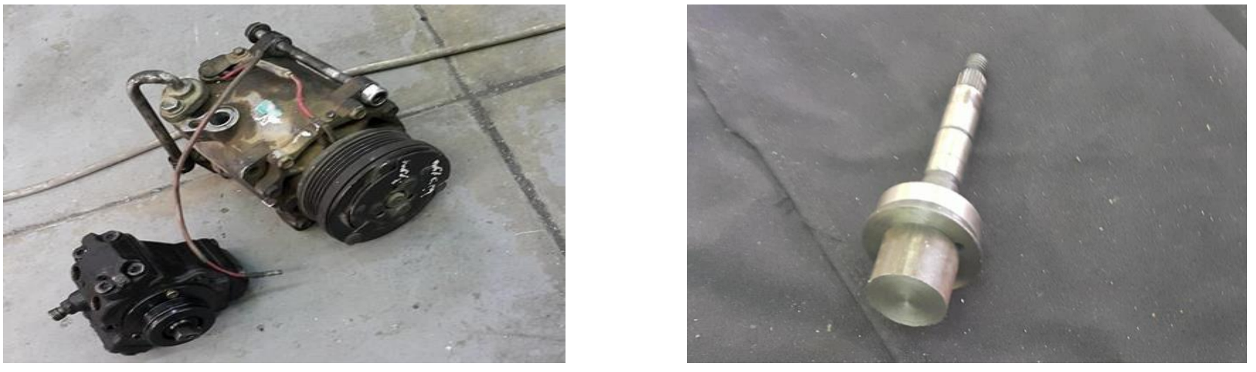
The assembled test rig is shown in Figure 4.6.

Figure (4.6): Engine test rig

4.2 Single point WIS prototype (water pump)

Water pump is responsible for pressurizing the water which will be supplied to the injector so that it can keeps it in required pressure. Figure 4.7 shows the selected pump that is added to the system

Figure (4.7) Water pump



a) b)

Figure (4.8): water pump construction a) compressor and diesel pump , b) shaft

This pump has been manufactured by combining the air conditioning compressor and diesel pump and these two parts were connected together by a shaft as shown in figure 4.8.

In this project, we used the front part of compressor which is the front case, the pulley and clutch. The aim of this part is to engage the pump with engine when the engine is completely warm up by tapping the signal coming from coolant temperature to the engine control unit.

4.2.1 Injector

The main duty of the injector is to supply the manifold of spray water. It is operated by tapping the signal from engine control unit to the fuel injector. Figure (4.9) shows the implemented injector.

a)

b)

Figure (4.9): Implemented injector: a) side view b) Top view

The injector is fixed in plastic case witch located between manifold and air filter as shown in figure 4.10.

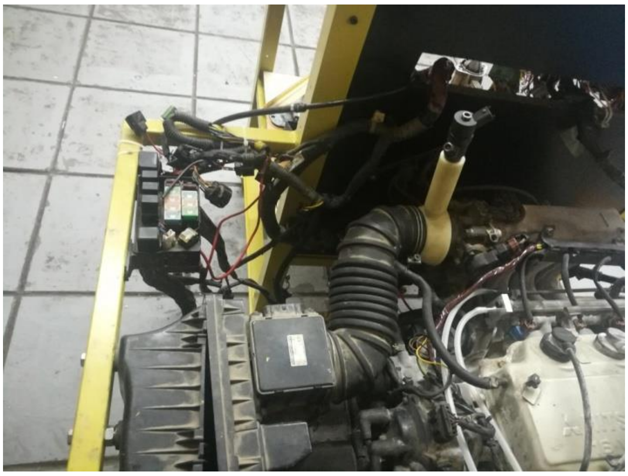


Figure (4.10): Single point WIS Prototype

- **Single point WIS operation**

  The water injection pump (the modified pump) is fitted to the engine block. This pump takes the rotational motion from the pulley fitted on the crank shaft by using timing belt.

  The pump is supplied with water from water tank to the inlet port of water pump. The outlet port is the water pressure line that is connected to the injector.

  If temperature of the engine is under the warm up temperature the clutch will not engage the pulley that is rotates freely. When engine temperature reaches warm up the clutch will engage and transmit the rotational motion into the pump and it will works and pumping the pressurized water to the injector.

  The pump takes its rotational motion from the engine and its flow rate depends on the number of cycles (rpm). So, as a result any increase in engine speed causes an increase in the pump water flow rate.

  In fact, we replaced water injection system by mechanical distributing pump because there are many reasons led us to go toward the mechanical distributing pump as we illustrate:

a- The high pressure obtained which causes many problems for injectors
b- The difficulty of controlling the electrical system.
c- The cost of electrical system is high.
d- The high pressure pump that reaches about 1300 bar
e- Need for accurate electronic control
f- one of injectors was out of use
g- high price of injectors
h- large size of injectors

The new system advantages:

1- low cost of all system component
2- easy to control
3- low pressure
4- mechanical control

4.3 Multipoint WIS Prototype

In this system, we have used diesel distributing rotary pump with mechanical governor. It is to control the quantity and timing of injected water.

The following subsections describes the system components:

4.3.1 distributer pump (rotary pump).

It's the heart of the system which is controlling the water injection at variable conditions, figure(4.11) and (4.12). It does many functions as follow:

a- It provides the necessary pressure because it has pressure valve .
b- Injects the necessary amount of water (water delivery control).
c- Set the necessary start of injection (start-off injection control).

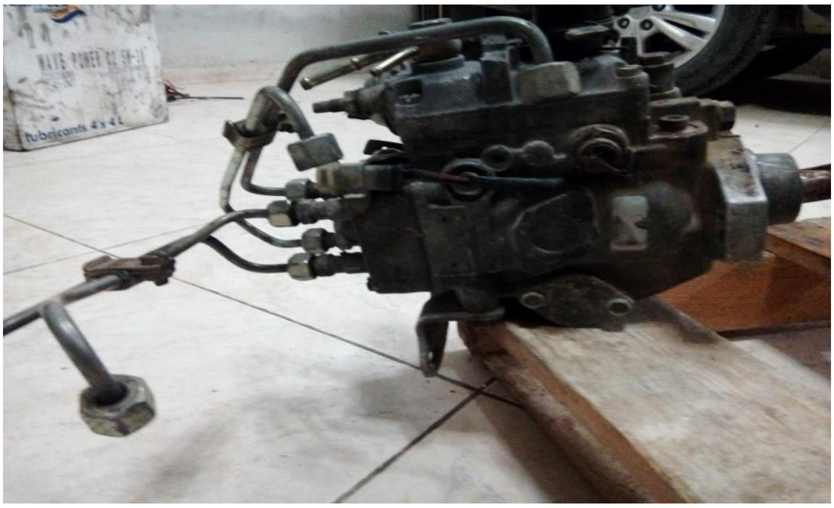


Figure (4.11): diesel distributing rotary pump with mechanical governor

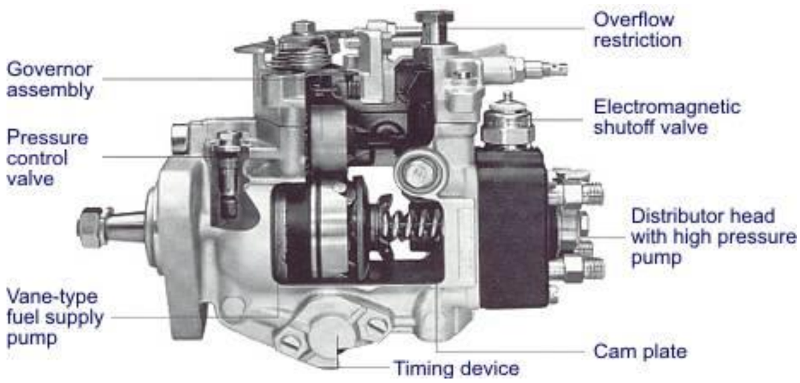


Figure (4.12): Distributor Pump components [21]

4.3.2 Injectors

These injectors are fixed on the intake manifold as in figure(4.13). They operate by the increase of pressure through the inlet of injector (activation pressure). When the inlet pressure becomes greater than the spring resistance, the injector opens and allows water to exit from nozzle to the intake manifold.

.

Figure (4.13): Injectors connected with pressurized water pipes

4.3.3 Pipes

The main goal of using these pipes -figure (4.14)- is to transfer the pressurized water from distributor pump into the injectors and return the excess water.

Figure (4.14): Water Pipes

4.3.4 Timing belt and pulley.

The timing belt and the pulley (see figure 4.15) are used for two main functions:

a)To transfer the rotary motion from cam shaft to the distributor pump

b) To distribute the injection order for injectors. To regulate fuel injectors and water injectors and make them working at same time.

We used three pulleys which have the same diameter to transfer the same cam shaft rotary motion to the pump to control the injection timing of the injectors.

Figure(4.15): the pulley and timing belt

4.3.5modification of distributer pump

The main part of the system is the distributor pump (see Figure 4.16), it is driven by engine. Its function is to distribute the water to each injector and regulate the opening to control the speed of engine injection amount in order to control engine speed. The pump is controlled by mechanical governor system located inside the injection pump which is controlled by acceleration pedal with cable.

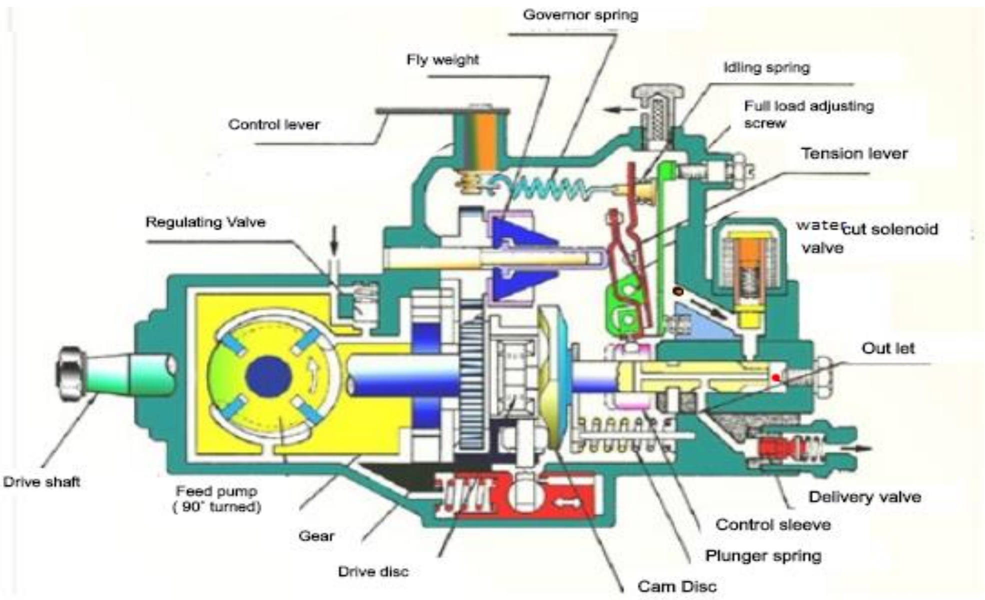


Figure (4.16):Distributor pump cross section

Each revolution, the pump delivers a constant amount of water from the water tank into the internal pump chamber.

The vane-pump housing (see Figure 4.17) is eccentrically arranged around the impeller. This creates a suction chamber which increases in size in the direction of rotation and a pressure chamber which decreases in size. The water is delivered in this way into the internal pump chamber. As engine speed increase, the water

pressure in internal pump chamber rises.

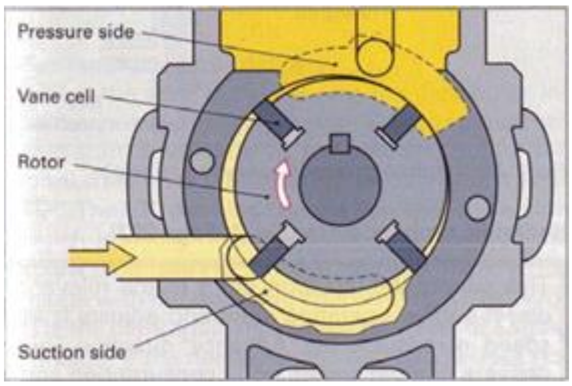


Figure (4.17): Vane pump [25]

This causes the internal-pump-chamber pressure to rise uniformly proportional to the engine speed. The maximum pressure is limited with maximum value of 12 bars. If the water pressure rises above this value, the valve plunger (see figure 4.18) opens to allow water to return from the internal pump chamber to the suction side of the vane pump.

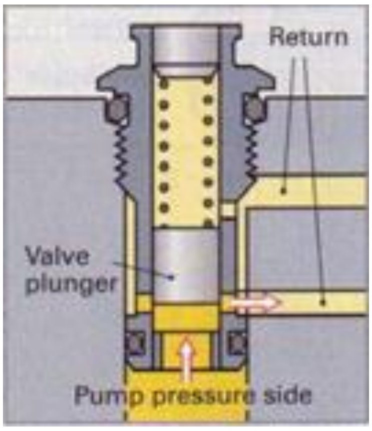


Figure (4.18): Pressure-control valve [25]

The overflow throttle (see Figure 4.19) allows a variable amount of water to return through a small bore to the water tank.

The following internal pump pressure is set by the pressure-control valve and the overflow throttle:

a-At idle speed the pressure is approximately set to 3bars.

b-At operating speed the pressure is approximately set to 8bars.

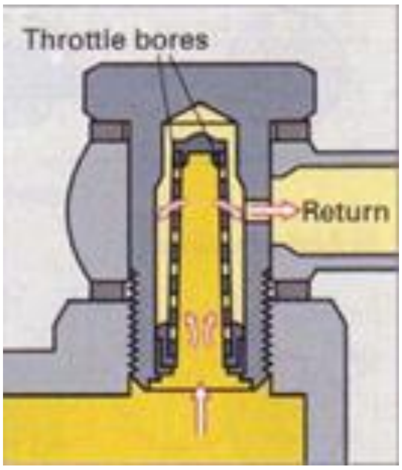


Figure (4.19): Overflow throttle [25]

From the internal pump chamber, the water flows through the inlet passage and through the filler groove in the distributer plunger into the pressure- chamber of the pump. The distributer plunger is made to rotate by the driving shaft. It's also made to lift by the cam plate. The cam plate is driven by driving shaft and it has as many cam lobes as the number of cylinders in the engine. These cams move in radial arranged roller follower fixed to a rotating roller ring and allow the cam plate to move axially.

The rotary motion of the distributer plunger causes its metering slots to open and close and establish a connection to the relevant spill port in the distributer head (see figure 20).

The pressure generation takes palace after the inlet passage is closed as a result of the lifting motion of the distributer plunger. The water delivery begins as soon as the distributer groove reaches the respective outlet port.

The delivery valves are lifted of their seat by the high pressure generated and the water is delivered via the injection lines to the injection nozzles.

The end of delivery is reached when the control collar opens the transverse passage of the distributer plunger. The water flows back into the internal pump chamber during the reminder of the lift. After the top dead center (TDC) is reached, the distributer plunger moves in the bottom dead center (BCD) direction again and closes the spill port by means of the control collar .The high pressure chamber is again filled via the next metering slot in the direction of rotation.

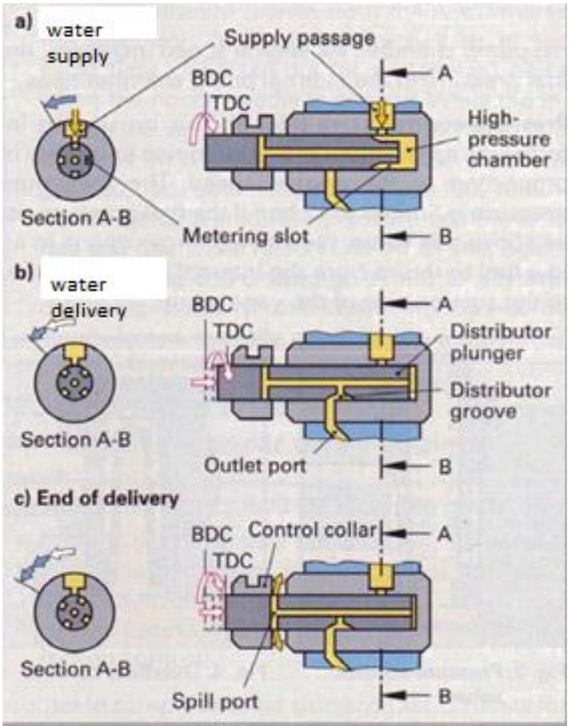


Figure (4.20): Pump-element operating principle [25]

The mechanical governor(see figure 21), consist of flyweights and a control sleeve, these are Devine via gear pair with a step-up ratio.

Flyweights move the control collar via a linkage depending on load and speed, the spill ports are opened and thus the delivery quantity is limited.

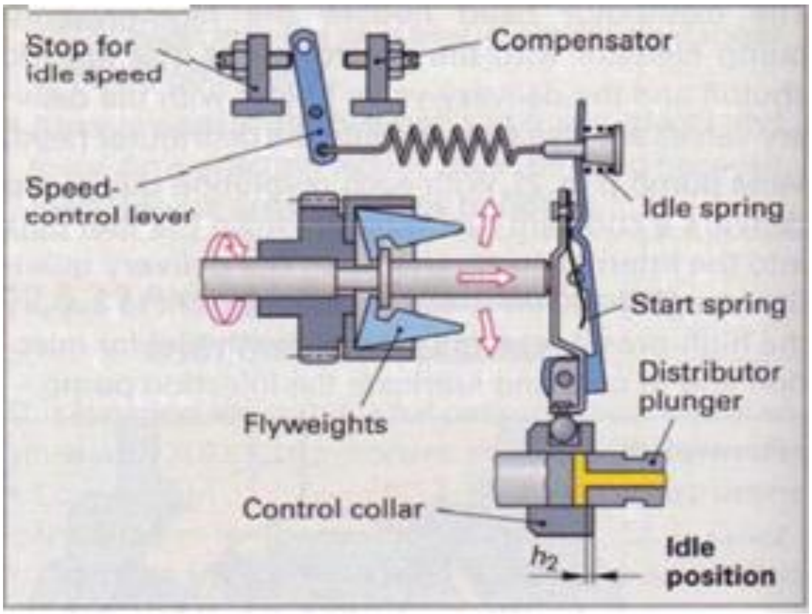


Figure (4.21): Mechanical-governor operating principle [25].

The governor functions are:

a) At idle-speed regulation prevents the speed from dropping below the idle speed.
b) At maximum-speed regulation the maximum speed must be limited when the load is removed.
c) At intermediate-speed regulation speed desired by the driver between idle and maximum speed are kept constant even in the event of load changes.

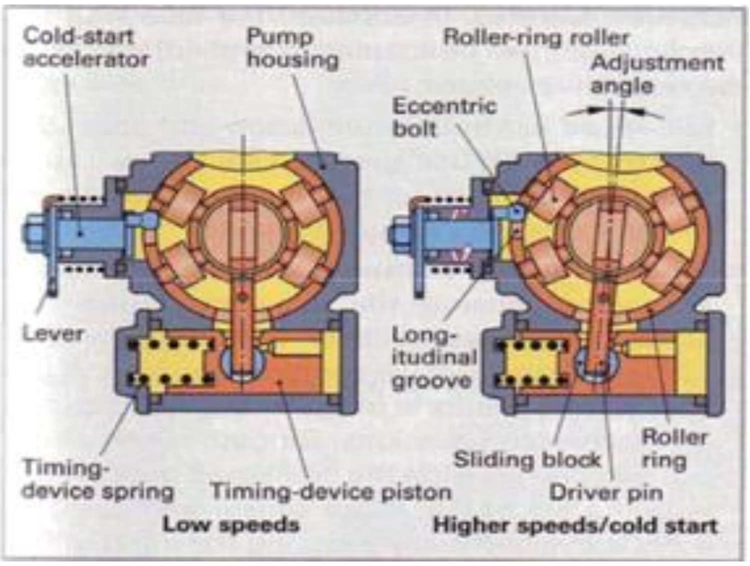
The working principle of mechanical governor

a) At start / idle speed the flyweights operate against the elastic force of the start/idle spring. The idle speed is thus kept constant.
b) At maximum speed the flyweights operate against the control spring they prevent the maximum permissible speed from being exceeded.

4.3.6 Hydraulic timing device

This adapts the injection point to the relevant water-engine operating state and adjusts it as speed increases in the (advance) direction.

The hydraulic timing device(see Figure 4.22)is installed transversally on the underside of the pump, and consist of a working cylinder with a spring-loaded hydraulic piston. This is connected by means of a bolt with the roller ring. The cam plate is raised earlier by the roller-ring rollers, thus, more advance injection point is achieved.



Figure(4.22): Hydraulic-timing device

Solenoid-operated shut off valve:

This consist of a solenoid valve which closes the inlet passage to the high-pressure chamber of the distributer plunger when the ignition switch turn off in order to switch off the engine . It can also be used as an immobilizer.

Operating principle:

When the engine is stopped, the timing-device piston is held in the initial position by the preloaded timing- device spring. When the engine is running, the speed-dependent internal pressure overcomes the spring force and moves the timing-device piston. The axial piston movement is transmitted to the pivoted roller ring which rotates for ignition- advance purpose against the pump pistons direction of rotation.

Summary of WIS control by modified distributor pump:

1- Water flow: the over flow throttle can change the amount of water
2- Water pressure: the pressure control valve can adjust the system pressure
3- Governor adjusts the amount of water that the system need while running.
4- Hydraulic-timing device adjusts the start of injection (advance and retard).
5- Injector opens when the resulting force from water pressure overcomes the elastic force of the spring inside the injector.
6- The water injector and fuel injector working together at the same cylinder by the timing belt adjustment which synchronize the distributor pump motion with the camshaft motion.

Chapter Five (5)

Theoretical calculations

5. Theoretical calculations

5.1 Theoretical calculations

In this chapter, we are concentrating on making calculations for Water flow, water velocity and nozzle diameter.

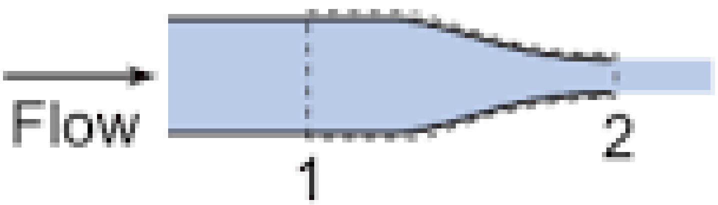
These calculations are based on –Daniel busutti,Mariofarrugit – model [26]

A- Model specifications

1- Engine capacity=592 cc (ml)
2- Single cylinder four stoke
3- Water injection pump pressure = 4 bar = 400 kPa
4- Water injection flow rate = (0.015-0.031) ml/cycle

B- Assumptions

1- Engine speed=4000 rpm
2- Water density=1000 kg/m^3
3- Air to fuel ratio A/F= 14.7 : 1 stoichiometric
4- Fuel density = 719.7 kg/m^3



Figure[5.1] Nozzle

5.1.1 Nozzle Velocity Calculation

❖ From Bernoulli equation

$$\frac{\text{p1}}{\varphi} + \frac{\text{V}^2}{2} = constat \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. [5.1]$$

Where,

P = pressure in Pascal =400 kPa

V = velocity in m/s

φ = water density =1ooo Kg/m^3

$$\frac{P1}{\varphi} + \frac{V1^2}{2} = \frac{P2}{\varphi} + \frac{V2^2}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. [5.2]$$

Assume that,

V_1=0, P_2=0

$$\frac{P\dot{1}}{\varphi} = \frac{V2^2}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{[5.3]}$$

V_2= $\left(2\frac{P1}{\varphi}\right)^{0.5}$ $\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$ [5.4]

V_2=$(2 \times 400 \times 10^3)^{0.5}$

V_2= 28.3 m/s

- ✓ The outlet water from nozzle make the water sprays at velocity =28.3 m/s

5.1.2 complete cycle Flow rate calculation

- ✓ **Project water injection specifications**

1- Engine capacity=1584cc (ml)
2- Four cylinders four stroke engine
3- Water injection pump= 4 bar = 400 kPa
4- Water speed from nozzle=28.3 m/s

❖ Assumption

Engine speed=4000 rpm

Q = $\frac{\text{project engine capacity}}{\text{model engine capacity}} \times$
m$odelwaterinjectionflowrate) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$ [5.5]

$$=\left(\frac{\mathbf{1584}}{\mathbf{592}}\right) \times \ \mathbf{0.031} \quad = \ \mathbf{0.094}\,\frac{\boldsymbol{ml}}{\boldsymbol{cycle}} = \mathbf{0.094} \times \mathbf{10^{-6}}\,\frac{\boldsymbol{m^3}}{\boldsymbol{cycle}}$$

- ✓ One cycle= two rpm
- ✓ 4000rpm= 2000 cycles

2000 cycle/min = $\mathbf{2000}\,\frac{\boldsymbol{cycles}}{\boldsymbol{min}} = \frac{\mathbf{2000}}{\mathbf{60}}\,\frac{\boldsymbol{cycles}}{\boldsymbol{s}} = \mathbf{33.33}\,\frac{\boldsymbol{cycles}}{\boldsymbol{s}}$

- ❖ **Water injection flow rate at 33.33 cycle/s =** $\mathbf{0.094} \times \mathbf{10^{-6}} \times \mathbf{33.33} = \mathbf{3.1} \times \mathbf{10^{-6}}\,\frac{\boldsymbol{m^3}}{\boldsymbol{s}}$

This flow rate is for complete cycle.
And, Complete cycle = four power stroke
So, The water injection flow rate for each cylinder = $3.1 \times \frac{10^{-6}}{4} = 0.8 \times 10^{-6}\,\frac{m^3}{s}$

$0.8 \times 10^{-6}\frac{m^3}{s}$ is the amount of water injected in one cylinder at speed **4000rpm**

5.1.3 Nozzle diameter calculation

$$\frac{waterinjectioflowrate}{watervelocity} = \pi \times \frac{nozzlediameter^2}{4} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [5.6]$$

$$\frac{\boldsymbol{Q}}{\boldsymbol{V}} = \frac{\boldsymbol{\pi D^2}}{\boldsymbol{4}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [5.7]$$

D=

$$\left(\frac{\boldsymbol{4Q}}{\boldsymbol{\pi V}}\right)^{\boldsymbol{0.5}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots [5.8]$$

$$\mathrm{D} = \left(\frac{4 \times 0.8 \times 10^{-6}}{28.3 \times 3.14}\right)^{0.5} = 0.2\ \mathrm{mm}$$

So, specifications of the model of the water injection :

1- Water injection pressure=4bar
2- Water injection flow rate=(0.04-0.094)ml/cycle for each cylinder
3- Four nozzles with diameter= 0.2 mm

❖ Water to fuel ratio

The water to fuel ratio range about (10%-52%) of gasoline **mass**[28]

In this project the water to fuel ratio is adjusted to be 1:10

By overflow throttle in distributor pump.

Chapter Six (6)

Experimental Results

6. Experiment data

6.1 Testing procedure

The experiment begins when the engine warm up by taking the engine data from dash panel and gas analyzer.

There are two runs for each different speed, first one is without the water injection system and the second one is the water injection system at the same throttle angle

Change the angle of the throttle at different angles as follow:

We use to change the throttle angle automatic gear lever (see Figure 6.1) when change the gear position the lever cable opens the throttle :

1- Position R=20% throttle opening.
2- Position N=30% throttle opening.
3- Position D=40% throttle opening.
4- Position 2=50% throttle opening .

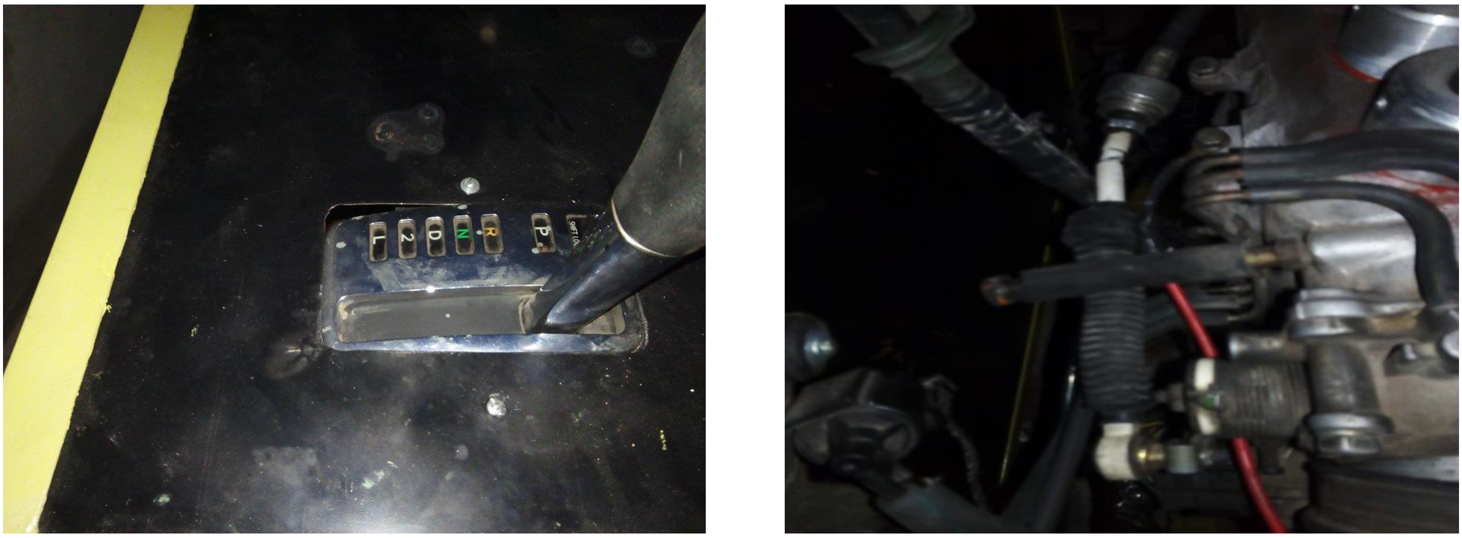


Figure [6.1] : Throttle changing

6.2 Experiment tests

Experiment result

The experiment consist of two parts:

First part –experiment without water injection and second part is with water injection

First part procedure and data:

After the engine reaches the warm-up temperature we started the first part which consist of four runs, each run has a different throttle opening (20-50) % throttle opening.

In every run we measured the engine speed and the fuel consumption by using gradient flask contains 100ml of fuel and we measured the time. The exhaust data was taken by using gas analyzer to read the (CO, NOx) values and the following data in table 6.1.

Second part procedure and data:

This part just resembles the first part but with the existence of water injection in addition water consumption is added to the tables which is calculated by measuring the quantity of water consumed coinciding with 100ml fuel consumption during a period of time and other data recorded in table 6.2.

Specifications:

1. Fuel sample=100ml
2. Engine temperature=75 C°
3. Without load

Table 6.1 1 Experimental results without water injection

Throttle %	**RPM**	**Running Time Second**	**Fuel consumption ml/s**	**CO %**	**NOX PPM**
20%	1100	125	0.800	0.062	550
30%	2000	115	0.869	0.13	603
40%	3000	97.5	1.02	0.26	638
50%	4000	82.5	1.21	0.29	697

Table 6.2 1 Experimental results with water injection

Throttle %	rpm	Water Volume ml	Running Time Second	Water consumption mL/s	Fuel consumption mL/s	WATER TO FUEL RATIO	CO %	NO_X ppm
20%	1150	8.75	125	0.07	0.800	1:11.4	0.060	413
30%	2100	9.75	115	0.085	0.869	1:10.2	0.11	462
40%	3200	10	97.5	0.102	1.02	1:10	0.23	480
50%	4250	10.5	82.5	0.127	1.21	1:9.5	0.27	540

- **Sample photo from experiment**

Engine Speed without water injection

Engine speed with water injection

Figure [6.2]: Engine speed with and without water injection

The following are graphs for comparison between water injection system and normal (without water system).

The following graphs show the comparison between engine performance with and without water injection.

Figure 6.3 shows the difference in engine speed at the same throttle with and without water injection, the engine speed is increased about 5% with water injection, which could indicate an increase of the output power.

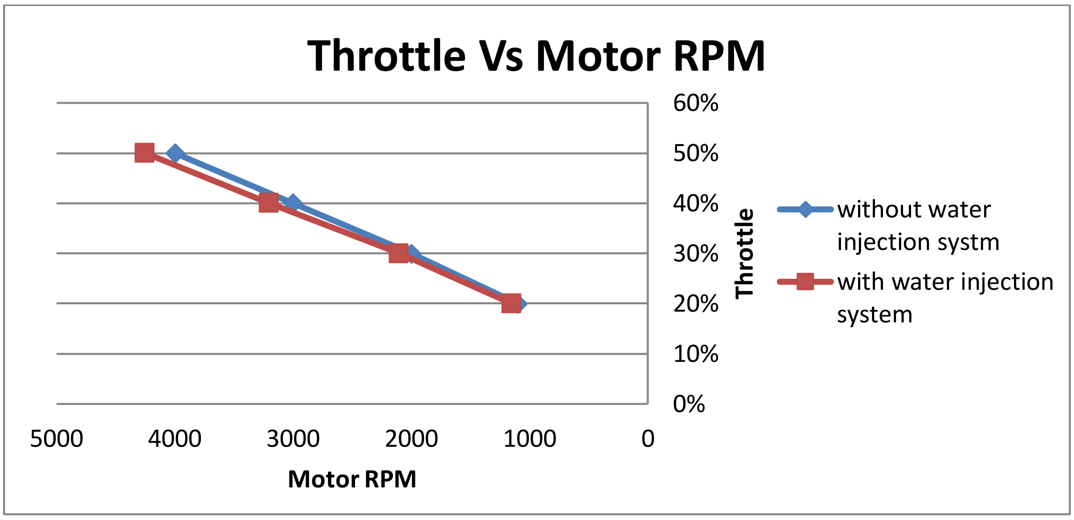


Figure (6.3) throttle vs. engine speed (experimental results).

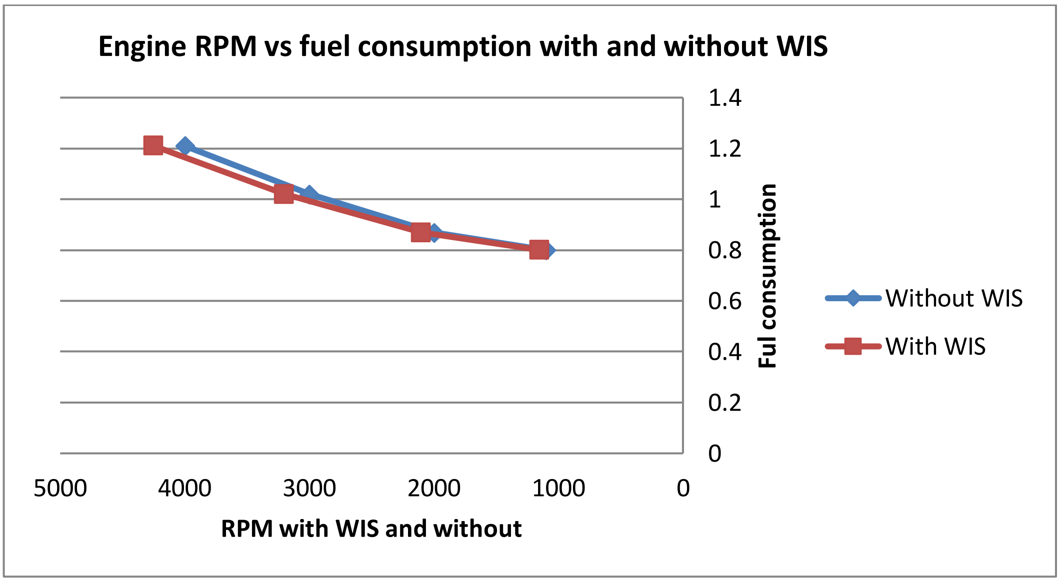


Figure (6.4) fuel consumption vs Engine RPM with and without WIS

Figure (6.5) shows the CO exhaust emission of the engine when operated with and without water injection, the effect of water injection decreases the volume of Carbon Monoxide (CO) about (3.3-6.8) in exhaust gases depends on speed and water quantity.

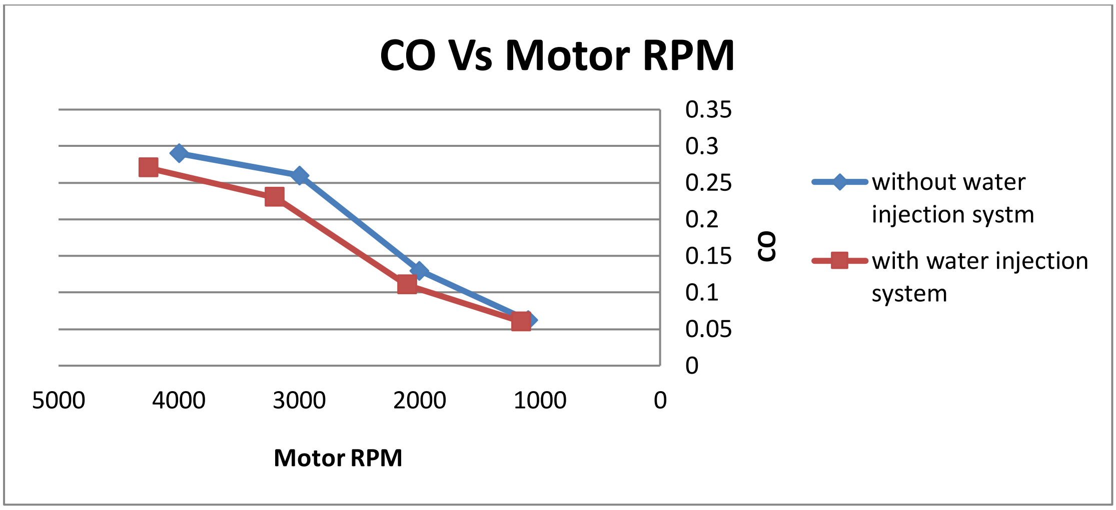


Figure (6.5) CO exhaust emission vs. engine speed (experimental results)..

Figure (6.6) shows the NOx exhaust emission of the engine when operated with and without water injection, the Nitric Oxides (NOx) decreased by about 25% when water is injected, this due to the cooling effect of the injected on the combustion chamber

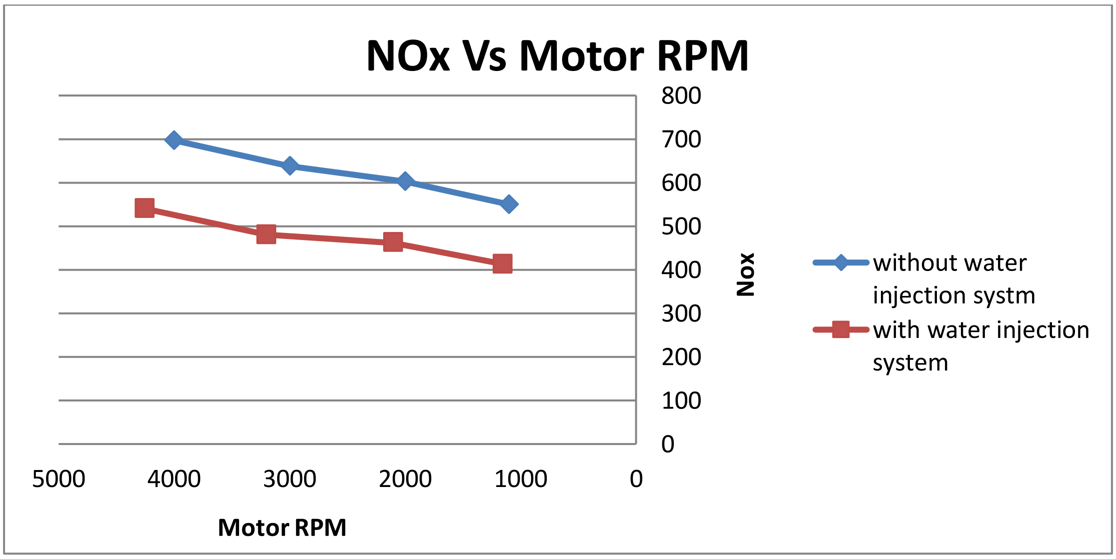


Figure (6.6) NOx exhaust emission vs. engine speed (experimental results).

Figure (6.7) shows the relation between water to fuel ratio and engine speed. The (Y) axis presents the value of water to fuel ratio which is a fraction of one over the number (12 means 1:12) etc.

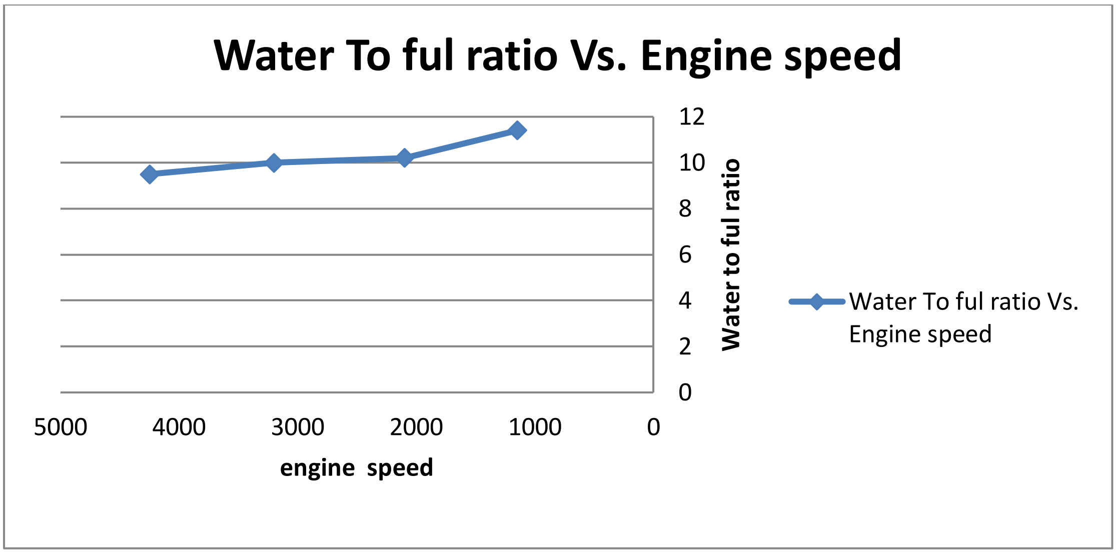


Figure (6.7) Water To fuel ratio Vs. Engine speed

6.3 Conclusion

From the result the water injection increase the engine speed about 5% which means increasing in engine power by relation:

Power=torque*omega

In other hand the water injection reduce the Carbon Monoxide (CO) about (3.3-6.8) %

And reduced Nitric Monoxide (NO_X) about 25% when the engine temperature rising

At high speed.

This caused by cooling the temperature of combustion and Using water as extra fuel By separating the water components to hydrogen and oxygen Induced high temperature and high pressure in engine cylinder.

6.4 **Recommendations**

At the end of the project, the following is recommended:

1- The use of single cylinder engine will be easier to study the effect of water injection.
2- The design of electronic control system of the water injection system.
3- Dynamometer should be used to measure and control the torque.
4- Thermodynamic should be used to analysis the results.
5- The water percentage in exhaust gases should be measured.

References

[1] https://shopeurocompulsion.net/blogs/technical-articles/water-injecton

[2] Nelson, Leonard Carl, "Water injection in the modern automotive spark ignition engine" (1949).*Masters Theses*. 6801.

[3] Ricardo, H.R. The High Speed Internal Combustion Engine. 4th ed. London: Blackie and Son Ltd., 1953.

[4] Nicholls, J.E., Messiri, I.A. and Newhall, H.K. "Inlet Manifold Water Injection For control of Nitrogen Oxides-Theory and Experiments."SAE Technical Paper Series 690018.

[5] Tsao, K.C. and Wang, C.L. "Performance of Gasoline-Water Fuel in a Modified SI Engine."SAE Technical Paper Series 841399

[6] Satpov, E.B., et al. "Effect of Water in Fuel on the performance of SI Engine." Research Center for Combustion Engines and Machinery.

[7] Lanzafame, R. "Water Injection Effects In A Single-Cylinder CFR Engine." SAE Technical Paper Series 1999-01-0568.

[8] Mr. ParamustJuntarakod, Analysis of Water Injection into High-Temperature Mixture
of Combustion Products in a Cylinder of Spark Ignition Engine

[9]J. Parley Wilson.” Effects of Water Injection and Increased Compression Ratio in a Gasoline Spark Ignition Engine”, 2011.

[10] Jaeheun Kim, Hyunwook Park ,” Effects of water direct injection on the torque enhancement and fuel consumption reduction of a gasoline engine under high-load conditions” 2015.

[11] K Pradeep G. Radha Krishna, “International Journal for Research in Applied Science & Engineering Technology (IJRASET)Experimental Investigation on Four Stroke Single
Cylinder Petrol Engine Using Water Cooling”, 2016

[12] http://www.bosch-presse.de/pressportal/de/media/migrated_media/pi8259/1-gs-19439-2.jpg

[13] http://i.ebayimg.com/images/g/ii4AAOxy0bRTEoFt/s-l1600.jpg

[13] http://www.ebay.com/itm/Water-Meth-Methanol-Alcohol-Injection-4-2-Gallon-Fuel-Reservoir-Ice-Sumped-Tank-/261678281233

[14] http://www.xtremediesel.com/aemwatermethanolinjectionfilter30-3003.aspx

[15] http://www.aemelectronics.com/?q=products/water-methanol-injection-systems/water-methanol-injection-kit-for-forced-induction-gasoline-engines

[16] https://images-na.ssl-images-amazon.com/images/I/31%2BG2772U4L.jpg

[17]
https://i1.ypcdn.com/blob/99e8e5b934ae1445c621a499edec09547ccde1d2_640.jpg

[18]
http://www.diytrade.com/china/pd/11404212/PVC_Cover_or_coated_metal_Flexible_Corrugated_Hose.html

[19] http://s98.photobucket.com/user/otownsrt4/media/WAM009.jpg.html

[20] http://www.superstreetonline.com/how-to/engine/impp-1101-water-methanol-injection/

[21] http://www.otelcimen.com/troy-bilt-pressure-washer-parts-diagram/powerboss-pressure-washer-020447-0-replacement-parts-pump-troy-bilt-2700-m/

[22] Bosch, 2004. "Diesel-Engine Management", Robert Bosch GmbH Breitbach, H., 2002. "Fuel Injection Systems Overview", Delphi Corporation, March 2002.

[23] https://www.andymark.com/product-p/am-2703.htm

[24] https://mechanical-engg.com/gallery/image/1875-carburetor-and-fuel-systemjpg/

[25] http://www.powerguru.org/process-flow-optimization/

[26] EXPERIMENTAL INVESTIGATION ON THE EFFECT OF INJECTING WATER TO THE AIR TO FUEL MIXTURE IN A SPARK IGNITION ENGINE (DANIEL BUSUTTIL, MARIO FARRUGIA, University of Malta, Msida Malta)

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