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Effect of Combined System (EGR and WI) on Diesel Engine Brake Power and NO_x Emissions

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مُسْتَخْلَص

نُفذ تحقيق تجريبي في معامل جامعة السودان للعلوم والتكنولوجيا, لدراسة أثرالأنظمة المشتركة (إعادة تدوير جزء من غاز العادم وحقن الماء) على القدرة الفرملية وإنبعاث غازات أكاسيد النيتروجين. نتائج التجارب أوضحت أن نظام حقن الماء يزيد من القدرة الخارجة للمحرك عند سرعات المحرك المتوسطة والعالية. بالنسبة للنظم المشتركة (حقن الماء + إعادة تدوير جزء من العادم) فإن قدرة المحرك تنخفض مقارنة بالقدرة الخارجة من المحرك ذي الشاحن التوربيني, وتظل القدرة أكبر مقارنة بتشغيل المحرك فقط بنظام إعادة تدوير جزء من غاز العادم. نظام إعادة تدوير جزء من غاز العادم يلعب دوراً مهماً في تخفيض إنبعاث غازات أكاسيد النيتروجين من محركات الديزل بصورة ملحوظة, وتزداد نسبة الانخفاض عند ظهور نظام حقن الماء, الانخفاض الأكبر في إنبعاث أكاسيد النيتروجين يمكن الحصول عليه من اعادة تدوير جزء من غاز العادم + حقن الماء)(تشغيل الأنظمة المشتركة

ABSTRACT

An experimental investigation was carried out at the laboratories of Sudan University of Science and Technology, to show the effect of Combined System (Exhaust Gas Recirculation (**EGR**) and Water Injection (**WI**)) on diesel engine brake power and the emissions of Nitrogen Oxides. The results of tests show that the Water Injection increases the power output of the engine particularly at mid and high engine speed. Combined system (EGR + WI) reduce the engine power, when compared to that obtained by turbocharged engine, and it is still greater than the power generated from an engine running with EGR system only. EGR will reduce the emissions of NO_x from diesel engine considerably. At the presence

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of (WI) system, NO_x emissions decrease as the injected water increases. A great reduction in NO_x emissions will occur at the combined system (EGR + WI).

Keywords: Brake Power, Nitrogen Oxides Emission, Exhaust gas Recirculation, Water Injection.

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breviations

	Brake power	NO_x	Nitrogen oxi
EGR	Exhaust gas recirculation.	WI	Water Injection
N	Engine speed		

1- INTRODUCTION

1-1 Background

Exhaust gas is emitted as a result of the combustion of fuels such as petrol, diesel fuel, fuel oil or coal, according to the type of engine and it is discharged into the atmosphere [1]. Gaseous components of diesel engine exhaust include carbon dioxide, oxygen, nitrogen, water vapor, carbon monoxide, nitrogen compounds, and sulfur compounds [2]. At a high combustion temperature the nitrogen oxides (**NO_x**) are formed, which react in the atmosphere to produce acids**.** It has harmful effects on plants, aquatic animals, and infrastructures [3]. Available evidence indicates that there are human health hazards associated with exposure to Diesel Engine. The hazards include acute exposure-related symptoms; chronic exposure related non cancer respiratory effects, and lung cancer [4].

Exhaust **G**as **R**ecirculation (**EGR**) is one technique used to reduce nitrogen oxides (NO_x) emissions in most gasoline and diesel engines. EGR works by the recirculation of a small portion of an engine's exhaust gas back to the engine cylinders. Intermixing the incoming air with recirculated exhaust gas dilutes the mix with inert gas, lowering the adiabatic flame temperature and (in diesel engines) reducing the amount of excess oxygen.

Because NO_x formation progresses much faster at high temperatures and the availability of oxygen, EGR serves to limit the generation of NO_x [5].
Water **I**njection (**WI**) has been used in turbine aircraft engines during World War II in order to increase takeoff power. It is a method for cooling the combustion chambers of engines by adding water injection to the incoming air, allowing for greater compression ratios. An additional effect comes later during combustion when the water absorbs large amounts of heat as it vaporizes, reducing peak temperature and suppose to reduce the resultant NOx formation [6].
In this paper an investigation will carry out to study the impact of combined systems (EGR and WI) in the diesel engine performance in terms of brake power and the characteristics of exhaust emissions (NO_x).

1-2 Objectives
The aim of this paper is to study the effect of introducing injected water to incoming fresh air beside the system of Exhaust Gas Recirculation. The main parameters that are interesting to study are: The Brake Power and Nitrogen Oxides Emissions.

2- MATERIALS AND METHODS
2-1 The Dynamometer
Dynamometer is a device for measuring force, moment of force (torque), or power. The hydraulic dynamometer type (HPA-Test) is used in this research; the diesel engine type (4D56) is mounted on a test bench of the dynamometer and connected to the hydraulic dynamometer with the propeller shaft. Fig (1) shows the details of the experimental set-up.

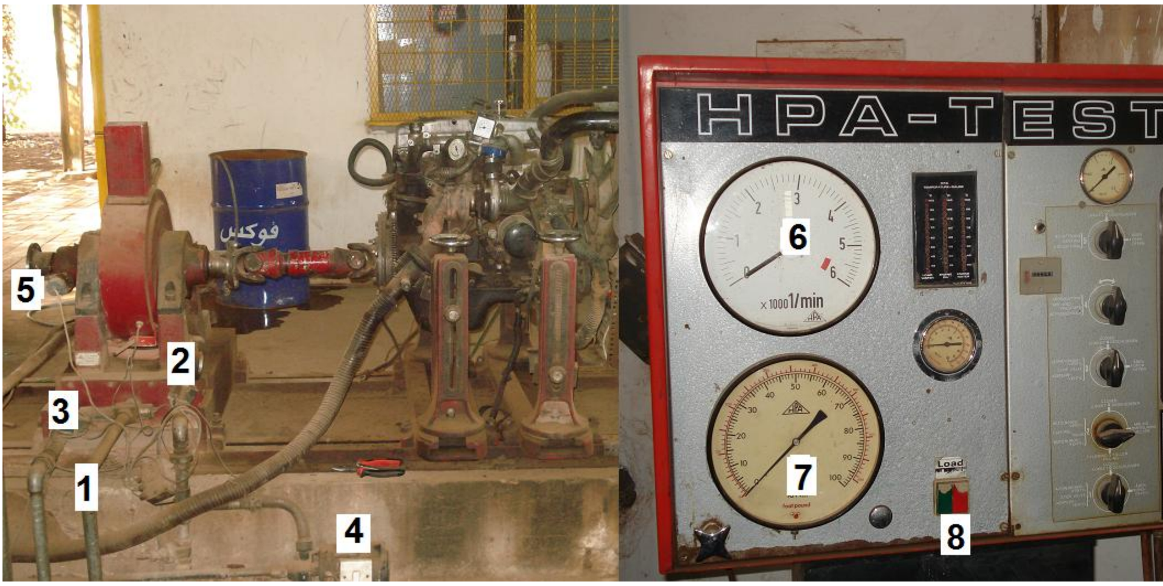

Fig (1): Experimental set - up. 1-Water pipes. 2 - Water pressure gauge. 3 - Adjustable valve. 4 - Water pump. 5 - Speed sensor 6- Speed gauge. 7 - Torque gauge. 8 - On – Off load.

2-2 Flue Gas Analyzer

The portable flue gas analyzer is the most important instrument used in this research, because one of the goals of this research is to find the effect of (EGR + WI) on engine emissions. Eurotron portable flue gas analyzer Green Line 8000 is used. The gas analyzer consists of two main sections: the gas analysis **M**ain **C**ontrol **U**nit (**MCU**) and the **R**emote **C**ontrol **U**nit (**RCU**). The MCU is a portable and a complete flue gas laboratory. The RCU is used to display the measured data. Figure (2), shows the main components of the portable gas analyzer MCU and RCU [7].

Fig (2): Flue gas analyzer. 1- Exhaust pipe. 2- Metal hole. 3- Steel tube and handle. 4- RCU power supply. 5- Communication cable. 6- Gas suction hose. 7- MCU power supply.

2-3 Exhaust Gas Recirculation Valve

Fig (3) shows the modifications added to the EGR valve to suit the conditions needed to run the experimental tests, operated manually instead of being controlled by manifold vacuum. This will be done with a bolt fixed to the valve head and a nut fixed with the poppet valve body. The other end of the bolt carries a pointer to determine the rotation in degrees. On the valve body, there is a 360 - degree protractor against the pointer for easier degree readings. The movement of the valve has been converted from linear to circular motion by using a screw and nut as pointed out previously.

Fig (3): EGR valve. 1- EGR valve. 2 – 360deg. Protractor. 3 – Pointer. 4- Rotating bolt.

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The geometrical dimensions of the EGR valve are 12mm EGR inlet diameter and 7mm for the stroke of the EGR poppet valve. The stroke length (7mm) was found equal to 1310^o measured by 360^o protractor as shown in Fig (3). The diameter of the inlet manifold (flow of the fresh air) was found to be 60mm, therefore the flow area of the EGR related to the intake manifold area is 0.20 (12mm/60mm). The engine must run at different EGR ratios (0, 10, 20%) controlling by valve opening percentages (0, 50, and 100%) respectively, if the test required setting of 10% EGR ratio (50% valve opening ratio), this means the poppet valve must be set manually at a mid distance by using the pointer against the protractor at 655^o (full rotation (360^o) + 295^o). Table (1) shows the relation between EGR valve open percentage and equivalent values in degrees.

NO.	EGR valve opening percentage	EGR Ratio	Equivalent Degrees
1	0%	0.00	0^o
2	50 %	10 %	655.0^o
3	100 %	20 %	1310^o

Table (1): Relations between EGR valve open percentages and EGR ratio.

2-4 Water Injection System

Figure (4) shows the arrangement of water injection pump, which was built locally to satisfy the needs of experimental tests. Initially, the pump of water injection is adopted to provide water at pressures 5 and 10bar with nozzle diameter 0.1, 0.3, and 0.5mm. The location of the nozzle has been selected to be through the intake manifold before the turbocharger, to lower the temperature of the air entering the compressor. Practical calculations have been carried out to determine the mass flow rate of water injection for each nozzle at pressures 5 and 10bar, and are sorted in Table (2).

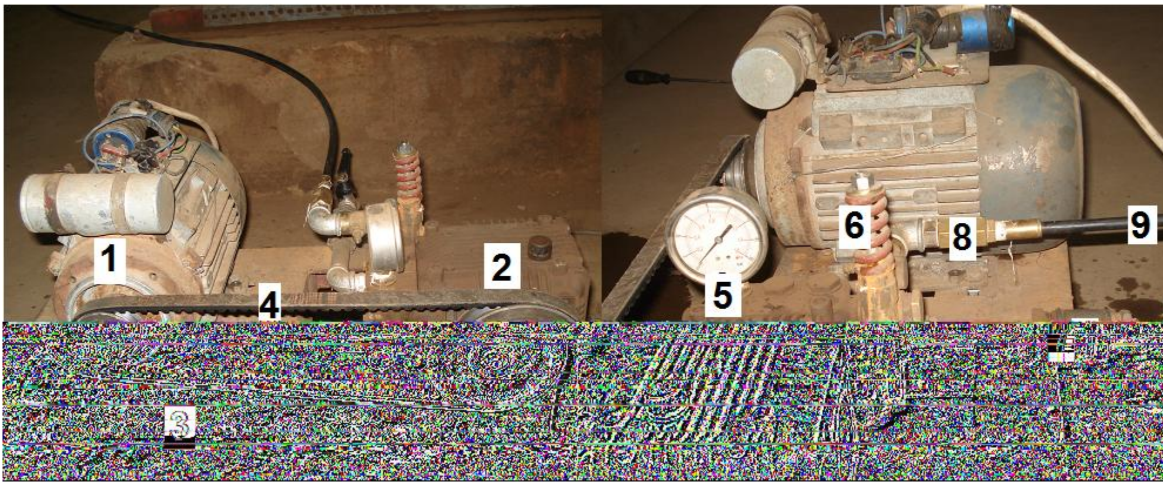

Fig (4): The water injection pump. 1- Motor drive. 2- Water pump. 3- Metal seat. 4- V – belt. 5- Pressure gauge. 6- Adjustable valve. 7- Water inlet. 8 – Water outlet. 9- Hose.

Nozzle Diameter (mm)		Mass flow rate (kg/s)		Mass flow rate (kg/s)
0.1	Pressure 5bar	1.367e-4	Pressure 10bar	2.2e-4
0.3		7.283e-4		9.2e-4
0.5		1.236e-3		1.52e-3

Table (2): Water mass flow rate

3- RESULTS AND DISCUSSIONS

3-1 Brake Power

3-1-1 Combined System (WI + 0% EGR)

Referring to Table (3), the influence of water injection at the EGR valve closed (0% EGR ratio) on diesel engine performance is shown graphically in Fig (5). Water injection will increase the engine brake power at mid and high engine speeds, e.g. the power of a TC engine at 2500rpm was found to be 23.554kW, and at engine set-up TC+WI (0.1mm at 5bar) the power will be equal to 26.173kW the increment about 10% when compared to TC engine, the maximum power can be obtained when using set-up TC+WI (0.3mm at 5bar) and will be equal to 27.303kW (+13.7%). Water greater than that obtained from set-up (0.3mm at 5bar) will cause the power to decrease when compared to TC engine, e.g. at test set-up TC+WI (0.5mm at

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5bar) the brake power will decrease to 20.734kW (- 11.9%), with more injected water when using test set-up TC + WI (0.5mm at 10bar), the power will decrease to 20.155kW (-14.4%) when compared to TC engine. At low engine speeds less than 1250rpm the power will decrease and reach values less than those obtained by the setup of TC engine, this because the rate of air flow is less at those speeds, and injected water volume will affect negatively towards the brake power. The interpretation of the increase the power is attributed to the injection of water to the engine incoming air, which will tend to cool the combustion chambers of the engine, allowing for greater compression ratios. Water injection, also known as anti-detonant injection, is a method of cooling the combustion chambers of engines by adding water to the cylinder or incoming air, allowing for greater compression ratios and largely eliminating the problem of engine knocking. This effectively increases the octane rating of the fuel, meaning that performance gains can be obtained when using turbocharger [6].

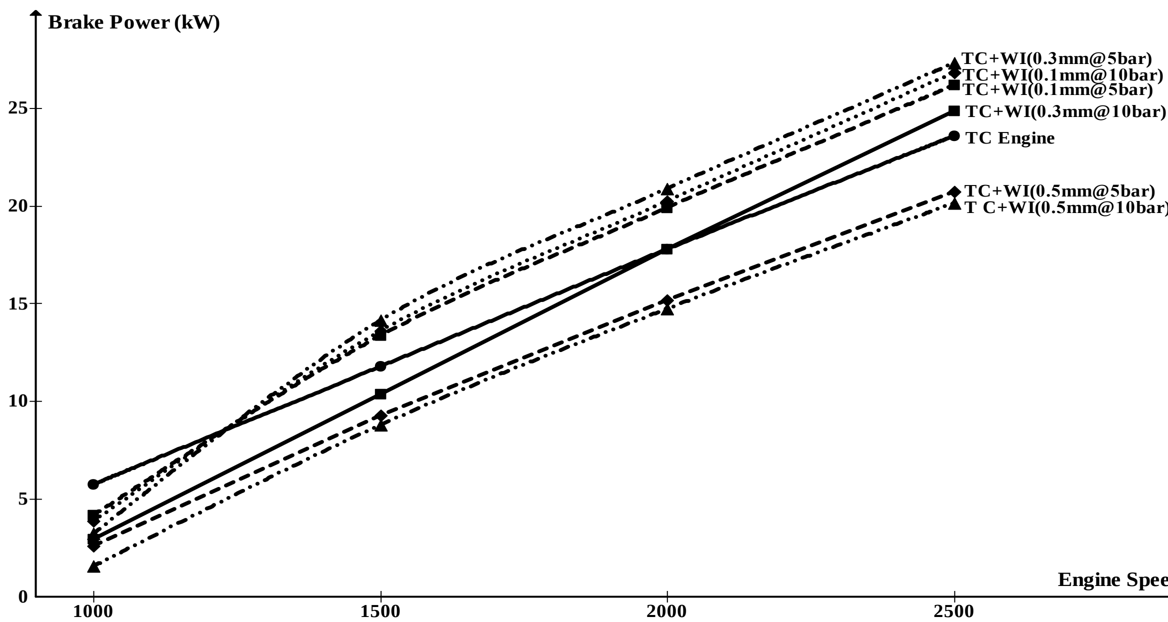

Fig (5): The effect of WI system on engine brake power.

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3-1-2 Combined System (WI + 10% EGR Ratio)

Referring to Table (3), Fig (6) shows the effect of different volumes of injected water with an EGR ratio by 50% valve opening percentage (10% EGR Ratio) on diesel engine brake power. The figure shows that at the least volume of injected water and at the presence of 10% EGR ratio, the power will decrease and reach to values less than those obtained from TC engine set-up. This is because the EGR will reduce the combustion flame temperature by mixing incombustible gas to the incoming fresh air. This process will limit and reduce the amount of oxygen to the combustion chamber. Reduction in flame temperature means a reduction in power converted from fuel to mechanical.

The brake power decreases as the volume of injected water increases, e.g. at 2500rpm and setup of TC engine the power was found 23.554kW, the power will decrease in the presence of 10% EGR ratio and will be 20.664kW, when WI is added to a system of intake by set-up WI (0.1mm at 5bar) and 10% EGR, the power will rise to 22.764kW when compared to the 10% EGR (+ 9.2%) and less in the case of TC engine (-3.3%). Adding more WI by using set-up 0.1mm at 10bar will likely to lead more dropping in engine power and will be 22.114kW (-6.1%) when compared to TC engine. When the injected water is increased by set-up 0.3mm at 10bar with 10% EGR, the power will decrease sharply to 17.805kW, about (- 24.4%) when compared to TC engine. At maximum volume of injected water (0.5mm at 10bar), the power will decrease to 15.776kW (-33%). At high engine speeds the volumetric efficiency decreases, the air flow rate will decrease and the engine cannot resist the addition of 10% EGR beside high rate of WI.

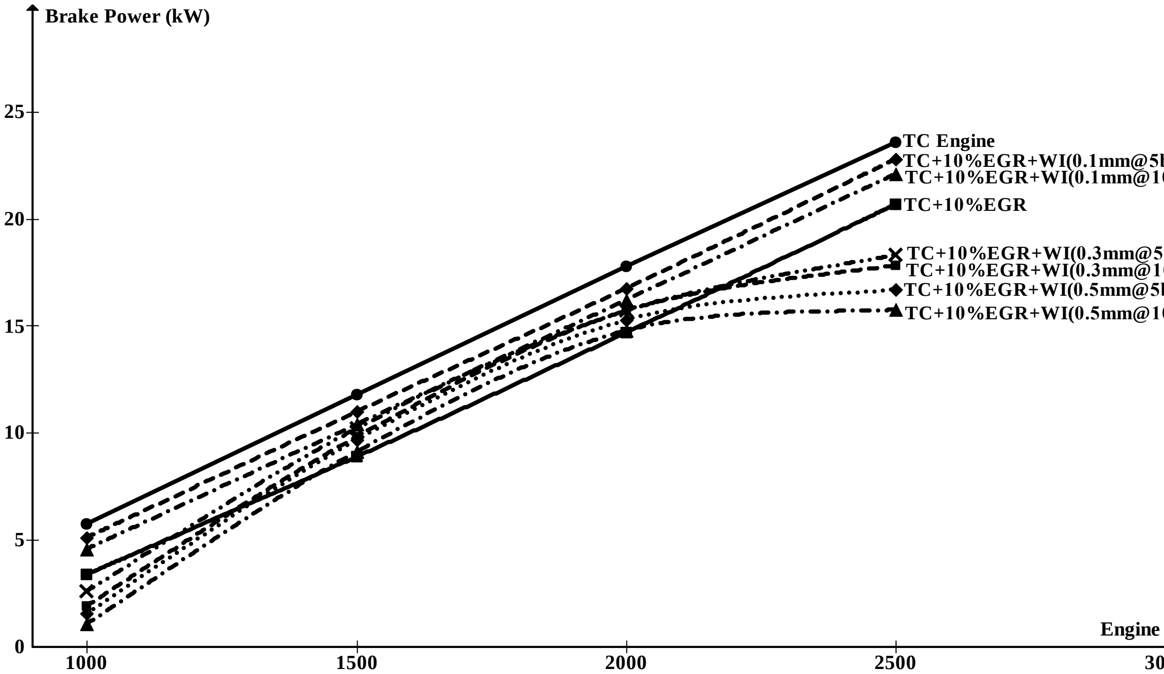

Figure (6): The effect of combined system (WI +10%EGR Ratio) on brake power.

3-1-3 Combined System (WI+20% EGR Ratio)

Referring to Table (3), Fig (7), shows the effect of combined system of water injection with EGR by fully opening valve (20% EGR ratio) on engine brake power, all the test set-ups give power less than that obtained by TC engine, and still the brake power in cases of 20% EGR + WI (0.1mm at 5 and 10bar) are located and plotted between test set-up of TC engine and TC + 20% EGR ratio, e.g. at 2000rpm the power will be equal to 17.798kW in case of TC engine, and at set-up (20% EGR + WI (0.1 mm at 5bar)) the power will decrease to 16.909kW. By increasing the injected water when using WI set-up (0.1mm at 10bar) more decrease in power will occur and it was found to be 14.519kW, while the brake power in the case of TC + 20% EGR will be equal to 13.369kW. The ratio of decline in the power as a result of adding injected water at the presence of 20% EGR when compared to TC engine set-up are -5, -18.4% respectively. When comparing the results of (WI + 20% EGR) set-ups to that obtained from set-up of 20% EGR only, quite clearly from the Fig (5) there are positive results, particularly at the WI

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set-ups been mentioned before. The increment percentages are +20.9, +7.9% respectively when compared to the 20% EGR set-up.

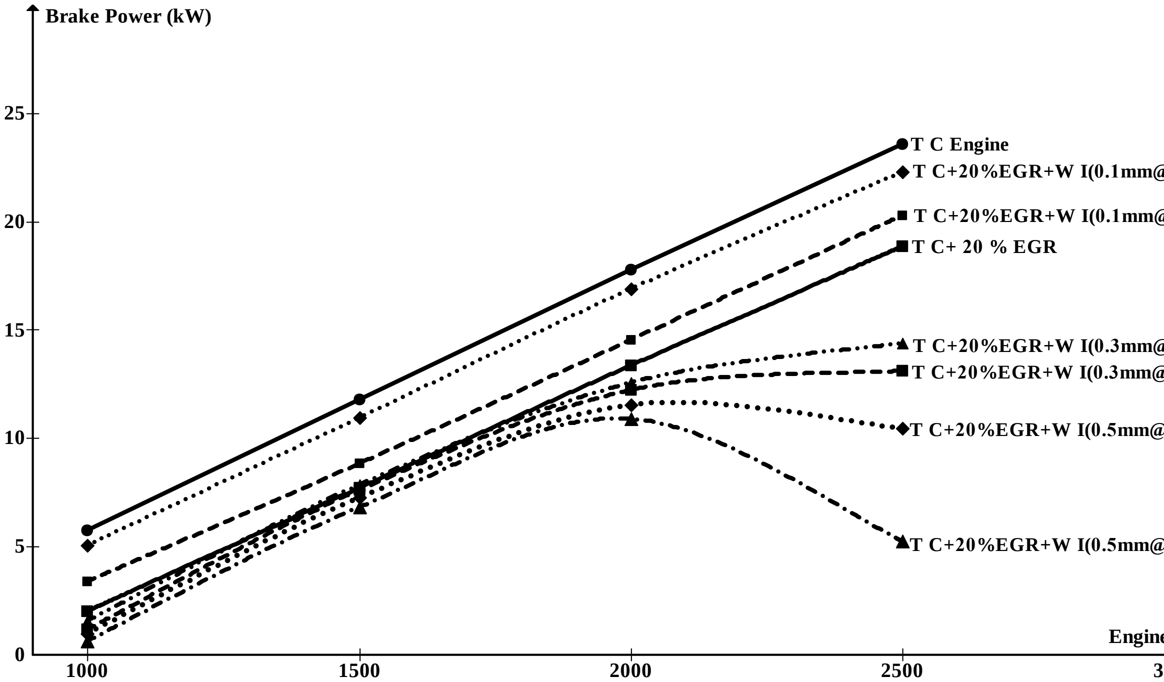

Figure (7): The effect of combined system (WI + 20 % EGR Ratio) on brake power.

As the injected water increases at the presence of 20% EGR the power will tend to decrease particularly at high engine speeds, for example at 2000rpm and WI set-up 0.3mm at 5bar the power will be 12.563kW, at WI set-up 0.3mm at 10bar the power will be subjected to more reduction and it was found 12.239kW, at WI 0.5 at 5bar the power will reach 11.519kW and at WI system set-up 0.5mm at 10bar, the power was found 10.909kW. The reduction percentages when compared to TC engine set-up are -29.4, -31.2, -35.3 and -39.4% respectively, and -6, - 8.5, -13.8 and -18.4% respectively when compared to set-up 20% EGR only. Referring to Figures (5), (6), and (7) the impact of combined system (EGR + WI) on diesel engine performance in terms of brake power can be summarized in the following points:

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- Combined system is not applicable on diesel engine at low engine speeds, the volumes of suction air are low, and combustion cannot resist the addition of flue gas or water.
- Great power will be obtained when using a certain volume water injection set-ups (0.1mm at 5 and 10bar, and 0.3mm at 5bar) at mid and high engine speeds.
- Generally, EGR system will cause a decrease in brake power through all engine speeds; this is because of the addition of incombustible gas to the fresh air [8].

3-2 Nitrogen Oxides

3-2-1Combined System (WI + 0% EGR)

In a piston engine, the initial injection of water cools the air significantly, which increases its density and hence the amount of air that enters the cylinder. An additional effect comes later during combustion when the water absorbs large amounts of heat as it vaporizes, reducing peak temperature and the resultant NO_x formation. Table (3) and Fig (8); show the effect of the WI system at different volumes of injected water on NO_x emissions. From the graph, all WI set-ups will affect positively and reducing NO_x emissions, and as water volume increases, the formation of NO_x decreases. This is because NO_x emissions depend mainly on peak temperature, and as the injected water increases, the resultant NO_x formation decreases. For example, at TC engine set-up and 2000rpm the reading of NO_x emissions is 111ppm, at WI set-up 0.1mm at 5bar NO_x decreases to 68ppm, at set-up 0.1mm at 10bar the NO_x will be equal to 65ppm, the NO_x decrease will continue as the volume of injected water increases, the decrease percentages of NO_x are 38.7 and 41% respectively. The maximum decrease in NO_x will be obtained at a maximum volume of injected water. At WI set-up 0.5mm at 10bar, the NO_x emissions are equal to 49ppm, about 60% reduction when compared to TC engine.

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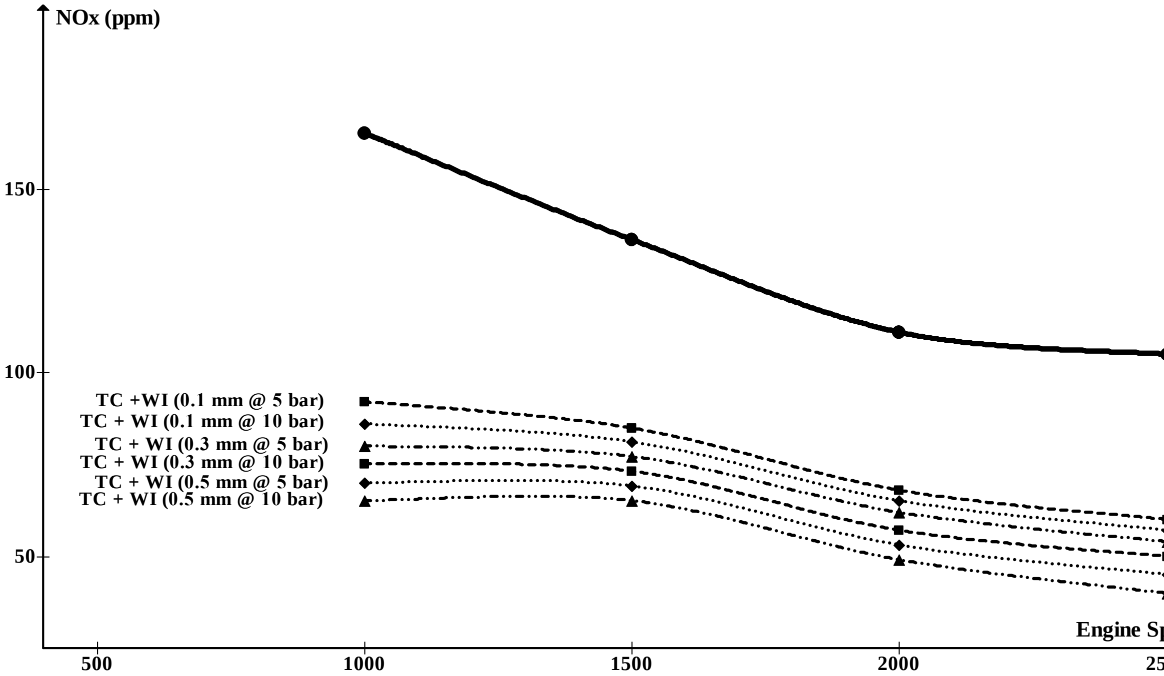

Fig (8): The effect of WI system on NO_x emission.

3-2-2 Combined System (WI + 10% EGR)

EGR is a useful technique for reducing NO_x formation in the engine combustion chamber when part of the exhaust is re-circulated to the cylinder to be mixed with the incoming fresh air. The specific heats of EGR are much higher than fresh air; hence EGR increases the heat capacity of the intake charge, thus reducing the temperature rise for the same heat release in the combustion chamber. Three popular explanations for the effect of EGR on NO_x reduction are increased ignition delay, increased heat capacity and dilution of the intake charge with inert gases. In the case of combined system of water injection and EGR with half opening valve (10% EGR ratio + WI), Fig (9) shows how the emissions of nitrogen oxides will decrease significantly when combined system are present at engine operation. First a considerable reduction in NO_x as a result of adding 10% EGR only, e.g. at 1500rpm and TC engine the NOx was found 136 parts per million (ppm), and at TC+10% EGR the NOx will decrease to 118ppm (- 13.2%). Great benefit could be achieved when adding injected water besides the 10% of EGR ratio, a significant reduction in NO_x emissions and will continue as the volume of injected water increases. For example, at test set-up (10% EGR + WI (0.1mm at 5bar)), the NO_x reading was found 44ppm, at (10% EGR +

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WI (0.1mm at 10bar)) the NO_x will reduce to 40ppm, increasing the water volume to set-up (0.3mm at 10bar) the NO_x will decrease to 33ppm. The value of 27ppm is obtained with engine speed of 2000rpm, whereas, at 1500ppm it is 26ppm. The reduction percentages when compared to the emissions of TC engine are -67.6, -70.6, -75.7 and -80.1% respectively. If the comparison was based upon the emissions of TC + 10% EGR set-up, the results would be -62.7, -66.1, -72 and -77.1% respectively. At low engine speeds, the formation of NO_x will reach to its minimum, this occurs because the air mass flow rate is reduced. At 1000rpm and test setup 10% EGR, NO_x emission is equal to 145 ppm, as WI is added to 10% EGR system, the NO_x emission is reduced. At WI setup (0.1mm at 5bars) NO_x will decrease to 27ppm (-81.7%), and at setup (0.5 mm at 10 bars) NO_x will reach 4 ppm (-97%), compared to setup TC + 10%EGR.

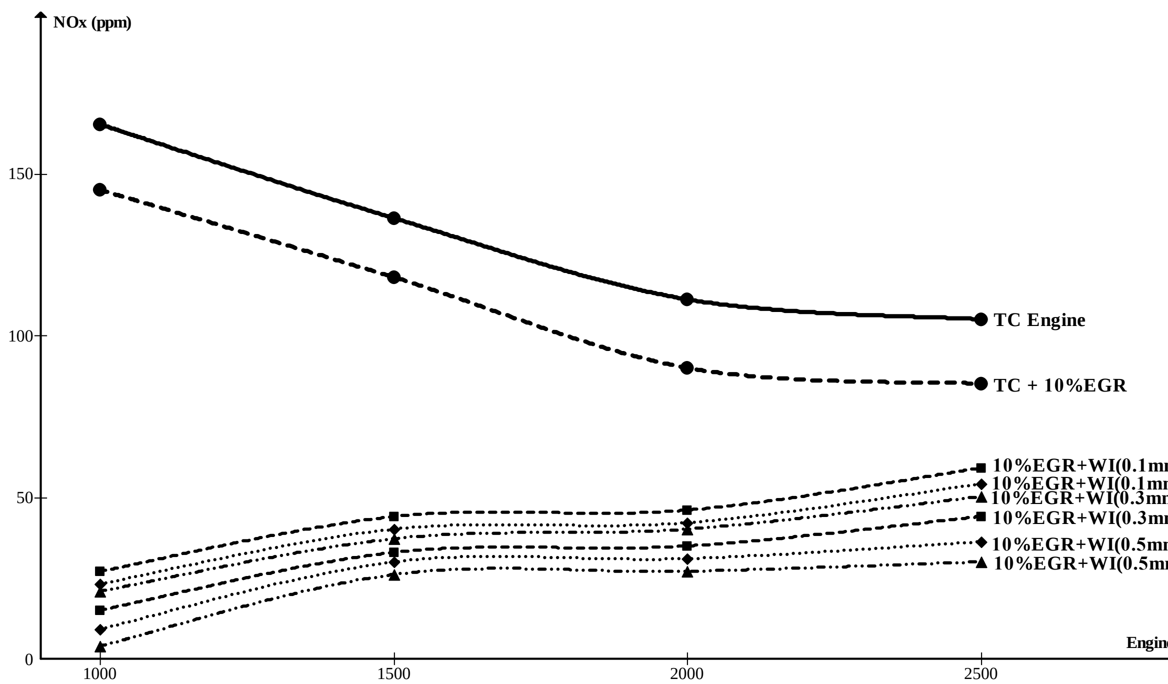

Figure (9): The effect of combined system (WI + 10% EGR) on NO_x emissions

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3-2-3 Combined System (WI+20% EGR)

Fig (10) shows a great reduction in nitrogen oxides, particularly at the presence of WI system and 20% EGR ratio (fully EGR valve open). As the volume of water injection increases, the NO_x decreases. First investigation will be taken to study the effect of 20% EGR only on NO_x emissions, e.g. at TC engine and 2000rpm the NO_x reading was 111ppm, when 20% is added the NO_x will decrease to 77ppm, about (-30%). Also as the engine speed increases, the NO_x emissions will decrease (at both test set-ups TC engine and TC+20% EGR) for example at test set-up (TC engine + 20% EGR) and 1000rpm the NO_x are found 131ppm, at 1500rpm the NO_x will lower to 105ppm, at 2000rpm will reach to 77ppm and finally to 72ppm at 2500rpm. The decrease percentages (based on emissions of 1000rpm), as a result of increasing engine speed are -19.8, -41.2 and -45% respectively. The occurrence of this phenomenon is attributed to that NO_x is a function of residence time (is the average amount of time that NO_x spends in formations); as residence time decreases at high engine speeds NO_x emissions decrease. When water injection is present at different volumes beside the 20% EGR, more decrease in NO_x emissions will occur, the two main factors affecting NO_x emissions (excess oxygen and high combustion temperature) will vanish, EGR will eliminate the amount of excess oxygen and WI will absorb large amounts of heat as it vaporizes, reducing peak temperature and resultant NO_x emissions. For example at TC engine and 2500rpm the NO_x was found 105ppm, at set-up TC + 20% EGR the NO_x will reduce to 72ppm, at set-up TC + 20% EGR + WI (0.1mm at 5bar) the NO_x reading was found 30ppm, when the volume of water increases by the set-up (0.1mm at 10bar), the NO_x will drop to 26ppm, at WI set-up (0.3mm at 10bar) the NO_x will be subjected to more reduction 17ppm, and at the maximum volume of injected water (0.5mm at 10bar) the NO_x will reach its minimum value of 10ppm. The reduction percentages of NO_x when compared to the emissions of TC + 20% EGR are -58.3, -63.9, -76.4, -86.1% respectively.

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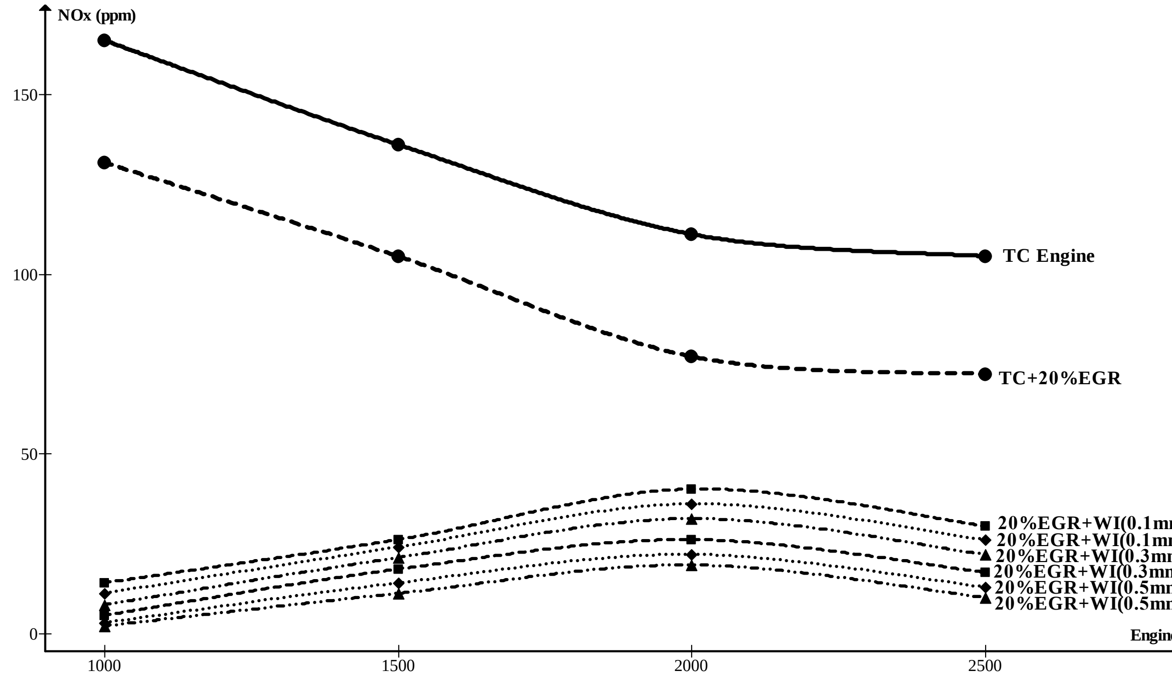

Figure (10): The effect of combined system (20% EGR + WI) on NO_x emissions.

When considering any test set-up of combined system in Fig (10), it is noted that the NO_x emissions will generate at low rates, the reasons which led to reduced the NO_x emissions at low engine speed are the presence of EGR and WI during the low - rate flow of fresh air, this in turn leads to lowering the amounts of sucked air when adding the EGR. Secondly the specific volume of water (constant through all engine speeds) will cool the air when the water injection gets into the system, these factors lead to a great reduction of nitrogen oxides at low engine speeds, e.g. at 1000rpm and setup of TC engine the NO_x reading was 165ppm. When adding 20% EGR ratio the NO_x drops to 131ppm. In the presence of Water Injection by set-up 0.1mm at 5bar + 20% EGR the NO_x will be 14ppm, more injected water at WI set-up (0.1mm at 10bar) the NO_x lowers to 11ppm. At WI (0.3mm at 10bar) the NO_x will reduce to 5ppm, and finally at WI set-up (0.5mm at 10bar) the NO_x equals 2ppm. The reduction percentages of NO_x when compared to emissions of TC+20% EGR and at low engine speed when using a combined system (EGR + WI) are -89, -91, -96.2, and -98.5% respectively.

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4- CONCLUSIONS:-

Using low volumes of injected water (0.1mm at 5 and 10bar and 0.3mm at 5bar), will increase the output power at mid and high engine speeds, when compared to TC engine. Combined system (10 and 20% of EGR + WI) will reduce the engine power when compared to TC engine set-up, but it is greater than the power obtained by set-up 10 and 20% EGR only. There is a negative effect of WI and (WI + EGR) on engine brake power at low engine speeds (less than 1250rpm). The NO_x will decrease significantly at 10 and 20% of EGR, when compared to emissions of TC engine. Water injection reduces the NO_x emissions significantly, but a great reduction of NO_x could be obtained by using the combined system (EGR + WI).

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Table (3): Experimental Results

Engine Condition	**N(rpm)**	**B Power (kW)**	**NOx (ppm)**	**Engine Condition**	**N(rpm)**	**B Power (kW)**	**Nox (ppm)**
T C Engine	1000	5.758	165	**TC + 10%EGR + WI 0.3mm @ 5bar**	1000	2.618	21
	1500	11.778	136		1500	10.208	37
	2000	17.798	111		2000	15.705	40
	2500	23.554	105		2500	18.323	50
TC + 10% EGR	1000	3.369	145	**TC + 10%EGR + WI).3mm @ 10ba**	1000	1.939	15
	1500	8.868	118		1500	9.828	33
	2000	14.659	90		2000	15.709	40
	2500	20.664	85		2500	17.805	50
TC + 20% EGR	1000	2.021	131	**TC + 10%EGR + WI 0.5mm @ 5bar**	1000	1.559	09
	1500	7.698	105		1500	9.678	30
	2000	13.369	77		2000	15.288	31
	2500	18.745	72		2500	16.716	36
TC + 0% EGR+ WI 0.1mm @ 5bar	1000	4.188	92	**TC + 10%EGR + WI).5mm @ 10bar**	1000	1.090	04
	1500	13.347	85		1500	9.148	26
	2000	19.898	68		2000	14.759	27
	2500	26.173	60		2500	15.776	30
TC + 0% EGR+ WI .1 mm @ 10 ba	1000	3.888	86	**TC + 20%EGR + WI 0.1mm @ 5bar**	1000	5.058	14
	1500	13.617	81		1500	10.958	26
	2000	20.208	65		2000	16.909	40
	2500	26.803	57		2500	22.294	30
TC + 0% EGR+ WI).3 mm @ 5 ba	1000	3.239	80	**TC + 20%EGR + WI).1mm @ 10bar**	1000	3.399	11
	1500	14.127	77		1500	8.848	24
	2000	20.848	62		2000	14.519	36
	2500	27.303	54		2500	20.265	26
TC + 0%	1000	2.969	75	**TC**	1000	1.571	11

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EGR+ WI .3 mm @ 10 ba	1500	10.378	73	**+ 20%EGR + WI 0.3mm @ 5bar**	1500	7.853	21
	2000	17.798	57		2000	12.563	32
	2500	24.863	50		2500	14.396	22
TC + 0% EGR WI).5 mm @ 5 ba	1000	2.619	70	**TC + 20%EGR + WI).3mm @ 10bar**	1000	1.180	05
	1500	9.268	69		1500	7.609	18
	2000	15.169	53		2000	12.239	26
	2500	20.734	45		2500	13.086	17
TC + 0% EGR WI .5 mm @ 10 ba	1000	1.569	65	**TC + 20%EGR + WI 0.5mm @ 5bar**	1000	0.990	03
	1500	8.778	65		1500	7.279	14
	2000	14.749	49		2000	11.519	22
	2500	20.155	40		2500	10.467	13
TC + 10%EGR + WI).1mm @ 5bar	1000	5.098	27	**C + 20%EGR WI (0.5mm @ 10bar)**	1000	0.660	02
	1500	11.008	44		1500	6.819	11
	2000	16759	46		2000	10.909	19
	2500	22.764	59		2500	5.239	10
TC + 10%EGR + WI).1mm @ 10ba	1000	4.578	23				
	1500	10.388	40				
	2000	16.199	42				
	2500	22.114	54				