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Research paper

Experimental study on effect of injection retard on emissions and performance in a diesel engines

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Abstract

In this research, engine OM 364 LA, made in IDEM Co. was studied. Engine emissions include CO, NOx and UHC were tested using ISIRI 6764 standard (ECE-R49) and ESC test cycle. The test cycle consisted of 13 steady states in the different range of rpm and loads (25 to 100 %). the goal was experimentally study on the effects of injection retard on NOx emissions and engine performance. The results indicated a 65% reduction in NOx emissions but at the cost of a 14% reduction in engine power. Although the overall results indicate a drop in performance and a reduction in engine thermal efficiency due to injection retard but in contrast, there is a significant improvement and reduc-tion of NOx emission.

Keywords: *Diesel Engines; Injection Retard; Performance; Emission*

1. Introduction

Air pollution is one of the environmental challenges and serious problems in the country that has been created due to the unbalanced development and futile human interference and put the health of plant species, animals and people at risk. The results of studies on the effects of air pollution have illustrated that the presence of SO_x, NO_x, CO_2, CO and PM increases the likelihood of congenital anomalies, abortions and increase high risk pregnancy and reduces immunity against infectious diseases. It has been also shown similar pathological changes in most of the animals tested. In large cities, airborne pollutants, NO_x and SO_X, are sitting down on old buildings and cause corrosion of building facades. The metropolis of Tehran, Karaj, Arak, Isfahan, Shiraz, Ahvaz, Mashhad and Tabriz are known as the polluted cities of Iran. And due to the high levels of air pollution in these areas, the air pollution index has been exceeded. Following the energy and environmental crises caused by car pollutants, most countries in the world, especially in Europe and the United States, have been forced car manufacturers into designing suitable engines to enforce strict fuel consumption rules and reduce air pollution. One of the things that carmakers have done is the production of diesel vehicles. Today, diesel engines which are referred as "green cars" have grown vastly. This type of vehicle includes more than 50 percent of European cars [1-2].

Several methods have been considered to reduce emissions from internal combustion engines. In most of these methods, there is a need for changes to the engine, and sometimes it feels like the need for new designs. Khabbazi et al [3] conducted the study on the effect of the content of sulfur and cetane number on the performance and pollutants of the diesel engine, and concluded that by increasing cetane number increases, NOx decreases and, on the contrary, increases the suspended particles. Khabbazi & Khoshbakhti sarrai [4] conducted a theoretical study on the effect of pressure, time and spraying of diesel fuel on the performance and emissions of direct injection diesel engine. The results showed that, with increasing spray pressure, NOx significantly increased and PM decreased by about 50%. Also, in return for these changes, engine efficiency increased by 12%.

In diesel engines, exhaust emissions, in addition to carbon monoxide (CO), unburned hydrocarbons (HC), and nitrogen oxides (NOx), also include suspended particles (PM or Soot). These engines usually operate within the range of the dilution equivalence ratio and the outlet smoke contains significant amounts of oxygen. Using a two-way catalyst, CO and HC are easily oxidized but due to the smoke conditions, NO_X reduction is very difficult and there is the need to use more sophisticated technologies to reduce NOx. For this reason, it attempts to reduce the production of NOx in these engines by using internal engine techniques such as exhaust gas recirculation (EGR) [5]. Montomori & Reitz [6] studied the effect of combining multiple fuel injection strategies and EGR to reduce the output of NOx. They showed that with the combination of EGR and multiple injections, the NOx outputs can have a greater reduction in maximum temperature inside the cylinder. However, soot increases due to the creation of several higher temperature zones due to the reduction of oxygen inside the cylinder. Adopting an optimized injection strategy for different engine operating conditions is a challenging task for modern diesel engines. It is very challenging to achieve high performance with the lowest possible fuel consumption and greenhouse gas emissions. Yamaki et al [7] conducted a test on a heavy-duty direct turbocharged diesel injection engine to achieve the effects of Pilot injection on exhaust emissions. They found that Pilot injection has been effective to reduce smoke at high load, especially in low speeds. Pilot injection was also effective in reducing NO_X and HC in low loads as well as to reduce noise throughout the engine operating range. Chida et al [8] performed an experimental analysis on a prototype heavy turbocharged diesel engine for optimizing combustion and greenhouse gas emissions using a common rail injection system. They found that Pilot injections could improve the fuel consumption. However, the combination of Pilot and EGR injections had little benefit in NOx and PM improvement because the PM increased with the decrease of NOx, especially in low load conditions. Park et al [9] examined multiple injections in an HSDI diesel engine equipped with a CR injection system. Based on the results, multiple injection strategies can reduce particle emissions by more than 40%.In addition, the effect of retard injection on the reduction of soot emissions was studied by Han et al [10] and Farel et al [11]. Their results showed that the high combustion temperature during mixing controls the combustion phase of the injection retard due to improved oxidizing of soot and reduced soot emissions.

2. Material and methods

The tested engine is a 4-cylinder turbocharged diesel engine, with OM 364 LA intercooler, produced by the IDEM Co. in Tabriz. According to the manufacturer's catalog, the nominal power is about 100 KW and the nominal torque is 430 Nm. The dynamometer used was a vortex flow of 400 KW and a range of 5000 rpm, produced by Dynamic Industry Development Co. The design of the control panel and its software, including the equipment such as the balance system and fuel consumption measurement, are all owned by this company. By the above equipment, it is possible to test the performance characteristics of a diesel engine, including power, torque and specific fuel consumption, and other required temperature and pressure data for functional calculations using the standard ISIRI 6483 (R85-80 / 1269 / EEC). Engine emission tests Including carbon monoxide (CO), nitrogen oxides (NOx) and unburnt hydrocarbons (UHC) and particulate matter (PM) output from the engine were performed using the standard (ECE-R49) ISIRI 6764 and the ESC test cycle. The test cycle consisted of thirteen basic modes in the range of rpm and loads (25 to 100 %). The Euro emission standards (Table 1) define the maximum permissible emission levels for emissions from vehicles sold in EU countries. Various standards are considered for different types of vehicles. The standard of an engine is investigated by engine testing in a given test cycle. Engines that do not comply with this standard can't be sold in Europe. But new standards do not apply to previous cars. There is no compulsion to use a particular technology.
In Iran, according to government-approved mandatory environmental regulations, a timetable is scheduled to promote the production of engines to the higher euro standards. For this purpose, fuel quality improvement projects are also defined and are in progress, and gradually products of Euro 4 and Euro 5 quality are expected to be launched.

Table 1: EU Emission Standard for HD Diesel Engine, G/Kwh (Smoke in M^{-1})

	DATE	Test cycle	CO	HC	NO_x	PM	smok
Euro I	1992, <85 kW	ECE R-49	4.5	1.1	8.0	0.612	
	1992,> 85 kW		4.5	1.1	8.0	0.36	
Euro II	October 1996		4.0	1.1	7.0	0.25	
	October 1998		4.0	1.1	7.0	0.15	
Euro III	*October 1999 EEVs only*	*ESC & ELR*	*1.0*	*0.25*	*2.0*	*0.02*	*0.15*
	October 2000	ESC & ELR	2.1	0.66	5.0	0.10 0.13*	0.8
Euro IV	October 2005		1.5	0.46	3.5	0.02	0.5
Euro V	October 2008		1.5	0.46	2.0	0.02	0.5
Euro VI	January 2013		1.5	0.13	0.4	0.01	

3. Result and discussion

3.1. Emission results

The OM 364LA engine emission tests (Except PM due to non-preparation of the PM-meter and also being out of range) according to the ESC test cycle as well as performance tests according to standard R85, were performed once for the base engine and again by adjusting the injector pump and fuel system leading to the retard of fuel injection of 6 degrees of crankshaft of the base conditions (12 CA BTDC) and reaching the test conditions (6 CA BTDC) and the results were recorded and calculated according to the tables 2 -4.
Considering the high cost of the above tests on the one hand and the calibration of all the equipment on the other hand, it was neglected to repeat and record all performance tests and emissions. It was only validated at several points, including the maximum range and maximum torque in the rounds B, which have the highest coefficient of calculation, without recording the repeat results. These points showed good repeatability.

Table 2: Results of Emission for Baseline Conditions in 13 Modes

Test date:95/03/13 Relative humidity(%) 26
Test No. : 1 Pressure: 646 mmHg
Remarks: OM 364 LA Base Test

Mode NO.	rev. (rpm)	percent load	Torque (N.m)	Wf	Mfuel (kg/h)	Texh. (deg.C)	T cell (deg.C)	Tw_{in} (deg.C)	Tw_{out} (deg.C)	Power (kw)	HC (PPM)	CO (PPM)	CO2 (%)	O2 (%)	Soot (B.N)	λ	NOx (PPM)
1	745	0	4	0.15	0.67	95	27	25	68	0.3	17	200	1.7	18.8		8.81	278
2	1650	100	427	0.08	15.45	221	28	33	68	73.8	16	300	10.3	7.1		1.481	1879
3	2115	50	214	0.1	10.63	296	29	52	71	47.4	13	100	7.1	11.6		2.144	1665
4	2115	75	322	0.1	14.96	283	29	51	71	71.3	13	100	8.1	10.1		1.874	1854
5	1650	50	214	0.05	8.29	282	29	51	72	37.0	15	100	8	10.4		1.911	1602
6	1650	75	322	0.05	11.64	291	29	49	71	55.6	14	200	9.4	8.5		1.631	1841
7	1650	25	105	0.05	5.01	260	30	46	70	18.1	15	200	5.4	13.6		2.748	921
8	2115	100	418	0.09	19.6	307	30	53	72	92.6	10	100	8.9	8.9		1.702	1791
9	2115	25	106	0.1	6.52	275	30	52	71	23.5	15	100	5.2	13.8		2.836	1100
10	2580	100	372	0.08	22.76	314	30	52	72	100.5	13	100	9.2	8.5		1.651	1368
11	2580	25	92	0.05	7.99	281	31	56	71	24.9	14	100	5.2	13.7		2.83	769
12	2580	75	280	0.05	17	289	31	54	72	75.6	14	100	7.7	10.4		1.945	1259
13	2580	50	186	0.05	12.66	289	31	55	72	50.3	15	100	6.6	12		2.28	996

BSHC= 0.245 gr/Kw.h BSCO= 0.772 gr/Kw.hr BSNOx= 13.608 gr/Kw.hr PM= gr/Kw.hr
BSFC= 226.98 gr/Kw.hr

EURO3: BSHC=0.66 gr/Kw.hr BSCO=2.1 gr/Kw.hr BSNOx=5.0 gr/Kw.hr P.M.=0.1 gr/Kw.hr

Table 3: Results of Emission for Test Conditions in 13 Modes

Test date:95/03/19
Test No. : 2
Relative humidity(%) 25
Pressure: 646 mmHg
Remarks: OM 364 LA with pump adjustment (Retarding)

Mode NO.	rev. (rpm)	percent load	Torque (N.m)	Wf	Mfuel (kg/h)	Texh. (deg.C)	T cell (deg.C)	Tw_{in} (deg.C)	Tw_{out} (deg.C)	Power (kw)	HC (PPM)	CO (PPM)	CO2 (%)	O2 (%)	Soot (B.N)	λ	NOx (PPM)
1	722	0	2	0.15	0.72	94	26	39	65	0.2	34	700	1.8	18.4		7.654	50
2	1650	100	398	0.08	16.17	288	26	41	70	68.8	10	500	11	6.5		1.412	617
3	2115	50	214	0.1	11.81	302	27	48	71	47.4	16	100	7.8	10.7		1.962	515
4	2115	75	322	0.1	17.39	317	27	49	71	71.3	12	100	8.7	9.5		1.767	498
5	1650	50	214	0.05	9.23	318	28	50	71	37.0	15	200	9.1	9		1.695	725
6	1650	75	322	0.05	13.5	333	28	48	71	55.6	11	300	10.2	7.5		1.51	630
7	1650	25	104	0.05	5.39	316	28	49	71	18.0	23	600	6.1	12.8		2.443	473
8	2115	100	395	0.09	21.52	349	29	47	71	87.5	6	200	9.8	7.9		1.566	532
9	2115	25	105	0.1	7.2	328	29	52	71	23.3	20	300	6	12.8		2.491	430
10	2580	100	343	0.08	24.72	361	29	50	72	92.7	9	400	10.3	7.3		1.489	484
11	2580	25	93	0.05	8.78	350	30	55	72	25.1	21	400	6.1	12.7		2.443	352
12	2580	75	280	0.05	19.9	345	30	51	71	75.6	14	200	8.9	9.1		1.712	463
13	2580	50	185	0.05	13.91	350	30	54	72	50.0	18	200	7.4	10.8		2.017	418

BSHC= 0.259 gr/Kw.h BSCO= 1.750 gr/Kw.hr BSNOx= 4.7509 gr/Kw.hr PM= gr/Kw.hr
BSFC= 259.83 gr/Kw.hr

EURO3: BSHC=0.66 gr/Kw.hr BSCO=2.1 gr/Kw.hr BSNOx=5.0 gr/Kw.hr P.M.=0.1 gr/Kw.hr

Table 4: Comparison of Emission Result

	Base Test	Retarding	EU3
HC (gr/Kw.hr)	0.245	0.259	0.66
CO (gr/Kw.hr)	0.772	1.75	2.1
NOx (gr/Kw.hr)	13.608	4.75	5

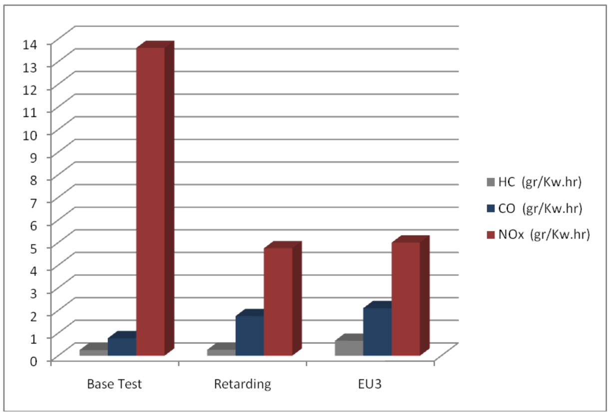

Fig. 1: Column Chart of Emission Results in Base Test and Injection Retard Test.

According to the observations of Fig.1, Nox emission has been faced to a significant reduction (about 65%) due to reduction in fuel ignition delay that is a result of its location near the TDC, the high pressure and temperature of combustion chamber during fuel spraying. As a result, the time required to form a premixed mixture is reduced and the combustion is pulled to the dispersion state. Consequently, by decreasing and reducing the release rate of the combustion energy, we will see a more favorable combustion without any violent and knocking sound and also reduce the temperature and pressure of the combustion peak. Therefore, with the reduction of combustion temperature, as the most important factor in the formation of Nox, this emission is also expected to decrease in the test engine.

In the case of UHC emission which is the main factor in their formation in diesel engines due to misfiring in the poor fuel area on the flame border, an increase in the share of combustion emissions will increase the contribution of such poor areas. Consequently, as expected, this emission will be faced with an increase in production, which, thankfully, is a small percentage of this increase in the tested engine.

Regarding the CO, which is the main reason for its formation in diesel engines due to incomplete combustion and the CO_2 decomposition phenomenon due to the reaction of heaters, it is expected that by increasing the contribution of combustion and thereby reducing the reaction of heat dissipation resulting from the reduction of combustion temperature, It will be reduced; but its significant increase in the test engine is due to an incomplete combustion increase which results in an increase in specific fuel consumption and hence a reduction in engine heat output. Of course, due to the fact that the share of CO (and also UHC) is inherently low, not only in this particular engine but also in general on all diesel engines. Therefore, the high percentage of it is considered as low number, and unlike No_x, it is not a matter of concern.

3.2. Results of performance

With an injection retard of 6 ° crankshaft in the test engine and starting to inject at 6 ° before TDC, we have encountered a 14% reduction in engine power and approximately 18% reduction in specific fuel consumption which has led to worse performance significantly (Fig. 2- 4).

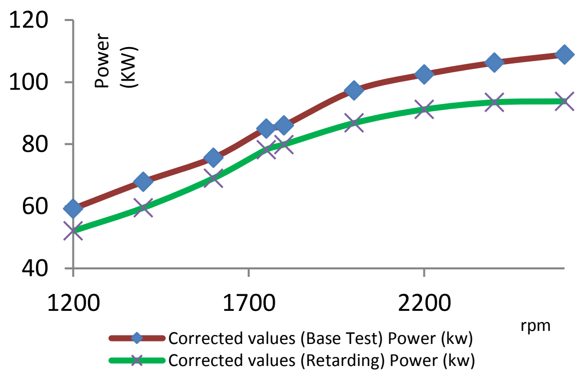

Fig. 2: Comparison of Engine Power In Base and Retard Test.

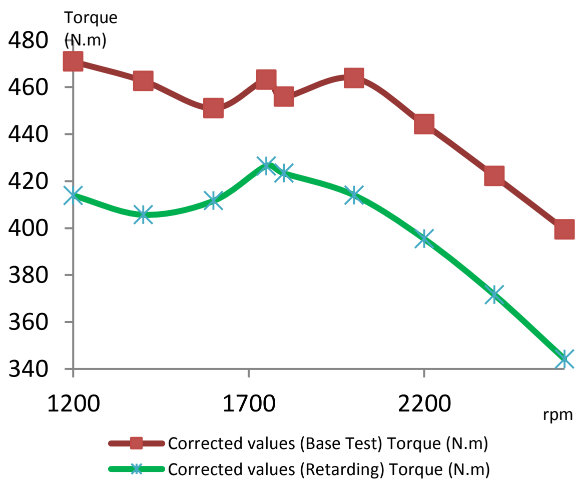

Fig. 3: Comparison of Engine Torque in Base and Retard Test.

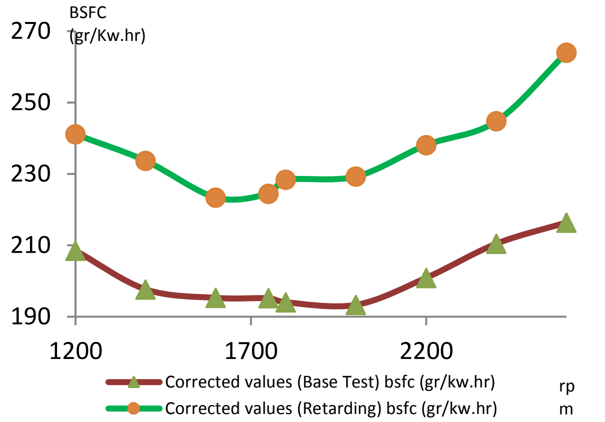

Fig. 4: Comparison of BSFC in Base and Retard Test.

4. Conclusion

Although the overall results indicate a decrease in performance and engine thermal efficiency due to injection retard, but in contrast, there is a significant improvement in No_x; Therefore, since Nox is one of the most harmful emission which for that has been determined stringent environmental laws in different countries, it is acceptable to reduce Nox at 65% even for a 14% reduction in engine power. In the end, it is suggested that in order to reach an optimal point which results in a reduction of the Nox with a slight reduction in engine performance, we must test different angles of the injection retard during several stages of the test and error.

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