EXPERIMENTAL STUDYING THE EFFECT OF AIR-INJECTION ON THE COMBUSTION BY AN AIR-CELL AND EMISSIONS CHARACTRESTICS IN A DI ENGINE

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ABSTRACT This research uses an experimental method to explore the effect of air-injection during the late combustion period produced by an air-cell on the combustion and emissions in direct injection diesel engine. In this work which is done at Motorsazan (Iran tractor manufacturing company), the engine considered is a 135TI test engine which was modeled with an air-cell included as part of the piston geometry. Pollutant emission and combustion characteristics measurements were performed according to the (ECE-R96) for baseline and modified engines. The comparing of the results shows that the emissions of the modified DI diesel engine are improved than the baseline engine while bsfc is remaining almost the same. In this study, a more improvement in particulates was obtained, while reducing of NOx by the mean of 5.4 percent, by the using of air-cells for injecting air into the combustion chamber to augment mixing and thereby increasing the rate of soot oxidation.
Keywords diesel engine air-cell emission combustion

INTRODUCTION

Stringent exhaust emission standards require the simultaneous reduction of soot and NOx for diesel engines; however it seems to be very difficult to reduce soot emission without increasing NOx emission. The reason is that there always is a contradiction between NOx and soot Emissions whenever the injection timing is retarded or advanced. Experience and simulation show that the fluid pattern in the combustion chamber has great influence on emission characteristics. Thus, to reach a superior design, investigation of this phenomenon is essential. However, an optimum fluid pattern for DI diesel engines has been always under investigation.
There are several ways for enhancing turbulent mixing, such as increasing the swirl ratio, injection pressure, multi stage injection and multi injector injection [1]. Enhancing air and fuel mixing, which is a result of increasing air turbulence, could lead to soot pollution reduction without increasing the emission of NOx. In part load condition, increasing swirl will lead to reduction in soot and HC pollutant and also decrease fuel consumption due to better air fuel mixing while the NOx pollutant is slightly increases by growing the inlet air swirl. At higher loads, increasing air swirl has smaller effect on soot and fuel consumption reduction, however higher temperature, can lead to increase of NOx[1,2]. The increased injection pressures offer the possibility better to include the complete air

charge in the mixture formation and combustion process. Due to a better mixture formation compared to the basic concept, this effect reduces the soot-NOx trade-off [1, 3, and 4].
Split fuel injection, which is produced by using multiple fuel injections per cycle and various novel injection rate patterns, can reduce both soot and NOx emissions significantly. With this particular multi-injector system, it was possible to operate the engine in several novel fuel injection 'modes,' which are difficult to achieve with conventional [1, 5-7].
Also, multiple injection strategies have been shown to be able to realize the simultaneous reduction of both NOx and particulate emissions, and experimental and numerical results have demonstrated that the soot-NOx trade-off curves can be shifted closer to the origin at DI and IDI diesel engines [1, 7- 9].
In another effort to increase the mixing rates during the late combustion period and reducing emission engines several numerical researchers have investigated the use of air-cells for injecting air into the combustion chamber to augment mixing and thereby increase the rate of soot oxidation. An air-cell consists of a small volume separated from the combustion chamber by a small passage. The air-cell charges with air from the combustion chamber during the compression stroke and the first part of the power stroke. Then, as the combustion chamber pressure falls below the air cell pressure, an air-jet emanates from the air-cell into the combustion chamber which augments mixing [10].

Takeyuki Kamimoto and et al [10] was developed a DI diesel engine with an air cell as one of the modified combustion systems for reducing soot emission from diesel engines. The air is accumulated in the air cell during the compression stroke and is injected into the main chamber during a period after the end of injection. They showed that the air jet stirs the stagnant flame and promotes soot oxidation.
The study of the relevant literature shows that no attempts have been done up to now in order to experimentally study the effect of air-injection by an air- cell on the combustion and emission characteristics in DI diesel engine. Present work, intended for a contribution to the open literature, deals with how to vary the combustion and emission characteristics for the modified engine at 8 modes according to the (ECE-R96) standard test modes.

EXPERIMENTAL SETUP AND METHODOLOGY

This study is done in Motorsazan 135TI four cylinder direct injection diesel engines. The engine under study is a commercial DI, water cooled four cylinders, in-line, turbocharged aspirated diesel engine whose major specifications are shown in table 1.
Figure1 shows Schematic diagram of experimental set-up. As shown in this figure, the mass flow meter operates on a hot wire anemometer principle. It is possible to cover a very large measuring range with constant accuracy (max. error 1% of the measured value). With a high accuracy mass flow sensor, the fuel consumption is determined continuously via direct mass flow measurement in kg/h. Temperatures of cooling water, lubricating oil, inlet air and exhaust gases were also measured to ensure proper engine operating conditions. A data acquisition system was used to collect the important data and store them in a personal computer for exact analysis.
A piezoelectric type pressure transducer (Indi Modul 621) was flush-mounted with the combustion chamber for routine sampling of the cylinder pressure traces. Cylinder pressure was measured at every 0.1 crank angles. Engine crank shaft position was determined by a crank angle encoder. The fuel injector was instrumented with a hall-effect needle lift sensor which provided indications of the

start and end of fuel injection events. Particulate concentrations were determined by measuring filter weight before and after sampling (AVL SPC 472_Model CE 97). A separate probe was used for particulate matter sampling. The temperature of the probe was maintained above 190°C to prevent condensation. The exhaust sample was then diluted in a mini-dilution tunnel using filtered and dried air. The total mass flow rate of the tunnel (G_{tot}) and the mass flow rate of diluted air (G_{dil}) were measured and controlled by SPC. The mass flow rate of the exhaust flow was calculated as the difference of the other two flows. The heated probe was mounted after the mixing tank to sample the gaseous emissions in the exhaust. Other engine emissions were measured using an AVL Dicom4000-class1 exhaust gas analyzer. Unburned hydrocarbons, CO and CO2 were measured using a non dispersive infrared detector while an electrochemical detector was used for O2 and NOx measurements.

Table1: 135TI engine specifications.

Number of intake valves	*1per cylinder*
Bore × Stroke (mm)	100 × 127
Compression ratio	17.5:1
Engine speed (rpm)	2000
Aspiration	Turbo charged
Fuel injection	DPA Pump
Start of injection (deg BTDC)	4
Duration of injection (deg)	20
Number of nozzle orifice × diameter (mm)	5 × 0.276
IVC to EVO (deg ATDC)	-146 to 95
Displacement (lit)	3.99
Rate of fuel injected (kg/hr)	15.22
Combustion chamber	Reentrant

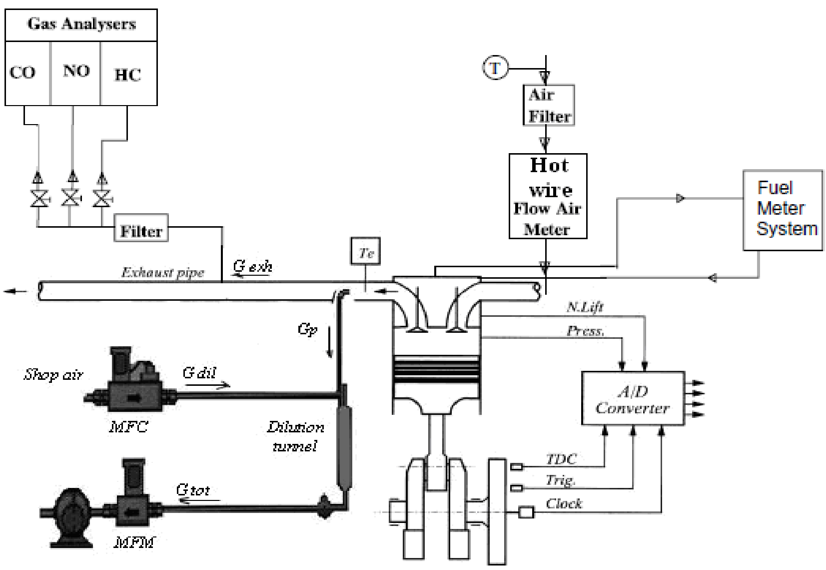

Figure 1. Schematic diagram of experimental set-up

Experiments were conducted on a DI diesel engine connected with a D.C. magnetic dynamometer. Pollutant emission and performance measurements were performed according to the (ECE-R96), at first mode of 8 mode procedure (full load power speed -2000 rpm) as shown in table2. To ensure the measurement accuracy, all emission analyzers were calibrated before and after each test run.
The emission measurements at each mode were repeated five times. The averaged values of repeated measurements were used in the analysis. From the repeated data points, the repeatability of the engine experiments can be estimated. The standard deviations over the means of the emission data are shown in table3.
It can be seen from table3 that NOx emission measurement repeatability is excellent, whereas all other measurements have good repeatability.

Table 2: 8-mode procedure.

mode	Speed (rpm)	Load (%)	Load (N.m)	Weighting Factor
1	2000	100	283	0.15
2	2000	75	212	0.15
3	2000	50	141	0.15
4	2000	25	28	0.1
5	1400	100	347	0.1
6	1400	50	260	0.1
7	1400	25	173.5	0.1
8	Idle	-	17	0.15

Table 3: repeatability of measurements.

Emissions	NOx	PM	Fuel Cons.
Std. Dev./Mean %	0.85	4.2	0.3

MANUFACTURING PROCESS OF MODIFIED PISTON WITH MORE DETAILS

According to previous investigations by various scientists four kinds of air-cell configurations were chosen to be modeled and analyzed: Air-cell below the bowl of the piston, air-cell below the piston crown with a slanted passage, air-cell below the piston crown with a straight passage and air-cell near the edge of the piston bowl. Since the maximum momentum in the combustion chamber is needed, the first profile configuration was selected to be manufactured.
There were two methods to make this piston. One was to design a new piston with an air-cell within it, precisely below the piston crown, and the other one was to alter a perfect piston by a manufacturing process as described below.
In spite of many difficulties the second approach was taken as manufacture process in this research. Thus the main idea was to drill the piston either from the top or bottom.
First off the piston crown was turned by depth of 11.1 mm and different radiuses using a CNC turning machine (Fig 1).The hatched part shown in Figure 1 has been removed.
The next step was to prepare a new crown which must be located instead of the previous one. Their profiles are same but the new one has a less depth. The materials of new crown and piston, decided

to be the same in order to prevent the problems such as pushing off because of different expansion coefficients.

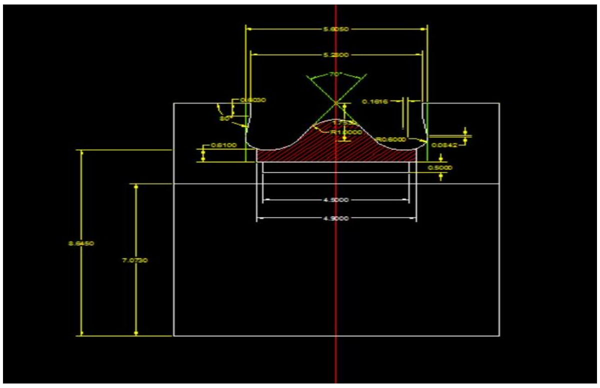

Figure 2. The hatched part was removed

The next step was to drill the new crown to have the passages. Four passages according to the location of the injector jets were considered to drill. Because of a good seal, the new crown was chilled up to -80 degrees meanwhile the piston was heated up to +80 degrees and eventually the new crown was put on the piston just like it's previous location by the pressure of 500 N. The prototype modified piston is shown in Fig. 2.

Figure 3. The prototype modified piston

Figure 4. The piston which was dismounted from the shattered engine

This piston was mounted on the engine and the engine started to work but after an hour the new crown jumped out and caused a tremendous damage. In other word the wall of the cylinder was shattered due to the collision of the cap and wall. The damaged piston is shown in Fig 3. Being not reliable, the second procedure decided to be pursued. First because of it's delicate shape the piston mounted on a four jaw chuck instead of three jaw chuck in order to prevent deformation due to the pressure. Then a curved tool started to drill a hole from the bottom side as shown in Fig 4.

Figure 4. Making a hole from the bottom of the piston

After drilling the passages as shown in Fig 5 and wiping its swerves a bonnet was made again to cover the air cell from the bottom. Its material was chosen as the same material of the piston just as before. It had a thin groove around it which made it feasible to be welded as it is shown in Fig 6. Therefore the cap was located in its place and then that welded manually with Argon gas as shown in Fig 7 in order to become safer during the test.

Figure 5. Making the passages of air-cell

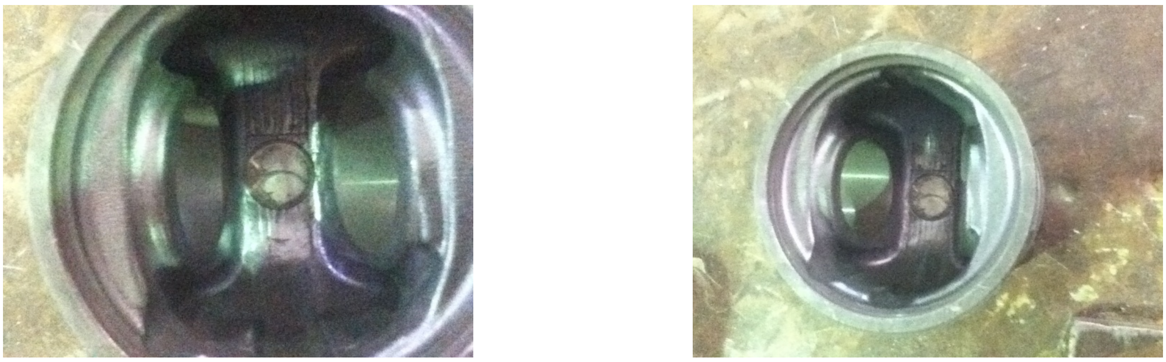

Figure 6. The groove around the bonnet which makes the piston feasible to be welded

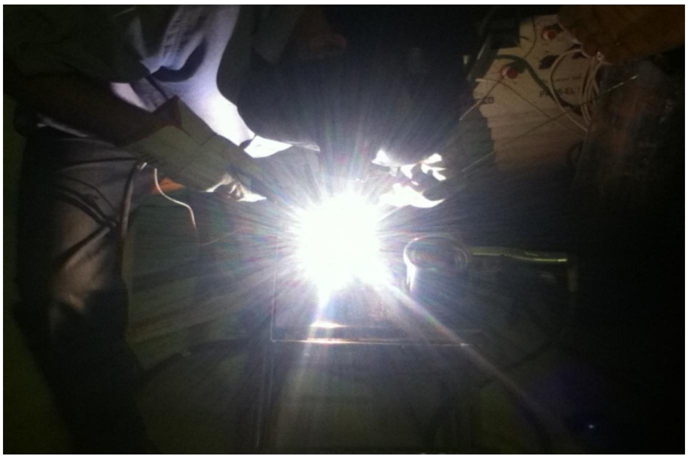

Figure 7. Welding the bonnet

Although this procedure had its difficulties, the pistons were made and mounted successfully on the engine and the engine performed without any problem.
However the first method which allows us to design a new piston with an air-cell could be more reliable because modifying the piston and having no change in other factors like clearance volume would reduce the maximum break power and torque due to the compression ratio reduction, but it is negligible in compare with the rate of soot emission reduction.

RESULTS AND DESCUSSIONS

The results have been categorized below:
Table 4 indicates the effects of the use of air-cell in engine emissions reduction. There is a big difference between amounts of emissions. In some modes the soot is reduced by even 50% and the NOx is reduced by 20% while the BSFC is approximately constant. More details are shown in table 4.

Table 4: 8-mode test results of engine for pollution (ECE-R96)

Number of mode	*Base NOx (gr/hr)*	*Air-cell NOx (gr/hr)*	*Base Soot (mg/lit)*	*Air-cell Soot (mg/lit)*
Mode1	459.8166	378.3515	0.0764	0.0496
Mode2	302.0477	261.1149	0.04482	0.02294
Mode3	156.7069	144.0374	0.03016	0.02213
Mode4	43.78264	50.77145	0.00295	0.00175
Mode5	339.9006	301.4403	0.2258	0.131
Mode6	261.9763	247.0384	0.04174	0.02928
Mode7	155.4619	148.4931	0.01735	0.0115
Mode8	20.13753	31.5833	0.00172	0.00587

Figure 8 demonstrates the diagrams of Heat Release Rate (the left axis) and the combustion pressure (the right axis) which is comparing the base engine and the air-cell one. It also indicates the times which the combustion is about to start.

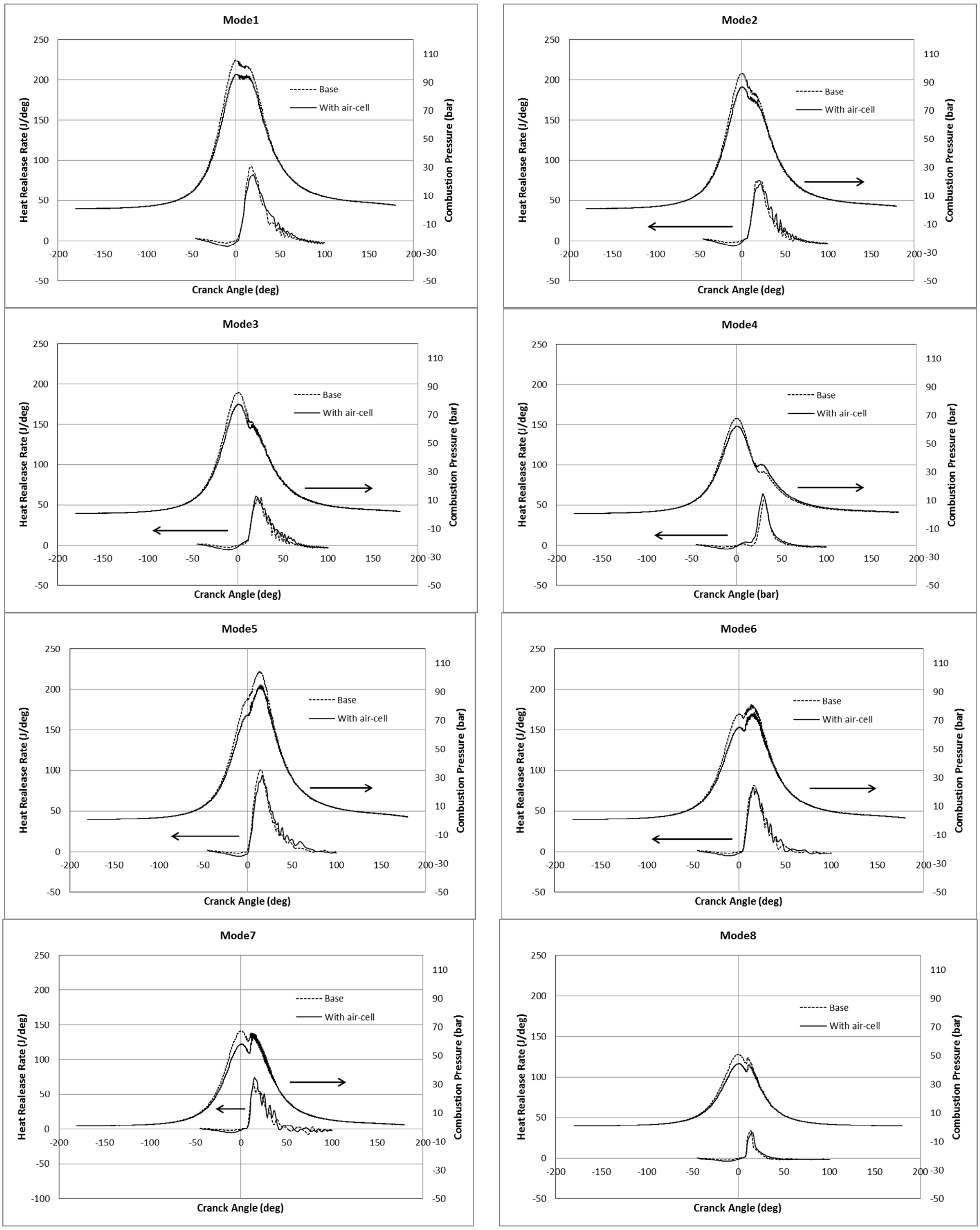

Figure 8. HRR and the combustion pressure diagrams

Table 5 shows the mean amount of emissions in both base and air-cell engine which has been elicited from the results of table 4. As it is shown in table 5 and figure 9 the air-cell has improved the mechanism of combustion proccess and also has enhenced in emmisions reduction.

Table 5: 8-mode test results of engine for pollution (ECE-R96)

	STAGE2 (37-75 kw)	*STAGE1 (37-75 kw)*	*Engine test Results(base)*	*Engine test Results(base)*
PM	0,4	0,85	0,44	0,29
HC	1,3	1,3	0,25	0,42
CO	5	6,5	1,52	1,69
Nox	7	9,2	7,22	6,83

Figure 9 indicates the charts of table 5 more clearly and compare it with the ECE-R96 stages.

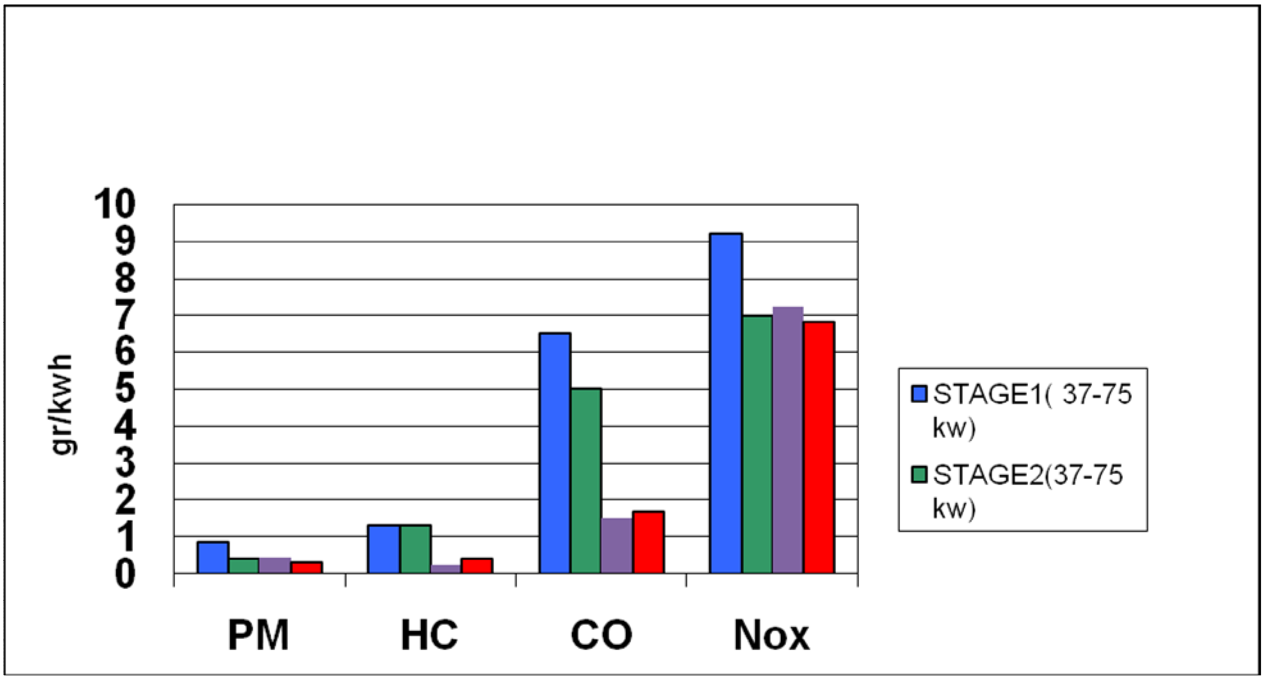

Figure 9. results of engine for pollution (ECE-R96)

In conclusion we can say the use of air-cell in engines seems to be esential in order to reduce the pollutant emmissions.

REFERENCES

[1] Carsten Baumgarten, "Mixture formation in internal combustion engines", Springer publications 2006.

[2] S. Shundoh, T. Kakegawa, K. Tsujimura, S.Kobayashi, "The Effect of Injection Parameters and Swirl on Diesel Combustion with High Pressure Fuel Injection," SAE Paper 910489, (1991).

[3]T. Minami, I. Yamaguchi, M. Shintani, K.Tsujimura, T. Suzuki, "Analysis of Fuel Spray Characteristics and Combustion Phenomena under High Pressure Fuel Injection," SAE Paper 900438,(1990).
[4]Reitz, R. D., "Modeling Atomization Processes in High-Pressure Vaporizing Sprays," Atomization and Spray Technology, Vol. 3, pp.309, 1987.
[5]Tow, T. C., Pierpont, D. A., and Reitz, R. D., "Reducing Particulate and NOx Emissions by Using Multiple Injections in a Heavy Duty DI Diesel Engine," SAE Paper 940897, 1994.
[6]. Montgomery, D. T., and Reitz, R. D., "Six-Mode Cycle Evaluation of the Effect of EGR and Multiple Injections on Particulate and NOx Emissions from a DI Diesel Engine,"SAE Paper 960316, 1996.
[7] Han, Z., Uludogan, A., Hampson, G., and Reitz, R. D.,"Mechanism of Soot and NOx Emission Reduction Using Multiple-injection in a Diesel Engine," SAE Paper 960633,
1996.
[4]Yoshinaka Takeda and Keiichi Niimura, "Characteristics of Diesel Combustion and Emissions with a Multi-injector System", SAE paper 952511, (1995).
[5]Tow, T. C., Pierpont, D. A., and Reitz, R. D., "Reducing Particulate and NOx Emissions by Using Multiple Injections in a Heavy Duty DI Diesel Engine," SAE Paper 940897, 1994.
[6]Han, Z., Uludogan, A., Hampson, G., and Reitz, R. D.,"Mechanism of Soot and NOx Emission Reduction Using Multiple-injection in a Diesel Engine," SAE Paper 960633,1996.
[7]Sinko, K.M., Shih, S., and Chehroudi, B., "Emission Characteristics of a Dual-injector Diesel Fuel Injection System", SAE Paper 960839, 1996.
[8] Uludogan. A, Xin. J, and Reitz,. R. D.,"Exploring the Use of Multiple Injectors and Split Injection to Reduce DI Diesel Engine Emissions", SAE Paper 962058, 1996.
[9] Yoshinaka Takeda and Keiichi Niimura., "Characteristics of Diesel Combustion and Emissions with a Multi-injector System", SAE Paper 952511, 1995.
[10] Kamimoto, T., Osako, S. and Matsuoka, S., "An Air Cell Diesel Engine and Its Soot Emission Characteristics," SAE Technical Paper 831297, 1983.
[11]Susumu. Nagano,Hiromitsu. Kawazoe, Katsuyuki. Ohsawa., "Reduction of Soot Emission by Air-Jet Turbulence in a DI Diesel Engine," SAE Technical Paper 912353, 1991.
[13] Nagano, S., Kawazoe, H. and K. Ohsawa., "Reduction of Soot by Air-Jet Turbulence in a D.I. Diesel Engine,"SAE Technical Paper 912353, 1991.
[14] Choi, C. Y., and Foster, D. E, "In Cylinder Augmented Mixing Through Controlled Gaseous Jet Injection," SAE Technical Paper 952358, 1995.
[15] Mather.D. K. and . Reitz R. D, "Modeling the Use of Air-Injection for Emissions Reduction in a Direct-Injected Diesel Engine," SAE Technical Paper 952359,1995.