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"Research Note"

EXPERIMENTAL STUDY OF THE EFFECTS OF AIR-INJECTION, INJECTION TIMING AND COOLED EGR ON THE COMBUSTION, EMISSIONS AND PERFORMANCE OF A NATURE ASPIRATED DIRECT INJECTION DIESEL ENGINE*

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Abstract– In this literature, a combined method has been employed to simultaneously reduce smoke (Soot) and oxide of nitrogen (Nox) and maintain the performance parameters of diesel engine. This includes creating an air jet by designing an air-cell inside the piston body, advanced injection timing and using cold exhaust gas recirculation. The tested engine was an MT4.244 engine that worked as natural aspiration. The air-cell causes reduction in both Soot and NOx emissions. Furthermore, applying cold EGR had a noticeable effect on NOx emission reduction. Advancing injection timing, the performance parameters of the engine could be improved. The tests were done in 25%, 50%, 75% and 100% load conditions, for the engine speed of 2000 rpm. The results showed that by simultaneous reduction of Soot and NOx emissions, performance parameters can be kept in a suitable range. The greatest reductions in NOx and Soot emissions have been observed in 100% load. There have been no considerable changes in BSFC (Brake Specific Fuel Consumption and power) while injection timing advances have been applied for 5° CA and 5% EGR.

Keywords– Air-cell, emissions, performance, DI diesel engine, nature aspiration, cold EGR, injection timing

1. INTRODUCTION

The main parts of the generated emissions in CI engine are Soot and NOx [1]. Due to the contrasting behavior of generating the two emissions [2] and effect of these pollutants control on engine's performance, a comprehensive view to the generating factors and behavior of these emissions in the combustion chamber is necessary. So far, many researches have been done to reduce Soot and NOx emissions simultaneously. Kawazoe et al [3] reduced a significant amount of the exhaust smoke through injecting air into the combustion chamber of the CI engine with a plunger pump, but this caused power loss in the engine. Gunabalan et al [4] studied fuel injection timing and EGR application on emissions and performance parameters. Nagano et al [5] reduced a significant amount of Soot and NOx emissions through creating an air jet with a compressed air generator. Jafarmadar et al [6-7] decreased the amount of Soot and NOx emissions in DI and IDI diesel engines by splitting the injection schemes. Khalilarya et al [8] studied the high rate of EGR and fuel injection pressure rise on Soot and NOx emissions behavior in a DI diesel engine. In an experimental work, Foster and Choi [9] studied the effect of mixing improvement on emissions by injecting high-pressure nitrogen gas and carbon dioxide jet into the combustion chamber in a DI diesel engine. Reitz et al [10] showed that applying exhaust gas recirculation along with multiple injections would cause a sharp decrease in Soot and NOx emissions with no negative effect on brake

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specific fuel consumption (Bsfc). Mather and Reitz [11] presented a method in which a secondary chamber would be embedded inside the piston and it would be connected to the main combustion chamber by throats, the results of their method indicated significant decrease in both Soot and NOx emissions. Jafarmadar et al [12] studied air-cell created inside the pistons and their insulation to improve the performance parameters by the numerical method. As mentioned before, there has been no experimental study to decrease Soot and NOx emissions while simultaneously maintaining the efficiency of CI engines. In this experimental study the tests have been done applying the hybrid method including: creating an air-cell inside the piston body, advancing injection timing and applying cold EGR in the 25%, 50% ,75% and 100% load by the engine speed of 2000 rpm.

2. DIESEL ENGINE SPECIFICATION AND MODIFIED PISTON

Research has been done on a MT4.244 engine. The tested engine was a compression ignition, four cylinder, direct injection, natural aspiration and water-cooled, the main specifications of the engine have been show in Table 1 and Fig. 1 shows the test room.

Table. 1. Specifications MT4.244 DI diesel engine

Number of cylinders	4-in line, Vertical
Number of intake valves	1per cylinder
Bore × Stroke (mm)	100 × 127
Cubic Capacity	3.99 liters
Compression ratio	17.5:1
Max power	82 bhp @ 2000rpm
Max torque	360 N.m @ 1300 rpm

Fig. 1. Experimental setup

Schematic view of modifying piston has been shown in Fig. 2 and the prepared piston has been shown from top view in Fig. 3. Creating air-cell has reduced the compression ratio from 17.5 to 16.5. After ensuring the dimension stability, the pistons are installed on the engine and the desired tests are done.

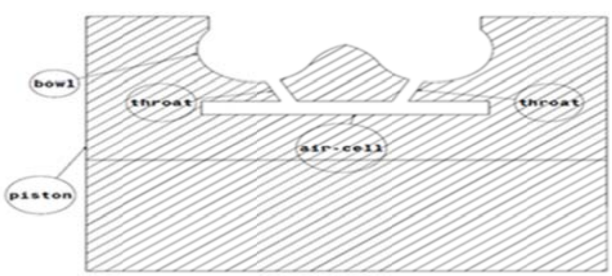

Fig. 2. Schematic view of modify piston

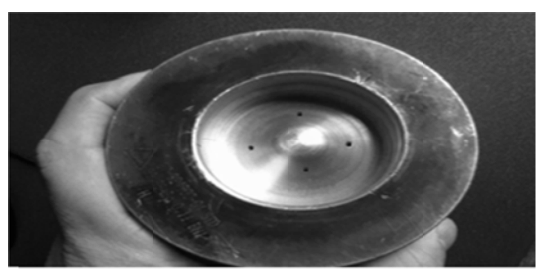

Fig. 3. The modified piston from top view

3. EMISSION STUDY

In this part, Soot and NOx emissions, the main generated pollutants in DI diesel engine, are being discussed. Figures 4 and 5 show the Soot and NOx variations, respectively. Using an air-cell can be an effective method in reducing Soot emission from a DI diesel engine by air injection and more soot oxidation in late combustion period. At the expansion course, the air has been injected into the main combustion chamber from air-cell to cause improvement in mixing process and to supply more oxygen in diffusion combustion period. In addition, it is possible that applying air-cell would cause a decrease in NOx emission due to air deficiency in the pre-mixed combustion step in main combustion chamber (due to the accumulation of air in the secondary chamber in compression stroke). Advanced injection timing would decrease the soot generation by increasing mixing period, while, improving combustion condition would increase NOx pollutant. Using exhaust gas recirculation and cooling them in a heat exchanger, it would be possible to reduce the generated NOx in the former step, due to the decrease in the available oxygen, mixing between fuel and air has not been done well and this would increase soot emission. It must be considered that the amount of NOx pollutant would be increased by raising the engine load due to increased intensity of combustion in the per-mixed period, since an improvement in the ratio of fuel compared to air in the diffusion combustion step would cause the rate of soot to go up.

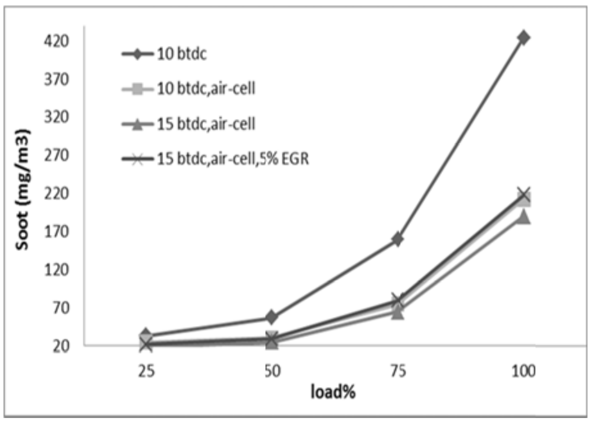

Fig. 4. Experimental results for soot emissions

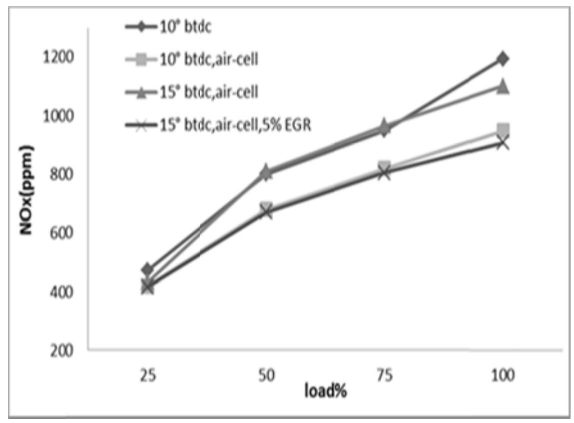

Fig. 5. Experimental results for NOx emissions

4. COMBUSTION ANALYSIS

Figures 6-9, respectively, represent the combustion chamber mean pressure and Figs. 10-13 show heat release rate at the constant engine speed in the 2000 rpm , 25%, 50%, 75% and 100% load conditions, respectively. In this paper the apparent rate of heat release $\left(\frac{dQ}{d\theta}\right)$ has been calculated from the measured pressure diagram using the following equation.

$$\frac{dQ}{d\theta} = \left(\frac{\gamma - 1}{\gamma}\right) P \frac{dV}{d\theta} + \left(\frac{1}{\gamma - 1}\right) V \frac{dP}{d\theta} \tag{1}$$

in which θ is the crank angle, V is the cylinder volume as a function of the crank angle, p is the pressure of the combustion chamber and γ is specific heat ratio.

The pressure curve peak and the heat releasing rate curve peak have been decreased using air-cells inside the piston, due to an increase in dead volume in the combustion chamber and lower available air for complete combustion. Advancing the injection timing the amount of 5° crank angle, the combustion chamber pressure peak and maximum of heat realizing rate value will rise (dQ/V.dθ), which is in pre-mixed combustion period. This is due to more fuel atomization and better mixing in ignition delay step. The next step is using 5% of cold EGR due to the decrease of the combustion chamber temperature and the decrease of the amount of necessary oxygen for a suitable combustion cause a decrease in maximum pressure and in the heat releasing peak.

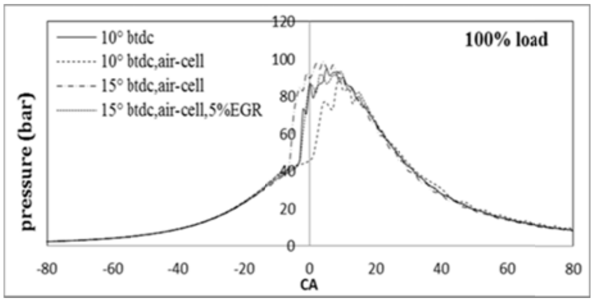

Fig. 6. Cylinder pressure against crank angle for 100%load

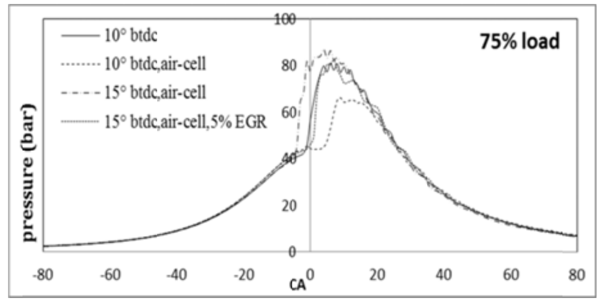

Fig. 7. Cylinder pressure against crank angle for 75%load

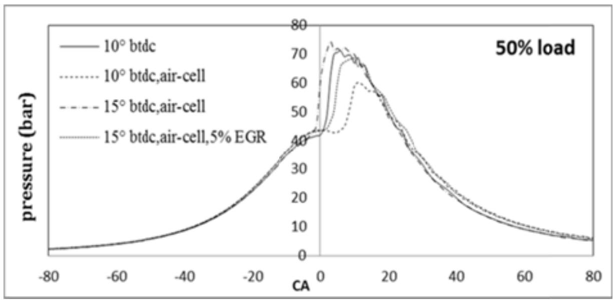

Fig. 8. Cylinder pressure against crank angle for 50%load

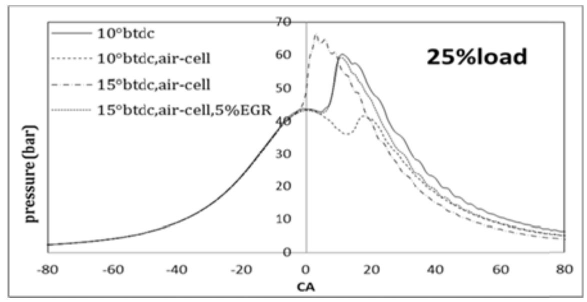

Fig. 9. Cylinder pressure against crank angle for 25%load

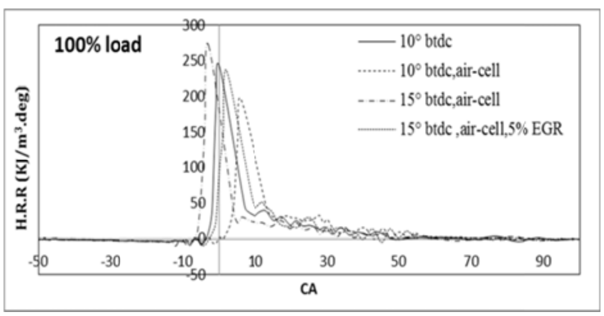

Fig. 10. Heat release rate against crank angle for 100% load

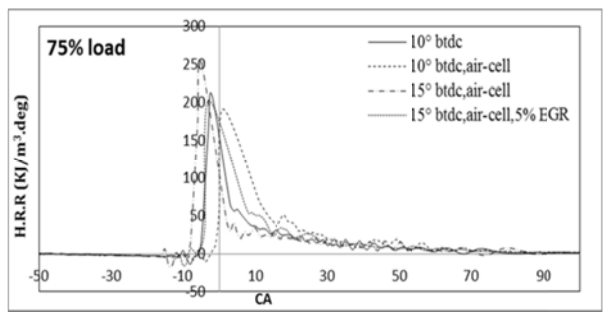

Fig. 11. Heat release rate against crank angle for 75% load

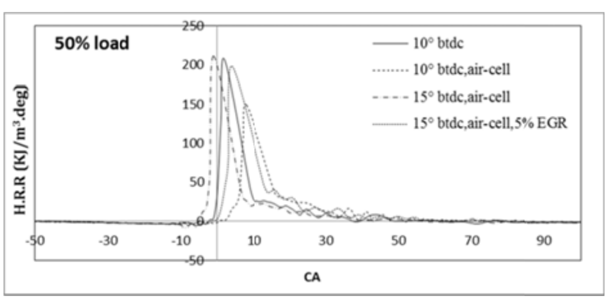

Fig. 12. Heat release rate against crank angle for 50% load

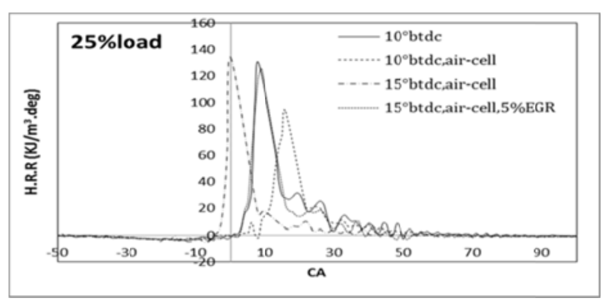

Fig. 13. Heat release rate against crank angle for 25% load

5. PERFORMANCE ANALYSIS

Applying an air-cell due to a decreased compression ratio and the amount of available air in the main combustion chamber, the pre-mixed combustion is incomplete, which causes brake power decreases and BSFC increases. In the next step, by advancing injection timing, mixing air and fuel were done. In the longer period, there will be a stronger combustion in the pre-mixed step; therefore, the engine power increases and the specific fuel consumption decreases. Finally, using the cold EGR causes a weakening the pre mixed combustion, thus the engine power decreases and BSFC increases. Figures 14 and 15 respectively show the brake power and BSFC variation with change in engine load.

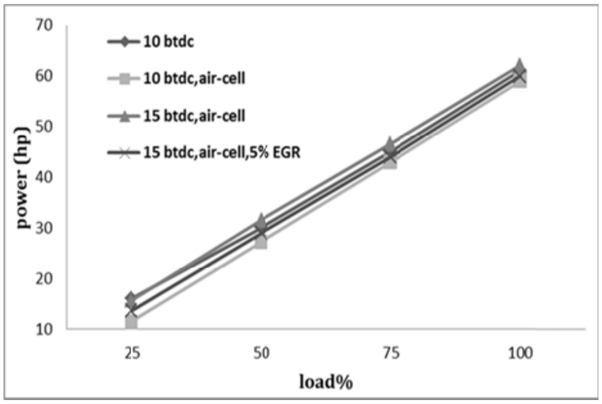

Fig. 14. Experimental results for brake power

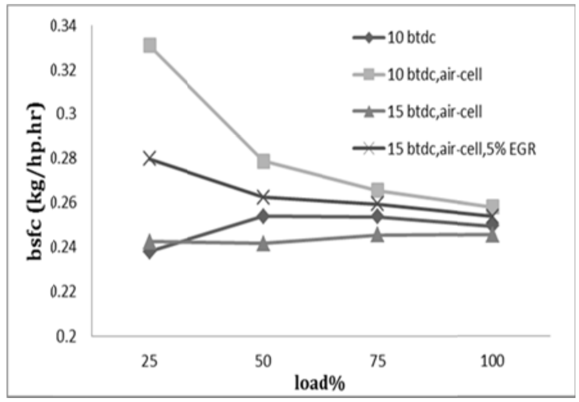

Fig. 15. Experimental results for brake specific fuel consumption

6. CONCLUSION

The obtained results in this experimental study could be classified into following parts:

- By storing some amount of air inside the air-cell in compression course, the amount of available air for the pre-mixed combustion would decrease and by incomplete combustion in the mentioned step, NOx decreases. During the expansion course, due to differential pressure between the main combustion chamber and the air-cell, the stored air returns inside the main chamber, and an increase in the amount of the available oxygen there will enable more complete diffusion combustion, and this involves more Soot oxidation.
- Advanced injection timing causes maximum pressure increase in the combustion chamber and an increase in the engine power, also a decrease in the amount of BSFC.
- Using cold EGR reduces NOx emission by reducing the combustion chamber temperature and the amount of available oxygen.
- In this study, by applying the combined method including using pistons with air-cells inside, and advanced injection timing for 5°CA along with using 5% of cold EGR the rate of Soot emission has been decreased by 48% in 100% load,50% in 75% load , 49% in 50% load and 33% in 25%load. The rate of NOx emission has been decreased by 23% in 100% load, 15% in 75% load, 16% in 50% load and 11% in 25% load. The value of brake power has been decreased by1.6% in 100% load, 2.2% in 75% load, 4.3% in 50% load and 15% in 25% load. The value of bsfc has been increased respectively by 1.6% in 100% load, 2.2% in 75% load, 3.3% in 50% load and 14% in 25% load, respectively.

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