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Enhancement of emission characteristics of a direct injection diesel engine through porous medium combustion technique

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Abstract
In this research work, a direct injection diesel engine with the implementation of porous medium combustion technique has been investigated for performance and emission characteristics. The porous medium combustion technique has been established in the present work by the introduction of porous ceramic material into the combustion chamber. The nitrogen oxide and soot emission of porous medium engine are found to be lower to that of conventional engine. However the soot emissions are higher in the porous medium engine under part load conditions.

Keywords: Combustion; Emission; Porous medium; Diesel engine.

1. Introduction
The diesel engines are being extensively used in transport sector owing to their excellent fuel efficiency, low emissions of carbon dioxide, unburned hydrocarbons and carbon monoxide. However, high emissions of nitrogen oxide and particulate matter place the diesel engines on the down side. It is extremely complex to reduce both the emissions at the same time, because of the trade-off between nitrogen oxide and particulate emissions. Even though the implementation of high pressure injection and common rail system could reduce both nitrogen oxide and particulate emissions all together, the cost involved would be high and unaffordable for many engine producers and consumers.
Reduction in diesel engine emissions, in particular nitrogen oxide and particulate emission is becoming serious problem to be tackled, as emission norms are getting more and more stringent now a days. The effects of in-cylinder fuel-air mixture formation, combustion and chemical reaction process on exhaust emissions remain largely unexamined. On the other hand, it is well proven that homogenous mixture results in lower particulate emission from diesel engines [1, 2]. Researchers are trying various technologies to accomplish homogenous mixture formation, combustion and subsequently lower particulate emission. One such technique to realize homogenous mixture formation and lower particulate emission from diesel engines is porous medium combustion [3]. Low nitrogen oxide emission will be the supplementary benefit of porous medium combustion technique [4, 5].
The most critical process in this technique is to be the fuel vapourization. Imperfections within this process directly influence the quality of the combustible fuel-air mixture, resulting in higher exhaust gas emissions of carbon monoxide, nitrogen oxide and unburned hydrocarbons [6]. Injecting the liquid fuels

into the porous medium leads to an excellent evaporation and in turn, in the presence of oxygen, rapid and complete combustion as well.

In this research work, the porous medium combustion was established in direct injection diesel engine with the inclusion of porous ceramic material into the space of combustion chamber. The previous works on porous medium combustion technique has limited themselves to part load engine conditions and lean A/F mixture. But in this study, the engine is operating from no load condition to peak load condition and the influence of porous medium on the performance and emission characteristics of the engine under investigation was analyzed and compared with the conventional engine

2. Development of porous medium engine

Highly Porous ceramic material was selected for the purpose of developing the porous medium engine. High porosity made the medium to be transparent for the gas flow, spray and flame. In general, the porous medium engine has been attained by the precise placement of porous ceramic material in either of the following locations: cylinder, engine head or piston. In this research work, the porous ceramic material was placed on the top of piston cavity and had been detained in its position through an appropriate locking mechanism. The photographic view of such a piston with porous medium implementation is shown in Figure 1. The chemical composition and mechanical properties of porous ceramic material are given in Table 1. In another case, the porous medium engine was developed by inserting a hollow mild steel tube of sufficient height into the combustion chamber cavity. Before insertion, this circumferential surface of the tube had been drilled with holes and the entire surface was duly coated with partially stabilized zirconium dioxide (ZrO_2) ceramic material. The ceramic coated tube with holes on their circumferential surface is shown in Figure 2 and the assembled view of piston with suitable locking mechanism is depicted in Figure 3.

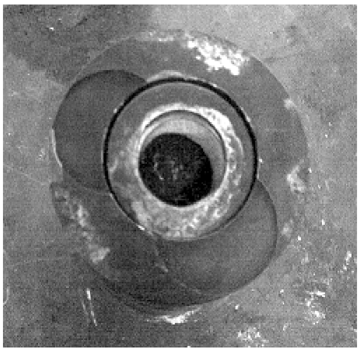


Figure 1. Photographic view of piston with porous medium implementation

Figure 2. Zirconium dioxide ceramic coated porous medium

Figure 3. Assembled view of piston with zirconium dioxide coated porous medium

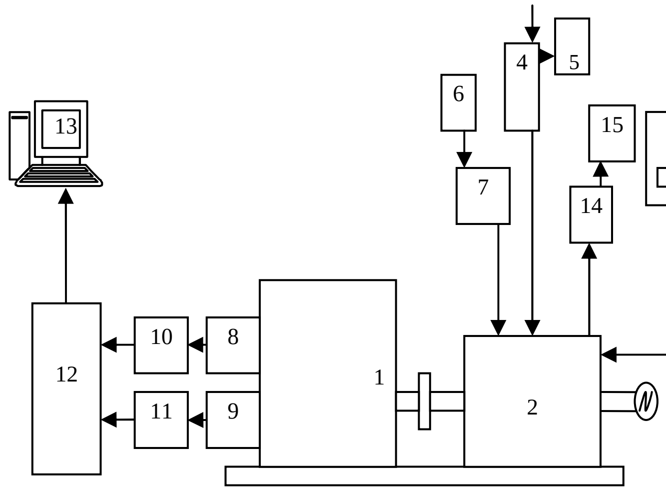
Table 1. The chemical composition and mechanical properties of porous ceramic material

Cu (%)	Fe (%)	C (%)	Sn (%)	Other (%)
87.5- 90.5	1.0 max	1.75 max	9.5 - 10.5	0.5

Density	6.4 - 6.8 kg/m^3
Porosity (% oil by volume)	18 %
K Strength Constant	26500
Tensile strength	96.5 MPa
Yield strength in compression	75.8 MPa

3. Experimental set up and testing procedure

The engine test up used for the experimental investigation is shown in Figure 4. The performance and emission tests were performed on 4.4 kW, constant speed, single cylinder, four stroke, naturally aspirated, air cooled direct injection diesel engine which was further coupled to an eddy current dynamometer. The main specifications of the test engine are given in Table 2.



1- Diesel Engine, 2 - Electrical dynamometer, 3 - Dynamometer controls, 4 - Air box, 5 - U tube manometer, 6 - Fuel tank, 7 - Fuel measurement, 8 - Pressure transducer, 9 - TDC position sensor, 10 - Charge amplifier, 11- TDC amplifier circuit, 12 - Analog to digital card, 13 – Computer, 14 - Exhaust gas analyzer, 15 - AVL smoke meter

Figure 4. Experimental set up

Table 2. Specifications of test engine

Make	Kirloskar
Model	TAF 1
Type	Direct Injection, Air Cooled
Bore x Stroke	87.5 mm x 110 mm
Compression ratio	17.5:1
Swept volume	0.0661 L
Rated power	4.4 kW
Rated speed	1500 rpm
Start of injection	23.4 ^{0} before TDC
Connecting rod length	220 mm
Injector operating pressure	250 bar

In order to determine the engine torque, the shaft of the test engine was coupled to an electric dynamometer, which was loaded by an electric resistance. A strain load sensor was employed to determine the load on the dynamometer. The engine speed was measured by an electromagnetic speed sensor installed on the dynamometer. The fuel consumption rate of the engine was determined with a weighing scale having a sensitivity of 0.1 g and an electronic chronometer having a sensitivity of 0.1 s. The engine was equipped with an orifice meter connected to an inclined manometer to measure mass flow rate of the intake air. An air damping tank was used for damping out the pulsations produced by the engine, thus obtaining a steady air flow.

A five-gas analyzer was used to measure carbon monoxide, unburned hydrocarbons by infrared sensors and nitrogen oxide by electrochemical sensors. A burette was used for measuring fuel consumption and a chrommel alumel thermocouple was used along with a digital temperature indicator for measuring the exhaust gas temperature.

All tests were performed under steady state conditions. Tests were first conducted with conventional engine to obtain the base data. Each test was repeated three times and the results of three repetitions were averaged. Under the same operating conditions, the testing was extended to the porous medium engine which was under investigation. However, the loading of engine was restricted to 50 % of peak load due to limitation imposed by the endurance strength of the porous ceramic material. The testing was also conducted on the porous medium engine which was developed using ZrO_2 coated porous medium. The emission characteristics of the porous medium engine developed using these two techniques were compared with those of conventional engine.

4. Study of emission characteristics of porous medium engine

The emission characteristics of porous medium engine had been analyzed under three considerations. In the initial stage, the emission characteristics of base engine were recorded at the actual compression ratio of 17.5:1. The placement of porous medium elevated the compression ratio to 21:1. In the second stage, the emission characteristics of porous medium were recorded at this compression ratio. In the third stage, the compression ratio was again reduced to actual compression ratio of 17.5:1 through suitable modifications in the test set up. The emission characteristics were documented at this compression ratio too. The emission testing was also performed on the porous ceramic metal implemented engine at the compression ratio of 21:1.

4.1 Unburned hydrocarbons

The porous medium engine has superior emission characteristics when unburned hydrocarbon emissions were being considered. This is shown in Figure 5. In the case of porous medium engine, the unburned hydrocarbons were mainly eliminate by extremely fast and complete vapourization of the fuel which was injected inside the porous medium and also due to complete combustion. The two phenomena responsible for unburned hydrocarbons in a conventional engine (over-mixing and under-mixing) were totally eliminated in porous medium engine, since the fuel was not injected in the free space of the cylinder but inside the porous medium.

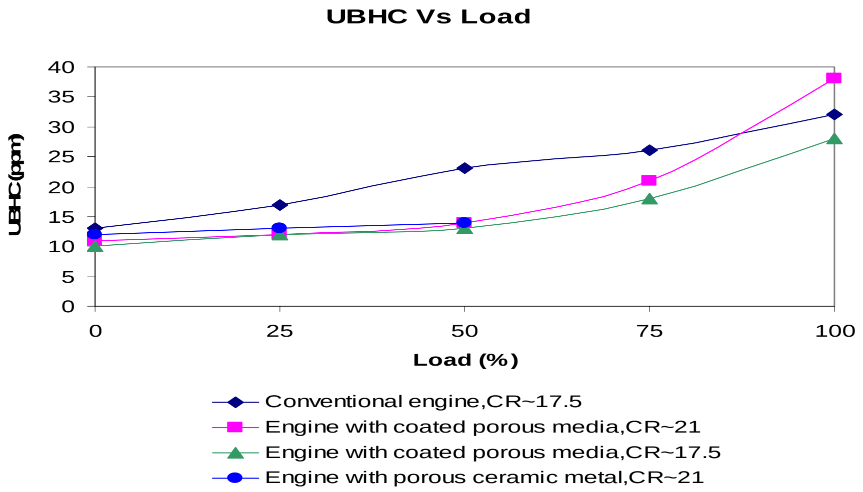


Figure 5. Comparison of hydrocarbon emission

4.2 Carbon monoxide

Figure 6 show that porous medium engine was producing low emissions of carbon monoxide. This was due to the fact that, in the porous medium engine, homogeneous temperature conditions had been accomplished inside the engine cylinder throughout the combustion process. This led to unbelievable low emissions of carbon monoxide in porous medium engine than a conventional engine.

4.3 Nitrogen oxides

The proper design of porous medium engine yielded temperature-controlled combustion, which also being characterized by low nitrogen oxide emissions which is shown in Figure 7. This was principally achieved due to the presence of solid phase of porous medium during combustion. This prevented the combustion heat from completely entering the combustion gases and therefore no temperature peaks occurred. This differentiated the porous medium combustion from the conventional engine combustion process.

4.4 Soot

It is evident from Figure 8 that soot emission tends to increase once the load on the engine had been increased. In the case of porous medium engine, the soot emission was primarily reduced by the following factors: the lower temperature in the reaction zone, very fast vapourization, more homogenous mixture composition and relatively long residence time in the reaction zone with a homogeneous temperature distribution [7].

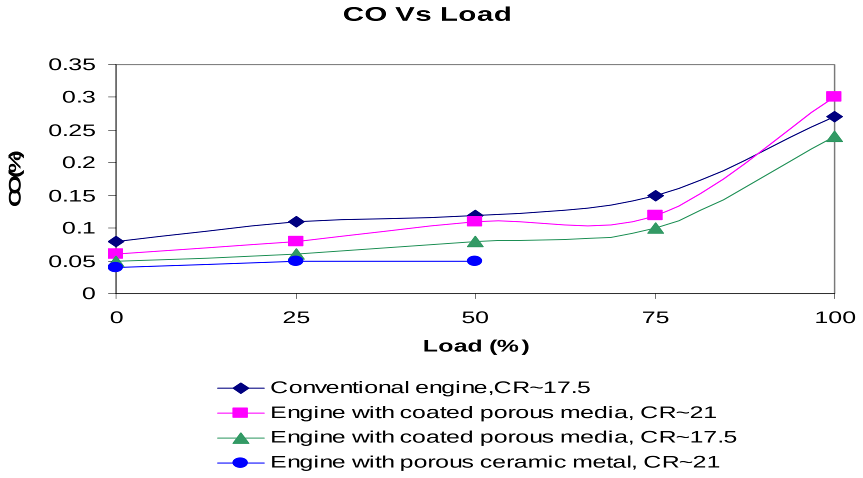


Figure 6. Comparison of carbon monoxide emission

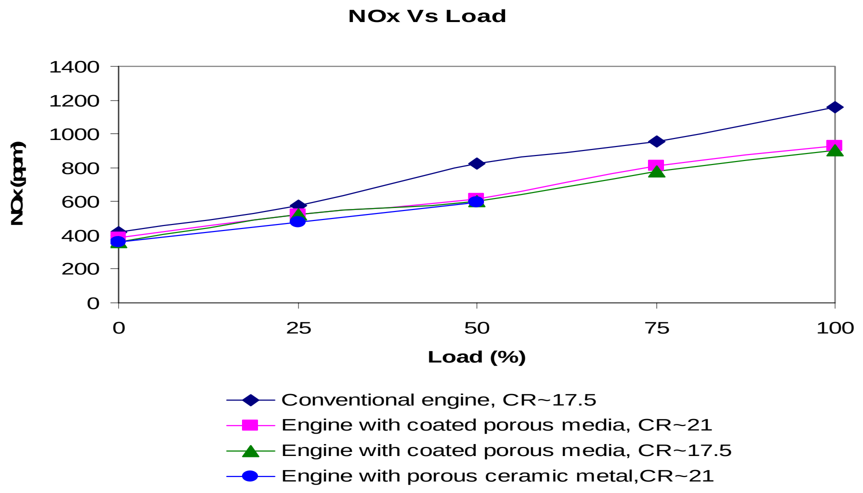


Figure 7. Comparison of nitrogen oxide emission

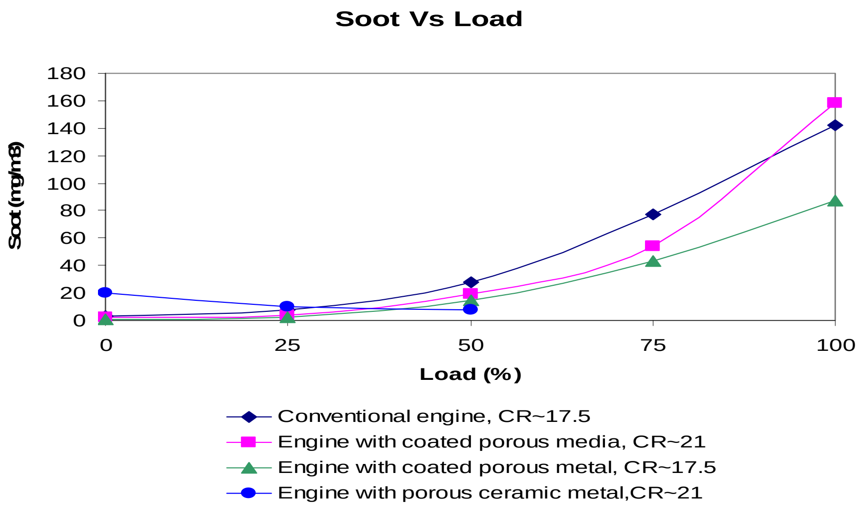


Figure 8. Comparison of soot emission

4. Conclusion

The major emission characteristics obtained from porous medium engine under investigation as summarized below.

- Reduced nitrogen oxide formation due to lower temperature peaks and homogeneous combustion conditions.
- Carbon monoxide and unburned hydrocarbon emissions were found to be lowest than the conventional engine owing to the complete vapourization and clean combustion of fuel.
- Soot emission was diminished due to fast and complete vapourization and the homogenous combustion conditions.

To some extent, the porous medium engine has inferior characteristics with respect to specific fuel consumption and brake thermal efficiency which had been imposed due to restriction to the incoming air inside the engine cylinder by the placement of porous medium. But if the air inside the engine cylinder would be maintained by some external means(supercharging or turbo charging), the porous medium was anticipated to give better results in terms of brake thermal efficiency and specific fuel consumption as well.

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