ENHANCEMENT OF DIESEL ENGINE EMISSION CHARACTERISTICS THROUGH POROUS MEDIUM TECHNOLOGY (PMT)

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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 condition Porous Medium (PM) combustion chamber in diesel engine has been considered as a promising concept to approach a near-zero emission system. It takes full advantage of PM geometry and material characteristics to perform homogeneous combustion, therefore reduces significantly emission under all operational conditions. This paper describes the result obtained from experimental data taken from inserting SiC porous medium in single cylinder diesel engine.

By inserting SiC as PM in cylinder head of single cylinder diesel engine brake thermal efficiency, brake thermal power are increased and brake specific fuel consumption, exhaust gas emission like CO, CO2and HC are reduced significantly.

Keyword: *- Porous Medium, Diesel Engine, Silicon Carbide (Sic), PM Technology*.

INTRODUCTION

Undesirable emissions in combustion engines are of major concern because of their negative impact on air quality, human health, and global warming. Therefore, there is a concerted effort by most governments to control them. Undesirable emissions include unburned hydro carbons (HC), carbon monoxide (CO), nitrogen oxides (NOx),and particulate matter(PM), we present the U.S. and European emissions standards, both for gasoline and diesel operated engines, and strategies to control the undesirable emissions.

The role of engine design, vehicle operating variables, fuel quality, and emission control devices in minimizing the above-listed pollutants are also detailed " Emissions" is a collective term that is used to describe the undesired gases and particles which are released into the air or emitted by various sources, Its amount and the type change with a change in the industrial activity, technology, and a number of other factors, such as air pollution regulations and emissions controls 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. Low nitrogen oxide emission will be the supplementary benefit of porous medium combustion technique.

The most critical process in this technique is to be the fuel vaporization. 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 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.

MECHANISM OF EXHAUST POLLUTANTS FORMATION

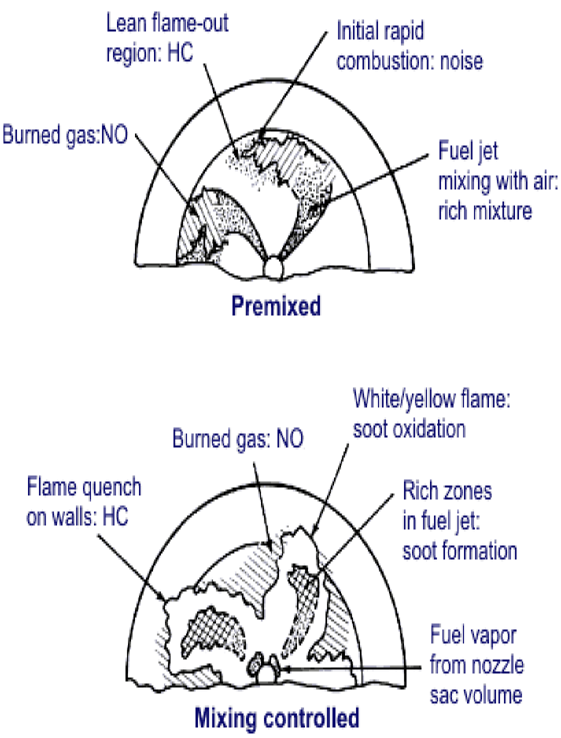


Fig. Pollutant formation mechanism from DI combustion systems

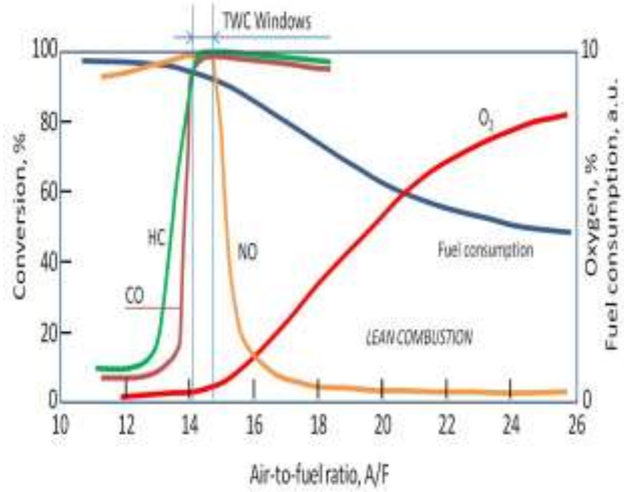


Fig. AS emissions vs air/fuel ratio

EMISSION STANDARDS FOR DIESEL ENGINE

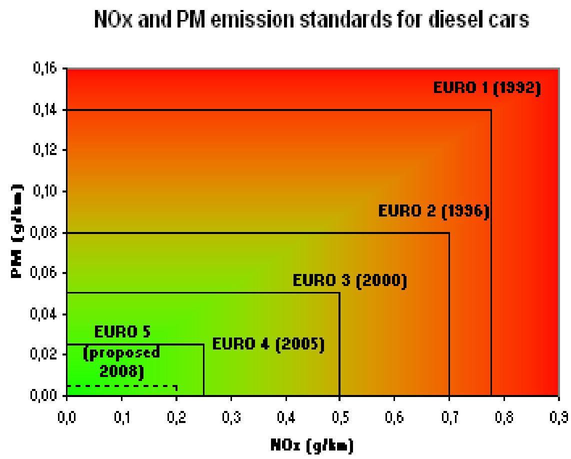


Fig. emission standards for diesel engine

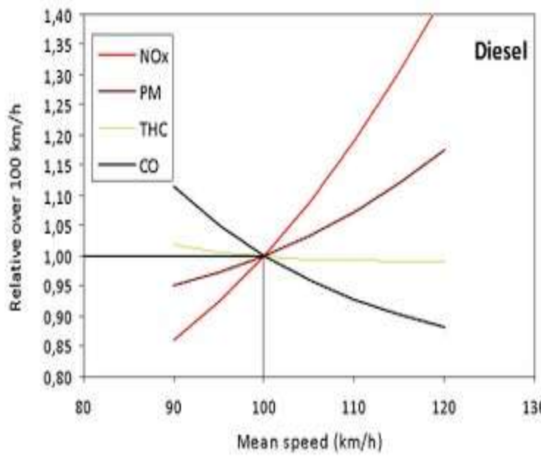


Fig. Diesel engine emissions relative to variable mean speeds.

The test cycle has been the ECE + EUDC for low power vehicles (with maximum speed limited to 90 km/h). Before 2000, emissions were measured over an Indian test cycle.

Engines for use in light-duty vehicles can be also emission tested using an engine dynamometer.

DIFFERENT MATERIALS AND STRUCTURES FOR ENGINE APPLICATION

There are two main groups of different applications of porous materials and structures to internal combustion engines:

1. Porous structures applied to exhaust after-treatment systems for reduction of engine emissions, (outside the engine cylinder (combustion chamber).
2. Porous structures applied to engine processes, especially inside the engine cylinder (combustion chamber) to support different individual processes as well as a complete combustion process. In the last case, heat recuperation in a material made of porous structures performs automatically, as the structure has contact with hot burned gases.

As already stressed, the present paper concerns possible applications of porous structures to in-engine (preferably in-cylinder) processes, especially for supporting the following processes: fuel vaporization, fuel distribution in space (combustion chamber), mixture formation (mixing) and charge homogenization, catalytically supported and thermal ignition as well as the combustion process itself, and heat recuperation in a PM reactor. The combustion process may partly be supported by the porous structure or may completely be performed in the porous reactor volume being homogeneous in nature.

From the point of view of the application of porous-medium technology to in-engine processes (e.g., fuel distribution and vaporization in the intake port) and in-cylinder processes (e.g., fuel distribution, vaporization and mixing, ignition, combustion, and heat recuperation).

There are a number of requirements on structures and material properties. For example, considering foam structures, porous media may have a mean pore diameter of 1 to 3 mm. In the case of non-foam structures, characteristic dimensions may be many millimeters to centimeters. Examples of 3D porous structures available are presented in Figure. Beside foam structures made of different (mostly high temperature ceramic) materials it is possible to create a 3D frame-like structure having large pores which may be homogeneous in space or may have different structures in different directions. Such structures may perfectly be adapted to the engine processes being supported by the porous structure. The side walls of a mixer structure in Figure have small holes (opening) making necessary connections with surrounding pores possible). In the structure, the frames are distributed in space having all necessary features of highly porous open-cell structure. The cells of ceramic foam can be idealized as a pentagonal do decahedron. The edges of the dodecahedron are the struts of the ceramic foam. In the case of gas or liquid flowing through the foams, the flow is forced to separate and reattach at the struts, resulting in good mixing and strong interaction between flowing fluid and the PM material. A similar effect is expected if a high-velocity liquid jet (e.g., Diesel jet) penetrates throughout the PM volume.

Characterization of Porous Media for Engine Applications

Generally, the most important parameters of PM structures as applied to engine processes, and especially to the combustion process, can be specified as follows: porosity, specific surface area, heat capacity, heat transport properties (optical thickness for radiation, emissivity, and conductivity), transparency for fluid flow and flame propagation, pore size, pore density, pore structure, thermal resistance, mechanical resistance and mechanical properties under heating-cooling conditions, PM material surface properties, and electrical properties (for electrical heating of PM structures).

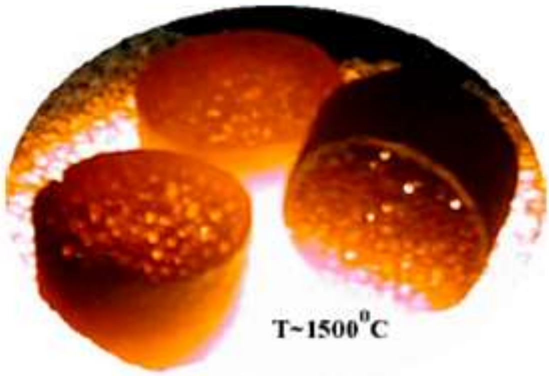
Large Inner Surface Area

Owing to its large inner surface area, the porous structure permits very effective inter phase heat transfer and liquid vaporization as well as the enlargement of the reaction (combustion) zone. Additionally, this large specific surface area SSA (on the order of 10^2–10^4 m^2/m^3) recommends the medium to be applied as a vaporizer and heat exchanger. This inner surface area depends on pore density, its geometry, and the structure used for the manufacturing of PM. For example, for metal foam made from Ni-Cr-Al, the specific surface area according to the mean pore diameter is: for mm, m^{-1}, for mm 1000 m^{-1}, and for mm is m^{-1}. A large specific surface area may be utilized for an excellent inter phase heat transfer in PM volume, fuel (spray) distribution throughout the PM volume, and for very fast liquid vaporization in a PM volume. This is supported by excellent heat transfer properties, especially by strong heat radiation of the solid phase.

Together with the high heat capacity and thermal resistance of the PM material, this kind of 3D structures may be used for realization of very clean and efficient combustion in a porous-medium volume. Depending on the application of a porous medium, a combination of thermal and mechanical properties of the materials, as well as their inner structure and pore size has to be chosen and optimized for the particular engine process. These requirements become especially critical if the porous medium is used directly for controlling the combustion process (PM reactor) under high-pressure conditions.

Large Heat Capacity

Owing to a large heat capacity of the solid phase compared with the heat capacity of the gas in the PM volume, it is possible that a part of the heat released during the combustion process may be "accumulated inside" the porous material, resulting in a high temperature of the solid-phase surface. The heat capacity of the porous reactor is on the order of hundreds to many thousands higher than the combustion-gas heat capacity trapped in the reactor volume. This could allow controlling the combustion temperature over a wide range of mixture compositions (corresponding to the air-to-fuel ratio) and engine operational conditions.



Very Good Heat Transport Properties

Heat transport and heat transfer properties of PM are characterized by efficient heat conductivity and very effective heat radiation of the solid phase inside PM. These excellent heat transport properties allow combustion in porous medium at much higher heat-release (combustion) rates than for a free flame. Additionally, there is strong cooling of the reaction zone and as a consequence the thermal NO formation may significantly be reduced (lower-temperature combustion). The porous-medium structure and pore density influence volumetric heat transfer conditions. A strong heat radiation of a solid phase permits very effective heat transfer inside the porous structure resulting in a homogeneous temperature field throughout the reactor volume

Transparency for Fluid Flow and Flame

Highly porous materials imply structures of porosity above approx. 80%. Owing to this large porosity, the PM materials are transparent for gas and liquid flows as well as for flames. This transparency permits very low-pressure losses in fluid (gas) flow through the PM volume. Example of pressure losses measured for wire packing is given in Figure 9, and for ceramic foams. The porous media are characterized in different ways because of different structures to be considered wire packing is characterized by density and wire diameter foam structure is characterized by pore density ppi). Please note that pressure losses are individual for a given reactor, as they depend on porous-structure geometry, number and thickness of the pore junctions, number of closed pores, and homogeneity of the structure. The efficiency of the flow process through a porous structure may be described by the permeability of the porous medium employed. Permeability is regarded as a macroscopic measure of the ease with which a fluid (e.g., gas) driven by a pressure gradient flows through the voids of a porous structure. Thus, permeability reflects the effectiveness of the interaction between fluid and porous structure. For the practical application of porous structures to the combustion process (stationary and non stationary combustion systems) the reaction can be developed according to the Peclet number criterion. According to this criterion, combustion can only occur when the Peclet number based on the properties of the solid material and the gas is higher than 65, using the following definition.

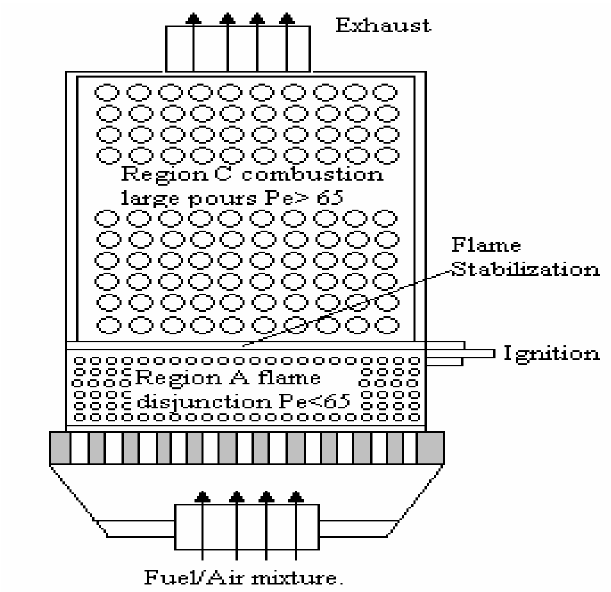
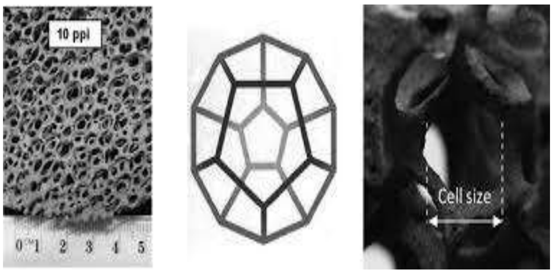
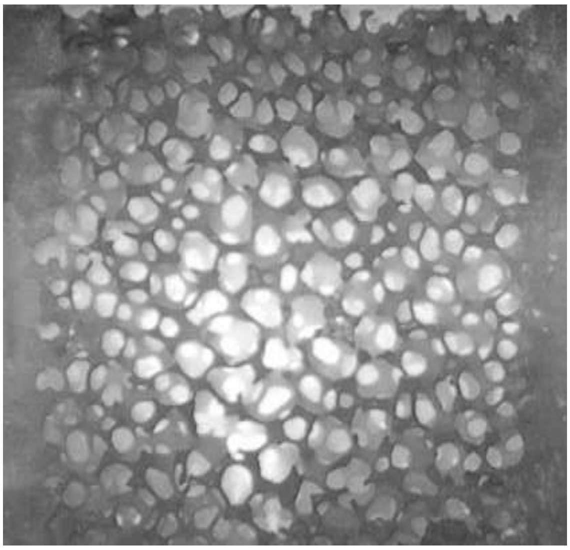


Fig. Impact of peclet number on combustion

Variable Pores Size, Pores Density, and Pores Structure

There are a number of available PM materials characterized by different pore sizes (pore densities) as well as pore shape and geometry. Foam structures of mean pore diameter of from 0.1 to 5 mm to mixer structures of a characteristic dimension of many centimeters are available (see also Figure 7). New development on macro cellular reactors and high-temperature wire structures offers quite variable size and pore structure quite dissimilar to foam structures.





Thermal Resistance

One of the most important features of porous materials used in combustion technology are their high thermal resistance, thermo shock resistance, and high heat capacity. Thermal shock resistance is of special interest for high-temperature application, for example, for combustion processes in the engine. Thermal shock is related to changes in the temperature leading to thermal stress. Usually, two different measures characterize the thermal shock properties of the porous.

Structure: hard and soft thermal shock parameters. The hard thermal shock parameter defines the maximum allowable temperature difference for a rapid superficial thermal shock. A real-case experiment could consists in placing a high-temperature porous structure (glowing at a high temperature, e.g., above 1000 K) in a cold-water reservoir. The soft thermal shock parameter includes thermal conductivity and considers a long-term effect of temperature gradient in the porous structure. In a practical case, it would consist of a glowing reactor slowly cooling in the air at ambient temperature.

Mechanical Resistance and Mechanical Properties under Heating-Cooling Conditions

Mechanical stability and mechanical resistance for combustion applications under pressure are important especially under high-temperature operation conditions. The mechanical properties correspond to primarily elastic module (Young's modulus), Poisson's ratio, fracture toughness, tensile strength, compressive (crushing) strength, and thermal stress/shock resistance. Different materials and structures have different mechanical properties in high-temperature operation with a typical tradeoff: the higher operating temperature, the lower mechanical stability.

PM Material Surface Properties

For porous structures it is necessary to define their macro porosity and micro porosity in relation to their surface properties. This surface can also be catalytically coated or modified. To practically operate a porous-medium structure in engine, there are additional properties required, such as an electrical heating of the structure for cold start conditions.

Electrical Properties

A porous structure may directly or indirectly be electrically heated, resulting in a homogeneous temperature field throughout the PM volume. This feature could be utilized for cold-start conditions or for liquid-fuel vaporization. A similar effect may be achieved by indirect electrical heating, owing to very good heat transfer properties of the porous structure. Time-dependent temperature distribution in electrically heated structures depends on the electrical properties of the material, pore size and structure, as well as on the electrical contacts with the foam, assuming that a (nearly) homogeneous temperature field is achieved in the PM volume. The dielectric properties of a porous structure mainly depend on the porosity and type of ceramic material.

The most important features of porous materials and structures for engine applications are summarized in Table 1. This table is given for fast reference to the various properties and features of porous structures as applied to internal combustion engines.

PM MATERIAL IN PISTON HEAD

PM activator was mounted on the piston head as in Fig. 2 and 3. During intake and early compression stroke, there is not remarkable influence of PM thermal capacitor on thermodynamic condition inside the cylinder. The heat exchange process (between PM material and compressed air) increases with upward motion of piston. At the TDC, almost all the air is compressed and closed to PM volume. Near the TDC of compression stroke, fuel is injected into PM volume and spreaded widely by interaction with a large number of PM pore junctions ("self – homogenization").

A strong heat transferred from hot PM surface to liquid fuel makes fast and complete fuel vaporization. Very fast mixing with gaseous charge occurs and the combustible mixture is ignited in the whole PM volume. Amount of burned gases that trapped in PM volume defines accumulated energy for next cycle. The three fundamental conditions for a homogeneous combustion are satisfied : homogenization of charge in PM volume, 3D thermal self ignition and volumetric combustion with a homogeneous temperature

Fig. Porous Media In Piston Head

TOP VIEW

POTENTIAL OF PM ENGINE

In the PM-engine the liquid fuel is injected directly in to PM-volume and fuel atomization and spray geometry are not critical. A self-homogenization process in PM-volume is observed permitting spatial distribution of the liquid fuel throughout the PM-volume. A strong heat transfer from hot PM-surface and gas to liquid fuel permits fast and complete fuel vaporization. No liquid or gaseous form of the fuel is present in a free volume of the cylinder. Injection timing, spray atomization or spray geometry are not critical in this system.

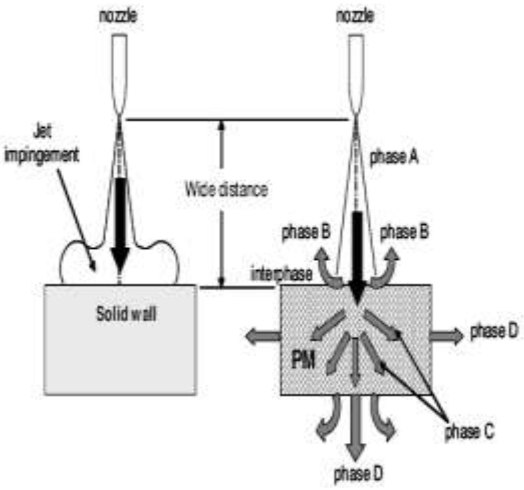


FIG. Model Describing Basic Phases of Diesel Jet Interaction with Porous Medium

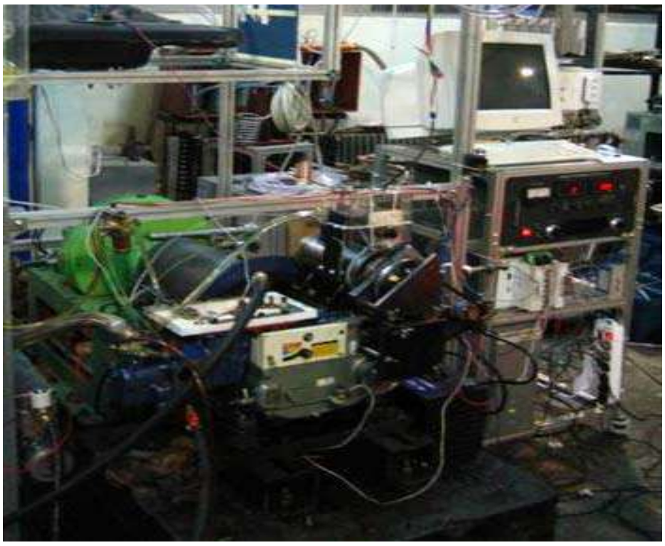
- Phase A: represents outlet from the nozzle and free jet formation.
- Phase B: represents jet interaction with PM interface.
- Phase C: represents liquid distribution throughout the PM-volume.
- Phase D: represents liquid leaving the PM-ENGINE

TESTING OF PM ENGINE WITH EXPERIMENT PROCEDURE

The engine test up used for the experimental investigation is shown in Figure. The performance and emission tests were performed on 7.5 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.

- ⦿ Vehicle- Piaggio ape auto rickshaw
- ⦿ Type – single cylinder, naturally aspired, air cooled DI diesel engine.
- ⦿ Max power – 7.5 bhp @ 3600 rpm
- ⦿ Max torque- 16.7 Nm@2400 rpm
- ⦿ Displacement-395 cc
- ⦿ Piston dimensions – dia 86 mm, stroke 68 mm
- ⦿ Pressure ratio -57.2:1
- ⦿ Compression ratio -18:1
- ⦿ Thermal efficiency – 58%

5.1 EXPERIMENT SETUP:



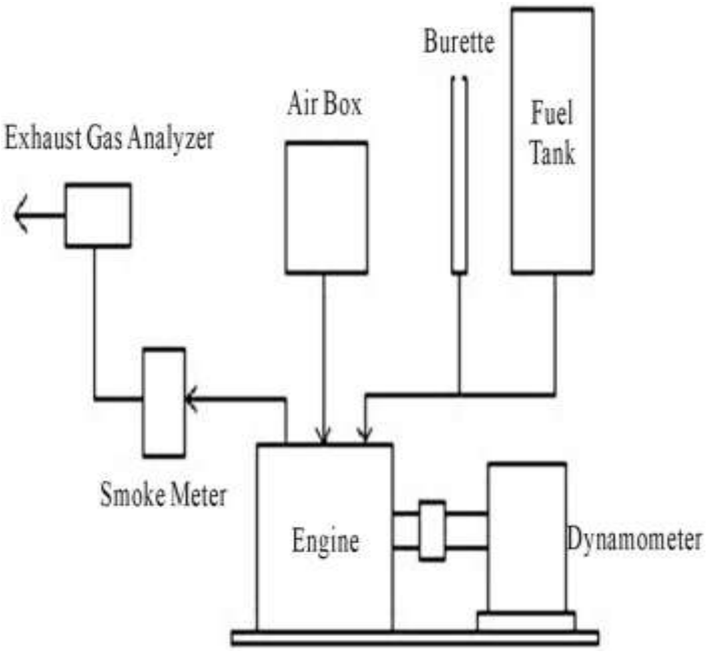
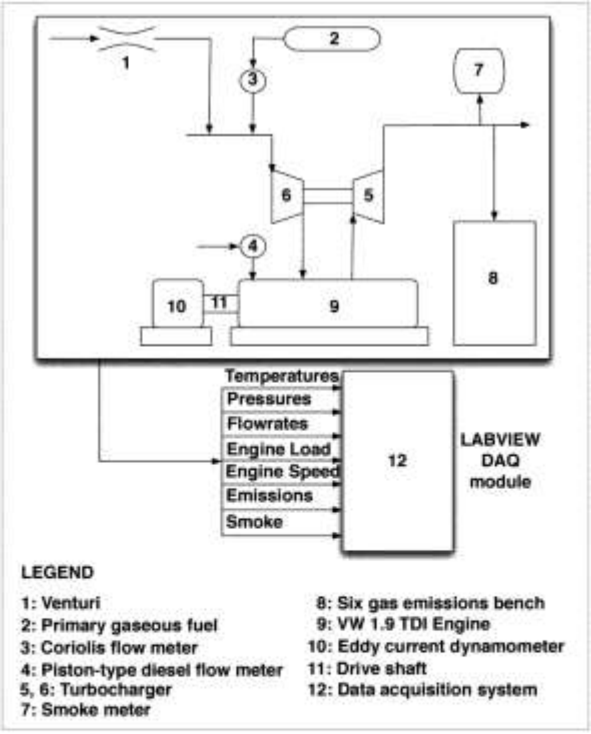


Fig. block diagram of experiment set up



PARTS OF TESTING SETUP

1. Dynamometer
2. Smoke meter
3. Exhaust gas analyzer.
4. Air box
5. Pressure transducer
6. Temperature sensor
7. Analog to digital card
8. Computer

Dynamometer:

A **dynamometer** or **"dyno"** for short, is a device for measuring force, torque, or power. For example, the power produced by an engine, motor or other rotating prime mover can be calculated by simultaneously measuring torque and rotational speed (RPM.

A dynamometer can also be used to determine the torque and power required to operate a driven machine such as a pump. In that case, motoring or *driving* dynamometer is used. A dynamometer that is designed to be driven is called an *absorption* or *passive* dynamometer. A dynamometer that can either drive or absorb is called a *universal* or *active* dynamometer.

Types of dynamometer test procedures:

There are essentially 3 types of dynamometer test procedures:

1. Steady state: where the engine is held at a specified RPM (or series of usually sequential RPMs) for a desired amount of time by the variable brake loading as provided by the PAU (power absorber unit). These are performed with brake dynamometers.
2. Sweep test: the engine is tested under a load (i.e. inertia or brake loading), but allowed to "sweep" up in RPM, in a continuous fashion, from a specified lower "starting" RPM to a specified "end" RPM. These tests can be done with inertia or brake dynamometers.
3. Transient test: usually done with AC or DC dynamometers, the engine power and speed are varied throughout the test cycle. Different test cycles are used in different jurisdictions.

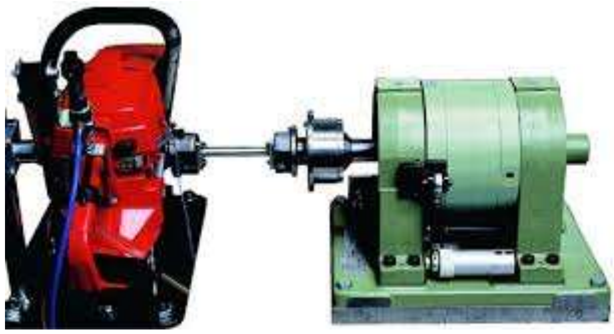


Fig. electric dynamometer

5.2.2 SMOKE METER:

The AVL Smoke Meter is a filter-type smoke meter for measuring the soot content in the exhaust of diesel and GDI engines. The variable sampling volume and thermal exhaust conditioning assures a wide applications range, e.g. measurements during engine development or DPF calibration. A defined flow rate is sampled from the exhaust pipe through a clean filter paper in the instrument. The filtered soot causes blackening on the filter paper which is detected by a photoelectric measuring head and evaluated in the microprocessor to calculate the result in FSN or mg/m³.

It's benefits:

- Due to variable sampling volume a detection limit of 0.002FSN (~20 µ g/m³) can be reached
- Can be used for engine test bed and chassis dynamometer
- Timely paper change due to remaining filter paper indicator
- Altitude measurements and simulation up to a sea level of 5000 m
- High reproducibility, improved cleaning efficiency and increased robustness against wet exhaust gas due to shop air purging of the entire gas path – option
- Extended application area up to 3bars exhaust back pressure for engines with exhaust after treatment systems - option
- Remote-control service with intuitive user interface – option.

Emission test results

The emission characteristics of porous medium engine had been analyzed under following considerations. In the process, the emission characteristics of base engine were recorded at the actual compression ratio of 18:1. The placement of porous medium elevated the compression ratio to 19.3:1 through suitable modifications in the test set up.

The emission characteristics were documented at this compression ratio too.

Heat

activator	rpm	load (kg-m)	N Ox	CO	UHC
Without PM	1200	0	24-33	245-290	0.052-0.059
With PM		1	2-5	150-255	0.041-0.047
Without PM	1200	0	88-98	330-350	0.055-0.061
With PM		1	2-8	220-260	0.048-0.058
Without PM	1500	0	36-38	330	0.054-0.058
With PM		1	1-5	210	0.051-0.055
Without PM	1500	0	63-56	620-700	0.071-0.072
With PM		1	1-10	545-600	0.068-0.069

CO, NOx and UHC are measured in grams/Kw-h.

Nitrogen oxide:

The proper design of porous medium engine yielded temperature-controlled combustion, which

Also being characterized by low nitrogen oxide emissions. 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 here fore no temperature peaks occurred. This differentiated the porous medium combustion from the conventional engine combustion process.

Carbon monoxide:
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.

Un burnt hydrocarbons:
PM engine enables complete combustion with even distribution of temperature field. This results in reduction in hydrocarbons to a large extent.

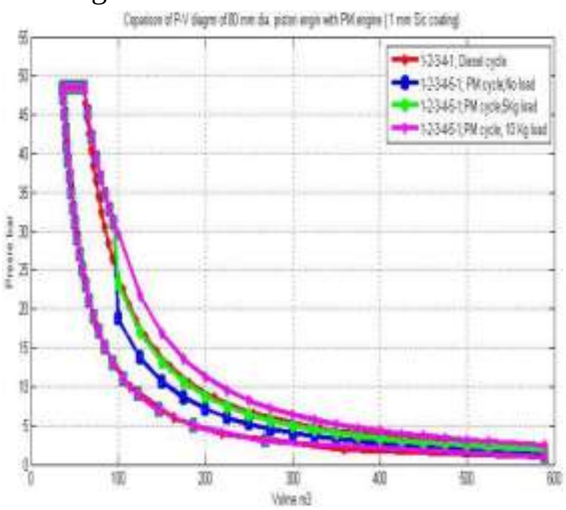


Fig. p-v diagram for PM engine

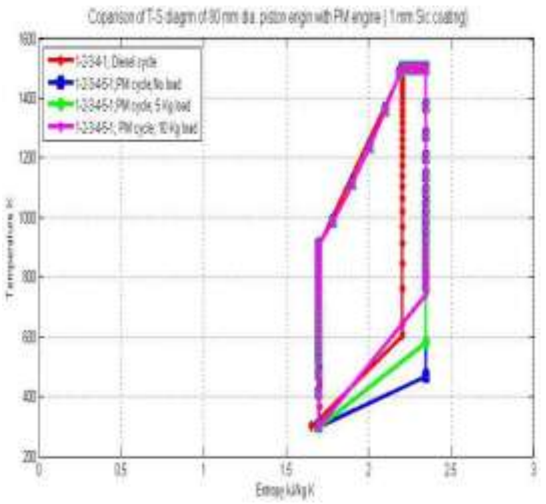


Fig. T-S diagram for PM engine

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 vaporization and clean combustion of fuel.
- Soot emission was diminished due to fast and complete vaporization 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. PM technology is very important due to its wide applicability in the field of energy Efficiency. The properties inherited by it, like low emission, high power density or compactness of the systems and wide range of power modulation makes it a good alternative in places of conventional Technologies. Selection of proper materials for any specific purpose would be achieved by the proper Knowledge of such materials. Parameters like specific heat capacity, maximum temperature range, Resistance to thermal shock and coefficient of thermal expansion etc. need to be known. This technology can be further applied to reciprocating engine power generation systems for load matching and to Make a higher dynamic power range, hence higher overall efficiency.

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