Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 3, Issue 2; January-March, 2016 pp. 140-145

http://www.krishisanskriti.org/Publication.html

Performance Comparison of Porous Medium Combustion Cycle with Diesel Engine

Akhilesh Singh[1] and R.R. Sahoo[2]

[1,2]Indian Institute of Technology (B.H.U) Varanasi, 221005 Uttar-Pradesh, India
Email: [1]akhilesh.singh.mec14@itbhu.ac.in, [2]rrs_iitbhu@rediffmail.com

Abstract—*Homogeneous combustion in internal combustion engines can reduces the emissions in exhaust with increase in efficiency. In Recent years study, porous medium (PM) engine is a new type engine based on the technique of combustion in porous medium, which can fulfills all conditions required to perform the homogeneous combustion. In present analysis, working processes of a PM engine are briefly introduced and an ideal thermodynamic model of the PM heat regeneration cycle in PM engine is developed. An expression for the relation between net work output, compression ratio, cutoff ratio and thermal efficiency is derived for the periodic contact and permanent contact cycle of PM engine. In order to evaluate of the cycle, the effect of the expansion ratio, initial temperature and maximum temperature on the net work and efficiency are discussed. Comparing the PM heat regenerative cycle of the PM engine against Diesel cycle shows that PM heat regenerative cycle can improve net work output with very little drop of efficiency. The aim of this current work is to predict the thermodynamic performance of PM heat regeneration cycle of periodic contact and permanent contact cycle of porous medium combustion engine and comparison with the diesel cycle for same input parameters.*

Keywords: *Porous medium PM, combustion, recuperation, material, homogeneous, emission*

Nomenclature

T = Temperature
Q_{in} = heat added in the cycle
Q_{out} = heat rejected from the cycle
r compression ratio
ρ cutoff ratio
γ specific heat ratio
η efficiency of cycle
W = work done

1. INTRODUCTION

Today emission from the IC engine is the main problem for all of us and future internal combustion (IC) engine will be characterized by a (nearly-) zero emissions level under possible lowest fuel consumption permitted at all operational conditions. This may be achieved by homogeneous combustion process in IC engine. In general, internal combustion (IC) reciprocating engines have reached a very advanced state of development, providing good overall performance and efficiency. In addition, continuous development, mainly in recent years, have resulted in considerable reduction in fuel consumption for both diesel and gasoline engines. Nearly all engine manufacturers have been successful in this field of development and further progress can be expected in the years ahead. In particular, the ongoing development of the direct injection (DI) concept still shows good potential to yield further reductions in fuel consumption. This concept also offers potential for the reduction of NO_x emission by applying exhaust gas recirculation (EGR) in the combustion region, both for stoichiometric and for lean-burn engine operating conditions. But it is difficult to achieve the homogeneous combustion in engine with varying load and speed of the engine. From this, non-homogenous temperature fields emerge and high level, engine-load-dependent emissions Steady combustion in porous media is a subject of interest and a number of publications exist that describe the advantages of PM combustion technique. The experiments carried out were demonstrative in nature and the results presented are intended as proof that the basic ideas put forward in the Further research and development work is needed to yield PM-IC engines to drive cars. Post-combustion exhaust gas treatments might not be needed or may be employed to work towards a nearly zero emission IC engine [5].

Homogeneous combustion with controlled temperature level in combustion zone is very useful for emission control and increasing the efficiency of an IC engine .The homogeneous combustion with 3D-thermal ignition of homogeneous charge with simultaneous heat release in whole combustion chamber and homogeneous temperature field .So it may be possible to lower the temperature level below the normal NOx formation and this process should not lower the engine efficiency and engine is able to operate in all operating condition of engine [6] . Due to the above reason three steps of mixture formation and combustion process may be considered for homogeneous combustion in IC engine i.e level of homogenization of charge, type of ignition, combustion process and developed temperature field.

Miroslaw [1] described the application of a highly porous open cell structures to internal combustion engines for supporting mixture formation and combustion processes.

Porous structures, materials and their properties for engine application. Also described application to a high temperature combustion processes, applications of PM-technology to mixture formation and combustion in IC engines: New combustion system with mixture formation and homogeneous combustion in PM-volume, so-called *"PM-engine concept"*. and concluded that porous medium can be used for a great variety of improvements in the combustion process.

Liu et.al.[8], developed an ideal thermodynamic model of the PM heat regeneration cycle in PM engine and introduced briefly working processes of PM engine. And he studied the influences of the expansion ratio, initial temperature and limited temperature on the net- work output and efficiency. The PM heat regenerative cycle of the PM engine in comparison to Otto cycle and Diesel cycle shows that PM heat regenerative cycle can improve net- work output greatly with little drop of efficiency. Dhale *et al.* [12] have taken experimental reading on single cylinder, four stroke, high speed direct injection diesel engine, water cooled, bore 80 mm, stroke 110 mm, 5 HP and compression ratio 16:1 and performance of the engine is recorded by calculating various parameters like efficiency, fuel consumption, plotting *P-V*, *T-S* diagrams, and recording soot formation initially without PM and the same reading with the porous medium, without changing the other specifications of the setup. The result of the experiment carried out on the engine with PM is compared with the normal engine and it is found that the efficiency of the engine has improved, exhaust emissions like NOx, CO, and UHC are reduced drastically and also it has been recorded that the soot formation is almost negligible. So PM could be used for a great variety of improvements in the combustion process, especially for elimination of soot emissions and significant reduction of NOx.

Hwan, Ou and Chein[9] mounted PM on the piston bowl of single cylinder diesel engine and observed that power increases and noise decreases because of reduction in maximum value of pressure, also amount of NOx decreases significantly while, unburned hydrocarbons and soot increase . Mao zaho [5] studied combustion and expansion processes. They used the two-zone model, effect of heat transfer from the cylinder wall, the mass exchange between zones and heat transfer from PM was considered to investigate the effect of inlet temperature and pressure and the compression ratio and excess air on the performance of engine and showed that the minimum value for compression ratio and initial temperature of PM on the start of combustion [16]. Based on the literature reviews the theoretical analysis of PM cycle is considered on this paper and the effect of various parameters on the power and efficiency has been discussed very well and comparison direct injection diesel cycle is done with PM cycle.

Table 1: Properties of the material for comparison

Type of Foam	Tempera ture(?C)	Thermal conductivity	Density	Specific heatC kJkg−1]	Thermal diffusivity	Application temperature(?C)
SiC	30	490	3165	0.68	2290	1400-1700
A12O3	30	368	8954	0.3831	11.23	1400-1500

PM engine is defined as internal combustion engine with a homogeneous combustion in a porous medium volume .The following individual process of PM–engine are considered in porous medium volume are heat recuperation, fuel injection, fuel vaporization, mixing with air, homogenization of charge,3D thermal self ignition, homogeneous combustion

Operating with a homogeneous combustion is the art of ignition. Four different ignition techniques may be selected, as local ignition (e.g. spark plug), thermal self ignition (e.g. compression ignition), controlled auto ignition (e.g. low temperature chemical ignition), 3-D thermal porous medium self ignition (3d grid structure with a high surface temperature).

The PM technology for IC engine means the utilization of specific features of a highly PM for supporting and controlling the mixture formation and combustion processes in IC engines.

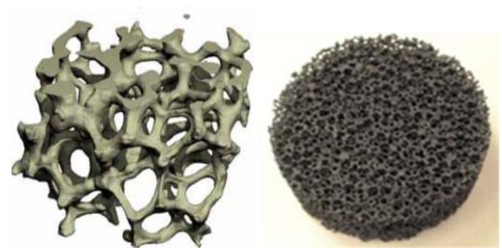


Fig. 1: View of SiC foam structure

1.1 Concept of PM engine

PM engine is defined as internal combustion engine with a homogeneous combustion in a porous medium volume .The following individual process of PM–engine are realized in porous medium volume: Heat recuperation Fuel injection**,** Fuel vaporization**,** Mixing with air**,** Homogenization of charge**,** 3D thermal self ignition**,** Homogeneous combustion**.** When piston is at TDC (top dead centre) compression volume is equal to the PM volume which creates the engine combustion chamber .and there is no combustion outside the PM volume .the PM engine is classified with respect to the timing of heat recuperation in engine as engine with periodic contact between PM and cylinder (closed PM-camber) and engine with permanent contact between Pm and cylinder (open PM-chamber)

Another type of classification of PM engine is possible by the position of the PM reactor. Here three possible position of PM reactor are: PM in cylinder head, Pm in piston, PM in cylinder. One of the most important feature of the PM engine is its ability to operate with different liquid and gaseous fuel i.e. multifuel can be used in PM engine .this engine is a 3D thermal self ignition engine.

1.2 Working PM engine with open chamber

As shown fig.2,during the compression stroke the cylinder charge is forced into the porous medium located in the cylinder head and the gas receives additional heat, causing its temperature to rise during compression.

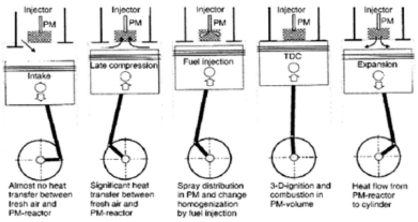


Fig. 2: Principle of PM engine with an open chamber

Near the TDC of compression, the fuel is injected into the PM volume by a conventional DI-diesel nozzle. high temperature inside the PM with a high specific surface area and a high heat capacitance, lead to rapid fuel vaporization. Finally, strong gas motion again acts to mix the vaporized fuel and air, producing a nearly homogeneous mixture for ignition. At TDC the temperature of the gas can be considered to be approximately equal to that of the PM, which maintains roughly the combustion temperature of the previous cycles. It can be considered to be higher than the gas temperature of a conventional engine, with equal compression ratio, prior to ignition. Because of the way in which the fuel is injected, ignition occurs only in the PM medium and the resulting in heat released in the PM volume, only. Hence, the entire combustion process can be considered to be limited to the PM, *i. e.* no free flame is present in the volume of the cylinder.

Part of the energy is diverted into the PM to be used in the next cycle for charge heating and fuel vaporization. As a consequence of the complete vaporization and effective mixing processes, the combustion quality in the PM is only weakly dependent on the spray atomization characteristics, *i. e*. the process is only weakly dependent on engine load. Again, all necessary conditions for a homogeneous combustion are fulfilled in the PM combustion volume. A practical realization of the PM engine concept has been described by Durst and Weclas[1].

2. MATHMETICAL MODELING FOR THERMODYNAMIC ANALYSIS OF PM-ENGINE

The following assumptions has been considered to study the ideal cycle of porous medium combustion engine as closed cycle, with working medium is air. No regeneration of exhaust gases. The heat capacity of porous medium is much larger than that of gas, thus the temperature of porous medium can be regarded as constant and not affected by the heat exchange between the porous medium and the working gas .Heat losses via the piston, cylinder wall and PM-chamber are neglected. The compression and expansion processes realized were considered adiabatic.

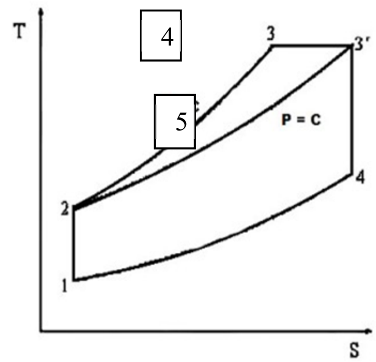


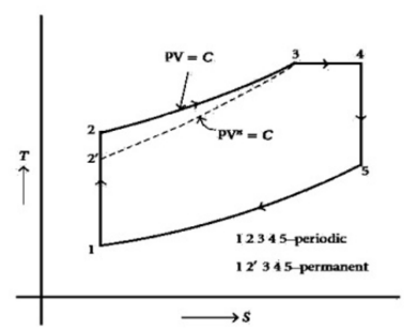
Fig. 3: T-S and P-V diagram of Pm cycle

Now net work done from the PM cycle with closed chamber is

$W_{net}=C_v[T_3\{1-(\rho/r)^{\gamma-1}\}+T_1(1-r^{\gamma-1})]+RT_3\ln\rho$ (1)

Efficiency of PM cycle with closed chamber

$\eta=1-[\{T_3(\rho/r)^{\gamma-1}-T_1\}/\{T_3-T_1r^{\gamma-1}+(\gamma-1)T_3\ln\rho\}]$ (2)



For permanent contact cycle, during intake there is a weak influence of PM heat capacitor on the in-cylinder air. Further, during compression also there is a small amount of air in contact with hot porous medium. The interaction increases as compression continues, and at TDC the whole air is assumed to be in the PM volume. Near TDC, the heat is released into PM volume.

Net total work done for the open chamber or permanent contact cycle ,

$W=(\gamma-n/n-1)C_v[T_1(r/b)^{\gamma-1}-T_3]+RT_3\ln\rho-C_v[T_3\{1-(\rho/r)^{\gamma-1}]$ (3)

Efficiency of permanent contact cycle

$\eta=1-[\{T_3(\rho/r)^{\gamma-1}-T_1\}/\{(\gamma-n/n-1)(T_3-T_1r^{\gamma-1})+(\gamma-1)T_3\ln\rho\}]$ (4)

Efficiency of diesel cycle is given by

$$\eta=1-[\{T_3(\rho/r)^{\gamma-1}-T_1\}/\gamma\{T_3-T_1r^{\gamma-1}\}] \quad (5)$$

3. RESULTS AND DISCUSSIONS

The results validated with Hongsheng Liu *, Maozhao Xie, Dan Wu with 2 % error [9].

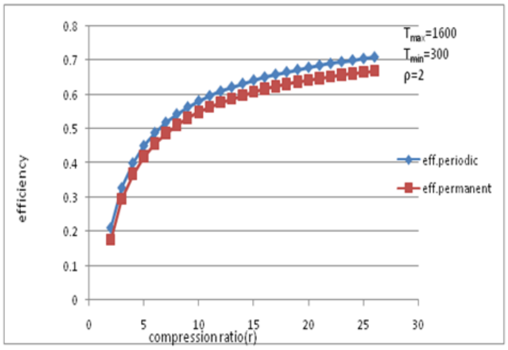


Fig. 4:, Effect of compression ratio on efficiency of PM cycle

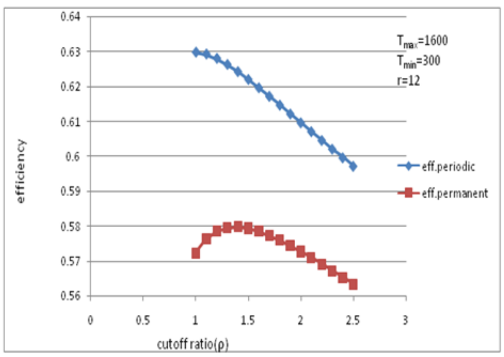


Fig. 5: Effect of cutoff ratio on efficiency of periodic and permanent contact cycle

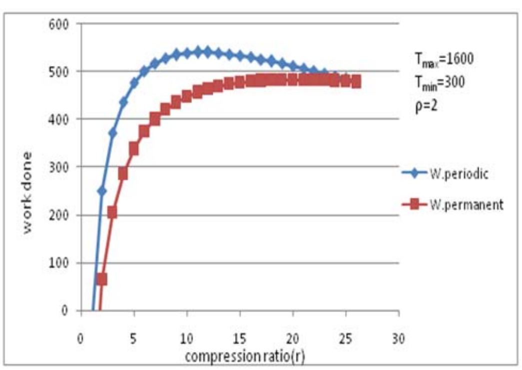


Fig. 6: work done v/s compression ratio for periodic and permanent contact cycle

Fig. (4-6), showed that the thermal efficiency of porous medium combustion cycle with periodic contact and with permanent contact increases with increase in compression ratio. And the thermal efficiency of periodic contact cycle is more than the thermal efficiency of permanent contact cycle for the same temperature range and cutoff ratio. the cutoff ratio increases the efficiency of periodic contact cycle decreases because heat addition increases at constant temperature and efficiency of permanent contact cycle first slightly increases then start decreases and the efficiency of periodic contact cycle is more than the efficiency of permanent contact cycle at same cutoff ratio. When the cutoff ratio is 1, the efficiency of periodic contact cycle is 63% and of permanent contact cycle is 57.2% and at cutoff ratio 2.4, the efficiency of periodic contact cycle is 59.4% and permanent contact cycle is 56.2%.The variation of work done with the compression ratio for the periodic and permanent contact cycle of PM engine the compression ratio increases the work done of both cycle increases but the work done for periodic contact cycle is more than the permanent contact cycle and start to decrease as compression ratio increase because for periodic contact the heat addition is constant volume process and for permanent contact cycle heat addition is polytropic process.

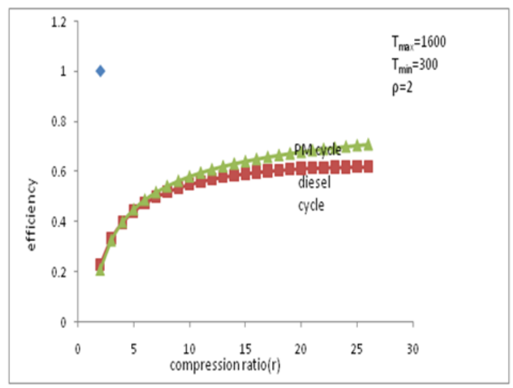


Fig. 7: Efficiency v/s compression ratio for comparison between PM cycle and diesel cycle.

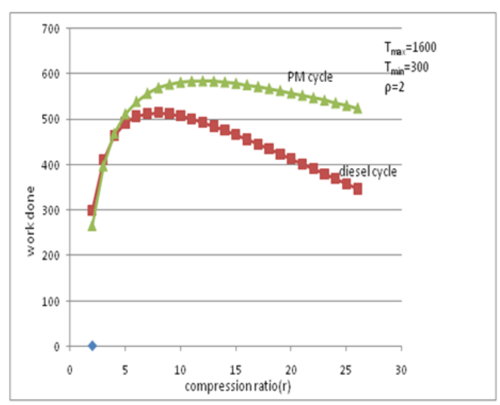


Fig. 8: work done v/s compression ratio for comparison between PM cycle and diesel cycle

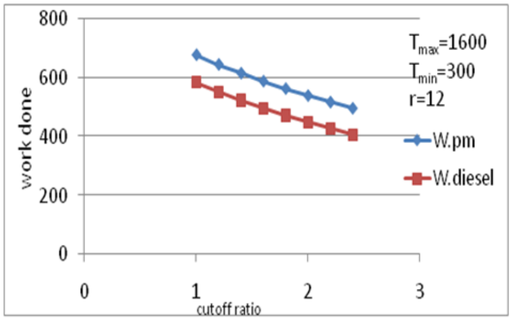


Fig. 9: work done v/s cutoff ratio for comparison between PM cycle and diesel cycle

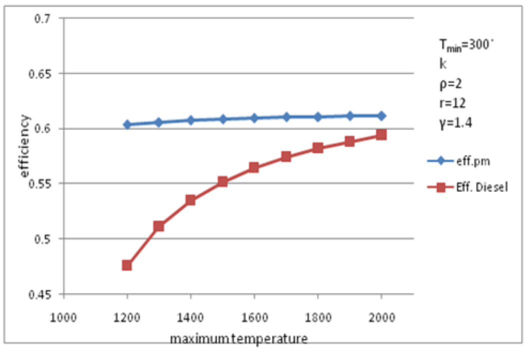


Fig. 10: efficiency v/s maximum temperature for PM cycle and diesel cycle

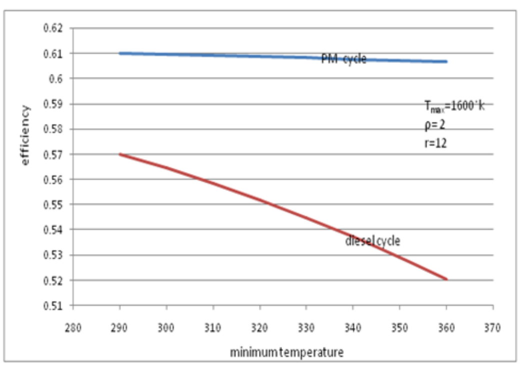


Fig. 11: efficiency v/s minimum temperature for

PM cycle and diesel cycle

Fig. (7-11), showed the comparison between the efficiency of diesel cycle to that of porous medium combustion cycle with compression ratio. And it is concluded that the efficiency of porous medium combustion cycle is more than the efficiency of the diesel cycle at same compression ratio. As compression ratio increase for both cycle, the efficiency of both cycle increase but after a certain compression ratio the efficiency of diesel cycle shows very less variation but the efficiency of porous medium combustion cycle increases as compression ratio increases with a large variation. When the value of compression ratio is 5, the efficiency of PM cycle is 45% and the efficiency of diesel cycle is 44%, but as compression ratio increases to 25, the efficiency of PM engine is 70.51% and efficiency of diesel engine is 61.721%. From the work done cycle, it is concluded that first as compression ratio increases the work done for both cycle increase but after a certain value of compression ratio the work done start to decrease. For diesel cycle the work done decrease very fast as compression ratio increases but the work done of porous medium combustion cycle decreases slowly with increase in compression ratio. As the cutoff ratio increases the work done of porous medium combustion cycle and of diesel cycle decreases from a maximum value to minimum. When cutoff ratio is 1 the work done for both cycle is maximum and as the cutoff ratio start to increase the work done decreases but the work done of porous medium combustion cycle is more than the diesel for any value of cutoff ratio. The efficiency of both porous medium combustion cycle and diesel cycle increases as maximum temperature in the cycle increases but the variation in efficiency of porous medium cycle much less than the variation in the diesel cycle. As the maximum temperature increases the efficiency of porous medium cycle increases but variation is very minor as compare to the variation in diesel cycle. So we can obtain nearly the same efficiency at lower temperature range for the porous medium combustion cycle which is help to reduce in the emission of NO_x from the IC engines. The minimum temperature in the cycle increases the efficiency of porous medium combustion cycle as well as diesel cycle decreases from maximum to the minimum. But the variation in the diesel cycle is much more as compare to the porous medium combustion cycle.

4. CONCLUSION

From the above analysis it can be concluded that the efficiency and work done of porous medium combustion cycle is more than of diesel cycle at same inlet temperature, maximum temperature, compression ratio, and cutoff ratio. And the thermal efficiency of periodic contact porous medium combustion cycle is more than the efficiency of permanent contact cycle. And the efficiency of diesel cycle is highly depending on the maximum temperature of the cycle but for porous medium combustion cycle the efficiency is not too much depending on the maximum temperature so the maximum temperature in porous medium combustion cycle is much lower than the diesel cycle which helps to reduce in emission.

REFERENCES

[1] Weclas, M., New strategies for homogeneous combustion in I.C. engines based on the porous medium (PM)-technology, ILASS Europe, June 2001.

[2] Weclas, M., Porous media in internal engines, [in:] Cellular Ceramics- Structure, Manufacturing, Properties and Applications, Scheffler, M., Colombo, P. (eds), Wiley-VCH-Publ.2005

[3] Durst, F., Weclas, M., A new type of internal combustion engine based on the porous-medium combustion technique, J. Automobile Engineering, IMechE, part D, 2001, Vol. 215, pp. 63-81.

[4] Durst, F., Weclas, M., A new concept of IC engine with homogeneous combustion in porous medium (PM), 5th International Symposium on Diagnostics and Modelling of Combustion in Internal Combustion Engines, COMODIA, 2001, Nagoya, Japan.

[5] Zhiguo Zhao, Cuihua Wang, Maozhao Xie, Numerical study on the realization of compression ignition in a type of porous medium engine fueled with Isooctane Fuel 88 22912296, (2009).

[6] Weclas, M., Die sel Soot (PM) Emissions and Technologies: State of the Art, Internal Report, 2004, Institute of Vehicle Technology, University of Applied Sciences, Nuremberg, Germany

[7] Weclas, M., Strategy for intelligent Internal Combustion engine with homogeneous combustion in cylinder, Sonderdruck Schriftenreihe University of Applied Sciences in Nuernberg, 2004, No. 26, pp.1-14.

[8] Y. Huang, C. Y. H. Chao, and P. Cheng, "Effects of preheating and operation conditions on combustion in a porous medium," *International Journal of Heat and Mass Transfer*, vol. 45, no. 21, pp. 4315–4324, 2002.

[9]. Liu H, Xie M, Chen S. *Thermodynamic analysis for ideal heat regenerative cycle in porous medium engine*. Chinese J. Engng. Thermophysic., 2006, 27(3): 553-555.

[10] Weclas, M., Melling, A., Durst, F., Flow Separation in the In let Valve Gap of Piston Engines, *Progress in Energy and Combustion Science, 24* (1998), 3, pp. 165-195

[11] Huang, Y., Chao, C. Y. H., Cheng. P., Effects of Pre heating and Operation Conditions on Combustion in a Porous Medium, *International Journal of Heat and Mass Transfer, 45* (2002), 21, pp. 4315-432

[12].Weclas M. *Strategy for Intelligent Internal Combustion Engine with Homogeneous Combustion in Cylinder*. ISSN1616-0762, 2004.

[13] Dhale Ashok A., Dr. Awari G.K., Dr.Singh M.P., Analysis of IC engine with a new concept of porous medium combustion for the future clean engine. Thermal Science International Scientific Journal, Volume 14, Number 4, Year 2010, pp. 943-956.

[14] Weclas, M., Application of Porous Medium (PM) Technology to IC Engines as a New Strategy for Reduction of Exhaust Emissions, 3th International Anniversary for the Development of Engines, Offenburg, Ger many, 1999, pp. 1-13

[15] M.Weclas, "Potential of porous media combustion technology as applied to internal combustion engines," *Journal of Thermodynamics*, vol. 2010, Article ID 789262, 39 pages, 2010.

[16] Durst, F., Weclas, M. S., A New Concept of Porous Medium Combustion in IC engines, Recent Trends in Heat & Mass Transfer, IIT Guwahati, 2002, pp. 316-332.