ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

Evaluation of combustion and emission characteristics on diesel engine with varying thickness of PSZ coated piston crown

Debasish Das[1*], Gautam Majumdar[2], Rajat Shubra Sen[2], B. B. Ghosh[3]

Department of Mechanical Engineering, National Institute of Technology, Hamirpur, India[1*]

Department of Mechanical Engineering, Jadavpur University, Kolkata, India[2]

Department of Mechanical Engineering, Indian Institute of Technology, Kharagpur, India[3]

Abstract: In this study, the comparative effect of combustion and emission of Standard diesel engine and partially stabilised zirconia coated piston were investigated. Primarily three piston crowns were coated with Al2O3 (bond coat) of 100µm thickness each by using Plasma spray coating technique. Then these piston crowns were coated with Partially Stabilized Zirconia (PSZ) with a thickness of 250µm, 350µm, 450µm respectively by using the same technique over the bond coat. Then these three coated and one uncoated piston inserted into the cylinder one by one of a single cylinder, water cooled DI diesel engine. The result showed that on the application PSZ as a ceramic coating increased oxidation, which increases the generation of CO_2. It has been also observed that coated piston engine increases the cylinder pressure and better heat release rate due to complete combustion.

Keywords- Diesel engine, partially stabilized zirconia, Engine emission, combustion.

I. INTRODUCTION

The state of art ceramic coating as a TBC improves the efficiency by reducing energy losses. The thermal barrier coating (TBCs) have been successfully applied to the various parts of the combustion chamber in internal combustion engine. TBCs were also applied in adiabatic engines not only for reduced in cylinder heat rejection and thermal fatigue protection of underlying metallic surfaces, but also for possible reduction of engine emission [1-5]. The TBCs often consists of a monolithic ceramic such as zirconia, which thermally insulates the system while sustaining high temperature gradients and in some cases, large temperature differences.

The bond coat is an intermetallic alloy that provides oxidation resistance at high temperatures and aids in the adhesion of the TBC to the substrate [6-7]. Main aims of TBCs applications of the piston surface are to reduce the heat flux into the piston, to protect the piston from thermal stresses, corrosive attack due to fuel contaminants and reducing emissions [8-10]. The coating of insulation materials used in the Low Heat Rejection (LHR) engine must have a high temperature strength, high expansion coefficient, good thermal shock resistance, low friction characteristics, light weight and durability [11]. Kamo and Bryzik, [12] used thermally insulating material such as silicon nitride for insulating different surfaces of the combustion chamber and an improvement of 7% in the performance was observed. Sekar and Kamo, [13] developed an adiabatic engine for passenger cars and reported an improvement in the performance to the maximum extent of 12%. Havstad, Garvin and Wade, [14] developed a semi-adiabatic diesel engine and reported an improvement ranging from 5 to 9% in indicated specific fuel consumption (ISFC) and about a 30% reduction in the in-cylinder heat rejection. The experimental results of Morel, Fort and Blumberg, [15] indicate that the higher temperatures of the insulated engine caused a reduction in the in-cylinder heat rejection, which is in accordance with the conventional knowledge of convective heat transfer. (Woschni, Splindler and Kolesa, [16] state that 5% of the input fuel energy can not be accounted for and which is of the order of the

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

expected improvement. The compression ignition engine was used for this experimentation at constant speed, variable load, and vertical diect injection engine. Fig. 1 shows the water cooled, single cylinder, four strokes, DI engine that was used for the study. The engine test rig is directly connected with eddy current dynamometer with suitable and control facility for loading the engine. The liquid fuel flow rate is measured on the volumetric basis using burette and stop watch. An AVL combustion analyser was used to measure the combustion characteristics of the engine. For measurement of cylinder pressure a pressure transducer was fitted on engine cylinder and a crank angle encoder was used for measurement of crank angle. The engine specification has been tabulated in table 1.

II. ENGINE TEST RIG

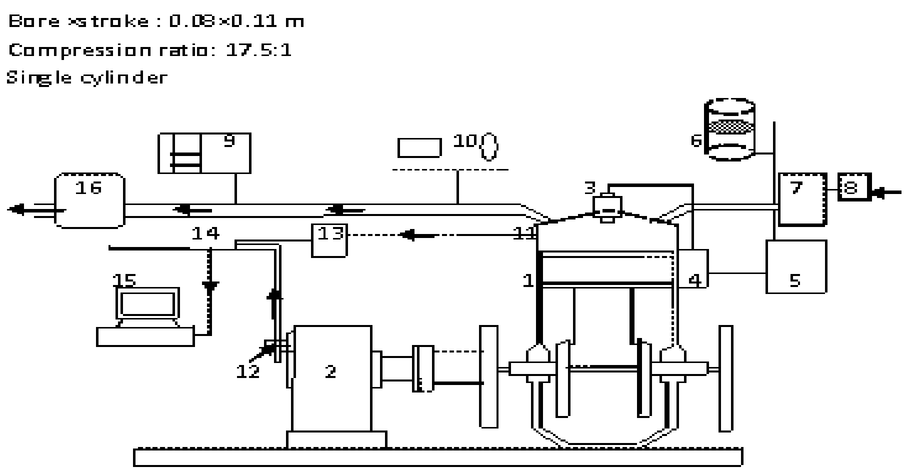

Fig 1: Experimental setup

The compression ignition engine was used for this experimentation at constant speed, variable load, and vertical diect injection engine. Fig. 1 shows the water cooled, single cylinder, four strokes, DI engine that was used for the study. The engine test rig is directly connected with eddy current dynamometer with suitable and control facility for loading the engine. The liquid fuel flow rate is measured on the volumetric basis using burette and stop watch. An AVL combustion analyser was used to measure the combustion characteristics of the engine. For measurement of cylinder pressure a pressure transducer was fitted on engine cylinder and a crank angle encoder was used for measurement of crank angle. The engine specification has been tabulated in table 1.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

Table1.Specification of the test engine

Type of Engine	Kirloskar TV-1
Intake Charge	Naturally Aspirated
Bore × Stroke	87.5mm × 110mm
Power	5.2 kW
Speed	1500 rpm
Compression Ratio	17.5:1
Injection pressure	220 Kg/cm^2
Injection Timing	23^0 before TDC
Injection Nozzle	3- hole
Injection pressure	200 r

III. EXPERIMENTAL PROCEDURE

The engine was maintained at 1500 rpm throughout the experimentation, and fixed injection pressure of 200 bar. The initial standard engine without coating was fully instrumented, connecting to the eddy current dynamometer. The first stage of experimentations was performed with standard diesel engine at five load levels via 20, 40, 60, 80% and the maximum load. The engine was tested at base line condition. The second stage of the investigation was carried out in the thermal barrier coated engine. Three differently coated PSZ pistons with thickness of 250µm, 350µm, 450µm respectively were inserted into the cylinder of a diesel engine one by one and three sets of experimental result were found out.

The engine was allowed to run with neat diesel fuel at a constant speed for nearly 10 min to attain the steady-state condition at the lowest possible load. The following observations were made twice for averaging/concordance. In each set of test readings, fuel consumption, exhaust gas temperature, peak cylinder pressure, concentrations of CO, HC and NO_X emission etc., were taken at constant engine speed, under five variable loads.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

IV. RESULT AND DISCUSSION

In this experimentation only CO_2 and O_2 emission were checked and recorded. To evaluate better combustion inside the combustion chamber required more heat which convert CO into CO_2. Therefore increased level of CO_2 means good combustion characteristic and more heat release inside the chamber, which directly predicts more NO_X generation. In the opposite sense less O_2 at the exhaust means more oxidation during combustion. Which also predict better breathing of engine during its operation. The uncertainties in the measured parameters are shown in table 2.

Table 2.Error Analysis

Parameter	Error
NO_X (ppm)	0.6
Smoke (HSU)	1.8
Cylinder pressure(bar)	0.5

The experiments were conducted in the standard engine and three differently thick coated pistons. These results are represented in the fig. 2 to 6.

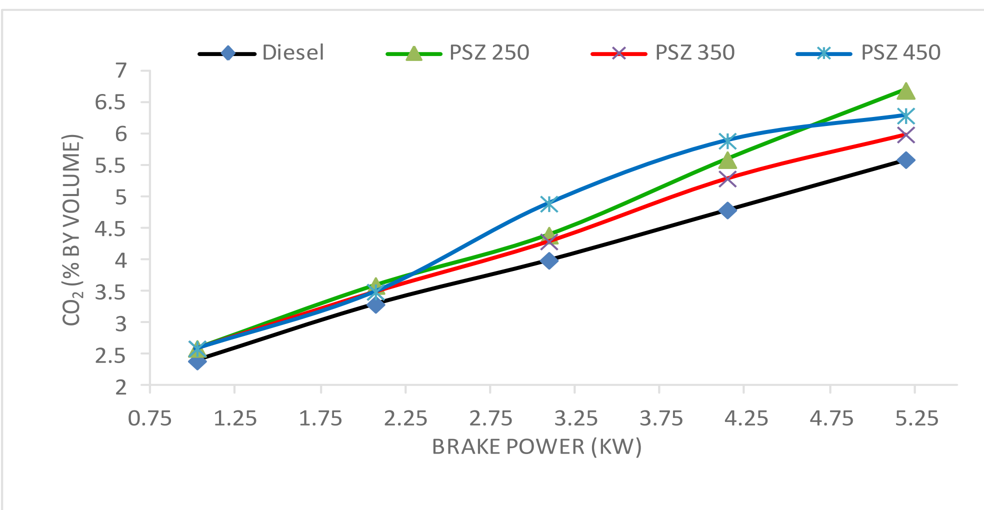

Fig 2: CO_2 against Break power

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

The variation of CO_2 with brake power for 250 µm, 350 µm, 450 µm coated piston diesel engine and standard diesel engine are shown in Fig. 2. The increase level of CO_2 emission had been observed in case of coated pistons diesel as compared to standard engine at this present study. Coated piston engine emit less heat and generate high in cylinder heat, which help for the complete combustion. The main reason of generating more CO_2 is because of complete combustion, as due to the coating more heat is available which convert CO with the presence of O_2 into CO_2. Experimental result shown, as compare to standard diesel engine 150 µm, 250 µm, 350 µm coated piston diesel engine emit 1.1%, 0.4% and 0.7% more CO_2 by volume.

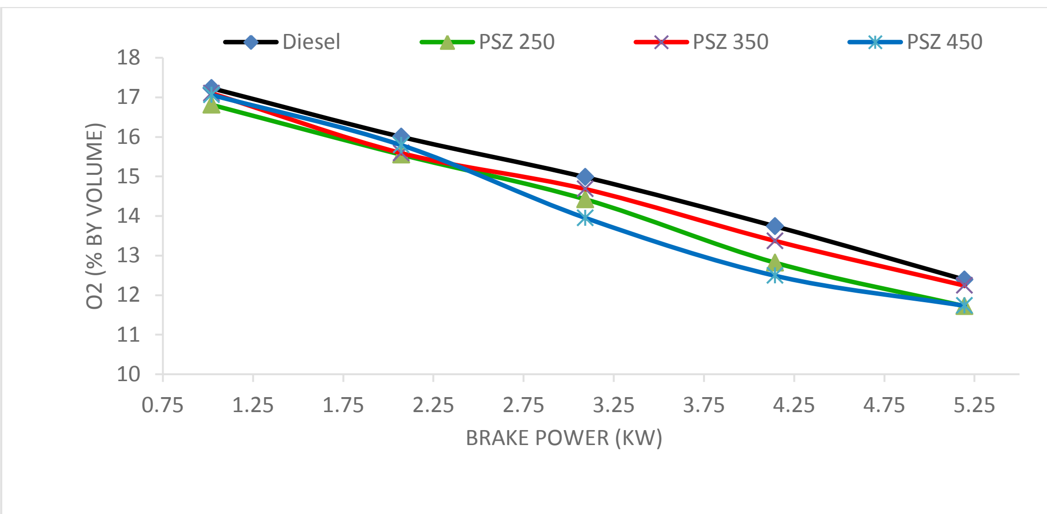

Fig 3: O_2 against Break power

Fig. 3 shows the emission of O_2 against Brake power. Result shows that for all types of coated piston the available O_2 at the exhaust is less as compared to standard engine. This is due to complete combustion. This is due to the formation of CO_2 from CO and NO_X generation more O_2 was utilized. Excess heat available in the coated piston is responsible for this oxidation. As compare to standard diesel engine 150 µm, 250 µm, 350 µm coated piston diesel engine emit 0.67%, 0.15% and 0.66% less O_2 by volume.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

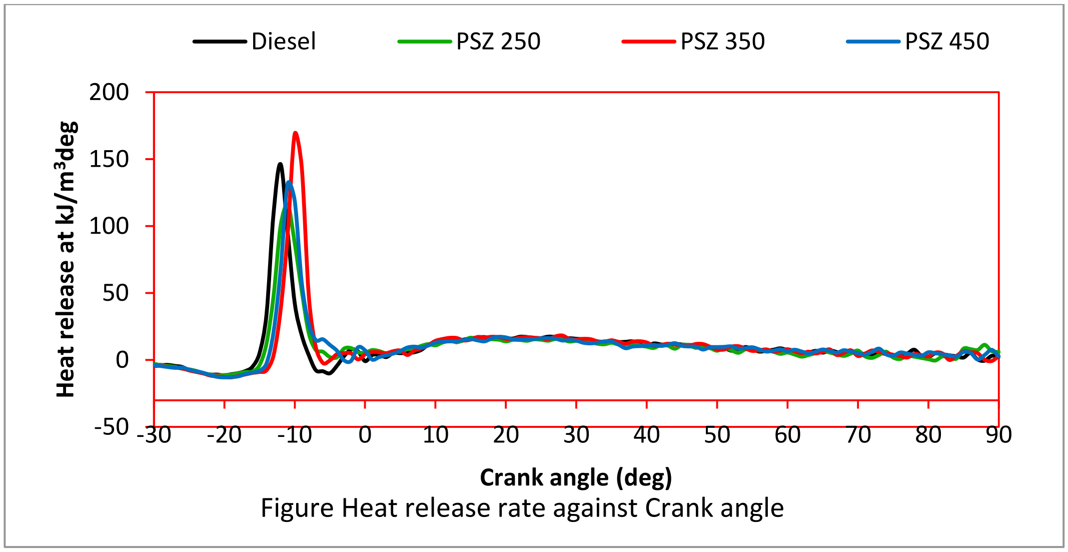

Fig 4: Heat release rate against Crank angle

Fig. 4 shows the comparison of heat release rate against crank angle for three types of coated piston diesel engine and standard diesel engine. For all three coated piston diesel engine the heat release rate was shifted toward TDC, which reduce ignition delay time. Although heat release started at the same time for all four cases but due to better combustion delay ignition time were less for all three coated piston.

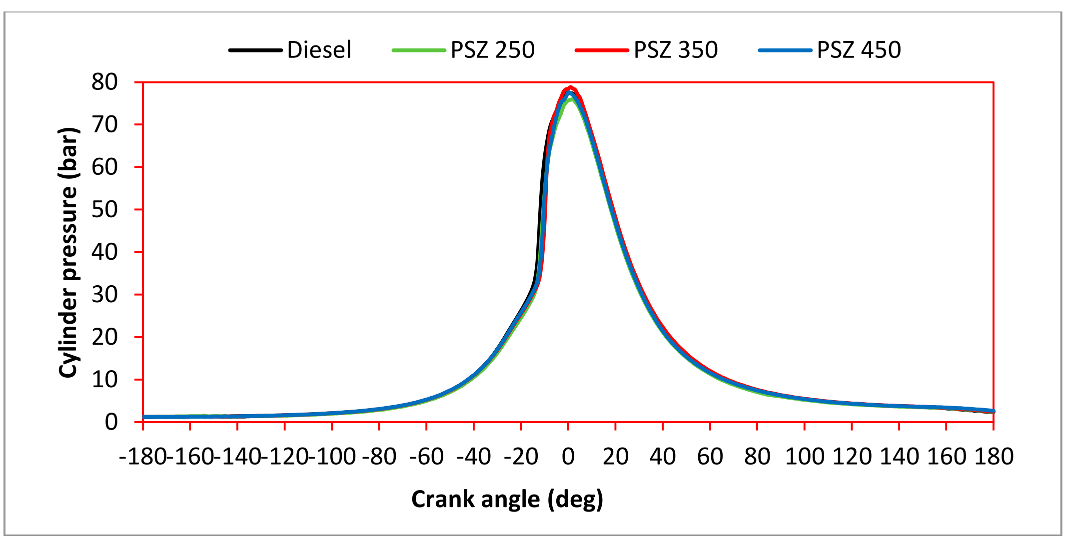

Fig 5: Cylinder pressure against Crank angle

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

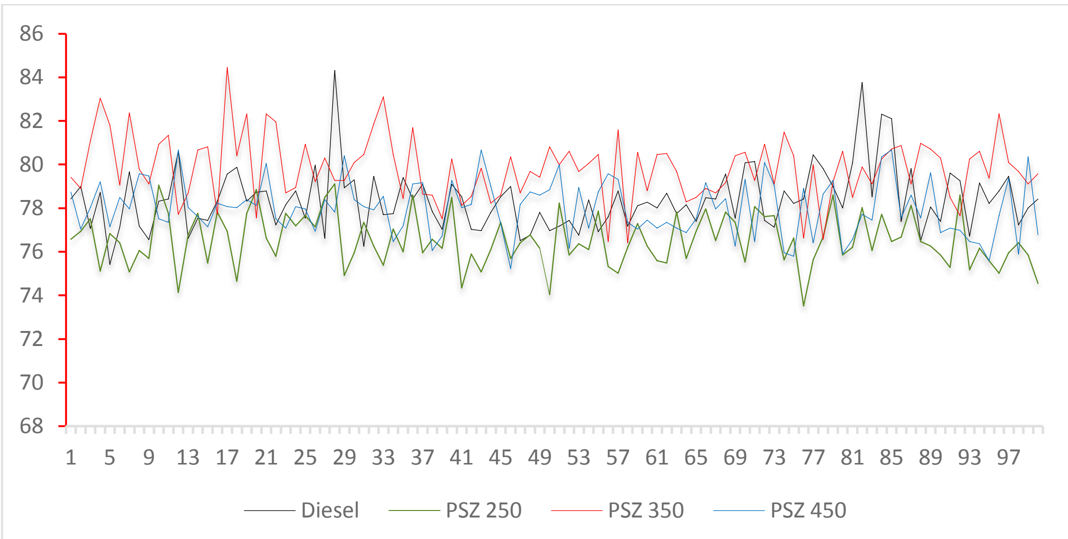

Fig 6: IMEP against number of cycles

Fig. 5 shows the cylinder pressure diagrams for the thermal-barrier-coated engine and the standard engine. It is found that the peak pressure was about 77 bar for standard engines. The peak pressure was slightly higher for coated engines when compared to the standard engine. This is may be due to the higher cylinder temperature prevail in case of ceramic coated pistons. The effects of the TBC engine of indicated mean effective pressure against 100 cycles are shown in Fig. 6. The average IMEP for the standard engine is 78 bar of pressure. It is found that IMEP for TBC engines are slightly higher than the standard engine. The reason for the higher pressure is due to the production of more power during combustion.

V. CONCLUSION

From the study, the following conclusions can be deduced:

1). partially stabilized coating can act like an insulator and prevent heat rejection from the engine. Due to this it produces more heat during combustion.
2). Because of above phenomena, the engine with TBC coating having high brake thermal efficiency.
3). Due to excess amount of heat more CO_2 produced.
4). TBC engine release less O_2 which indicates better oxidation during combustion.
5). Heat release rate curve slightly shifted towards TDC, which predict less ignition time delay for TBC engine.
6). PSZ is a costly ceramic material; therefore more research can be performed to lower its cost.

ACKNOWLEDGEMENT

Debasish Das, wish to place on record his deep gratitude and heartfelt thanks to Dr. C. G. Saravanan, Professor, Department of Mechanical Engineering, Annamalai University, Tamil Nadu for experimentation and discussion.

REFERENCES

[1] Beardsley,M.B., Happoldt,P.G., Kelley, K.C., Rejda, E.F. and Socie, D.F. (1999), "Thermal Barrier Coatings for Low Emission, High Efficiency Diesel Engine Applications", SAE Paper Number: 2255.

[2] Vittal, Manohar, Jeffrey Borek, M.B., Boehman Andre L. and Okrent, D.A. (1997), "The Influence of Thermal Barrier Coatings on the Composition of Diesel Particulate Emissions", SAE Paper Number: 970799.

[3] Matthew, F. Winkler and Daniel, W. Parker (1993), "Ceramic Thermal Barrier Coatings Provide Advanced Diesel Emissions Control and Improved Management of Combustion-Exhaust System Temperatures", SAE Paper Number: 931106.

[4] Kahl, W.K. (1993), "Thermal Barrier Effects on Performance and Emissions of a Methanol Fuelled DI Engine", SAE Paper Number: 892163.

[5] Dhananjaya, D.A , Mandya, Karnataka, Surathkal, Manipal, P Mohan, Surathkal, C. V. Sudhir, (2009),"Combustion and Emission Characteristics of Diesel, B100 and B20 Fuel on A Thermal Barrier Coating on Piston Crowned in Direct Injection C.I. Engine At Optimum IOP And IT",SAE Paper Number: 2009-28-0042.

[5] Buyukkaya, E., Cerit, M. (2007), "Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method", Surface and Coatings Technology, Vol. 202, pp. 398 – 402.

[6] Gilbert, A., Kokini, K. and Sankarasubramanian, S. (2008), "Thermal Fracture of Zirconia-Mullite Composite Thermal Barrier Coatings under Thermal Shock: An Analytical Study", Surface and Coatings Technology, Vol. 203, No. 1-2, pp. 91-98.

[7] Gilbert, A., Kokini, K. and Sankarasubramanian, S. (2008), "Thermal Fracture of Zirconia-Mullite Composite Thermal Barrier Coatings under ThermalShock:An Experimental Study", Surface and Coatings Technology, Vol. 202, No. 10, pp. 2152-2161.

[8] Jesse, G., Muchai, Ajit D. Kelkar, David E. Klett, Sankar Jagannathan, (2002), "Thermal- Mechanical Effects of Ceramic Thermal Barrier Coatings on Diesel Engine Piston", Mat. Res. Soc. Symp, Proc., Vol. 697, Material Research Society.

[9] Hejwowski, T., and Weronski, A., (2002), "The effect of thermal barrier coatings on diesel engine performance", Vacuum, Vol. 65, pp. 427-432.

[10] Buyukkaya, E. (2008), "Thermal analysis of functionally graded coating AlSi alloy and steel pistons", Surface and Coatings Technology, Vol. 202, pp. 3856 – 3865.

[11] Prasad, R., and Samria, N. K. (1990), "Heat Transfer and Stress Fields in the Inlet and Exhaust Valves of a Semi-adiabatic Diesel Engine", Comput. Struct., Vol. 34, pp. 765-777.

[12] Kamo, R. and Bryzik, W. (1979), "Ceramics in heat engines", SAE International, Paper No. 790645.

[13] Sekar, R.R. and Kamo, R. (1984), "Advanced adiabatic diesel engine for passenger cars", SAE International, Paper No. 840434

[14] Havstad, P. H., Garvin, I. J., Wade, W. R. (1986), "A Ceramic Insert Uncooled Diesel Engine" SAE Paper Number: 860447.

[15] Morel, T., Fort, E. F., and Blumberg, P. N. (1985), "Effect of Insulation Strategy and Design Parameters on Diesel Engine Heat Rejection and Performance", SAE Paper Number: 850506.

[16] Woschni, G., Splindler, W., and Kolesa, K., (1987), "Heat Insulation of Combustion Chamber Walls – A Measure to Decrease the Fuel Consumption of IC Engines", SAE Paper Number: 870339.