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AN EVALUATION OF THE EFFECTS OF COATING WITH THERMAL BARRIER ON ENGINE PERFORMANCE IN DIESEL ENGINE

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Abstract

Increasing the performance of an internal combustion engine requires the transformation of total fuel energy to useful energy at the highest as possible. Increase of inner cylinder heat plays important role in the increase of engine performance and decrease of exhaust emissions. It is understood as a result of literature studies that coating combustion chamber elements with thermal barriers contributes a lot to the increase of inner cylinder heat. This study includes an evaluation of experimental studies and its results carried out upon the methods applied on coating with thermal barrier in diesel engines, the effects of coating on the performance of engine and exhaust emissions.

Keywords: Thermal barrier coating, diesel engine, engine performance, exhausts emissions.

1. Introduction

Researches on the issues of cost reduction and decrease of fuel consumption and technological in parallel to this studies have been carried out in automotive industry. In the studies carried out, improvement works of engine yield with desigNEents on engine design have gained profound importance today. In order to increase the performance of internal combustion engine, total energy must be transformed to useful energy as much as possible [1]. It is known that utilizable energy in an internal combustion engine is around 30-40%. Part of the rest is used for cooling system done for protecting the parts of engine from high heat, and the rest is discarded to atmosphere passing through exhaust gases in 500-600 °C [1-4].

The heat of coolant in cooling system is an important factor that detects the average heat of engine parts of internal combustion engines [5-6]. Therefore, it can be said that as the heat of coolant increases so does the heat of engine parts. Decrease of coolant means cooling of motor block which in contact with coolant; cylinder head, piston, cylinder sleeve in other words the cylinder in which the cycle is carried out. Decrease of cylinder wall heat causes increase of heat energy rate which is named as lost energy and which passes to coolant. These situations causes decrease of pressure and heat due to compression and therefore decrease of brake mean effective pressure and increase of fuel consumption [5-7]. Thermal shock, pressure and negative effects of exhaust gases as a result of combustion reaction cause chemical corrosion and deformation on the surface of combustion chamber elements (cylinder sleeve, valve, piston, piston head etc.). Since this chemical corrosion would shorten the mechanic life of elements in time, it causes gradual performance in engine, increase of fuel consumption and worsening in emission values. Preventing these surface deformations is possible with preventing high temperature, pressure and direct contact of chemical corrosion on the surface of main elements during combustion [8]. Transforming lost energy to utilizable energy can be enabled by increasing useful work in expansion stroke, decreasing the heat that moves to exhaust and cooling system. Producing or coating elements that constitute combustion chamber with material with low thermal conductivity and resistant to high working heat revealed the concept of Coated Engine (CE) [1]. Achieving low heat-loss engines or in other words adiabatic engines that are insulated from outer enviroNEent is enabled with Thermal Barrier Coat (TBC). Thermal barrier coats prolong the life of the parts of diesel engines and serve as a barrier against corrosion [2].

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2. Coating in Internal Combustion Engines and Coating Methods

Usage of tribological coatings in internal combustion engines have been increasing everyday. Metal and metal alloy are needed in many fields due to fast developing technology. One of these fields are engines. With various methods combustion chamber elements are coated with coating materials in internal combustion engines. Leading method among these is thermal barrier coating. Thermal barrier coatings are used in order to increase reliability and strength of hot parts of metal components, increase yield and performance of engines. Engine parts which are coated with thermal barrier are; piston, cylinder head, cylinder sleeve and exhaust valves. Engines with thermal barrier coating are called low heat loss engines (Lower Compression Ratio – LCR). LCR lowers insulation of combustion chamber elements of engine and heat transfer between gas and cylinder sleeve in cylinder. LCR concept is based on the control of heat moving coolant and reclaiming energy [8-12].

Different methods are used in order to coat the surface of metals. These methods differ according to characteristics of material to be used; suitable to the intended use [13].

- Physical Vapour Decomposition (PVD)
- Chemical Vapour Decomposition (CVD)
- Ion Coating
- Splash Coating
- Electron Beam Evaporation Coating (EBE)
- Flame Spray (FS)
- Plasma Spray (PS)
- Sol-gel (SG)
- Detonation Gun (DG)
- Reactive ion coating (IP)
- Hot izostatical press coating (HIP)

Büyükkaya expressed that; in order to enhance better protection on the steel wings of compressors, using Cr_7C_3 with chemical vapur decomposition in the place of Ti (CN) would enable better strength towards thermal and mechanic shock and better strength towards corrosion [1].

Dalkılıç expressed in his study that today two basic methods being Plasma Spray and Physical Vapour Decomposition with Electron Bunch are used in the application of thermal barrier coating systems [14].

In their study, Vaz et al. Expressed that popular hard coatings used in order to increase the corrosion strength of Titanium nitride materials are generally produced with PVD method industrially [15].

Yaşar listed the thermal spray methods used commonly in industry as flame dust and fiber spray, electric arc spray, detonation gun technique, fast-speed oxy-fuel spray and plasma spray [16].

Kvernes et al. Expressed that thermal spray coating technology is used in plane and space industry and automative industry being former; in textile, paper and mining industry; medical applications, materials science and in metalurgy as well [17].

Yeşildal and Günay expressed in their sudy in which they coated turbin and jet engines combustion chamber and turbine palet elements that in order to increase bond strength in plasma spray coatings; blaster plate should be roughened before coating [18].

3. Studies

Haşimoğlu et al. achieved low heat loss control engine by coating with Yitriya Stabilized Zirconia ($Y_2O_3ZrO_2$) with plasma spray method on Uncoated Normal Engine (NE). Before coating, NE cylinder, cylinder head and valves are 0.5 mm – as thick as the coating- machined. 0.15 mm Nickel Chrome Aluminum (NiCrAl) prime coat was used on the surface to be coated in order to adhere better. Prime coat was coated with 0.35 $Y_2O_3ZrO_2$ mm material. Testing apparatus they have used is given in Figure 1 [19].

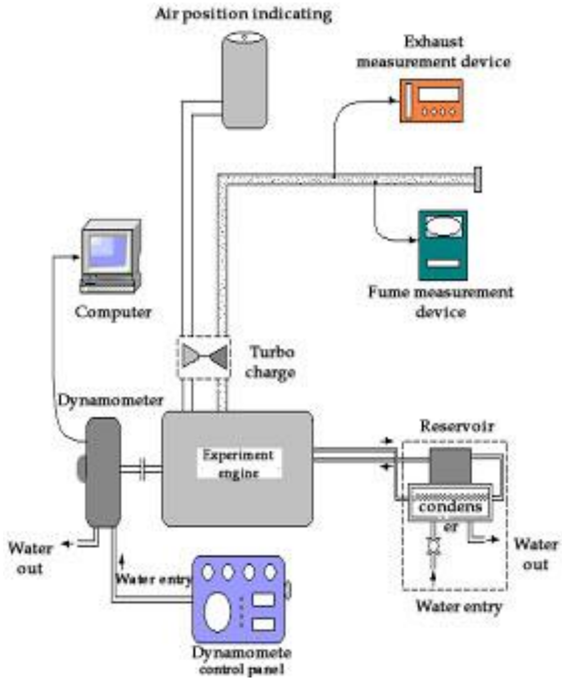


Figure 1. Schematic testing apparatus [19].

Hazar and Öner, in their study, coated the cylinder surface of diesel engine with CrN in cathodic Arc PVD. In their study, they have used uncoated engine in same features apart form coated engine. They tested both engines in specific load numbers and revolution by binding to dynamometer bench. Exhaust gas emission measurement was carried out with MRU 95/3D model gas analyses equipment and the values are compared in graphics [20]. They observed comparatively the change of exhaust gas output heat of Ceramic Coated Engine (CCE) and normal engine (NE) according to engine revolutions and exhaust gas change results are given in graphic below (Figure 2-3) [20].

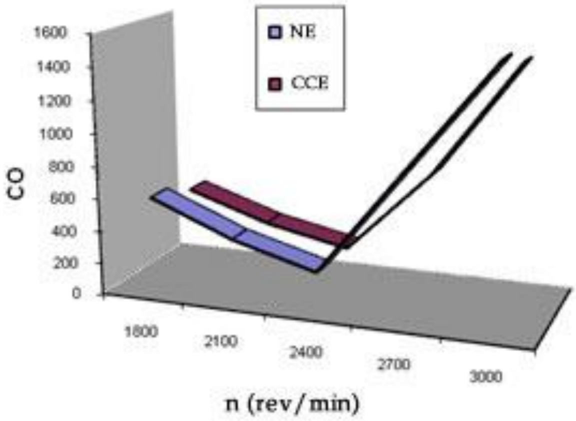


Figure 2. Change of carbon monoxide (CO) emissions with revolution [20].

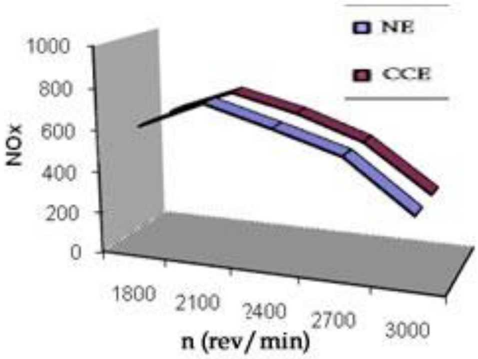


Figure 3. Change of nitrousoxide (NOx) emissions with revolution [20].

Yaşar, in his study, compared CCE engine by which he attained coating with zirconia on NE engine via plasma spray method with NE engine. Results of exhaust emission are given in Figure 4 – 6 in graphics. As a result of this study; he expressed that emission values in CCE engine are in the trend of decrease and this rates are %48 in particle emissions, %35 in carbon monoxide emissions and %40 in hydrocarbon emissions [16].

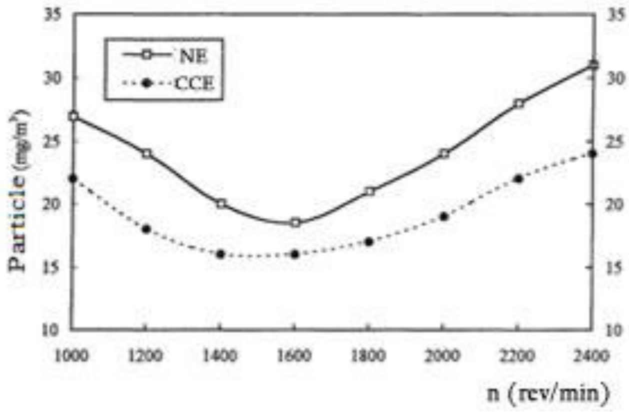
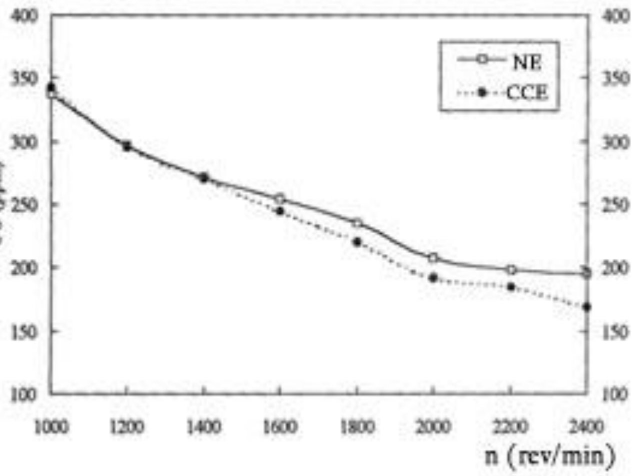


Figure 4. Change of CCE particle amount with revolution [16].



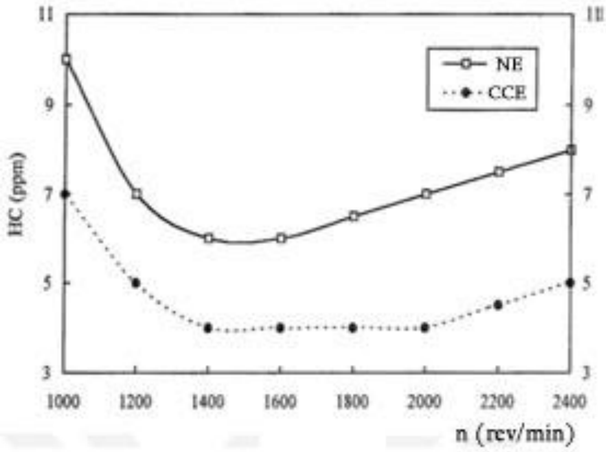


Figure 6. Change of hydrocarbon amount in CCE with revolution [16].

In their study in which Haşimoğlu et. al. attained LCR1 engine by coating cylinder head with Yitriya Stabilized Zirconium (Y_2O_3–ZrO_2) in plasma spray method and then attained LCR2 engine by coating the pistons of same engines detected that NOx emission increased together with engine load and while NOx emission increased %8 for LCR1, it increased %21.5 for LCR2 (Figure 7) [21].

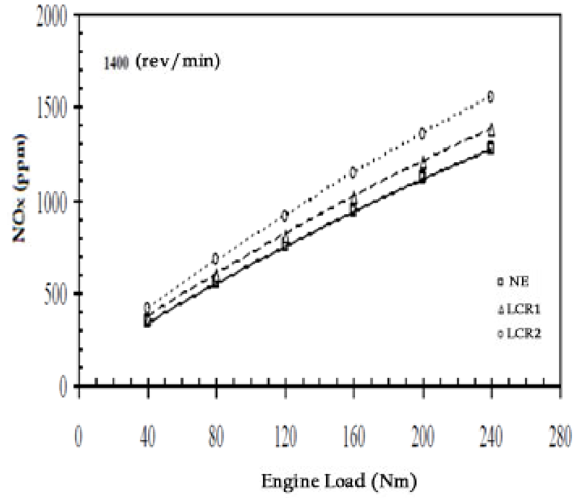


Figure 7. Change of NOx emission due to engine load [21].

Gatowski expressed in his study in which he coated combustion chamber elements of single-cylinder ordinary diesel engine that there was an 23% increase in NOx emission [22].

Osawa et. al. in their study upon single-cylinder, air coolant low heat loss diesel engine expressed that there was 16% increase in NOx emission while 1% decrease in CO emissions [23].

Hazar and Öner expressed that heat decrease transferred from combustion chamber elements in CCE coated engines are enabled and in the chemical reaction that occurs as a result of combustion chamber heat increase Hydrocarbons (HC) react with more oxygen. Therefore it is expressed that hydrocarbons which are discarded unburned would be burned and the amount of HC in exhaust emissions would decrease [20].

In another study, Hazar and Öner expressed that combustion temperature of CCE engine is higher than that of NE engine. They have conveyed the results of their experiments on graphics (Figure 8) [24].

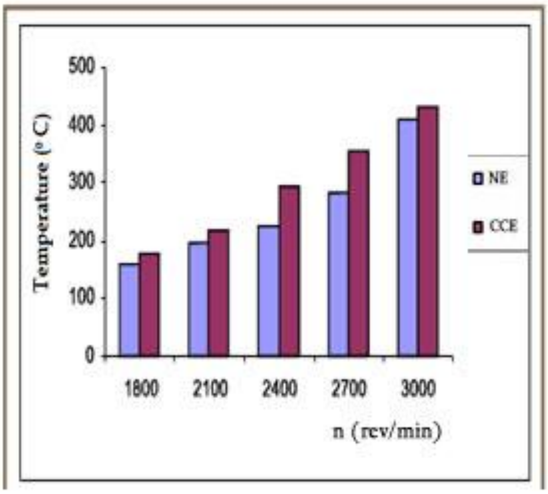


Figure 8. Change of exhaust temperature with revolution [24].

In a study carried on single-cylinder, direct spraying, supercharged, low heat loss diesel engine; Kawamura et al. expressed that good-insulation of cylinder side wall decreases heat loss more than 70% [25].

In his study carried out by coating combustion chamber elements with ceramic material, Sudhakar expressed that as a result of ceramic coating there is 20-25% decrease in energy amount which passes from engine cylinder to cooling system, 1.7% decrease in the specific fuel consumption, an important increase in NOx emissions [26].

In a report of thermal barrier coating study of Hay et al., they expressed that there was 30% decrease in heat transfer low speed and loads and at least 3.6% specific fuel consumption amendment [27].

In his study Yaşar showed specific fuel consumption curves for CCE and NE by using iso specific fuel consumption and effective pressure curves (egg curves), and expressed that specific fuel consumption has decreased significantly in CCE engine (Figure 9-10) [16].

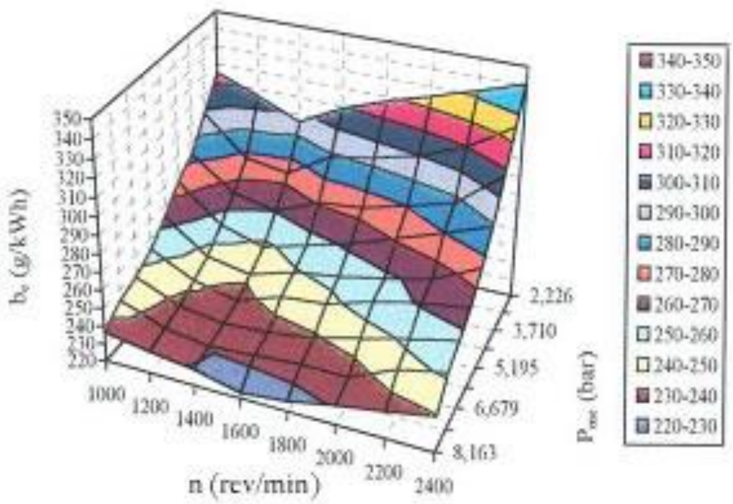


Figure 9. Three dimension presentation of iso-specific fuel consumption curves of NE (b_c) [16].

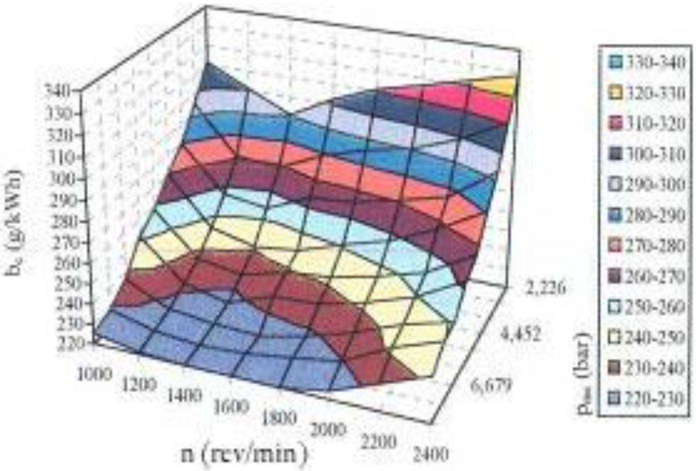


Figure 10. Three dimension presentation of iso-specific fuel consumption curves of CCE (b_c) [16].

In their study upon ceramic coated adiabatic engine, Büyükkaya expressed that specific fuel consumption for CCE and NE engines are minimum 1200 – 1600 rev/min and average pressure is between 3.5 – 4.75 bar (Figure 11,12) [1].

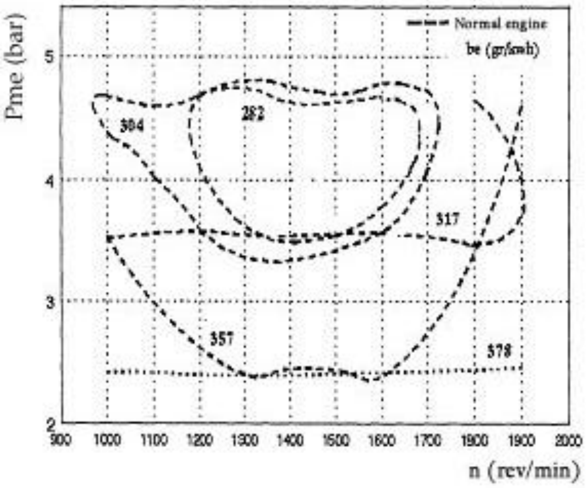


Figure 11. Egg curves (iso-specific fuel consumption) of experiment values for NE [1].

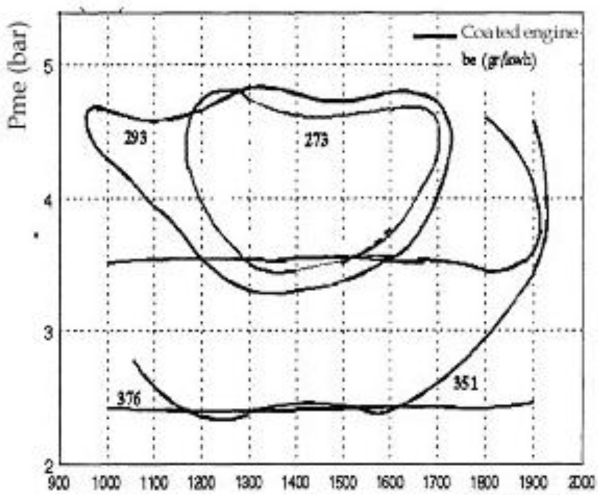


Figure 12. Egg curves (iso-specific fuel consumption) of experiment values for CCE [1].

4. Assessment and Suggestions

It is desired for the cost and fuel consumption to be less in automotive industry. This is possible with long-life engine parts and utilizing much as possible of the energy obtained from fuel. Decrease of fuel consumption and prolonging life of engine parts can be enabled by coating combustion chamber elements with thermal barrier material.

In this study, literature study about thermal barrier coating of diesel engine and engine performance changes as a result of coating is carried out and coating methods and their effects on exhaust gas temperature, exhaust emissions, fuel consumption, effective power.

- Generally ceramic materials are used as coating material. The reason of using ceramic materials is its ability in good heat insulation.
- Material used, heat insulation and usage life change according to coating method. Generally PS method which gives quite good results in heat insulation was used. PVD and CVD methods were used in the coating of materials such as TiN TiAlN.
- As a result of the studies, it is detected that there is an increase in exhaust gas temperature, decrease in HC and CO emissions which are harmful for living beings, there is amendment in fuel consumption. There is little increase in NOx emissions. It is detected that smoke emission due to ceramic coating; ignition lag shortened due to increasing internal cylinder gas temperature and this caused decrease of particles.
- It is detected that there is 6-12% increase in engine power due to thermal barrier coating.
- It is detected that in order to decrease unused lost energy combustion chamber elements of engines can be coated with thermal barrier.
- Type of venerable material can be enhanced and materials such as BOR, TiA1N can be used.
- In order to decrease heat loss further, studies upon coating cylinder sleeves can be carried out.
- The effect of thermal barrier coating technique on gasoline engines can be studied.

References

1. Büyükkaya E., “Ceramic Coating Applications and Performance Analysis in a Diesel Engine” Post-Graduate Thesis, 1994.
2. Taşdıvar D., Erkmen Z. E., “Thermal Barrier Coating of Internal Combustion Engines” Science – Technology July – August No.16, 2006.
3. Topal A., “Performance Yielding of Aluminum Alloy Piston Material with Ceramic Coating”, Post*Graduate Thesis, İstanbul, 2002.
4. Safgönül, B., "Piston Engines", İTÜ Library, Issue 1207, İTÜ Press, 1981.
5. Borat, O., Balcı, M. Ve Sürmen, A., Internal Combustion Engines, Technical Education Institution Press, Volume 1, Ankara, 1995.
6. Malaev, V. L., “Internal Combustion Engines, Mc Graw-Hill International Book Company”, 1983
7. Topgül T., Çınar C. “An Experimental Study about the Effects of Coolant Heat in Internal Combustion Engines on Engine Performance” Selçuk-Technical Online Journal, ISSN 1302-6178, Volume: 2, Number:1, 2001
8. Hazar H., Öztürk U. “Observation of Surface Micro Structures of Piston and Valves coated with Al2O3-Tio2 in a Diesel Engine” Machine Technologies Electronic Journal Volume: 6, No: 1, (11-16), 2009.
9. Zhou, H., Yi, D., Yu, Z., Xiao, L., “Preparation and thermo physical properties of CeO2 doped La2Zr2O7 ceramic for thermal barrier coatings” J. Alloys Compds 438 217–221, 2007.
10. Uzun, A., Cevik, I., Akcil, M., “Effects of thermal barrier coating on a turbocharged diesel engine performance” Surf. Coat. Technology, 116–119 505–507, 1999.
11. Parlak, A., Yasar, H., Eldoğan, O., “The effect of thermal barrier coating on a turbo-charged diesel engine performance and exergy potential of the exhaust gas” Energy Convers Manage 46 489–499, 2005.
12. Afrasabi, A., Saremi, M., Kobayashi, A., “A comparative study on hot corrosion resistance of three types of thermal barrier coatings: YSZ,YSZ+Al_2O_3 and YSZ/ Al_2O_3” Mater Sci Eng A., 2007.
13. Çelik, E., "Ceramic Coating Technology”, Post-Graduate Thesis, June, 1993.
14. Ö) Dalkılıç S., “Observation of Wearing Behavior of a Thermal Barrier Coating System” Doctorate Thesis. 2007.

15. Vaz, F., Machado, P., Rebouta, L., Mendes, J.A., Lanceros-Mendes, S., Cunha, IL., Nascimento, S.M.C., Riviere, J.P., Alves, E., Sidor, A., Physical And Morphological Characterization Of Reactively Magnetron Sputtered Tin Films, Thin Solid Films, 420, 421-428, 2002.
16. Yaşar H., "The Effect of Thermal Barrier Coating on the Performance of Turbo-Filling Diesel Engine", Doctorate Thesis, 1997.
17. Kvernes, L, Lvgscheider, E., Lindblom, Y., "Protection Materials Coatings Thermal Barrier and Wear Resistance", Proc. 2 T H Euro Symp. On Engineering Ceramics, 1987.
18. Yeşildal R., Günay Y. Z. "Observation of the Characteristics of Coating and Spray with Plasma Spray Method" Dokuz Eylül University Engineering Faculty Science and Engineering Journal Volume: 9 Number: 1 S. 59-76, 2007.
19. Haşimoğlu C, Ciniviz. M, Salman M.S.,"Exhaust Emission Change of Low Heat Loss Diesel Engine for Different Insulation Levels", Technological Studies Transportation Technologies Electronic Journal, (3) 1-9, 2009.
20. Hazar H., Öner C. "The Effect of Thermal Barrier Coating on Exhaust Emissions in Diesel Engines" East Anatolia Region Researches, 2004.
21. Kawamura, H., Sekiyama, S. And Hirai, K., "Observation Of The Combustion Process İn A Heat Insulated Engine", Sae Paper No 910462, 1991.
22. Gataowski, J.A., "Evaluation Of Selectively-Cooled Single-Cylinder 0.5-L Diesel Engine", SAE 900693.
23. Osawa, K., Kamo, R., Valdmanis, E., "Performance of Thin Thermal Barrier Coating on Small Aluminum Block Diesel Engine", International & Congress and Exposition, Detroit, Michigan, 1991,
24. Hazar H., Öner C. "The effect of Crn coating on a diesel Engine" Engineering and Machine • Volume: 48 Number: 574
25. Kawamura, H., Sekiyama, S. And Hirai, K., "Observation of the Combustion Process in a Heat Insulated Engine", SAE Paper No 910462, 1991.
26. Sudhakar, V., Performance Analysis Of Adiabatic Engine, SAE International Congress And Exposition, 54, 1984.
27. Stone, R., "Motor vehicle fuel economy", Macmillan education ltd. Hong Kong, 1989.