Pamukkale Üniversitesi
Mühendislik Bilimleri Dergisi
Cilt 16, Sayı 1, 2010, Sayfa 87-94

Performance Evaluation of A Low Heat Rejection Diesel Engine for Different Insulation Levels

Farklı İzolasyon Seviyeleri İçin Düşük Isı Kayıplı Bir Dizel Motorunun Performans Değerlendirmesi

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Geliş Tarihi/Received : 29.05.2009, Kabul Tarihi/Accepted : 09.09.2009

ABSTRACT

This experimental study focuses on investigating of effects of low heat rejection engine application to a diesel engine at different insulation levels. For this purpose cylinder head and valves of the test engine were thermally insulated with yttria-stabilized zirconia (Y_2O_3–ZrO_2) layer at first stage. Then in addition to cylinder head and valves, pistons of the test engine were coated with the same material. Brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), brake thermal efficiency and volumetric efficiency of the test engine were investigated for two different insulation levels. After the engine tests it was determined that BSFC was improved by 4 - 7.1 %, EGT was increased by 3.5 - 6.8 %, brake thermal efficiency was improved by 4.1-7.9 % and volumetric efficiency was increased by 0.9 - 2.6 % with LHR application. It was also determined that these improvements in engine performance are proportional with the insulation levels of the test engine.

Keywords : *Low heat rejection engine, Thermal barrier coating, Diesel engine, Engine performance.*

ÖZET

Bu deneysel çalışma bir dizel motoruna farklı izolasyon seviyelerindeki düşük ısı kayıplı motor uygulamasının etkilerinin incelenmesine yöneliktir. Bu amaçla ilk aşamada deney motorunun silindir kapağı ve supapları termal bariyer oluşturmak için yitriya ile stabilize zirkonya (Y_2O_3–ZrO_2) ile kaplanmıştır. Daha sonra silindir kapağı ve supaplara ilaveten deney motorunun pistonları da aynı malzeme ile kaplanmıştır. Deney motorunun özgül yakıt tüketimi, egzoz gaz sıcaklığı, fren ısıl verimi ve hacimsel verimi iki farklı izolasyon durumu için incelenmiştir. Düşük ısı kayıplı motor uygulaması ile motor testlerinin sonucunda özgül yakıt tüketiminde % 4-7,1 iyileşme, egzoz gazı sıcaklıklarında % 3,5–6,8 artış, fren ısıl verimde % 4,1–7,9 iyileşme ve hacimsel verimde % 0,9–2,6 artış tespit edilmiştir. Ayrıca motor performansındaki bu iyileşmelerin deney motorunun izolasyon seviyesi ile orantılı olduğu belirlenmiştir.

Anahtar Kelimeler: *Düşük ısı kayıplı motor, Termal bariyer kaplama, Dizel motoru, Motor performansı.*

1. INTRODUCTION

Turbocharged diesel engines are generally preferred as prime mover from light to heavy duty applications due to their high reliability and fuel economy. However, rapid depletion of fossil based fuel reserves has focused the researches on improving fuel economy further. Thermodynamic considerations declared that raising the highest temperature in a cycle also raises the thermal efficiency of the engine. The highest temperature in the cycle is limited by the maximum temperature that combustion chamber components such as piston, cylinder head and valves, can withstand. Hence, low heat rejection engines become popular as they allow the use of higher combustion temperatures. Engine which is insulated to reduce the rejected heat through its cooling system is known as Low Heat Rejection (LHR) Engine (Zhou, 1995; Çengel and Boles, 1996; Beard, 2006; Giakoumis, 2007).

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The heat rejected through the cooling system is a precursor of inefficiency. If the combustion chamber components are insulated thermally, thermal efficiency of the engine may be improved. However, this may cause problem due to thermal resistance of hot section components in the engine. In order to improve the reliability and durability of hot section metal components in advanced engines and enhance engine performance, thermal barrier coatings (TBCs) were applied on the surface of these components. The use of TBCs can result in a significant temperature decrease between the hot gas and the surface of these components. TBCs are multilayer systems consisting of a metallic bond coat a stabilized zirconia top coat (to provide the thermal barrier) and an intermediate alumina protective layer that forms during high temperature exposure (Zhou, 1995; Zhou et al., 2007; Sidhu et al., 2007).

The LHR engine technology has the potential for gains in fuel efficiency, increased power density, reduction in cooling system size, reduced noise, higher exhaust gas energy, ability to operate on lower cetane fuels. With in the LHR engine concept some of combustion chamber elements are coated with high temperature resistant ceramic material. The ceramic coated engine parts are pistons, cylinder head, valves, cylinder liners and exhaust port (Zhou, 1995; Parlak et al., 2004; Parlak et al., 2005).

Since 1970s many studies have been done about LHR engines. Due to the increased exhaust gas temperatures turbocharged diesel engines have been preferred. However, as there is no standard about LHR engine design, the results from these studies may contradict each other (Gatowski, 1990; Sun, 1994; Yaşar, 1997; Haşimoğlu, 2005). This study has two aspect one is to determine the loss or benefits of LHR application and the other is to determine the effect of insulation level to them. For these purpose performance characteristics of a turbocharged LHR diesel engine was evaluated for two different insulation levels.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were performed in a turbo charged direct injection diesel engine. Some important specifications of the test engine are given in Table 1 and schematics of the test set up can be seen in Figure 1. Other major part of the experimental set-up is a hydraulic dynamometer (Go-Power Dt 100) which is used to load the engine.

Table 1. Specifications of the test engine.

Engine Type	Mercedes-Benz OM364A
Number of cylinders	4
Displacement (l)	3.972
Compression ratio	17.25/1
Max. engine power (kW)	66@2800 rpm
Max. engine torque (Nm)	266@1400 rpm

The constant-speed various-load tests were performed for engine speeds of 1400 and 2800 rpm. The fuelling rate and, hence, the load (between 40 and 200 N m with increments of 40 Nm) was varied at each engine speed. The dynamometer load was measured using a load cell. The load cell was calibrated with standard weights. The engine speed was measured by an optical sensor. Both the engine speed and the load values were collected by a data acquisition system and then recorded by a computer. The hydraulic dynamometer was rated for 999 N m maximum torque and 7500 rpm maximum operating speed having accuracies of 0.1 N m and 1 rpm respectively. Exhaust gas temperature before the turbine inlet was measured by NiCr-Ni type thermocouples. Fuel consumption was measured with a digital scale. It had a maximum capacity of 8 kg and a precision of 0.1 g. Air consumption was measured with an air flow meter. Exhaust gas temperature (EGT), fuel and air consumption values were recorded manually during the tests. Measurements were taken after reaching the working temperature of the engine. The uncertainty of the measured parameters is important for verifying the accuracies of the test results. The uncertainties of the measured and calculated parameters are shown in Table 2.

Table 2. The uncertainties of the measured and calculated parameters.

Parameter	Errors (%)
BSFC	1.00
EGT	0.28
Brake thermal efficiency	1.00
Volumetric efficiency	0.23

First test of standard (STD) engine were done. Then, cylinder head and valves of the test engine were coated with atmospheric plasma spray coating method to obtain LHR1 engine. Before the coating process, material 0.5 mm thick was removed from surfaces by machining to keep the compression ratio of the LHR1 engine the same as that of the STD engine. As for plasma gas, a mixture of Ar + 5 % H2 was used. The cylinder head and valves were coated with yttria-stabilized zirconia (Y_2O_3–ZrO_2) layer 0.35 mm thick over a nickel – chromium –aluminum bond coat 0.15 mm thick. The Y_2O_3–ZrO_2 was chosen as the ceramic material because of its durability in a high-temperature environment. The coating was applied with the plasma spray method, as this method was both economic and easy to accomplish. After completing the test of LHR1 engine (cylinder head and valves coated engine), pistons of the test engine were coated with the same procedure as mentioned above. So LHR2 engine (cylinder head, valves and piston coated engine) was obtained. Same test procedure was applied to LHR2 engine. And the results for STD, LHR1 and LHR2 engine were compared.

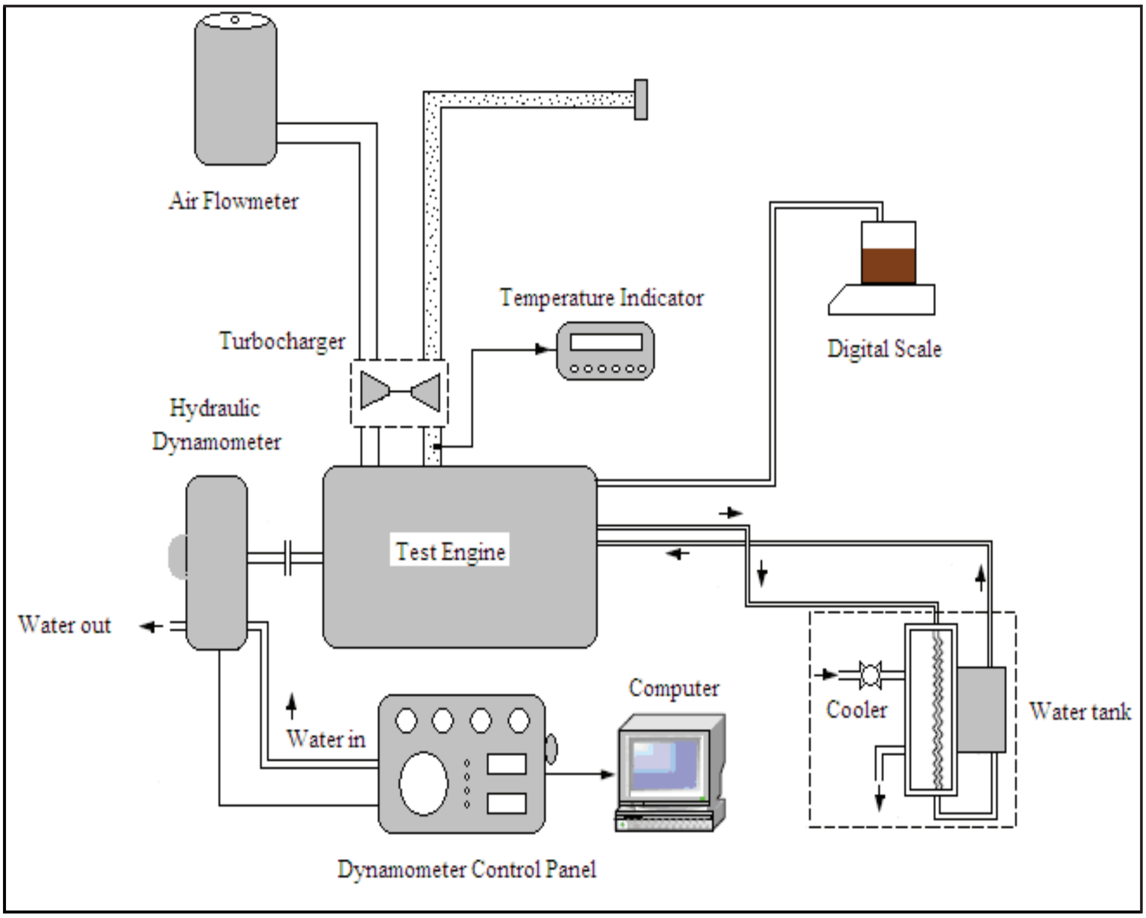

Figure 1. Schematics of test set-up.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The experimental results of brake specific fuel consumption (BSFC), exhaust gas temperature (EGT), brake thermal efficiency and volumetric efficiency values by engine load are given as graphics in Figure 2 to 9. There are there insulation levels in the experiments: non insulated engine (STD engine), cylinder head and valves coated engine (LHR1 engine) and engine cylinder head, valves and piston coated engine (LHR2). Comparisons were done according to non insulated engine.

As can be seen from Figure 2-3, BSFC was decreased with increased engine load generally. Reduction in BSFC was increased as the insulation level increased. For LHR1 and LHR2 engine BSFC was decreased by 4 and 6.7 % at 1400 rpm and decreased by 4 and 7.1 % for 2800 rpm, respectively.

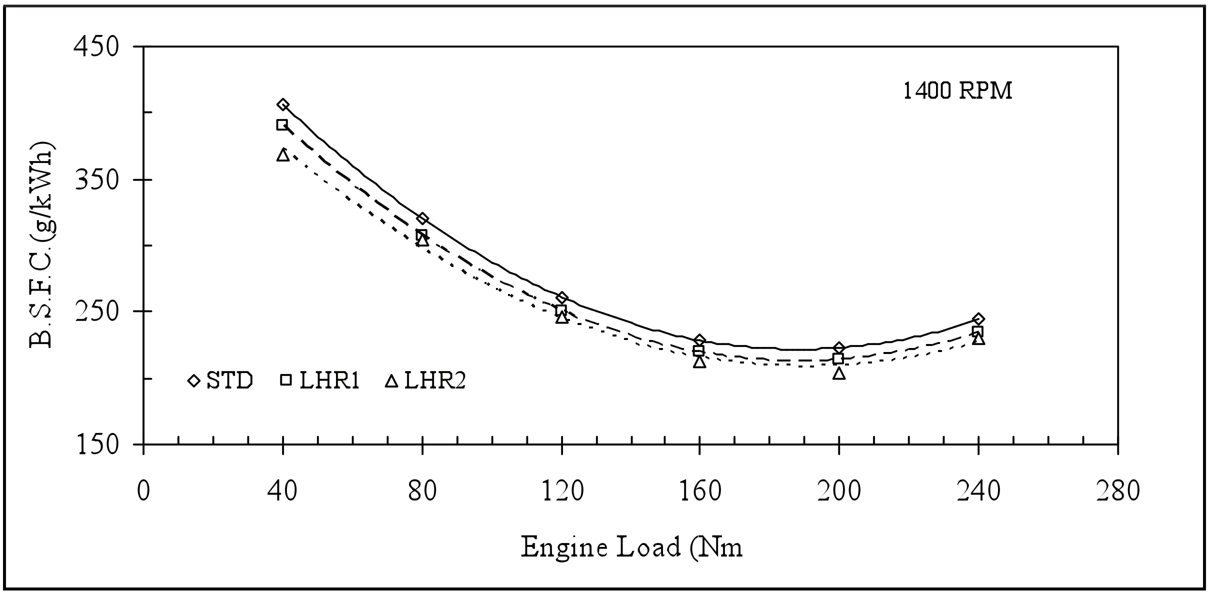

Figure 2. Comparison of BSFC by engine load at 1400 rpm.

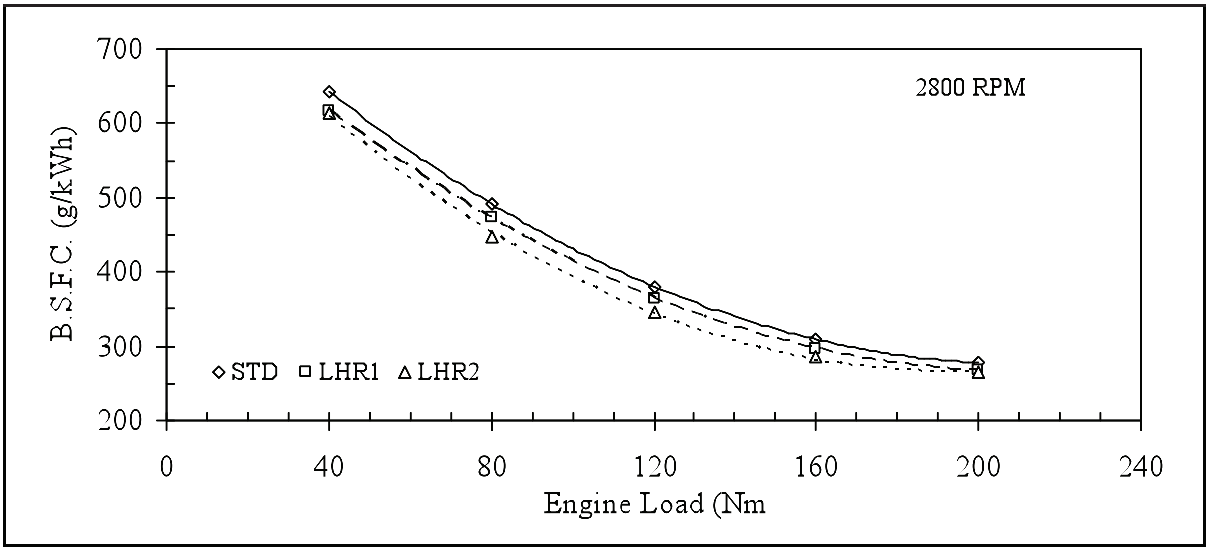

Figure 3. Comparison of BSFC by engine load at 2800 rpm.

Kvernes et al., (1990) were determined 5 % reduction in fuel consumption of a medium duty LHR diesel engine which's pistons and valves were coated with 0.5 mm thick partially stabilized zirconia. (Büyükkaya et al., 2006) obtained 1-6 % reduction in BSFC of a six cylinder, direct injection (DI), turbocharged LHR diesel whose pistons, valves and cylinder head were coated with magnesia stabilized zirconia ($MgZrO_3$). Also, (Parlak et al., 2003) was reduced BSFC of a single cylinder, pre-combustion chamber LHR diesel engine by 3 % with coating of cylinder head, valves and piston 0.35 mm thickness of $MgO–ZrO_2$ over a 0.15 mm thickness of NiCrAl bond coat. (Sun et al., 1994) reported that diffusion burning period of LHR diesel engine increases while diffusion burning and ignition delay periods shorten in comparison to standard diesel engines. So oxidation of fuel will be improved due to thermal insulation during LHR combustion and BSFC decreases.

The EGT before turbine inlet was increased with the increase of engine load generally (Figure 4-5). The EGT values were increased with the increasing of insulation level. For LHR1 engine EGT was increased by 3.5 to 6.3 %, for LHR2 engine EGT was increased by 5.2 to 6.8 % at 1400 rpm. At 2800 rpm, EGT was increased by 5.3 to 6.8 % for LHR1 engine, for LHR2 engine EGT was increased by 17.9 to 19.6 %. (Parlak, 2005) was measured that EGT of an indirect injection (IDI) diesel engine was increased by 11-22.8 % with LHR application. (Yaşar et al., 1996) were declared that EGT of a DI turbocharged LHR diesel engine was increased by 5-13 %.

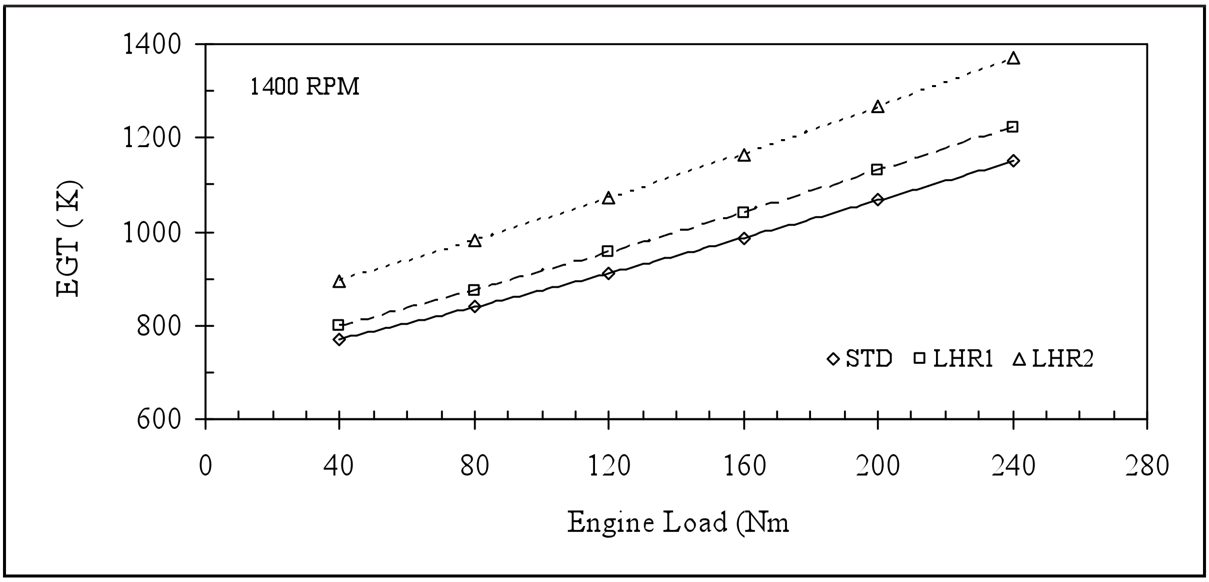

Figure 4. Comparison of EGT by engine load at 1400 rpm.

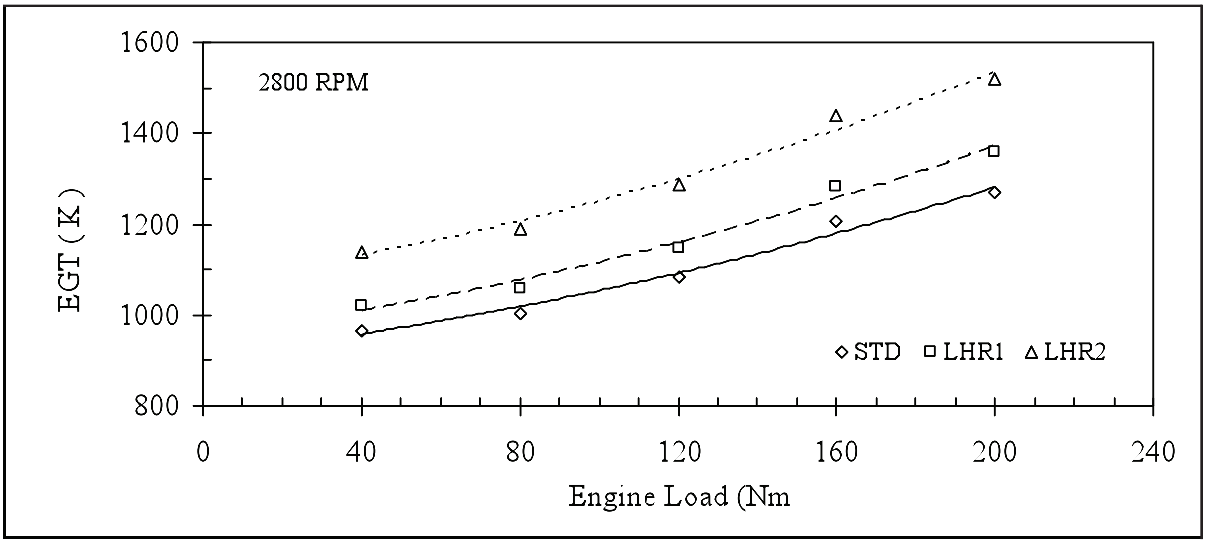

Figure 5. Comparison of EGT by engine load at 2800 rpm.

The increase of EGT temperature in LHR conditions may be explained in two ways: One is the decreasing of the heat loss to the cooling system, and the other is the increasing of the total combustion duration in LHR engine. The increase of total combustion duration causes extending of the combustion into the exhaust process, thus leading to the exhaust temperature increases (Reddy et al., 1990; Sun et al., 1994; Parlak, 2005).

Generally, brake thermal efficiency was increased with the increasing engine load. As the insulation level increased, brake thermal efficiency of the test engine was improved (Figure 6-7). At 1400 rpm, brake thermal efficiency of LHR1 and LHR2 engine was increased by 4.2 and 7.3 %, respectively. At 2800 rpm, brake thermal efficiency of LHR1 and LHR2 engine was increased by 4.1 and 7.9 %, respectively. (Parlak et al., 2005) obtained 2 % increment in brake thermal efficiency with LHR application to a six cylinder DI turbocharged diesel engine. Due to the reduction of BSFC with LHR application, the brake thermal efficiency {$\eta t = (3.6 \times 10^6) / (be \times Hu)$, be - specific fuel consumption (g/kWh), Hu- lower heating value of test fuel (kJ/kg)} was increased.

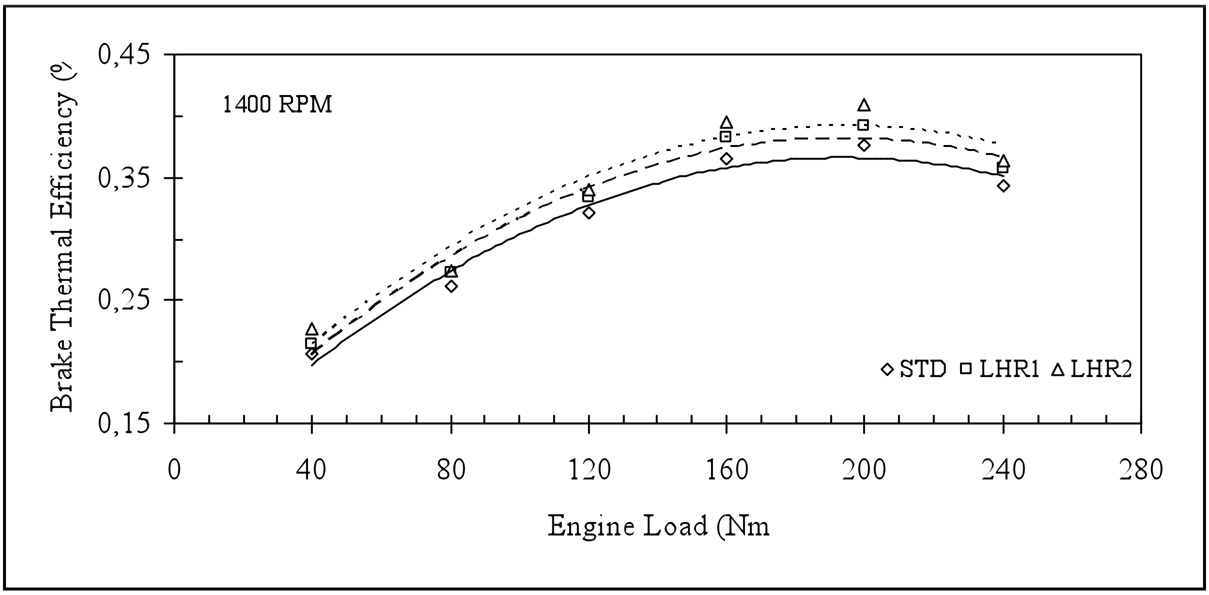

Figure 6. Comparison of brake thermal efficiency by engine load at 1400 rpm.

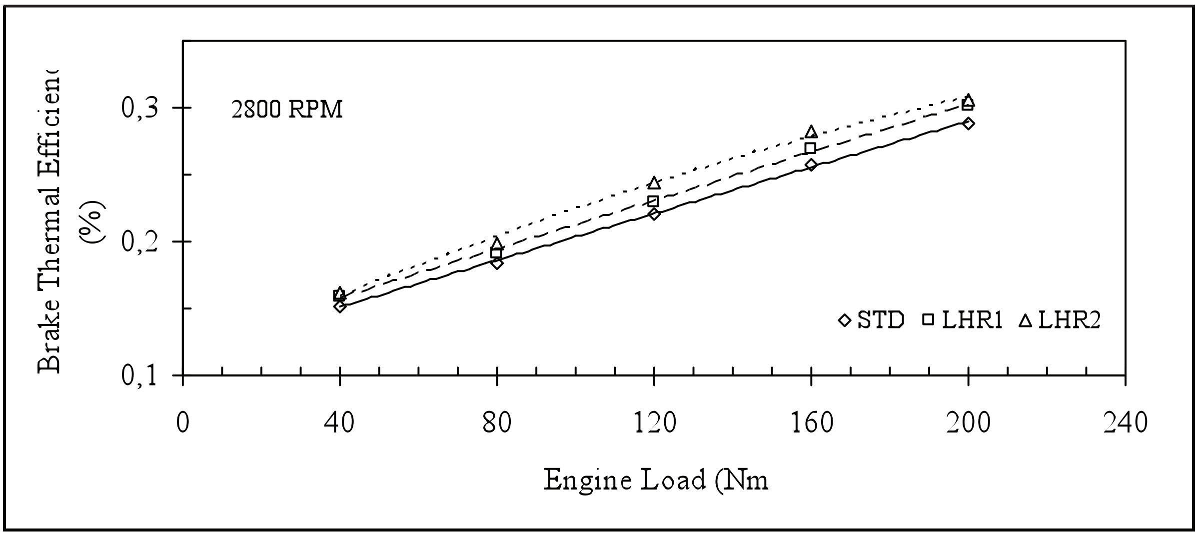

Figure 7. Comparison of brake thermal efficiency by engine load at 2800 rpm.

The volumetric efficiency of test engine was increased with increased engine load. The volumetric efficiency was improved as the insulation level increased (Figure 8-9). While the volumetric efficiency of LHR1 engine was improved by 1 %, LHR2 engine's volumetric efficiency was improved by 2.5 %, at 1400 rpm. At 2800 rpm, the efficiency of LHR1 and LHR2 engine was improved by 0.9 and 2.6 %, respectively. (Yaşar et al., 1996) declared that volumetric efficiency of a DI turbocharged diesel engine was improved by 3 % with LHR application. The improvement of the volumetric efficiency in LHR engines can be attributed to the higher EGT. Therefore, the turbocharger will induce more air to the cylinders, so the volumetric efficiency will be increased in LHR operations.

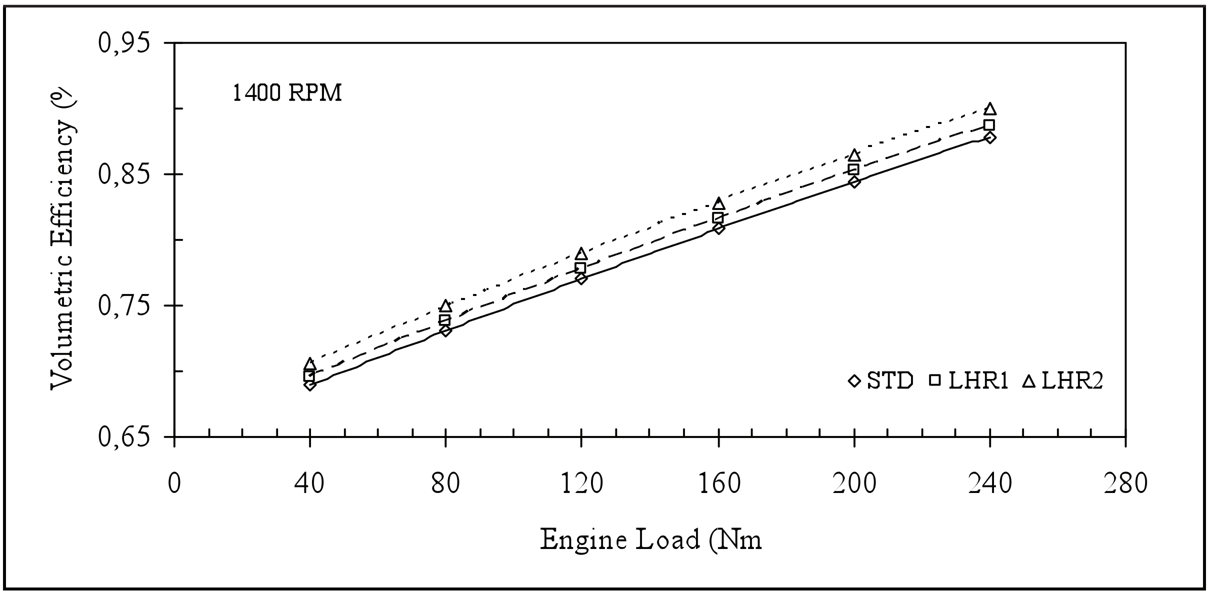

Figure 8. Comparison of volumetric efficiency by engine load at 1400 rpm.

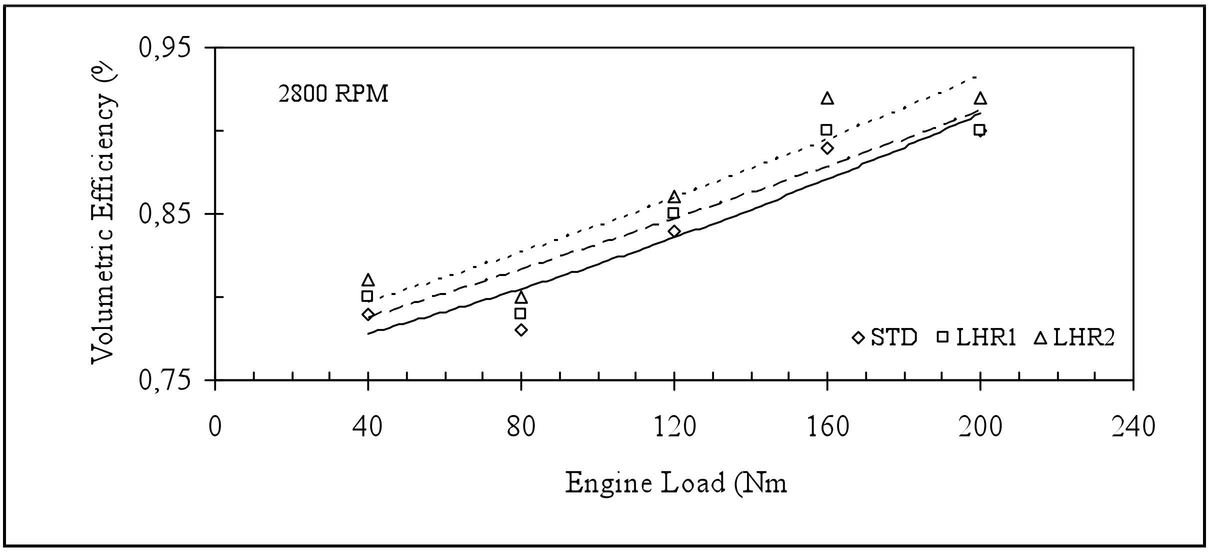

Figure 9. Comparison of volumetric efficiency by engine load at 2800 rpm.

4. CONCLUSIONS

After the experiments it was determined that all performance parameters investigated in this study were improved with LHR application. Also, the improvement level was increased as the insulation level of the test engine was increased.

Due to the increasing of diffusion burning period in LHR combustion, more fuel will be oxidized in this period. This improves combustion process in LHR engine so BSFC of LHR engines get better.

With thermal insulation less heat would be transferred to cooling system thus in-cylinder temperature levels would increase. Besides the extending of total combustion duration in LHR engines, average in-cylinder gas temperature increases when exhaust valve opens. Consequently, the increase of in-cylinder temperature levels and the extending of combustion duration in LHR conditions cause to increase in EGT before turbine inlet.

Brake thermal efficiency is a measure of engine's capability to convert fuel's chemical energy to useful work. As the BSFC of LHR engines were decreased the brake thermal efficiency was improved.

The increase of EGT in LHR engines augmented the energy which turbocharger can be extracted from the exhaust gases. Thus the turbocharger could induce more air to engine's cylinders and volumetric efficiency improved in LHR engines.

5. NOMENCLATURE

BSFC : Brake specific fuel consumption

EGT : Exhaust gas temperature

LHR : Low heat rejection

STD : Standard

TBC : Thermal barrier coating

6. ACKNOWLEDGEMENTS

The authors would like to thank Gazi University Scientific Research Council for supporting of this study under Project No. 07/2003–18.

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