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FULL LOAD PERFORMANCE AND EMISSION CHARACTERICTICS OF A LHR DIESEL ENGINE FOR DIFFERENT INSULATION LEVELS

ABSTRACT

This study was focused on determining of the effect of insulation level on performance and emission parameters of a turbocharged LHR diesel engine. As first insulation level cylinder head and valves were coated with plasma sprayed yttrium stabilized zirconium ($Y_2O_3ZrO_2$) with a thickness of 0.35mm over a 0.15mm thickness of NiCrAl bond coat (LHR1 engine). At last stage pistons have been coated with the same material and procedure (LHR 2 engine). As the insulation level was increased change in the measured parameter was increased. The results have shown that engine power increased by 6.6-9.6%, engine torque increased by 6.9-10%, bsfc decreased by 4-7.8%, EGT increased by 13-22%, excess air ratio decreased by 3-4%, smoke emission decreased by 10-18% and CO_2 emission increased by 3-6.5%.
Keywords: Low Heat Rejection, Insulation, Ceramic Coating, Engine Performance, Exhaust Emissions, Diesel Engine

FARKLI İZOLASYON SEVİYELERİ İÇİN DİK BİR DİZEL MOTORUN TAM YÜK PERFORMANS VE EMİSYON KARAKTERİSTİKLERİ

Bu çalışmada motorun yalıtım seviyesinin aşırı doldurmalı DIK bir dizel motorunun performans ve emisyonlarına olan etkilerinin belirlenmesi üzerinde durulmuştur. İlk yalıtım seviyesi olarak silindir kapağı ve supaplar plazma sprey yöntemi ile 0,15 mm NiCrAl bağlayıcı tabaka üzerine 0,35 mm kalınlığında yitriya stabilize zirkonya kaplanmıştır (DIK1 motor). Son aşamada ise bunlara ilaveten aynı malzeme ve yöntem ile pistonlar da kaplanmıştır (DIK2 motor). Yalıtım seviyesi arttıkça ölçülen parametrelerdeki değişim miktarı da artmıştır. Sonuç olarak motor gücünün %6,6-9,6 arttığı, motor torkunun %6,9-10 arttığı, fren özgül yakıt tüketiminin %4-7,8 azaldığı, egzoz gazı sıcaklığının %13-22 arttığı, hava fazlalık katsayısının %3-4 azaldığı, duman emisyonunun %10-18 azaldığı ve CO_2 emisyonunun %3-6,5 azaldığı görülmüştür.
Anahtar Kelimeler: Düşük Isı Kaybı, İzolasyon, Seramik Kaplama, Motor Performansı, Egzoz Emisyonu, Dizel Motor

1. INTRODUCTION (GİRİŞ)

The quest for increasing the efficiency of an internal combustion engine has been going on ever since the invention of this reliable workhorse of the automotive world. In recent times, much attention has been focused on achieving this goal by reducing energy lost to the coolant during the power stroke of the cycle.

The motivating force behind the low heat rejection (LHR) engine has been the prospect to decrease of cooling load. That system is there to keep engine-operating temperatures down to levels tolerated by currently used constructional materials and lubricants. If the energy normally rejected to the coolant could be recovered instead on the crankshaft as useful work, then a substantial improvement in fuel economy would be obtained. Increased thermal efficiency and elimination of the cooling system are the major promises of the LHR engine. On the other hand, the LHR engine designs promise to meet the increasingly stringent regulations in the areas of fuel economy and permissible emissions levels. At the same time, exhaust energy rise, which accompanies this, can be effectively used in turbocharged engines. Higher temperatures in the combustion chamber can also have a positive effect on diesel engines, due to the self-ignition delay drop [1].

Insulating the combustion chamber of an internal combustion engine theoretically results in improved thermal efficiency according to the second law of thermodynamics. However, this may not be the case practically due to the complex nature of the internal combustion and the mechanical and thermal limitations of the insulation material and lubricants. Several investigators have reported, based on their own test results that the overall thermal efficiency of a low heat rejection (LHR) Diesel engine could be lower or higher than the noninsulated one depending upon the engine configuration, test conditions, and methods used. TBCs for Diesel engines have generally been accepted to improve engine thermal efficiency and reduce emissions as well as specific fuel consumption because of their ability to provide thermal insulation to the engine components. The generally known principle that increased operation temperatures in energy conversion systems lead to an increase in efficiency, fuel savings and reduced emissions as particles, carbon monoxides (CO), hydrocarbons (HC) and limited reductions of NOx [2].

The concept of low heat rejection (LHR) engine aims to reduce the heat transferred to cooling system. So this energy can be converted to useful work. Some of the major advantages of LHR engines are as follows: Better fuel economy, increased engine life, reduction in HC, CO and PM emissions, and lower combustion noise due to reduced pressure increasing rate, increased exhaust gases exergy and ability operating low cetane fuels [3].

In a normal Diesel engine, about thirty percent of the total energy is rejected to the coolant. The low heat rejection (LHR) engine concept is based on suppressing this heat rejection to the coolant and recovering the energy in the form of useful work. Some important advantages of the LHR concept are improved fuel economy, reduced hydrocarbon, smoke and carbon monoxide emissions, reduced noise due to a lower rate of pressure rise and higher energy in the exhaust gases. The fuel with low cetane can also be burnt in LHR engines. This is enabled by a higher temperature at the time of fuel injection. Within the LHR engine concept, the Diesel combustion chamber is insulated by using high temperature materials on engine components, such as pistons, cylinder head, valves, cylinder liners and exhaust ports. By reducing lost energy and eliminating the need for a conventional cooling system, this engine system will dramatically improve overall performance and could potentially result in 50% volume and 30% weight reductions in the entire propulsion system [4].

As a result of insulation, injection profile of a STD diesel engine alters and affects the performance of the engine in a large scale as reported by some investigators. They pointed out that as shorter ignition delay was taken place in the case of LHR engine, a decreased premixed fraction and a corresponding increase in the amount of fuel burned during the diffusion phase of combustion was observed. Thus, since the heat release shifted to late phase in the cycle, less useful work would be extracted from the insulated engine [3].

Ciniviz et al. [5] report that the effect of thermal barrier coated piston top and combustion chamber surfaces on turbocharged diesel engine performance investigated experimentally. Compared with a standard diesel engine, engine power increased 2%, the engine torque increased 1.5-2.5%, and brake specific fuel consumption decreased 4.5-9%. The NOx emissions increased 10% in diesel engine with TBC coatings compared with a standard diesel engine. Experimental studies have shown that there is a reduction in smoke emissions up to 18% as a result TBC application.

Haşimoğlu et al. [6] showed that specific fuel consumption and the brake thermal efficiency improved and exhaust gas temperature before the turbine inlet increased for both fuels in the LHR engine.

Parlak et al. [7] explained that Injection timing was retarded from 38 crank angle (CA) to 32 CA. Optimum performance was obtained at 34 CA. At this injection timing, in comparison to the standard Diesel engine, the decrease in the specific fuel consumption and the increase in the brake thermal efficiency were about 6% and 2%, respectively.

Parlak et al. [8] declare that in comparison to a standard Diesel engine, specific fuel consumption decreased by 6%, and brake thermal efficiency increased by 2%. It was concluded that the exhaust gas process was the most important source of available energy, which must be recovered via secondary heat recovery devices. The available exhaust gas energy of the LHR engine was 3–27% higher for the LHR engine compared to the standard (STD) Diesel engine. However, it is impossible to recover all the exhaust gas energy in useful work. It is found that the maximum extractable power is less than 47% of the exhaust power.

Hazar [9] report that a thermal barrier was provided for the elements of the combustion chamber with these coatings. Tests were performed on the uncoated engine, and then repeated on the coated engine and the results were compared. An increase in engine power and decrease in specific fuel consumption, as well as significant improvements in exhaust gas emissions and smoke density, were observed for all test fuels used in the coated engine compared with that of the uncoated engine.

Hejwowski et al. [10] explained that an experimental study of the effects of thin thermal barrier coatings on the performance of a diesel engine was conducted. Results obtained from the engine with thermally insulated pistons were compared with the baseline engine data. The performance of the modified engine-driven car was found satisfactory. The ceramic coating did not produce observable knock in the engine, no significant wear of piston skirts or cylinder liners was found.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

The purpose of this study was to investigate the engine performance and emission parameters of turbocharged diesel engine which is selected parts of the combustion chamber were coated with ceramic material.

3. EXPERIMENTAL PROCEDURE (DENEY ESASLARI)

A direct injected (DI), turbocharged, four-cylinders diesel engine used as test engine. Other important parts of the experimental set-up are hydraulic dynamometer (GO Power), gas analyzer, and smoke meter. Some of the engine specifications and schematic diagram of the test set-up can be seen in Table 1 and Figure 1, respectively.

Table 1. Specifications of the test engine
(Tablo 1. Test motorunun özellikleri)

Engine Type Mercedes-Benz / OM364A	
Bore X Stroke (mm)	97.5 X 133
Displacement (l)	3.972
Compression ratio	17.25/1
Max. engine power kw	66@2800 rpm
Max. engine torque Nm	266@1400 rpm

An exhaust gas analyzer using electrochemical sensors used to measure the exhaust gas emissions. The smoke emission was given as smoke absorption coefficient. This is a coefficient which is an indicator of the smoke emission's density. The smoke level measured using a smoke meter. The smoke meter measures the smoke absorption coefficient (K) by optical sensors. The calibrations of these devices were checked regularly. Engine torque, gravimetric fuel consumption, exhaust gas temperature, excess air ratio, NOx (ppm), CO_2 (per cent), and smoke emission (K values) recorded manually, after allowing sufficient time for the engine to stabilize. The uncertainties in the measured parameters are shown in Table 2.

The engine tests were performed at full load condition for the engine speeds of 1100, 1200, 1400, 1600, 1800, 2000, 2200, 2400, 2600 and 2800 rpm. The dynamometer load was measured using a strain gauge load sensor. The sensor calibrated with standard weights. The engine speed 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 exhaust gas temperature measured before the turbine inlet by a NiCr-Ni type thermocouple. Fuel consumption measured with a digital scale (Ohaus). It had a maximum capacity of 8 kg and a precision of 0.1 g. Measurements were done after reaching the working temperature of the engine.

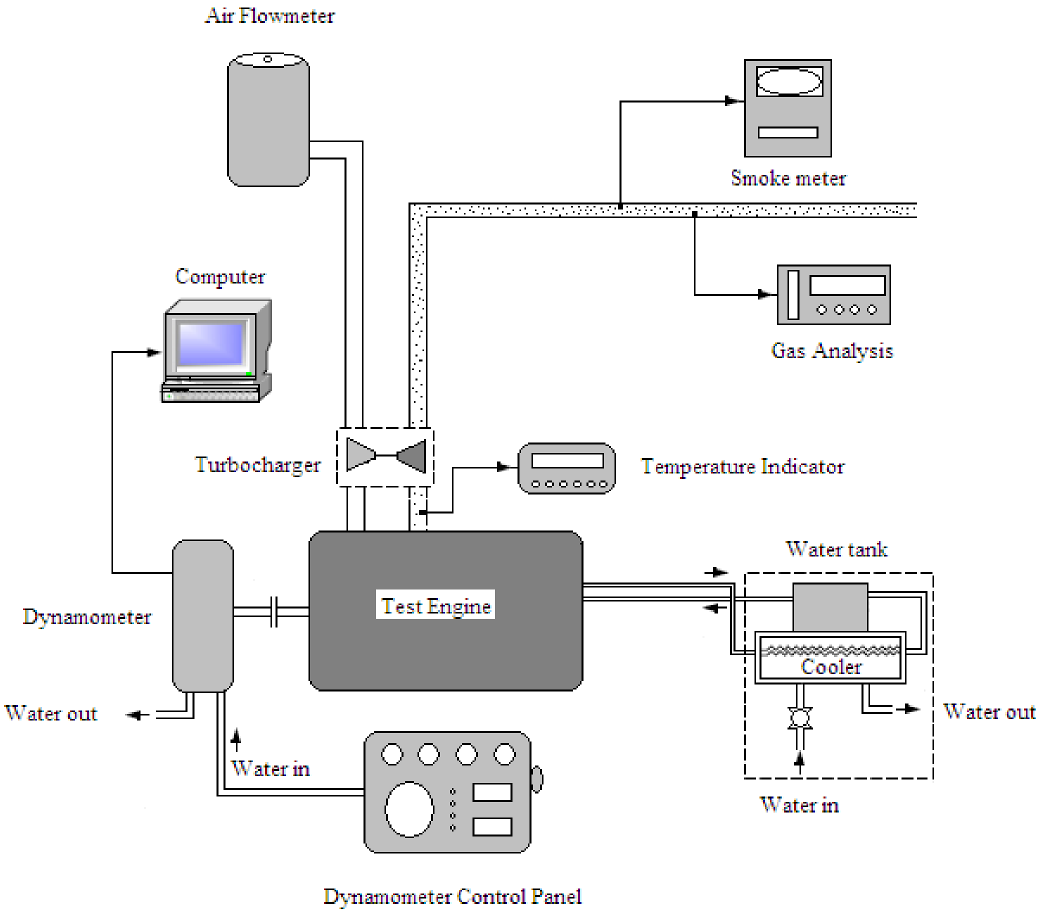

Figure 1. Schematic diagram of test set up
(Şekil 1. Test düzeneğinin şematik diyagramı)

Table 2. The uncertainties of the measured parameters
(Tablo 2. Ölçülen parametrelerin belirsizliği)

Parameter	Maximum errors (± %)
Power	0.19
Torque	0.33
Brake specific fuel consumption	1.01
Exhaust gas temperature	0.28
Excess air ratio	0.79
NOx	0.54
Smoke absorption coefficient	1.03
CO_2	1.05

The experiments were performed at three stages. At first stage, standard (STD) engine tests were carried out. At second stage, the cylinder head and valves coated with plasma sprayed yttrium stabilized zirconium ($Y_2O_3ZrO_2$) with a thickness of 0.35mm over a 0.15mm thickness of NiCrAl bond coat (LHR1 engine). At third stage, pistons coated with the same material and procedure which was mentioned above (LHR 2 engine). To keep the same combustion chamber volume of STD engine, 0.5mm chips removed from the surface of the cylinder heads, piston tops, and valves. Experiments on coated engines were carried out under the same experimental conditions of STD engine. Ceramic coated parts of the test engine can be seen in Figure 2.

Figure 2. Ceramic coated parts of the test engine
(Şekil 2. Test motorunun seramik ile kaplanmış kısımları)

4. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

The engine test results are given in Figs. 3-10 for each condition. These conditions are STD engine (uncoated engine), LHR1 engine (cylinder head and valves coated engine), LHR2 engine (cylinder head, valves and pistons coated engine). The graphics include engine power, torque, brake specific fuel consumption (bsfc), exhaust gas temperature (egt), NOx, smoke and CO_2 emission changes according to engine speed. All comparisons were made according to STD engine.

As seen in Fig.3 and Fig. 4 engine power and torque increases with the increase of the insulation level. The maximum engine power and torque was obtained for LHR2 engine during all operating range. The engine power increased by 6.6 and 9.6% for LHR1 and LHR2 engines, respectively. And the engine torque increased by 6.9 and 10% for LHR1 and LHR2 engines, respectively.

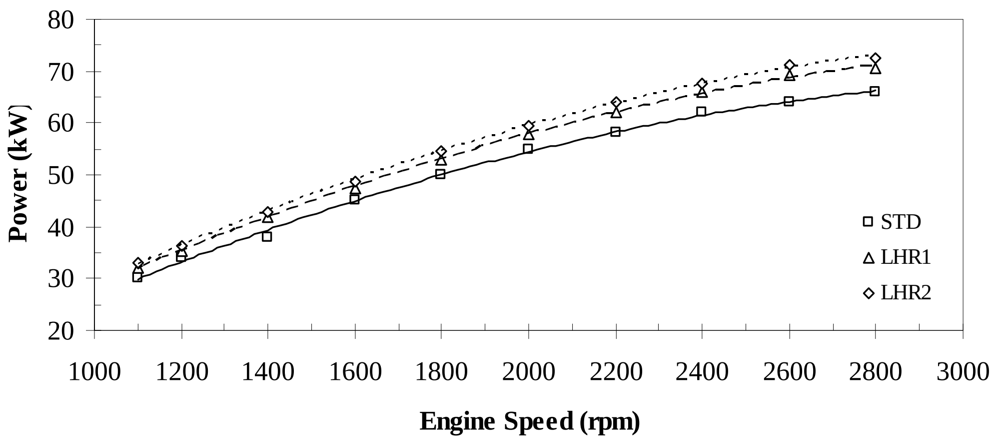

Figure 3. The variations of engine power by engine speed for different insulation levels
(Şekil 3. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak motor gücünün değişimleri)

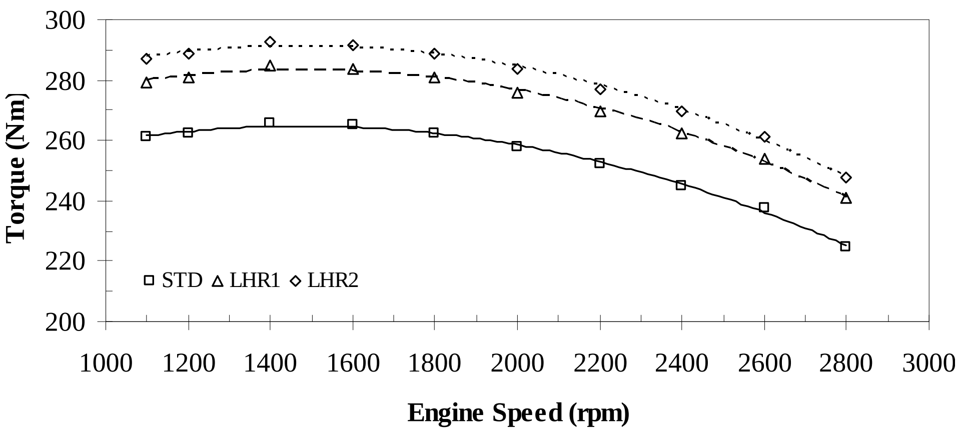

Figure 4. The variations of engine torque by engine speed for different insulation levels
(Şekil 4. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak motor torkunun değişimleri)

As the EGT of the LHR engine increased, the work extracted from exhaust turbo-compressor increased too. So, more air was induced to engine cylinders. These enable more fuel to be burnt without increasing engine smoke (see Fig.6 and 9). Consequently, engine power and torque increased with the increase of insulation level.

Brake specific fuel consumption decreased with the increase of the insulation level (Fig.5). The minimum bsfc was obtained for LHR2 engine during all operating range. The bsfc decreased by 4 and 7.8% for LHR1 and LHR2 engines, respectively. The increase in cylinder gas temperatures due to thermal insulation increases the combustion efficiency so bsfc in LHR engine conditions decreased.

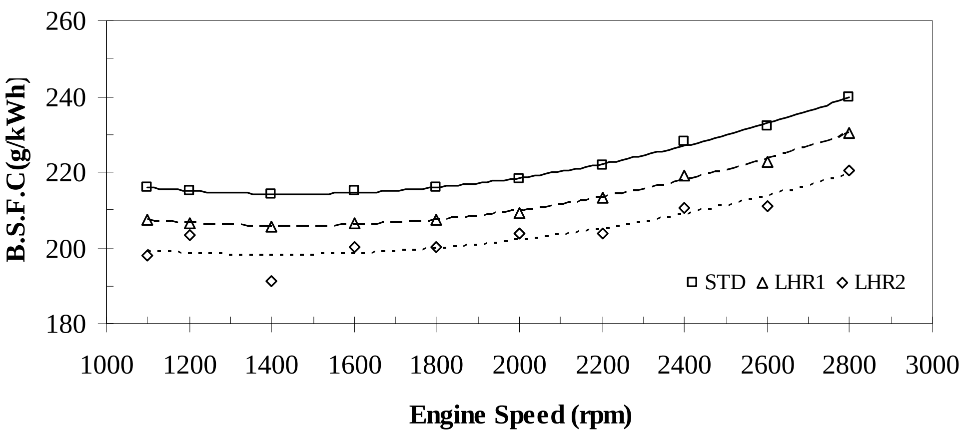

Figure 5. The variations of bsfc by engine speed for different insulation levels
(Şekil 5. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak fren özgül yakıt tüketiminin değişimleri)

Due to heat insulation less heat was transferred to cooling system so EGT increased for LHR engines (Fig.6). As the insulation levels increases, the EGT increases too. The EGT increased by 13 and 22% for LHR1 and LHR2 engines, respectively.

Excess air ratio of test engine decreased with the increased engine speed (Fig.7). The minimum excess air ratio was obtained for

LHR2 engine. The reduction in excess air ratio is related to insulation level. Excess air ratio of LHR1 and LHR2 engines decreased by 3 and 4%, respectively.

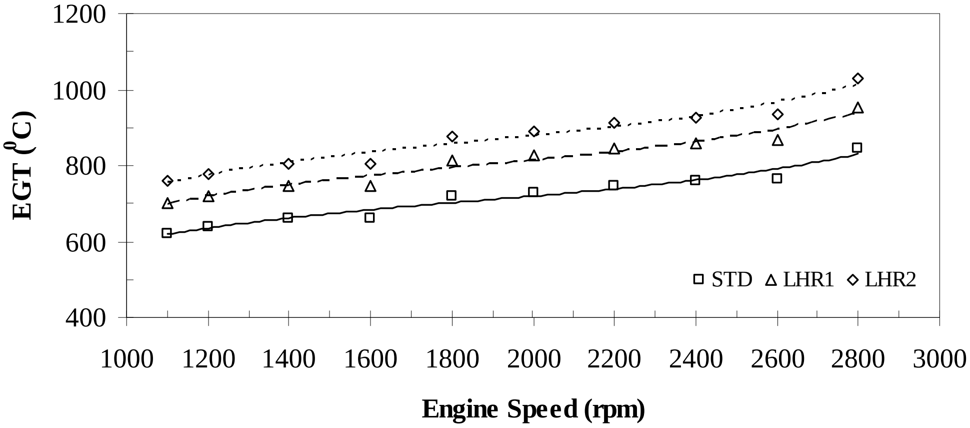

Figure 6. The variations of EGT by engine speed for different insulation levels
(Şekil 6. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak egzoz gazı sıcaklığı)

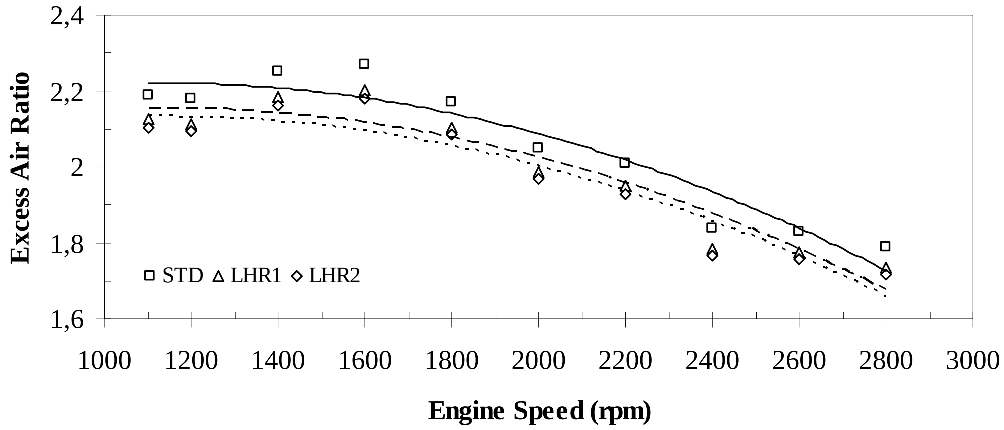

Figure 7. The variations of excess air ratio by engine speed for different insulation levels
(Şekil 7. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak hava fazlalık katsayısı değişimleri)

NOx emissions increased with the increment of insulation level (Fig.8). The maximum NOx emission was obtained for LHR2 engine. NOx emissions of LHR1 and LHR2 engines increased by 20 and 35%, respectively. In LHR engines in-cylinder gas temperatures increased in comparison to STD engine. This elevated temperature is the main reason of the increase of NOx emissions.

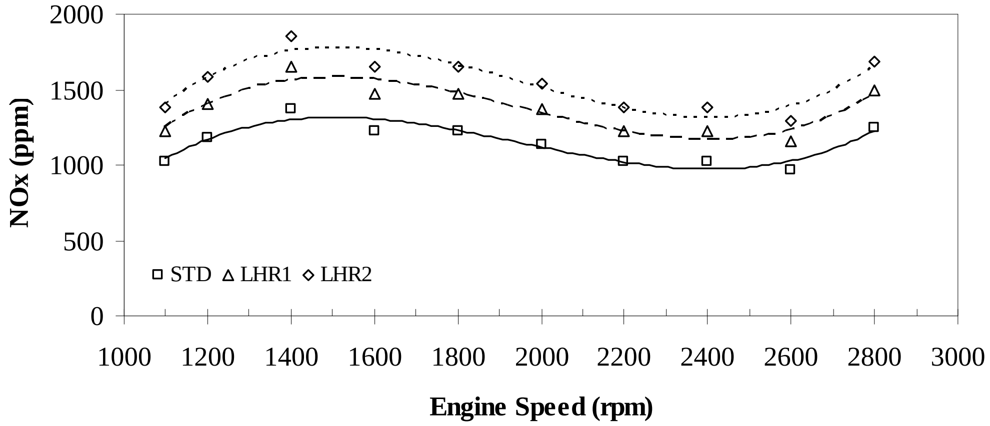

Figure 8. The variations of NO_x emission by engine speed for different insulation levels
(Şekil 8. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak NO_x değişimleri)

Smoke absorption coefficients of LHR engines are lower than that of STD engine (Fig.9). The minimum smoke absorption coefficient was obtained for LHR2 engine. Smoke absorption coefficient of LHR1 and LHR2 engines decreased by 10 and 18%, respectively. The increasing in-cylinder gas temperatures were increased soot oxidation rate so smoke absorption coefficients decreased in LHR engines.

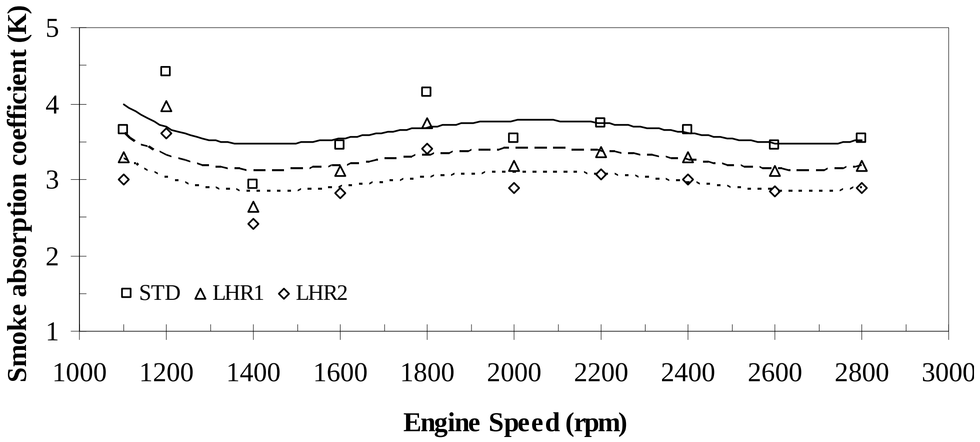

Figure 9. The variations of smoke emission by engine speed for different insulation levels
(Şekil 9. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak duman absorbsiyon katsayısının değişimleri)

CO_2 emissions increased with the increment of thermal insulation level (Fig.10). Maximum CO_2 emission was obtained in LHR2 engine. CO_2 emissions of LHR1 and LHR2 engines increased by 3 and 6.5%, respectively. CO_2 emissions decreased due to improvement of overall combustion process in LHR engines.

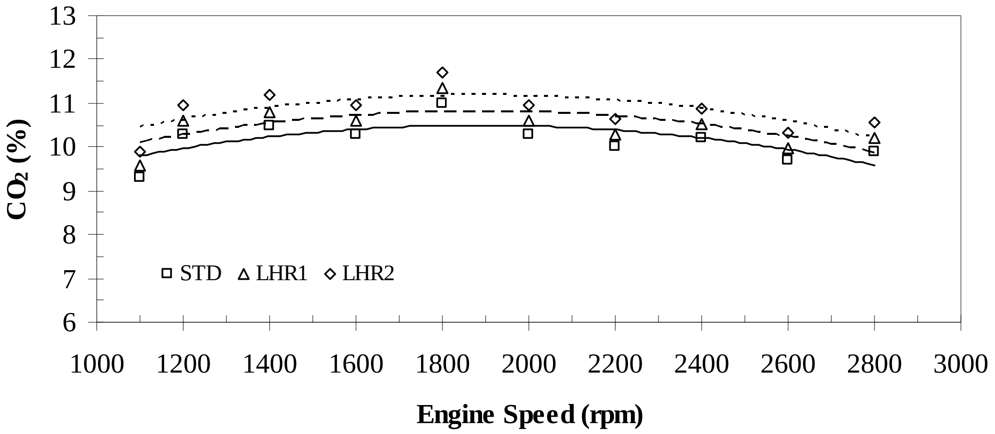

Figure 10. The variations of CO_2 emission by engine speed for different insulation levels
(Şekil 10. Farklı izolasyon kalınlıkları için motor hızına bağlı olarak CO_2 değişimleri)

5. CONCLUSIONS (SONUÇLAR)

Full load tests were applied to the test engine to determine performance and emission characteristics of a turbocharged LHR diesel engine for different insulation conditions. It was determined that there is a strong relation between performance and emission values with insulation levels of the of the test engine. The results have shown that engine performance parameters of brake power, torque and brake specific fuel consumption improved while the EGT increased with the increment of the insulation level. As for emission parameters of the test engine, excess air ratio and smoke emission decreased; NOx and CO_2 emissions increased.

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