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Research Article

THE EFFECT OF INCREASED INTAKE AIR PRESSURE OF A NATURALLY ASPIRATED DIESEL ENGINE ON PERFORMANCE AND EMISSIONS

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ABSTRACT

In this study, the effects on the performance and emissions of a diesel engine operated with excess air by increasing the intake air pressure were investigated. For this purpose, the performance and emissions of a single-cylinder, compression-ignition, naturally aspirated engine at constant speed (2800 rpm) and different loads (25%, 50%, and 100%) were experimentally investigated first fed by natural suction pressure (NA), and then by feeding it with additional intake air pressure of 5, 7.5, 10, 12.5, 15, 17.5 and 20 kPa. As a result of our experiments it was found that by increasing the intake air pressure at certain ratios, brake specific fuel consumption(bsfc)decreased by 18%, CO emission by 78%, HC emission by 70% and soot emission by 63%, while NO_x emission is increased by 5%, and exhaust gas temperature decreased.
Keywords: Natural aspiration, boost pressure, diesel engine, performance, exhaust emissions.

1. INTRODUCTION

Environmental awareness is increasing day by day and a large part of the pollutant emissions are due to motor vehicles. Therefore, it is desired to continuously lower the emission limits. In terms of global warming and climate change, the improvement of the combustion in the engines and therefore the reduction of negative emissions in terms of the environment has a significant importance [1]. To meet these demands, a number of methods such as fuelimprovement, engine-based technologies (combustion chamber design, fuel injection strategies, HCCI etc.) and post-combustion technologies are being investigated. Almost similar fuel improvement and engine-based strategies are applied for spark ignition engines (SIE) and compression ignition engines (CIE). However, different methods are applied to improve post-combustion exhaust emissions. This is because the CO, HC and NOx emissions can be improved by the three-way catalytic converter because of SIEs homogeneous mixture and approximate stoichiometric air/fuel ($\lambda = 1$) ratio. However, since diesel engines work with heterogeneous fuel mixture and the high excess air ratio, the three-way catalytic converter is not sufficient alone to convert three harmful gases. Therefore, more expensive devices are needed to improve diesel engine emissions. For example; oxidation catalyst for CO and HC emissions, diesel particulate filter (DPF) for PM, and selective catalytic reduction (SCR), lean nitrogen oxide trap (LNT) and EGR are being used for NOx emissions. This increases price and fuel consumption of a diesel engine. Researches have been

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carried out recently on operating diesel engines by stoichiometric air/fuel ratio (SDC-Stoichiometric Diesel Combustion or SCI-Stoichiometric Compression Ignition) in order to convert NOx emissions to similar to SIEs [2-11]. It is understood from the studies done that the NOx emission decreases, the combustion efficiency, and the effective pressure decrease, and the specific fuel consumption (SFC) increase. For example; Lee et al. [3.4] found that SFC increases 7% in an engine with SDC at low load. In stoichiometric diesel combustion, the main cause of dete rioration of engine efficiency is attributed to insufficient air flow around the injected fuel assembly [11]. Cha et al. [9] in their study, have found that NOx emissions are reduced, the induced effective pressure decreases, and the soot emission increases. Junepyo et al. [10], in their study, showed that it increased total HC and CO emissions and significantly increased soot emission level. It has been stated that to improve SFC and combustion efficiency in SDC, some researchers have applied single spraying [2,3] while some researchers have applied multiple spraying strategies [4], but have not achieved a satisfactory improvement [11]. The reason for this is, although it is given that λ=1.4, mixture preparation time to be short, not sufficiently benefitting from the air for reasons such as homogeneous mixture etc., and the air to be even more choked in SDC. As the air is further reduced, the advantages of diesel engines operating with excess air (such as high volumetric efficiency) will be obscured, the combustion will become worse as the heterogeneous and rich mixing zones will increase, and especially the emissions will become worse. The fact that there is little mention of CO and HC emissions in SDC studies has further reinforced this opinion. Unlike the SDC, it is thought that increasing the amount of air entering the cylinders by increasing the air pressure entering naturally aspirated diesel engine cylinders may improve the performance and emissions of diesel engines that burn the heterogeneous mixture. When reviewing the literature, it is seen that engine performance and emissions are improved in a homogeneous combustion-related study [12]. Yoshimoto et al. [13], in their study, noted that increasing the input air pressure by supercharging significantly improves the combustion characteristics. Yang et al. [14]. Studied the compliance of the turbocharger system to the altitude and showed in their study that in spite of the turbocharger system, the lack of air increases the brake specific fuel consumption and reduces the output torque. In his study, Karabektaş [15] has shown that turbocharging reduces CO emissions and somewhat increases the NOx emissions. A similar study by Luft and Skrzek [16] investigated the effect of a dual-fuel compression ignition input air pressure on NOx, soot and non-HC emissions. At first glance, it seems that there is a limited number of studies to be aimed at this, but a closer scrutiny of the studies suggests that they are more about the effect of a turbocharger or supercharger on the performance and emissions of a naturally aspirated diesel engine without changing the fuel system [13-15] and it is also understood that the charging pressures applied (1.4, 1.8 bar, etc.) without any modification are very high [17].

The purpose of this study is to investigate the effects of different pressures (NA, 5, 7.5, 10, 12.5, 15, 17.5 and 20 kPa) in the air intake on a single-cylinder, naturally aspirated and compression-ignited engine, with different engine loads (25%, 50%, and 100%) at constant engine speed (2800 rpm).

2. EXPERIMENTAL SETUP AND PROCEDURE

The experimental study was carried out at different speeds (25%, 50%, 100%) at a constant speed of 2800 rpm with a naturally aspirated, single-cylinder compression ignition engine given in table 1; both naturally aspirated, and intake air pressures were increased by 5, 7.5, 10, 12.5, 15, 17.5 and 20 kPa, respectively. The characteristics of the fuels used in the experiments are given in table 2. In the experimental study, data such as fuel consumption and duration, engine torque, air pressure and temperature entering the cylinder, exhaust gas temperature, excess air ratio (λ) and exhaust emissions were measured. The amount of fuel consumed, and its duration is calculated by the electronic scale and digital stopwatch. The engine power was determined with an electric D.C dynamometer capable of absor bing 10 kW of power. the exhaust gas temperatures were measured with a TES 1320 K thermocouple digital thermometer and the intake air temperature and the pressure was measured with the help of a TECHNI-C A930C type digital thermometer and a KELLER PA 21SR / 25/80 520.5 type pressure sensor&computer software, respectively. An intercooler turbocharged engine with four cylinders and a total cylinder volume of 1.9 liters was used for compressed air supply. The air hose connected to the intake manifold of this motor has been removed and connected to the test motor intake via the damping tank. The reason for using the damping tank in between is to stabilize the air flow and the pressure. The intake air pressure has been controlled by gassing the turbocharged engine. Emissions of CO (% v), HC (ppm) and NOx (ppm) have been measured with the MRU DELTA 1600 L exhaust gas analyzer, and the soot emissions, (%) with the MRU Optrans 1600 opacimeter. Figure 1 shows the general view and schematic diagram of the experiment set. The characteristics of gas and soot emission devices are given in table 3.

Power and brake specific fuel consumption has been calculated from the obtained data. The sensitivities of the measuring instruments and the uncertainties of the calculated quantities are given in table 4. Uncertainty (δ) analysis of torque, power, and brake specific fuel consumption $z = f(x, y)$ as given,

$$\delta_z = \sqrt{\left(\frac{\partial z}{\partial x}\delta x\right)^2 + \left(\frac{\partial z}{\partial y}\delta y\right)^2} \tag{1}$$

calculated based on the equation [18].

Figure 1 b) Schematic view of the test setup (1- Dynamometer, 2- Test engine, 3- intake air temperature sensor, 4- Air damping tank, 5- intake air pressure sensor, 6- Intercooler, 7- Turbocharger, 8- Turbine, 9- Exhaust Manifold, 10- Intake Manifold, 11- Air filter, 12- Digital thermometer, 13- Computer (for the intake air pressure reading software), 14- Electronic scale, 15- Fuel container, 16- Exhaust gas analyzer, 17- Soot measuring indicator, 18- soot measuring device, 19- Digital 20- Dynamometer control panel, 21- Load cell indicator)

Table 1. Experiment engine specifications

Model	Katana KM 170 F
Specifications	Four strokes, air cooled, direct injection
Cylinder number	One cylinder
Bore (mm) x stroke (mm)	70 x 50
Cylinder size (cm^3)	298
Compression ratio	18:1
Engine power (kW)/rpm	4/3600
İnjection advance timing	31 deg
İnjection pressure (bar)	200 ± 5
İnjector nozzle hole number	4
İnjector nozzle hole diameter (mm)	0,1

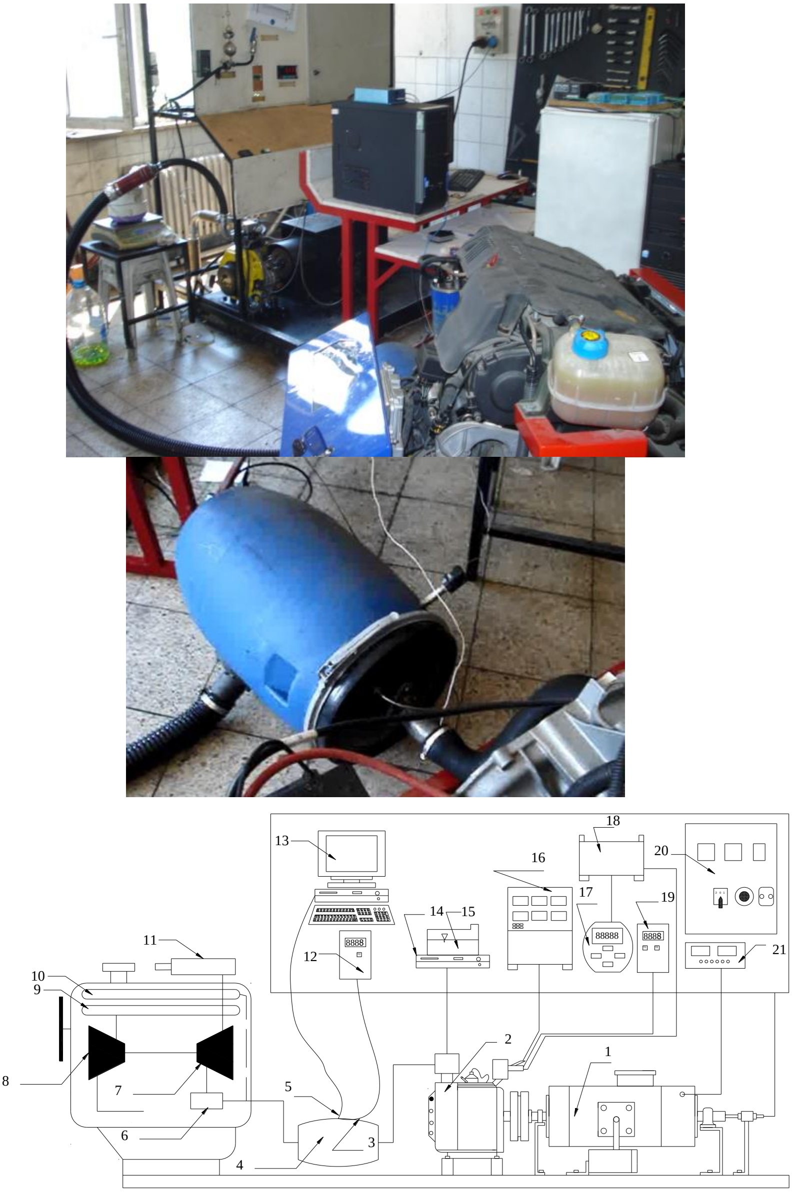

Figure 1. a) General Appearance of the Experiment Set and Air Damping Tank

Table 2. The properties of the diesel fuel

Fuel	Density(kg/m^3)	Kinematic viscosity(mm^2/s)	Cetane number	Flashpoint (°C)	Cloud point (°C)	Sulfur(ppm)
V-Power Diesel	0,842	2,0-4,5	49,8	62	-20	1670

Table 3. Technical features of the exhaust gas analysis devices.

Versions	Measuring range	Accuracy
Lamda (-)	0-9,99	
CO (%,v/v)	0 – 15,00	±0,01
HC (ppm)	0 - 20000	±1
NOx (ppm)	0 - 4000	±1
Opacimetry (%)	0-100	±2

Table 4. Measurement precision and the uncertainties of calculated results.

Measure	**Accuracy**
Force	±%0,6 N
Weight arm	±%0,1 m
Speed	±1 rpm
Time	±%1 s
CO (%vol)	±0,06%
NO_x (ppm)	±5
HC (ppm)	±12
Temperature (°C)	±1°
Smoke tone (%)	±%2
Calculated result	**Uncertainty**
Torque	±%0,4
Force	±%0,4
Specific fuel consumption	±%0,7

3. RESULTS AND DISCUSSION

The numerical values of all findings in the experimental study are given in table 5.

3.1. Engine Performance

The variation of brake specific fuel consumption by the intake air pressure is given in Figure 2. As can be seen, the brake specific fuel consumptionhas been reduced as the pressure increases at each stationary engine load. The reduction in brake specific fuel consumptionhas been found to be approximately 18%, at full load, and approximately 8%, at 50% and 25% load. Increasing the input air pressure of the engine at full load has affected the brake specific fuel consumption significantly. The reason for this is that when the naturally aspirated engine is in full load state, the excess air ratio to be at the lowest, and the amount of the fuel not contacting the air to be at the highest.

Table 5. The numerical values of all findings in the experimental study.

		BSFC (g/kWh)	LAMDA (λ)	Exhausttemperature (°C)	Aspirationtemperature (°C)	CO %	HC	NOX	Soot
FullLoad	NA	352	1,4	557	30	1,4	43	552	60
	5	330,7	1,626	554	33	0,76	25	618	41
	7,5	321	1,659	545	39	0,67	21	664	35
	10	321	1,77	533	43	0,46	16	643	30
	12,5	303,1	1,834	528	47	0,37	13	668	35
	15	303,1	1,86	521	52	0,41	14	706	23
	17,5	294,9	1,89	520	56	0,39	15	632	22
	20	287,2	1,96	515	59	0,29	13	704	22
% 50 Load	NA	376,3	2,8465	289	25	0,075	11	626,5	5,5
	5	365,3	2,955	294	30	0,065	15	646	5,5
	7,5	334,5	3,297	288,5	37	0,065	10	647	4,5
	10	330,7	3,192	284	40	0,065	14,5	648,5	3,2
	12,5	328,2	3,254	282	43	0,065	11,5	581	3,2
	15	349,2	3,3115	278,5	51	0,065	15,5	630	5,7
	17,5	350,6	3,391	277,5	55	0,065	15,5	652,5	5,2
	20	346,4	3,4645	276	57	0,065	14	616,5	5,1
% 25 Load	NA	553,3	4,038	226	32	0,08	8	385	4,5
	5	523,8	4,024	226	35	0,08	9	418	4
	7,5	516,9	4,145	225,5	39	0,08	12	455	3,5
	10	467,7	4,382	223	43,5	0,07	14	462	2,7
	12,5	491,1	5,147	220	49	0,07	10	364	2,6
	15	497,3	5,17	217	52,5	0,07	12	392	4,6
	17,5	510,2	4,833	215	51,5	0,07	8	371	4,5
	20	510,2	4,693	216	56	0,07	14	451	4,4

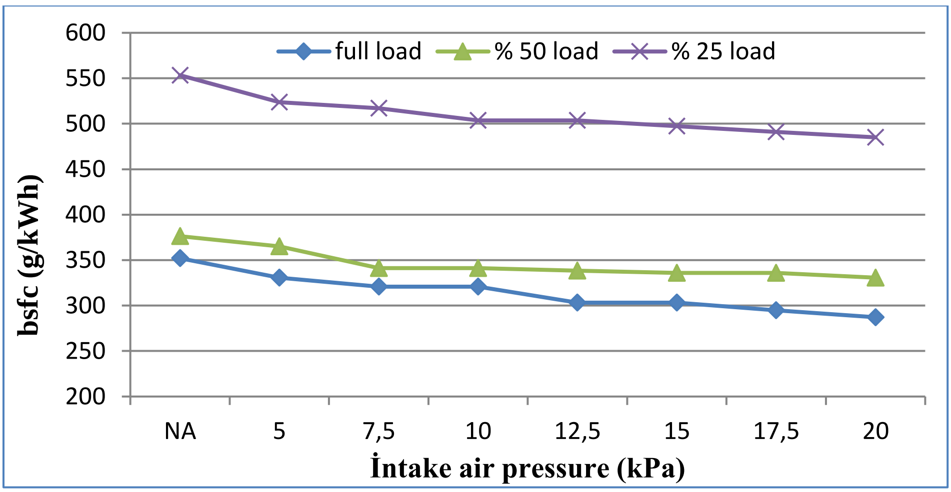

Figure 2. Variation of brake specific fuel consumption (bsfc)

The change in excess air ratio due to intake air pressure increase is shown in Figure 3. In the study, increasing the air intake pressure of the diesel engine, which started to operate at 2800 rpm constant speed with natural aspiration, increased the air excess coefficient by approximately 40%, full load 50% load 21% and 25% load 28%.

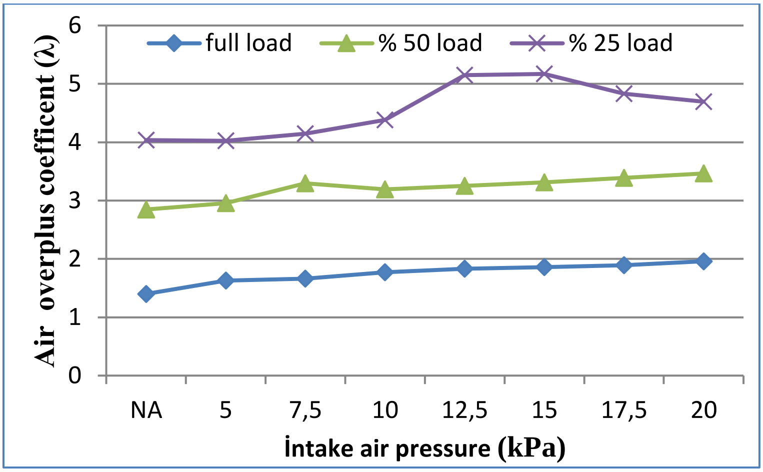

Figure 3. Excess air ratio (λ) change due to an increase in engine air intake pressure.

The change in the exhaust gas temperature depending on the air intake pressure increase is given in Figure 4. In the experiments performed, it can be observed that at full load, the EGT falls as the intake air pressure increases, and as the pressures increased by 20 kPa, the EGT decline rates have been by 4.5% at 25%, 6.5% at 50%, and up to 8% at 100%, respectively. It is thought that the main cause of the decrease of the exhaust gas temperature is the result of the improvement in the combustion.

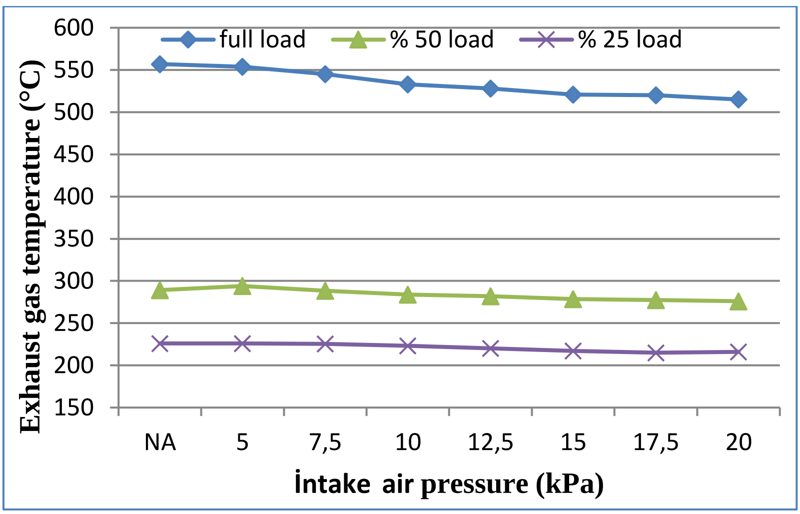

Figure 4. Exhaust gas temperature change due to an increase in engine intake air pressure.

The change in temperature depending on the increase in air pressure given to the engine, is shown in Figure 5. As can be seen, in each load case, the temperature increases linearly with increasing pressure. It has been understood that the incoming air temperature is affected considerably by the incoming air pressure and is not affected much by the load. It is thought that the reason why the intake air temperature is not very affected by the load is that the air is aspirated unrestrictedly in diesel engines.

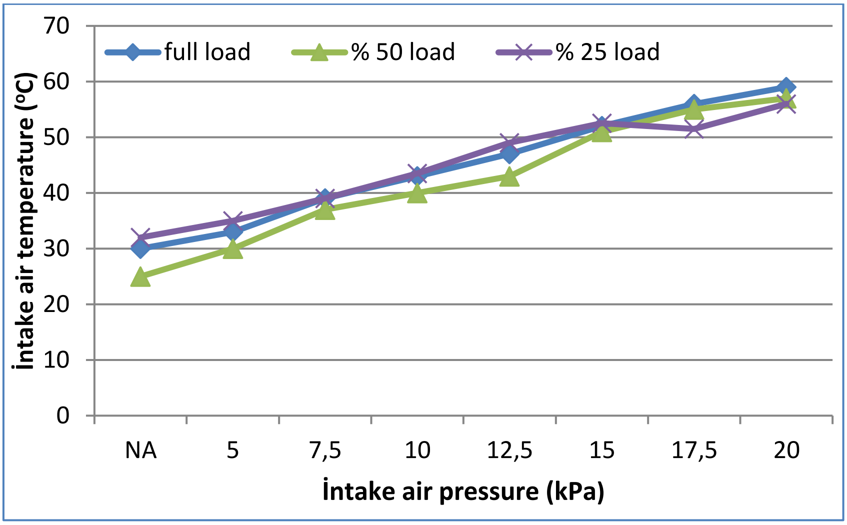

Figure 5. Change in the intake air temperature by the intake air pressure.

3.2. Exhaust Emissions

The change in carbon monoxide (CO) emissions due to the increase in intake air pressure of the diesel engine are given in Figure 6. In diesel engines, the fuel mixture around the fuel assembly becomes poorer towards the outside of the assembly, even if it is locally rich [19]. Generally, CO emissions are low because diesel engines work with lean mixture even at full load. However, the CO emissions increase with the increase in the load. This increase is due to the inability of the fuel to make enough contact with the air due to the heterogeneous mixture, even though there is more air compared to fuel, even at full load.

As a matter of fact, it is seen in this study that CO emission is very low (0.08%) because of the fact that air is more abundant in the naturally aspirated engines at partial loads and it is not affected much by the increase in the intake air pressure, however CO emission of naturally aspirated engines at full load is considerably high (about% 1,4), decreases rapidly with increasing intake air pressure and to decrease in CO emissions by about 78% with the increase of the pressure by 20 kPa. As the engine intake air pressure has been increased at full load, the improvement in carbon monoxide emissions has also been increased. However, when the intake air pressure has been increased above 20 kPa, it has been understood from the engine noise that the engine has started to work with knocking.

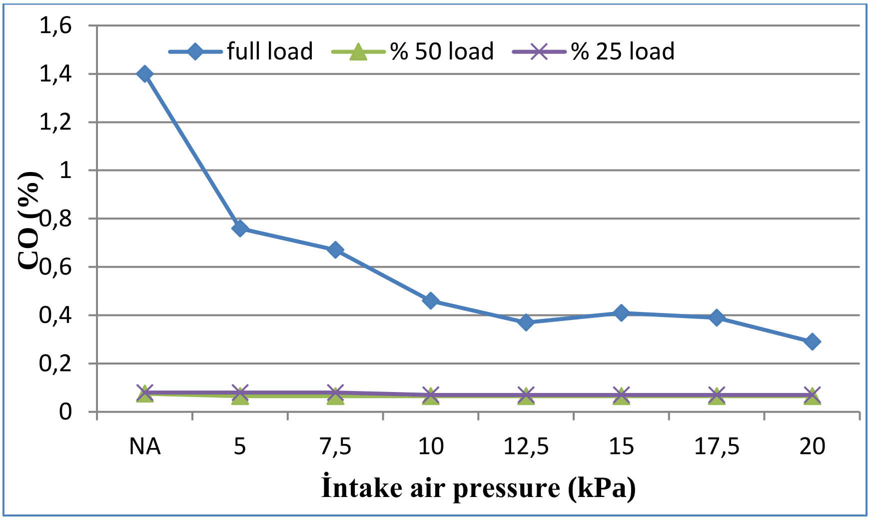

Figure 6. Change in CO amount due to an increase in engine intake air pressure.

The change in hydrocarbon (HC) emissions due to intake air pressure increase are given in Figure 7. It is observed that the HC emissions improve similar to CO emissions with an increase in intake pressure by 20 kPa at a constant engine speed of 2800 rpm and decrease 43% at 25% load, 30% at 50% load, and 70% at 100% load (full load). The reason for this improvement is that a large amount of hot (60 °C) air has been supplied, which is required, especially towards the end of the spraying time, for the combustion of the rich mixture of the large granulated fuel that is difficult to mix with the air and evaporate [20].

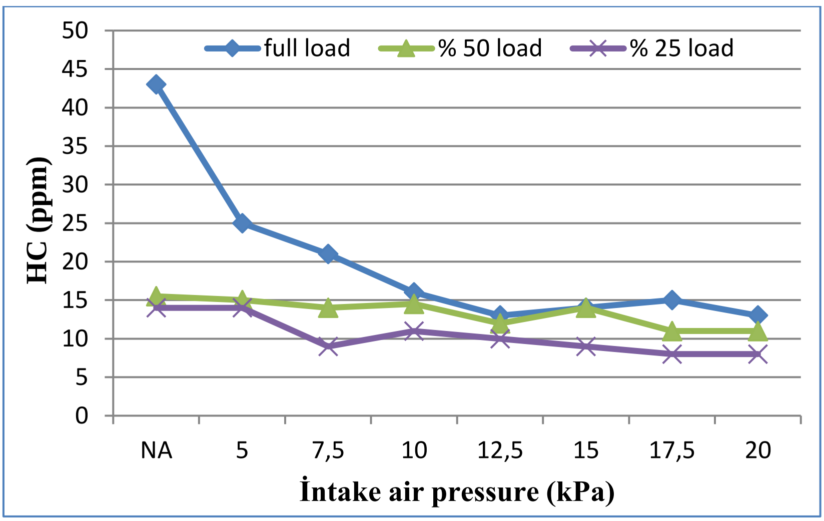

Figure 7. Change in HC amount due to an increase in engine intake air pressure.

Changes in the Nitrogen oxide (NO_x) emissions are given in Figure 8. Emissions of nitrogen oxides (NO_x) at each load have increased slightly due to the intake air pressure increase. It has been observed that with the engine air intake pressure increased by 20 kPa, the NO_x emissions increased by 15%, 5%, and 8%, respectively, at 25%, 50%, and 100% load. In diesel engines, NOx emissions are known to decrease as the excess air increases [21]. In this study, however, as the air quantity increased, that is, as the engine air intake pressure increased, the NOx emissions increased. Karabektaş [15] have shown that NOx emissions are slightly increased similarly, in his study. This is thought to be caused by the simultaneous increase in the air intake temperature as the air intake pressure increases.

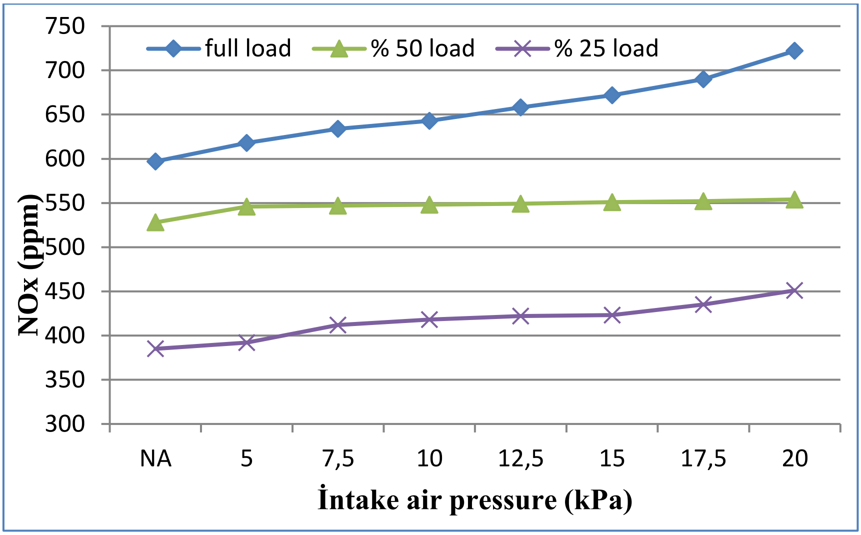

Figure 8. Change in NOx amount depending on engine intake air pressure increase.

The change in the soot emissions depending on the intake air pressure increase is given in Figure 9. It has been observed that at 2800 rpm constant engine speed and at 25% and 50% load cases, the soot emissions are between 4% and 5%, and increasing the intake air pressure does not significantly affect the soot emissions at low loads. It has been found that when the amount of soot emission is 60% at 100% load, it decreases to 30% by increasing the intake air pressure ratio by 10 kPa and to 22% by 20 kPa; in other words, it is found that the soot emissions have been decreased by 63%.It has been noted that a significant portion of the soot emissions is due to the heterogeneous combustion process [20].In this study, it was found that of the soot emission is originated rather by the rich mixture on full load and the positive effect the increase of the inlet air pressure in these conditions is very important.

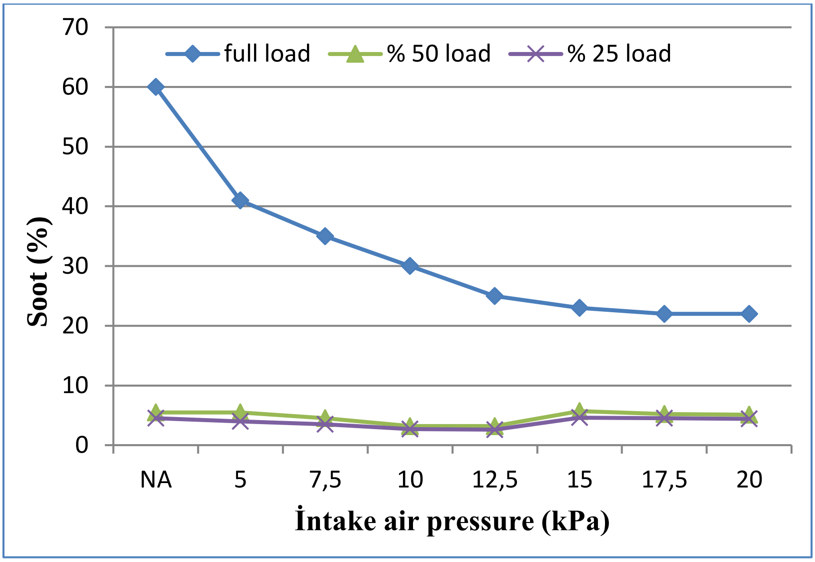

Figure 9. Change in the amount of soot depending on the increase in engine intake air pressure.

4.CONCLUSIONS

The following conclusions are drawn as a result of the experimental investigation of the effect of increasing the intake air pressure (maximum 20 kPa) on engine performance and exhaust emissions of a single cylinder, naturally aspirated, 4-stroke and direct injection diesel engine at constant speed and different load positions.The intake air pressure has the greatest effect at full load at almost all parameters and accordingly (at full load) it was observed that;

- In this study we have conducted, with a lower input air pressure of 0.2 bar, significant improvements in the performance and the emissions of the engine have benne achieved.
- Brake specific fuel consumption decreased by 18%.
- CO emissions decreased approximately by 78%, soot emissions by 63% and HC emissions by 70%
- NOx emissions increased by 5%.
- EGT was decreased by 5%.

In conclusion, it has been determined that there is a significant improvement at a naturally aspirated diesel engine, in engine performance and emissions with the exception of NOx emissions, by a limited increase in the air pressure (and hence the amount of air) entering the engine, without any modification.

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