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Research Article

Experimental Investigation of Diesel Engine Characteristics under Various Loads

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Abstract – Internal combustion engines (ICEs) are widely used in the road, sea, air and railway vehicles and stationary such as generators, pumps elevators or agricultural and construction machinery. The features expected from the ICEs differ according to the usage areas. For example; a vehicle engine should operate at a certain lower and upper engine speeds according to the engine load in constant gas condition and the features of the engine should be known in this range. On the other hand, a power plant engine must work at a constant speed under various loads for the electricity produced to be at a desired frequency. Diesel engines are widely used as stationary engines due to the higher fuel economy, especially in places where high power is required. Therefore, it is important to be known of the characteristics of the stationary engine under various operating conditions. In the presented study, it is aimed to determine experimentally the characteristics of a diesel engine under variable loads and at constant speed. In the experimental study, the characteristics of the engine such as air excess coefficient, torque, brake power, various efficiencies and fuel consumption were determined under variable loads by using a single–cylinder, four–stroke and water–cooled direct injection experimental diesel engine. Experimental results show that the variation of engine load affected considerably the investigated engine characteristics.

Keywords: Internal Combustion Engine, Vehicles, Generators, Power And Torque, Efficiency, Fuel Consumption

I. INTRODUCTION

Internal combustion engines (ICEs) is the heat engines that converts chemical energy in a fuel into mechanical energy, usually made available on a rotating output shaft. Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine. ICEs are divided into two main groups as spark–ignition (or gasoline) and compression–ignition (or diesel) engines according to their working principle [1]. ICEs are the prime movers in road, sea, air, railway transportation and in power plants such as generators, pumps elevators, agricultural and construction machinery [2]. The properties are required from the ICEs alter in accordance with the usage places. The characteristics of the ICEs are determined by means of the experiments in a realistic way. The characteristics such as torque, power, efficiency and fuel consumption of ICEs are discovered in the basic experimental studies [3–4]. Thus, ICEs are produced in a suitable way for the usage areas and also developed. In the present study, the characteristics of the engine such as air excess coefficient, torque, brake power, various efficiencies and fuel consumption were determined under variable loads by using a single–cylinder, four–stroke and water–cooled direct injection experimental diesel engine.

II. EXPERIMENTAL SETUP AND MEASUREMENTS

The experimental setup is a closed–circuit system consisting of an experimental engine loaded by an eddy current electrical dynamometer, a water tank, an air tank, the measuring devices and a control unit. The schematic layout of the experimental setup is as in Fig. 1. The test engine is single–cylinder, four–stroke and water–cooled engine. The test engine can be operated as a gasoline or diesel engine by changing its head and compression ratio of test engine can be adjusted in the range of 6–18 by means of a system on the engine cylinder block. When the compression ratio is adjusted to 17.5 in the case of a diesel engine, it produces 3.5 kW at 1500 rpm, and when the compression ratio is adjusted to 8 in the case of a gasoline engine, it produces 4.5 kW at 1800 rpm. The cylinder diameter is 87.5 mm, the stroke length is 110 mm, the connecting rod length is 234 mm and the stroke volume is 661 cc (0.661 lt) of test engine [5].

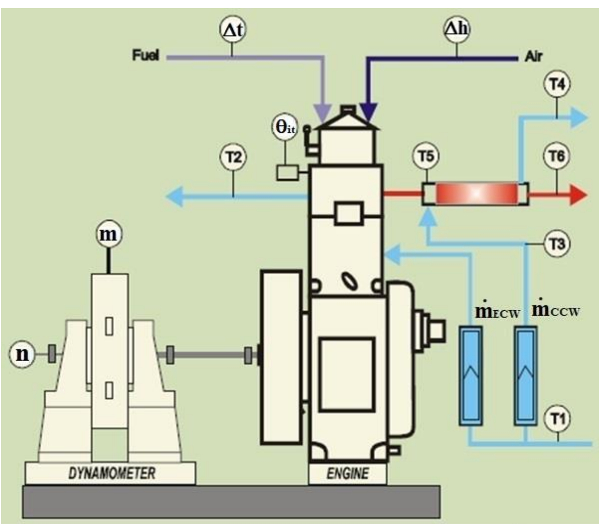

Fig. 1. Schematic layout of experimental setup [5]

An eddy current electrical dynamometer for loading of the test engine and measuring the engine load (m), an electrical tachometer to measure the engine speed (n), a scaled vessel for measuring fuel consumption (ΔV) and a stop watch for the measuring of fuel consumption duration (Δt), an orifice and a liquid U manometer to measure the air mass flow rate (Δh), a calorimeter for determining the energy transferred by means of the exhaust gases, rotameters for measuring cooling water mass flow rates ($\dot{m}_{ECW}$ and $\dot{m}_{CCW}$), thermometers for measuring coolant inlet and outlet temperatures (T_1, T_2, T_3 and T_4) and thermocouples for measuring the inlet and outlet temperatures of the exhaust gases into the calorimeter (T_5 and T_6) were used in the experimental setup. The measured values in the experiments are given in Table 1.

Table 1. Measured values in the experiments

Ambient conditions	Ambient pressure (p_{amb}) [mmHg]	772.5				
	Ambient temperature (T_{amb}) [°C]	18				
Operating conditions	Compression ratio (r_c) [–]	17				
	Injection timing (θ_{it}) [°CA]	23				
	Engine speed (n) [rpm]	1500				
Engine load (m) [kg]		m_1= 0.1	m_2= 3	m_3= 6	m_4= 9	m_5= 12
Fuel consumption duration (Δt) [s]		72.46	42.27	35.26	29.86	25.06
Height of manometer (Δh) [mm]		76	72	71	68	66
Mass flow rate of engine cooling water ($\dot{m}_{ECW}$) [kg/h]		150	150	150	150	150
Mass flow rate of calorimeter cooling water ($\dot{m}_{CCW}$) [kg/h]		80	80	80	80	80
Inlet temperature of ECW (T_1) [°C]		29	29	29	29	29
Outlet temperature of ECW (T_2) [°C]		40	43	46	49	52
Inlet temperature of CCW (T_3) [°C]		29	29	29	29	29
Outlet temperature of CCW (T_4) [°C]		33	36	38	42	45
Temperature of exhaust gases in calorimeter inlet (T_5) [°C]		161	235	286	340	405
Temperature of exhaust gases in calorimeter outlet T_6 [°C]		126	174	210	244	281

III. CALCULATION OF ENGINE CHARACTERISTICS

When the test engine was running under a certain load, the force (F), engine torque (M)

and brake power (P_b) are determined as follow [1–4].

$$F = m.g \text{ [N]} \quad (1)$$

$$M = F.l \text{ [Nm]} \quad (2)$$

$$P_b = \frac{M.n}{9549} = \frac{BMEP.V_h.n.z}{60.k} \text{ [kW]} \quad (3)$$

$$V_h = \frac{\pi.D}{4} H \text{ [lt]} \quad (4)$$

Here; n is engine speed, $BMEP$ is the brake mean effective pressure, gravitational acceleration is g=9.81 m^2/s, the length of moment arm is l=185 mm, cylinder number is z=1, stroke number is k=2 for four stroke engines and k=1 for two stroke engines, cylinder diameter is D=87.5 mm, stroke length is H=110 mm and cylinder swept (stroke) volume is V_h=661 cm^3.

The mass flow rate of air ($\dot{m}_{air}$), density of air (ρ_{air}), mass flow rate of fuel ($\dot{m}_{fuel}$), volumetric efficiency of the engine (η_v), and air excess coefficient (α) are determined as follow [1–4].

$$\dot{m}_{air} = 3600.C_f \frac{\pi.d^2}{4} \rho_{air} \sqrt{\frac{2.\rho_{water}.g.\Delta h.10^{-3}}{\rho_{air}}} \text{ [kg/h]} \quad (5)$$

$$\rho_{air} = \frac{p_{amb}.T_{amb}}{R} \text{ [kg/m}^3\text{]} \quad (6)$$

$$\dot{m}_{fuel} = 3600 \frac{\Delta V}{\Delta t} \rho_{fuel} \text{ [kg/h]} \quad (7)$$

$$\eta_v = \frac{\dot{m}_{air}}{\dot{m}_{air,\ therotical}} = \frac{\dot{m}_{air}.k}{60.\rho_{air}.V_h.n.z} \text{ [–]} \quad (8)$$

$$\alpha = \frac{h}{h_{min}} \text{ [–]} \quad (9)$$

$$h = \frac{\dot{m}_{air}}{\dot{m}_{fuel}} \left[\frac{\text{kg air}}{\text{kg fuel}}\right] \quad (10)$$

Here; h is the actual air–fuel ratio, orifice diameter is d=20 mm, friction coefficient of the orifice is C_f=0.6, density of water is ρ_{water}=1000 kg/m^3, universal gas constant is R=287 J/kgK, the minimum (or theoretical) air–fuel ratio is h_{min}=14.45 for diesel fuel and density of fuel is ρ_{fuel}=830 kg/m^3 for diesel fuel.

Finally, the brake specific fuel consumption ($BSFC$) and brake thermal efficiency (BTE) are determined as follow [1–4].

$$BSFC = \frac{\dot{m}_{fuel}}{P_b} \left[\frac{\text{kg}}{\text{kWh}}\right]$$

$$BTE = \frac{3600}{Q_{LHV}.bsfc} \text{ [–]}$$

Here; the lower heating value of the fuel is Q_{LHV}=42000 kJ/kg for diesel fuel.

IV. RESULTS AND DISCUSSON

The diesel engine characteristics were calculated by using the equations given above and the graphics drawn from the calculated engine characteristics under various engine loads were presented in this section. Fig. 2 shows the variation of volumetric efficiency with engine load. Volumetric efficiency for an internal combustion engine is described as a ratio of the quantity of air that is trapped by the cylinder during induction over the swept volume of the cylinder under static conditions. Volumetric efficiency of the test engine decreases with the increasing engine load as seen in Fig. 2. This is mainly because the cylinder gas temperature increases as the engine load increases and this leads to higher intake manifold temperature, thus engine volumetric efficiency decreases continuously with increasing engine load due to reducing the density of intake air with temperature [6]. It is also considered that increase of the intake manifold pressure with the increasing engine load makes additional contribution to reduction of engine volumetric efficiency. As a result, engine volumetric efficiency was determined as 81.27, 79.21, 77.91, 76.91 and 75% at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.

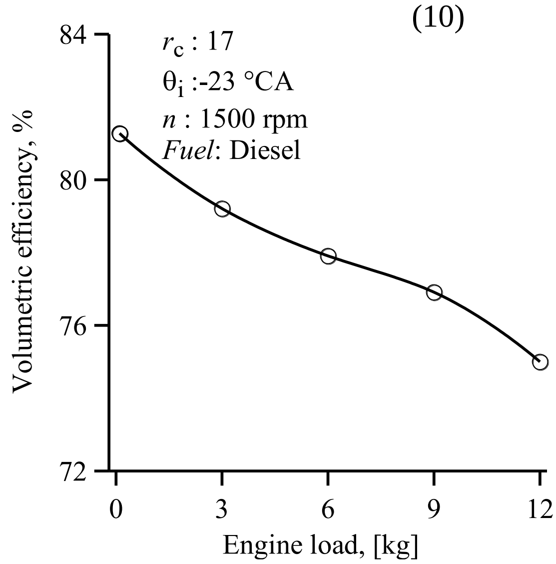

Fig. 2. Variation of volumetric efficiency with engine load

Fig. 3 shows that the variation of air excess coefficient with engine load. Air excess coefficient is stated as the ratio of the total amount of air used in the combustion to the amount of stoichiometric (theoretical) air. Air excess coefficient of the test engine decreases with the increasing engine load as seen in Fig. 3. It is considered that this is sourced from the decreasing engine volumetric efficiency and increasing the injected fuel into the cylinder as the engine load increases. For these reasons, air excess coefficient increases with the increase of engine load and thus engine air excess coefficient was determined as 4.7, 2.7, 2.2, 1.8 and 1.6 for the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.

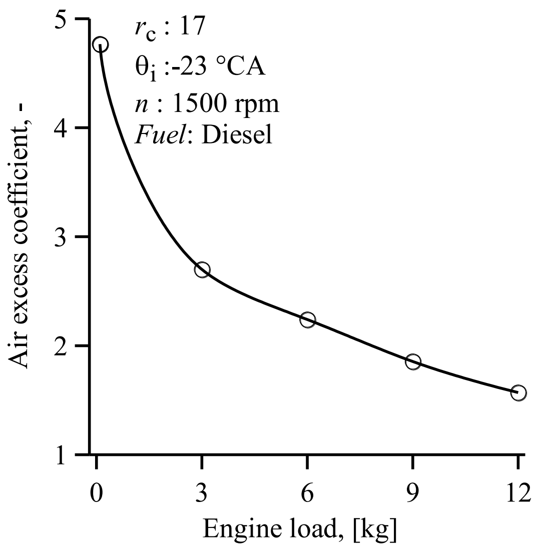

Fig. 3. Variation of air excess coefficient with engine load

Fig. 4 shows the variation of torque and Fig. 5 shows the variation of brake power with engine load. The torque and brake power of the test engine increases almost linearly with the increase of engine load as seen in Figs. 4 and 5. This is result of the injected fuel amount into the cylinder, because more fuel generates naturally more torque and power as expected. Therefore, torque of the test engine was determined as 0.18, 5.4, 10.89, 16.33 and 21.73 Nm for the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively. Brake power was determined as 0.28, 0.85, 1.71, 2.56 and 3.42 kW at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.

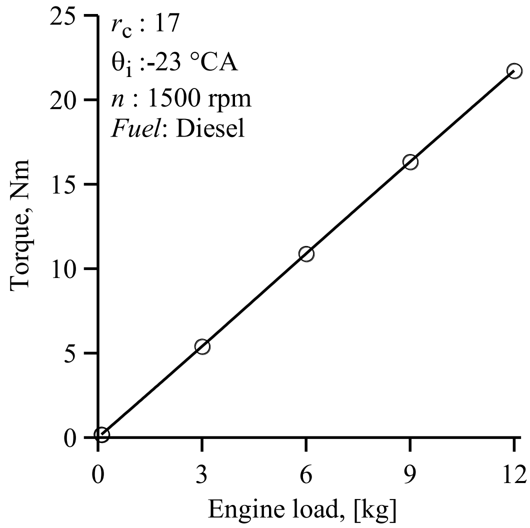

Fig. 4. Variation of torque with engine load

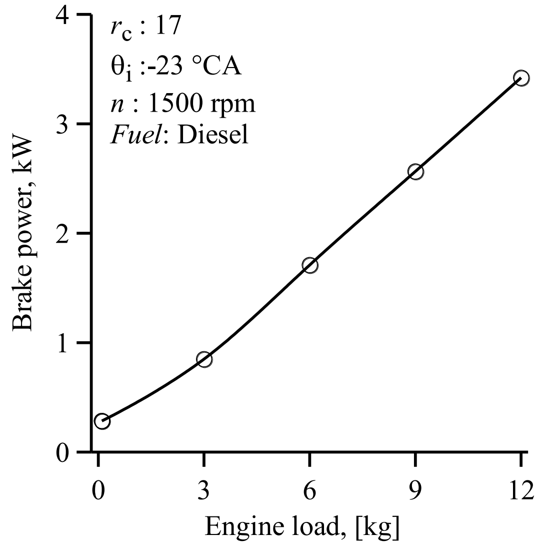

Fig. 5. Variation of brake power with engine load

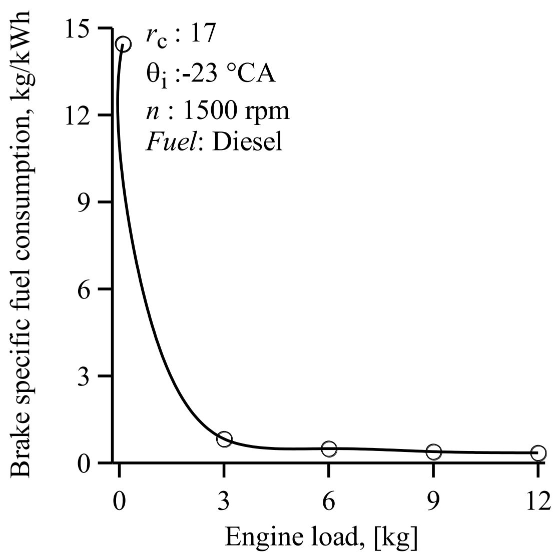

Fig. 6. Variation of brake specific fuel consumption with engine load

Fig. 6 shows the variation of brake specific fuel consumption with engine load. Brake specific fuel consumption (BSFC) is a measure of the fuel efficiency of any prime mover that burns fuel and produces rotational or power. It is typically used for comparing the efficiency of internal combustion engines with a shaft output. It is the rate of total fuel consumption divided by the power produced by an engine. BSFC of the test engine decreases with the increasing engine load as seen in Fig. 6 due to more power produces by test engine with the increasing engine load. BSFC of the test engine was determined as 14.45, 0.83, 0.49, 0.39 and 0.35 kg/kWh at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively. Fig. 7 shows the variation of brake thermal efficiency with engine load. Brake thermal efficiency (BTE) is the ratio of the brake power obtained from the engine to the fuel energy supplied to the engine. BTE is the indication of how efficiently the heat is converted into useful work. BTE depends on the various parameters such engine design, fuel type, and operating conditions. BTE increases with the increasing engine load as seen in Fig. 7. It is thought that this variation is a sourced from the increasing of combustion efficiency. As result of this, BTE of the test engine was determined as 5.93, 10.3, 17.31, 21.37 and 24.53% at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.

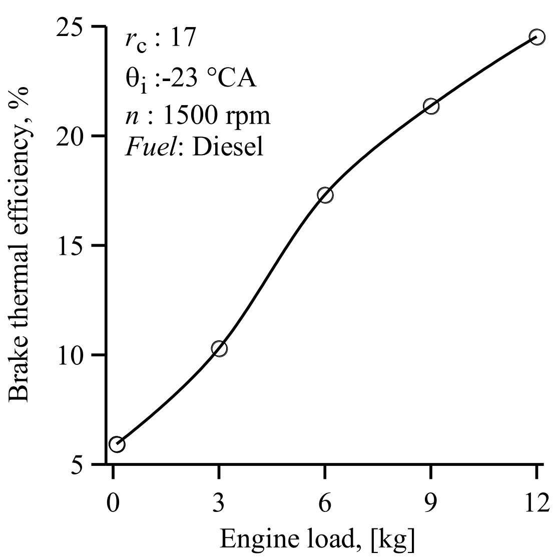

Fig. 7. Variation of brake thermal efficiency with engine load

V. CONCLUSIONS

In the present study, the characteristics of a diesel engine such as volumetric efficiency, air excess coefficient, torque, brake power, brake specific fuel consumption and brake thermal efficiency have been investigated experimentally. The following conclusions can be summarized from the results of the study.

- It was determined that the volumetric efficiency decreased with the increasing engine load due to the increase of cylinder gas temperature of the test engine. The volumetric efficiency of the test engine was determined as 81.27, 79.21, 77.91, 76.91 and 75% at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.
- It was determined that the air excess coefficient decreased with the increasing engine load due to the decreasing engine volumetric efficiency and the increasing injected fuel mass. The air excess coefficient of the test engine was determined as 4.7, 2.7, 2.2, 1.8 and 1.6 for the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.
- It was determined that the torque and brake power increased with the increase of engine load because more fuel generates more torque and power. The torque of the test engine was determined as 0.18, 5.4, 10.89, 16.33 and 21.73 Nm for the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively. The brake power of the test engine was determined as 0.28, 0.85, 1.71, 2.56 and 3.42 kW at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.
- It was determined that the brake specific fuel consumption decreased with the increasing engine load due to more power produces by the test engine with the increasing engine load. The brake specific fuel consumption of the test engine was determined as 14.45, 0.83, 0.49, 0.39 and 0.35 kg/kWh at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.
- It was determined that the brake thermal efficiency increased with the increasing engine load because of the increasing combustion efficiency. The brake thermal efficiency of the test engine was determined as 5.93, 10.3, 17.31, 21.37 and 24.53% at the engine loads of 0.1, 3, 6, 9 and 12 kg, respectively.

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