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The Influence of Ambient Conditions on Compression Ignition Engine performance: (Experimental Study)

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ABSTRACT: In I.C. engines, the variation of temperature and relative humidity for intake air play a paramount role in the engine performance therefore, these parameters were investigated experimentally to study and improve their design and operations. The performance of diesel engines can be expressed in terms of five variables (Brake specific fuel consumption (BSFC), Exhaust temperature (T_{ex}), Air/Fuel ratio (A/F), Brake thermal efficiency (Z_{bth}) and Mechanical efficiency (Z_m)). A four-stroke diesel engine type (TD212) and capacity of 232 cc was utilized as the test engine. The inlet air was acclimated to required humidity and temperature values by using a humidifier before entering the inlet port of the engine. All the tests were achieved at constant speed of (1600 rpm) with the variation of loads from (2-10 N.m). The results showed that the A/F ratio, mechanical efficiency and brake thermal efficiency decrease, while the BSFC and T_{ex} increase with increasing of both I.A.T. and RH of the inlet air. Also, at constant values of I.A.T and RH of inlet air, the results show increasing of T_{ex}, brake thermal efficiency, and mechanical efficiency values with increasing engine loads while increasing the BSFC and A/F ratio with decreasing engine loads.

KEYWORDS: BSFC; T_{ex}; A/F ratio; brake thermal efficiency; intake air temperature; mechanical efficiency

INTRODUCTION

Diesel engines are the main sources of electricity besides being used in transport vehicles on land and sea. There are several reasons behind choosing diesel engines amongst them are the simple mechanism, outstanding performance, low-fuel costs, high-pressure ratio, high energy/weight ratio, and high-thermal efficiency [1]. The operation of the diesel engine and subsequent contaminants is effected by the inlet air temperature to the engine. Whenever the inlet air is cold, the temperature of the compressed gas in the engine cylinder is reduced according to the unheated received charge coming from the inlet which quickly cools down transferring heat to walls of cold combustion chamber. Because this reason, the engine does not ignite and, consequently, a suitable mechanism with modifications is needed. A series of mechanical modifications have been proposed to prevent the case of cold operation such as the use of heating elements, different fuels, adding other materials to the used fuel, increase the variable compression ratio (VCR) or change the Variable Valve Timing (VVT). The change of VVT, for example, results in reaching the temperature of the ignition in less time and fewer heat cycles and, meanwhile, the high amounts of exhaust gases remaining from previous cycles allow good combustion [2].

The performance of a diesel engine, of high compression rate, and the amount of NOx by certain variables such as injector pressure, compression rate, and inlet air temperature were studied and analyzed [3]. The resulting engine was found to operate at a low rate subjecting to increasing as the air entry temperature increases and, meanwhile, it is important to keep watching the effect of the octane number of fuels on the delayed fuel ignition period. A direct-injection of water-cooled diesel engine was used for test the stability of the speed as air pressure inside the engine varies using the EGR system similar to that employed by agricultural machinery. The tests were implemented out to test the engine performance and the pollution quantities while employing the Exhaust Gas Recirculation (EGR) at the suitable domain of the air pressure entering the engine. It was found that the effect of using the EGR system alone results in better outcomes compared to considering either the air pressure or the compressed air entering the engine in regards to the emission of NOx and the decrease in T_{ex}. However, an emission of HC, CO, and CO2 was observed to increase in the case of using the two systems at the same time [4].

The effect of intake air pressure was employed by an engine using ULSD fuel. They found that as a pressure of intake air decreased, the performance of the engine and the pollutants decrease. It was concluded that an increase in drop of pressure would increase the thermal consumption of (BSFC), which slightly decreases in efficiency at partial load while the emission of NOx increases when pressure decreases [5]. The mixing of diesel fuel with monoacetate ethylene glycol in different percentages to obtain an oxidized diesel fuel was experimented by [6]. Then, using this oxidized fuel to examine the effect of the air at the room temperature and the humidity on performance and pollutants. The results revealed that increasing I.A.T. causes an increase in BSFC and an increase in the emission of carbon monoxide and carbon dioxide in addition to an increase in the T_{ex}, while there was a decrease in the amount of additional air, the oxygen, and the emission of NOx [6].

A practical and theoretical study to examine the influence of inlet air temperature on the performance and contaminants of spark ignition engines, the experiment is summarized by using a four-cylinder engine powered by gasoline fuel. The intake fuel and air were heated and cooled by raising and lowering the air temperature using the air conditioning while placing the pipe in the air duct exit to obtain the following six temperatures of 10, 20, 40, 50, 60, 70 °C. The results, compared with the working condition at the air temperature of 20°C and 50 °C, the comparison showed that an improvement in BSFC and thermal efficiency as the air temperature increased to 14% and 16%, respectively [7]. The effect of increasing air temperature before entering the diesel engine on fuel quality consumption was employed by [8] many tests were conducted a hydro cooled and direct injection diesel engine and the inlet air can be controlled by using an electric heater. The results showed that the specific consumption of fuel increased as the air temperature into the engine increased [8]. The effect of humidity and air temperature entering the engine on the performance and the emissions of pollution from the diesel engine was developed. These results showed that air consumption, torque, and NO_x decrease, while the consumption of CO_2 and sulfur oxide increases as the inlet temperature and relative humidity increases [9]. The current work focused on the effect of ambient conditions, specifically the temperature and relative humidity on the performance of a direct injection and water cooled diesel engine at constant speed and variable loads

METHODOLOGY

The experimental part was conducted in the Laboratory of I. C. Engines belongs to the Institute of Technology/ Central Technical University - Baghdad using a diesel engine type (TD212) made by T-equipment, UK, all details are shown in Table (1). This engine is characterized by a single-cylinder, water cooling, direct injection, and natural air supply which allow measuring the effect of inlet temperature and relative humidity on the performance at different torques. For air temperature measurement, a piezoelectric transducer thermometer, type K, of the accuracy of ±0.5 ℃ was used. The speed of the engine was measured using the ECA100. All equipment is connected to an electronic software of ECA100 which was modified with a cylinder containing head pressure transducer and crank angle encoder.

Figure (1) shows the schematic diagram and test rig. The present test rig is digitally controlled and all data were instantaneously saved on pc. The engine loads was controlled using a hydraulic type dynamometer. All signals (specific fuel consumption, power, pressure and loads) were interfaced to the computer. The compression ratio was constant (CR = 22:1), the engine torque varies from (2 to 10) N.m. The (process indicator, time measurement, fuel measuring unit, pressure measurement, and engine indicator) were used in this test. High temperatures pressure sensors type (Kistler) and (PCB) JCP piezoelectric accelerometers were used also. A piezoelectric pressure transducer was used to measure the cylinder pressure. All signals from these sensors are analyzed to establish baseline information for engine, these information are used to detect any error in simulation test of engine. The sensing element were mounted into the combustion chamber (in head of cylinder), this part consists of a diaphram which deflect as a result of pressure, and these deflections were converted to a voltages proportional with the pressure.

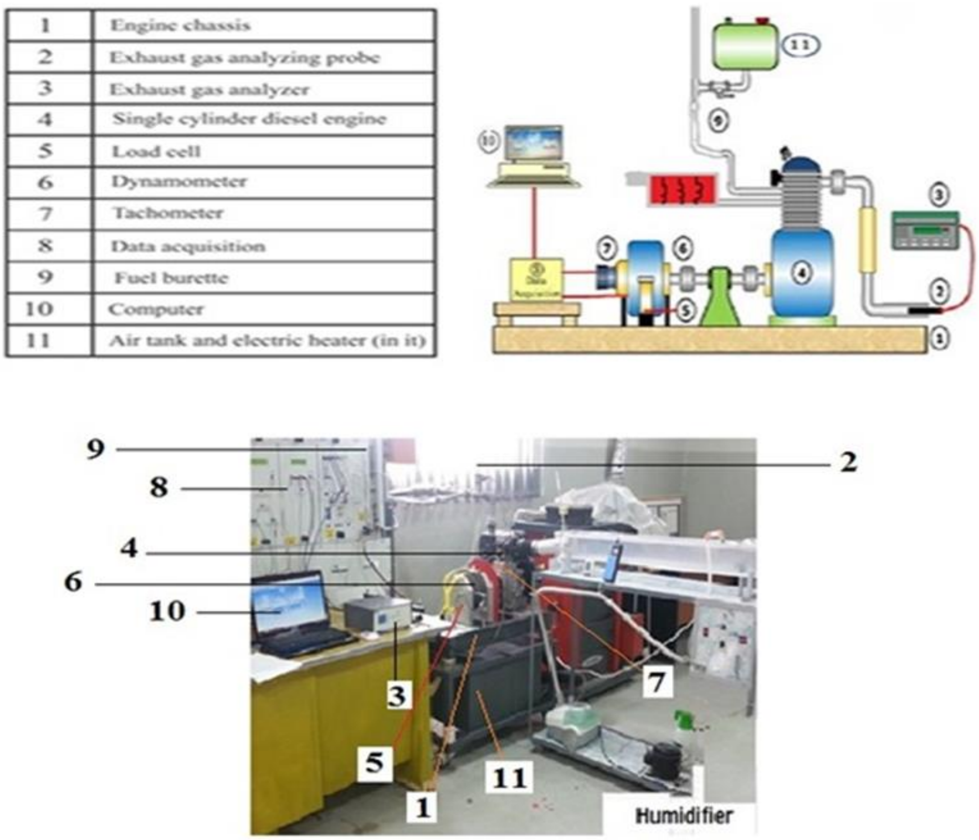

Figure 1. Schematic diagram and test rig

This engine includes an exhaust thermocouple, a half coupling to link to the testbed dynamometer to measure the power, and all essential hoses and fitting. There is a heater applied through the air intake manifold to heating air within the diesel engine, and thermocouple was applied in air manifold to indicate intake air temperature. Water vapor can be obtained from boiling water by an external heater and then a manually controlled quantity of steam can be inserted with the air intake port to examine the effect of relative humidity on the performance of engine at variable loads and constant speed.

Table 1. Engine specifications

Item	Specification
Engine Manufacturer	TQ (TD 212), UK
Fuel	Diesel
Max. Power	3.5 kW at 3600 rpm
Max. Torque	16 N.m. at 3600 rpm
Bore	6.9 cm
Length of Connecting Rod	10.4 cm
Capacity	232 cc
CR	22:1

Oil	Multi-grade SAE 5W-40

To conduct an integrated study of engine performance, the following variables have been taken into account: the intake air temperature, speed, torque, and humidity. In terms of the temperature of the intake air, the following temperatures were taken: 20, 30, 40, and 50 ℃. The speed was fixed at 1600 rpm, the torque can be changed from 2, 4, 6, 8 to 10 N.m, the air humidity inside the engine has been changed from 30%, 40%, 50% to 60% at the same speed.

RESULTS AND DISCUSSION

All readings were taken at similar conditions of fixed speed at 1600 rpm while the torque (load) varies from 2 to 10 N.m. All variables were tested as a function of I.A.T (20, 30, 40 and 50°C) and RH (30, 40, 50 and 60 %)

Behavior of (BSFC)

Two tests were performed on the diesel engine to investigate the relationship between (BSFC) with (I.A.T) and relative humidity (RH) as shown in Figure (2) (a and b) respectively. From the first test figure (2-a) it can be seen that BSFC decrease as the load on the engine increase from 2 to 10 N.m. regardless of the change in I.A.T. This increase could be attributed to the turbulent air which improves fuel/air mixture reaching the full fuel combustion. As the load increases, a large part of the gaseous fuel found in the oxidation process will lead to a high chemical reaction, which, in turn, leads to a decrease in BSFC. The results also show that BSFC decreases as I.A.T decreases. The ignition delay is reduced by lowering the temperature of intake air due to the increasing availability of the oxygen. This allows combustion to occur at the beginning of the expansion cycle and the end of the compression cycle where a large portion of fuel will be converted energy and useful work.

BSFC becomes more important as I.A.T increases, and its value decreases as engine torque (load) increases. When the heat of the intake air increases, it improves the fuel efficiency and when the engine load is increased as a result of the increased usage of most of the internal energy stored in the fuel due to the good mixing of the air and fuel mixture. When the load increases, it increases the speed of flame spread, reduces the delay of ignition, and increases the likelihood of complete fuel combustion, thereby increasing the resulting capacity, resulting in a decrease in the value of BSFC.

The second test on BSFC was performed to investigate how BSFC varies with relative humidity as shown in Figure (2-b). BSFC seems to behave almost in the same trend as reported with I.A.T which shows that BSFC decreases as the torque increases from 2 N.m. to 10 N.m. However, the increase in the relative humidity between (30 to 60 %) causes a small increase in BSFC at loading between 4 to 10 N.m. while at a load of 2 N.m., BSFC increases exponentially between 0.33 to about 0.44 kg/kWh. Generally speaking, at various engine loads, more fuel is needed to overcome the effects of increased heat loss of exhaust gases and the subsequent of the decreased amount of heat and various reactions as reported by [10]

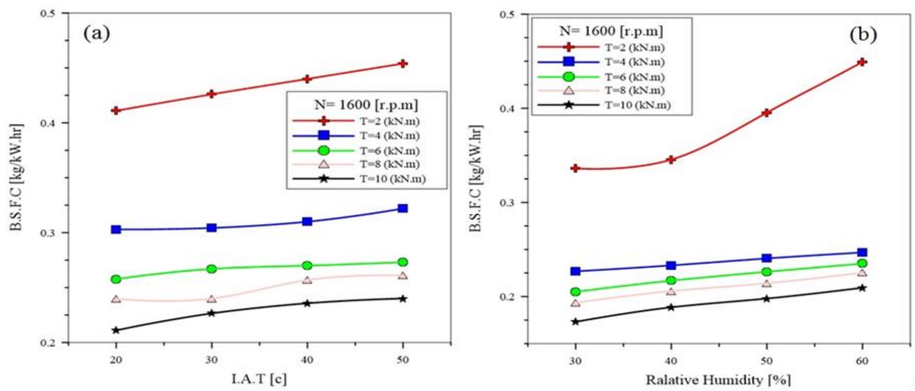

Figure 2. BSFC behavior with (a) I.A.T and (b) relative humidity

Behavior of exhaust gas temperature (T_{ex})

The second band of tests deals with the engine exhaust gas temperature and how it varies with I.A.T and relative humidity as shown in Figure (3) (a and b) respectively. The gas temperature in this report was considered as the temperature of the gas outside in the exhaust stream of the single cylinder. The first test on the diesel engine was conducted to investigate the effect of outlet gas temperature on I.A.T as shown in Figure (3-a), it can be seen that as I.A.T increase the outlet gas temperature increase slightly when the load on the engine was between 4 to 10 N.m. and increase significantly at lowest minimum load (2 N.m.). The increase in exhaust gas temperature due to the increase of (I.A.T) can be attributed to the air/fuel (A/F) ratio. When the temperature of air rises in the engine, the air/fuel ratio will be lower due to the low air consumption rate during the preparation of the fixed fuel pump, which tends to rises up the T_{ex}. The second factor is the ignition delay, which has an opposite effect, but it is insignificant on the T_{ex}, as the warming of air will shorten the delay of ignition [11]. The proportion of fuel burned at different stages of combustion changes accordingly; however, the difference in ignition delay is very small and is not significant in changing the combustion stages or the T_{ex}.

The other test that investigates the effect of the relative humidity on the exhaust temperature is shown in Figure (3-b). Similarly, the trend of decreasing the outlet temperature as the increasing the load from 2 N.m. to 10 N.m. has been shown again here regardless of the amount of the relative humidity. However, at the relative humidity of 30%, the outlet temperature was reduced from 265 ℃ to 132 ℃ (or reduction by 133 ℃), while the corresponding reduction at a maximum relative humidity (60%) was from 361 ℃ to 120 ℃ (or reduction by 241 ℃), which is approximately doubled compared to lower relative humidity. A possible explanation for this could be attributed to the water quality temperature compared to the dry air. The air with high humidity inside the engine has high-quality temperature, which leads to a decrease in the temperature during combustion in the cylinder, and finally lowers exhaust gas temperature for the air charge.

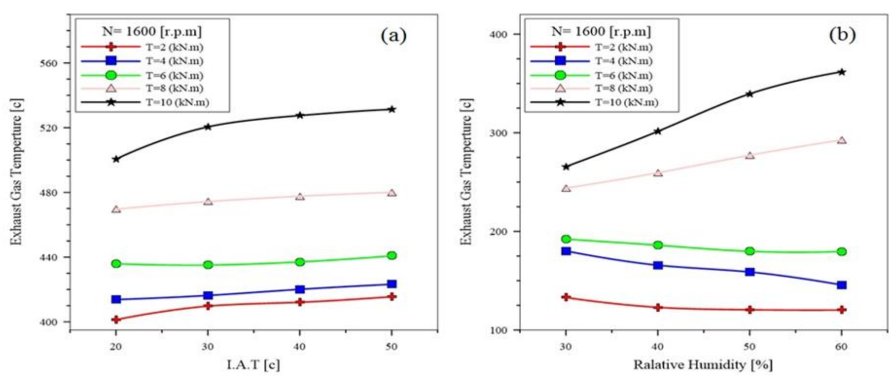

Figure 3. Exhaust gas temperature (T_{ex}) behavior with (a) I.A.T and (b) relative humidity

(A/F) Ratio

The other two tests on diesel engine were carried out to investigate the I.A.T and relative humidity on the A/F ratio under the same conditions as shown in Figure (4) (a and b), respectively. The effect of I.A.T on the A/F ratio is shown in Figure (4-a). The results shown clearly that A/F decreases with an increase of I.A.T and reduced as the load on the engine increased from 2 N.m. to 10 N.m. The decrease in A/F ratio at the various loads and at the cold air inlet temperature of 20 ℃ is estimated at 69%, while at a higher temperature of 50 ℃ was at 66%. It seems that there is no effect of the inlet temperature on the reduction of A/F ratio within the load operating conditions. Diesel engines operate under poor fuel conditions, resulting in excess oxygen left in the exhaust gas. It has been shown that throughout several engine tests that were performed when the fuel pump remains at the same speed, the amount of oxygen consumed is almost constant. However, at high inlet air temperatures, both the amount of air and the concentration of excess oxygen in the exhaust gas will be lower. Hence, depending on these conditions, the A/F ratio decreases as the humidity of the air entering the engine increases. For diesel engines, the rate of fuel consumption is affected by the air/fuel ratio, which can be poor combustion when the A/F ratio is poor and the fuel consumption is low, while the combustion is good when the A/F ratio is rich and fuel consumption is high [12].

The other test on the diesel engines was to investigate the effect of the relative humidity on the A/F ratio as shown in Figure (4-b) it can be seen that when the relative humidity increase the A/F ratio is decreased, from these it can be concluded that the fuel consumption rate depends on the inlet air temperature and the humidity because of the rising in density of the air inside the engine which leads to a drop in on the intensity of the discharged air and thus reduces the rate of air consumption. The moisture of intake air also affects air density because the density of air containing water vapor is lower than dry air. The fuel consumption rate loosely depends on the air inlet temperature and the relative humidity at any given load between 2 N.m. and 10 N.m. Generally, an increase in I.A.T leads to a decrease in the density of the cloud charge and thus reduces the rate of air consumption. It is important to note that all experiments were conducted at a constant engine speed where the volumetric efficiency of the diesel engine remained almost constant. This normally leads to the conclusion that the air consumption rate depends mainly on the density of I.A.T. Although the engine naturally pulls air, it is expected that the air humidity inside could also affect the air density.

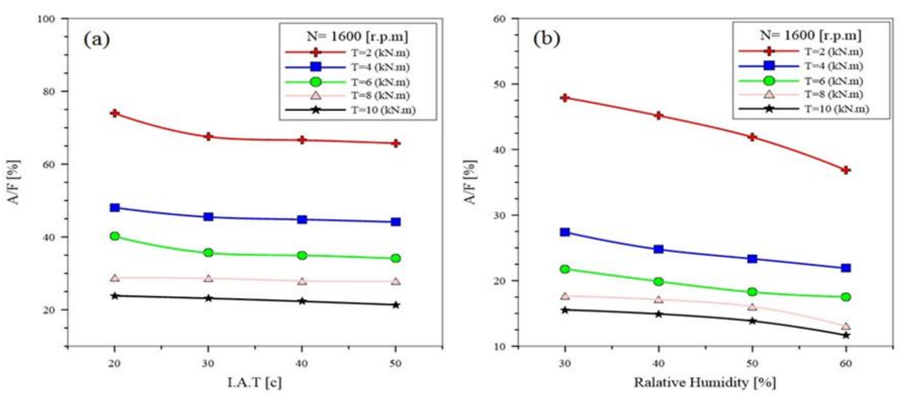

Figure 4. Air/fuel ratio behavior with (a) I.A.T and (b) relative humidity

Brake Thermal Efficiency (Z_{bth})

The concept of efficiency is very important in the field of engineering because it could be the most important part of evaluating any system. The first efficiency discussed in this study is the brake thermal efficiency (Z_{bth}). This efficiency was discussed in terms of I.A.T and the relative humidity as shown in Figure (5) (a and b), respectively. Figure (5-a) clearly shows the effect of I.A.T on the brake thermal efficiency, at any given I.A.T between 20 ℃ and

50℃, Z_{bth} values increases as the load increases while at any given load, Z_{bth} decreases as I.A.T increases. This result is expected because of the decrease in Z_{bth} corresponds to an increase of frictional power losses of the engine. Also, it can be seen that the increase of I.A.T from 20℃ and 50 ℃ is doing not cause a considerable change in Z_{bth}. This is because of the effect of I.A.T on BSFC, exhaust gas temperature and A/F is not enough to cause considerable change in Z_{bth}, as shown in Figures (2-a), (3-a), and (5-a), respectively.

The effect of the relative humidity on Z_{bth} is shown in Figure (5-b), it can be seen that Z_{bth} increases as the load increase which is normally expected and has been observed in the effect of I.A.T on Z_{bth}. While it was found that the Z_{bth} decreases significantly as the moisture of the inlet air to the engine increases a possible explanation for this could be attributed to the air with high humidity inside the engine has high-quality temperature, which leads to a decrease in the temperature during combustion in the cylinder, and finally lowers Z_{bth} for the air engine.

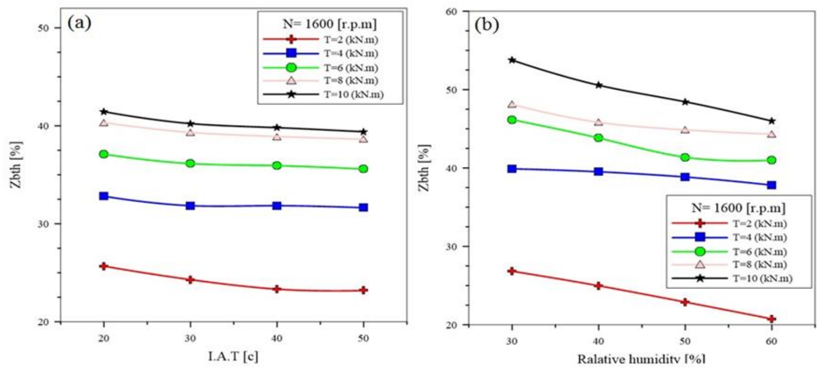

Figure 5. Brake thermal efficiency behavior with (a) I.A.T and (b) relative humidity

Mechanical Efficiency (Z_m)

The mechanical efficiency (Z_m) was tested as a function of I.A.T and the relative humidity as shown in Figure (6) (a and b), the rapport between Z_m and I.A.T of the diesel engine was seen in Figure (6-a). Generally Z_m increases as the applied load increases on the engine. At the coldest air inlet temperature of 20℃ or the highest temperature of 50℃ increases at the same amount from about 35% to 67%. This result has shown that it is independent of the I.A.T, also Figure (6-a) shows that Z_m slightly go down as I.A.T increases from 20℃ to 50℃. This slight change could be attributed to the decreased braking power with the increase of I.A.T as presented in Figure (5-a). A possible interpretation may be related to the decrease in the amount of oxygen entering the engine, which, in turn, decreases pressure and temperature of combustion, and, thus, decreases mechanical efficiency.

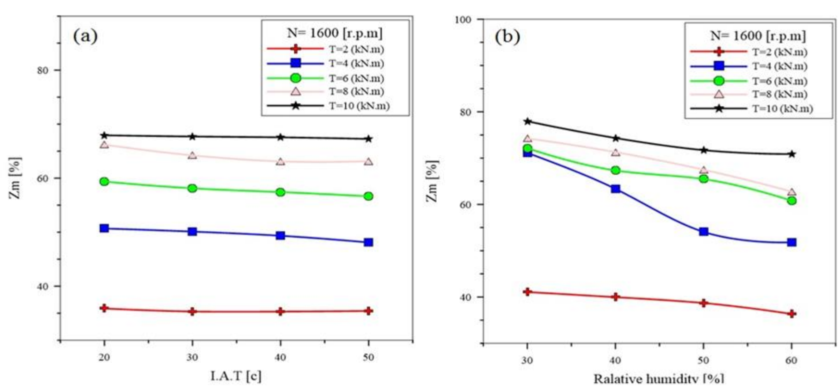

Figure 6. Mechanical efficiency behavior with (a) I.A.T and (b) relative humidity

The effect of the relative humidity on Z_m is shown in Figure (6-b) it can be seen that Z_m decrease as the relative humidity increase, while it was found that the Z_m decreases significantly as decreases engine loads this could be attributed to the air with high humidity inside the engine has high-quality temperature, which causes a decrease in the temperature during combustion in the cylinder, and finally lower Z_m for the air engine.

CONCLUSION

In current work, the influence of intake ambient conditions (temperature and relative humidity) on (BSFC, T_{ex}, A/F ratio, Z_{bth}, and Z_m) in diesel engine is examined in detail. From the results, It can be deducing the following: -

- As a results of increase I.A.T. the in cylinder traps mass were reduced and, therefore reducing the heat capacity and oxygen of the charged air. This is because an increase of BSFC at low load but slightly lowering at higher load when the charge air temperature is increased.
- A/F ratio, Z_{bth}, and Z_m decrease, while the BSFC and T_{ex} increase with increasing of both I.A.T. and RH of the intake air.
- The values of (T_{ex}, Z_{bth}, and Z_m increase with increasing of engine loads while the BSFC and A/F ratio values increase with decreasing engine loads for both I.A.T. and RH at constant values of them.
- As the intake air temperature increases the density of air will decrease which leads to decrease volumetric efficiency, as a result, less air volume draws into the cylinder.
- The increase of intake air humidity leads to displacing the air thereby reduction in volumetric efficiency which reduces output power.
- The engine output power is directly proportional to air mass (volumetric efficiency) ingests by an engine.

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