EFFECT OF FUEL TEMPERATURE ON SOME PERFORMANCE INDICATORS AND EXHAUST GAS EMISSIONS OF A FOUR CYLINDER DIESEL ENGINE

Haitham N. A — Researcher
N. S. Kadhim — Assistant professor
Dept, Agric. Mach. and Equipment., Coll. Agric. Engin. Sci
University of Baghdad
Haitham.Najm1203a@coagri.uobaghdad.edu.iq drnaseeriq@gmail.com

ABSTRACT

This study was aimed to evaluate the effect of diesel fuel temperature on engine performance and emissions. A 4-cylinder 4-stroke water cooled direct injection (DI) diesel engine was tested at three fuel temperatures (50, 60 and 70) °C. The fuel temperatures were controlled by A thermoelectric cooling system (TEC) fixed on the fuel supply line before the injection pump. The engine was run with two speed levels, included 1200 and 1500 rpm, with constant load (full load). An electric dynamometer was connected to the engine to make load by electric heaters. Gas emission was measured using gas analyzer type AirRex - HG540 and Texa gas box. Results obtained from the experiment were statistical analyzed using the factorial experiment system. The experiment design is (CRD), the averages of the results were tested using the least significant difference (LSD) at the probability level (0.05) using the (Genstat) program and showed that the fuel temperatures (50 °C) detected a sharp reduction in each of the brake specific fuel consumption (BSFC) by (6.95,4.34%) , Exhaust Gas Temperature(EGT) by (4.98,2.38%), Nitric Oxide (NO_x) by (29.09,27.08%), and Particulate matter (PM) by (46.25,31.25%) and registered a slight increase brake thermal efficiency (BTE) of (7.12,4.40%) respectively, compared to the fuel temperature of (60,70) °C.

Key Words; internal combustion engine. exhaust opacity. thermoelectric cooling system, brake specific fuel consumption, exhaust gas temperature.

***Part of Misc. dissertation of 1st author .**

تأثير درجة حرارة الوقود على بعض مؤشرات الأداء و غازات العادم لمحرك ديزل رباعي الاسطوانات

هيثم نجم عبدالله — باحث
نصير سلمان كاظم — استاذ مساعد
قسم المكائن والآلات الزراعية/كلية علوم الهندسة الزراعية/جامعة بغداد

المستخلص

تم اجراء تجربة لتقييم محرك ديزل رباعي الأسطوانات ورباعي الأشواط يعمل بنظام الحقن المباشر (DI) يتم تبريده بالماء ضمن ثلاثة مستويات من درجات حرارة الوقود (50،60، 70) م°، تم التحكم في درجة حرارة الوقود باستخدام منظومة تبريد كهروحرارية وتم شغيل المحرك بمستويين من السرعة هما 1200 و 1500 دورة \ الدقيقة مع مستوى حمل ثابت (حمل كامل)عن طريق توصيل داينموميتر كهربائي بالمحرك. تم قياس انبعاث الغازات باستخدام جهاز تحليل الغازات نوع AirRex – HG540 وجهاز Texa. تم تحليل النتائج إحصائياً باستعمال نظام التجربة العاملية وتصميم التجربة هو تام التعشية (CRD) ، تم اختبار متوسطات معدلات النتائج باستخدام اقل فرق معنوي (LSD) عند مستوى احتمالية (0.05) باستخدام برنامج (Genstat) وأظهرت أن درجة حرارة الوقود (50 م°) سجلت انخفاضًا في استهلاك الوقود النوعي المكبحي (BSFC) بنسبة(6.95،4.34٪)، ودرجة حرارة غاز العادم (EGT) وبنسبة (2.38،4.98٪)، وأوكسيد النيتروجين(NOx) وبنسبة (29.09،27.08٪)، والجسيمات الدقيقة (PM) بنسبة (46.25،31.25٪) وزيادة في كل من الكفاءة الحرارية المكبحية (BTE) بنسبة (7.12،4.40٪) على التوالي مقارنة بدرجة حرارة الوقود (60 ، 70) م°

كلمات مفتاحية: محرك احتراق داخلي ،عتامة العادم ، منظومة تبريد كهروحرارية ، استهلاك الوقود النوعي المكبحي ، درجة حرارة غازات العادم.

***جزء من رسالة ماجستير للباحث الاول**

Received:26/4/2022, Accepted:24/7/2022

INTRODUCTION

One of the world sustainable development agenda is to find alternatives to decrease global warming (11, 19). Engines and power play a crucial role in enhancing food security by transforming farms into more sustainable operations and lowering operational costs (1,2,3,4). Optimizing and managing the use of engines promotes sustainable agricultural practices and significantly increases efficiency, productivity, and the ability to manage large-scale farming operations (1, 4, 20). Diesel engines are used in various road transport vehicles, ships and construction works that require high energy. These vehicles and machines often operate in different weather conditions; they may be cold, such as snow plowing mechanisms, or work in desert areas, road construction equipment, or electric power generators in oil well drilling, in addition to the machine used in agriculture (20). These engines use the energy inherent in diesel fuel, which is converted into kinetic energy by burning this fuel, which is a mixture of several hydrocarbons, this type of engine has relatively low operating costs, low maintenance and high reliability (15). After the fuel is circulated through the engine, the surplus fuel is returned to the fuel tank. This return fuel, if it is not treated, will carry heat gained from the engine through direct conduction or radiation, as this heat will affect some physical properties of the fuel such as density and viscosity, especially if it rises more than (70℃), and thus loses one of its functions in lubricating the injection system and pistons in the high pressure pump (16, 18), fuel temperature returning from the high pressure pump can sometimes reach (140℃) when the engine is running, which causes deterioration in the efficiency and durability of the fuel pump and the rubber tubes used to deliver fuel in some parts of the fuel system. One of the requirements for the work of internal combustion engines that run on diesel fuel with high efficiency is to maintain the main components of these engines, as minimize fuel consumption and reducing noise from the engine as well as eliminate emissions are among the most important reasons for conducting research on these engines (10). Emissions from a diesel engine are highly dependent on the nature of the fuel/air interactions in cylinder, which in turn depend on the detail of the fuel injection process. High temperatures, which promote soot oxidation (16), the increase in fuel temperature from (30 ℃) to (40 ℃) for the fuel used to run a 4-stroke 6-cylinder water-cooled diesel engine has reduced the viscosity and density of the fuel reduce the (BSFC) and engine performance improvement (17). A research by (2) mention that changing fuel temperature from (40°C) to (50°C) has reduced the (BSFC) from to A 4-cylinder, 4-stroke, water-cooled tractor diesel engine by (4.506 kg/kW.hr) to (3.922 kg/kW.hr),while increasing the rpm from (1760 rpm) to (2200 rpm) for a single-cylinder 4-stroke water-cooled internal combustion diesel engine raised the (BSFC) from (0.258 kg/kW.hr) to (0.340 kg/kW. hr). (13) pointed that increasing engine speed from (1500 rpm) to (3000 rpm) has led to an increase in the (BTE) from (11%) to (22%) for a single-cylinder, four-stroke, air-cooled diesel engine. A study that carried out by (16) found that raised fuel temperature from (40, 45, 50℃) has effected on (EGT) that recorded (133.3, 133.7, 143.2℃), respectively. The concentration of (NO_x) emitted from a water-cooled 4-cylinder 4-stroke diesel engine increased from (600 ppm) to (700 ppm) when the engine r.p.m raised from (1200 to 3000) r.p.m (5, 8). A study made by (9) found that the amount of (PM) emitted was reduced when the fuel temperature was raised from (12 ℃) to (38 ℃). While (8) showed that the amount of (PM) emitted from a water-cooled 4-cylinder 4-stroke diesel engine increased when the engine speed was increased from (1250) to (3000 rpm).

MATERIALS AND METHODS

Fuel

Fuel diesel from the Al-Dora refinery was used at three levels of temperatures (50,60,70°C). These samples Analyzed at the Iraqi Ministry of Oil/ Petroleum Research and Development Center, results analysis as shown in (Table 1).

Table 1. Laboratory test results

Fuel temp.	Cetane index (Calc)	Kinematic viscosity	Density g/cm^3	Calorific Value, kJ/kg
50 °C	57.1	2.304	0.79703	45301
60 °C	57.1	2.030	0.78986	45301
70 °C	57.1	1.809	0.78264	45301

Engine Test: Four–stroke four–cylinder direct injection (DI) water–cooled diesel engine was used in the experiment. The technical specification of the engine is given in table 2.

Table 2. Engine test specification

parameters	Specification
Engine Manufacturer	Kia Bongo (Korea)
Type of engine	J2 2701
Engine cylinder number	4
Cooling system	Water type
Piston Displacement	2694cm^3
stroke	95mm
Bore	95mm

The engine was coupled to an electric dynamometer to produce load. The thermoelectric system was fixed on the line of fuel supply at the low pressure line after the main filters and before the high pressure injection pump Figure (1). The engine test rig including instrumentation unit to illustrate and control the speed, load, fuel consumption measured, exhaust and water cooled temperature measured by thermometer type K. Air consumption was measured by using orifice method . A schematic diagram for the test rig was showed in Figure 1.

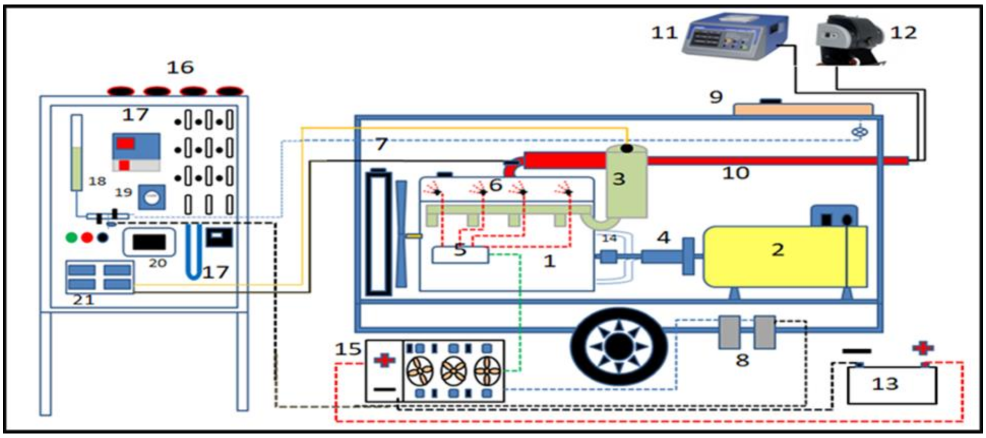

Fig 1. Engine test rig

1-engine 2-alternator 3-air box 4-flexible coupling 5-fuel pump (high pressure) 6-nozle 7-radiator 8-filters 9- fuel tank 10- exhaust pipe 11- exhaust gas analyzer 12- exhaust opacity analyzer 13- battery 14- torque device 15- electrothermal system 16- load (electric heaters) 17- multi-current reader 18-burette 19- rpm counter 20- weather station 21- sensor reading display panel

Thermoelectric system

It is an electrothermal system that converts the (12V) Direct current taken from the engine alternator into thermal energy through three stages of double (TEC) plates to either heat or cool the fuel. Thermoelectric cooling uses the Peltier effect to create a heat flux at the junction of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other by consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC) and occasionally a thermoelectric battery. It can be used either for heating or for cooling, although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cools.as shown in Figures (2 ,3,4).

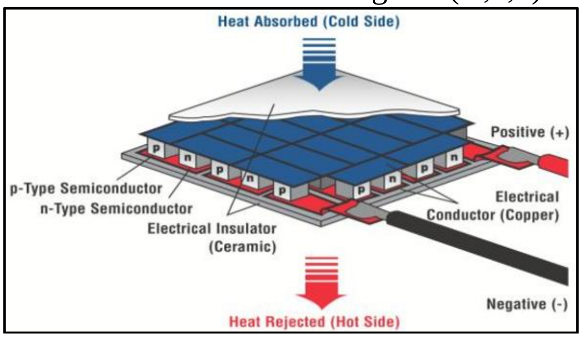

Fig 2. Cross section of thermoelectric refrigeration (TEC) components (14).

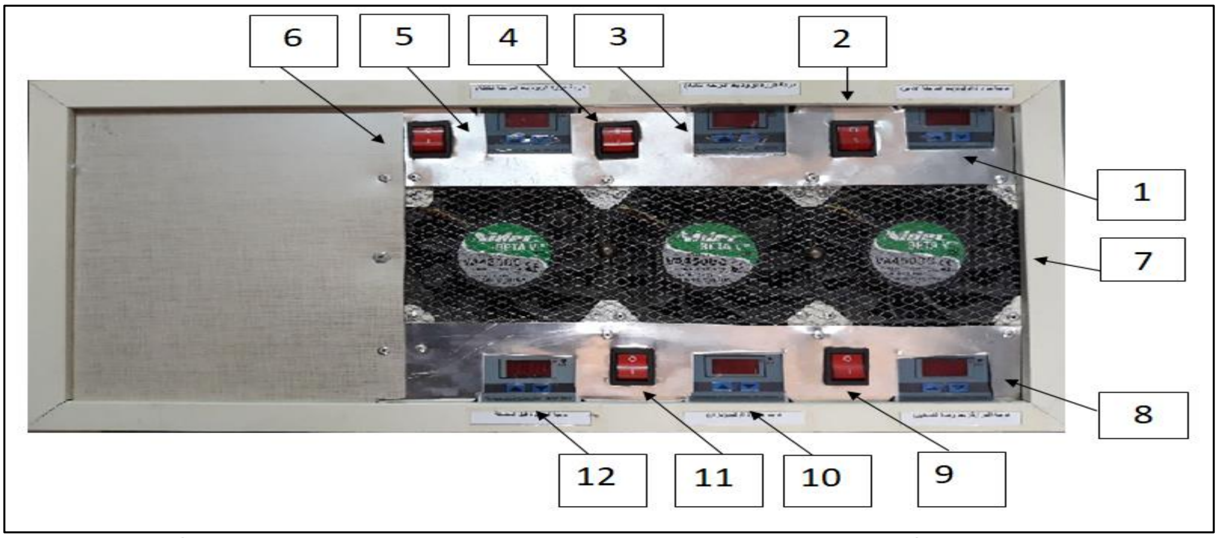

Fig 3. Pictures Of Actual prototype Model shows the thermoelectric system from the outside.
1- The temperature sensor and controller after the first stage 2- The switch for operating the first stage 3- The temperature sensor and controller after the second stage 4- The switch for operating the second stage 5- The temperature sensor and controller after the third stage 6- The switch for operating the third stage 7- Cooling fans 8 - Temperature sensor and controller after the fourth stage 9- The switch for the fourth stage operation 10- The temperature sensor in the tank 11- The switch for operating the fans 12- The temperature sensor (for fuel) before the high pressure pump

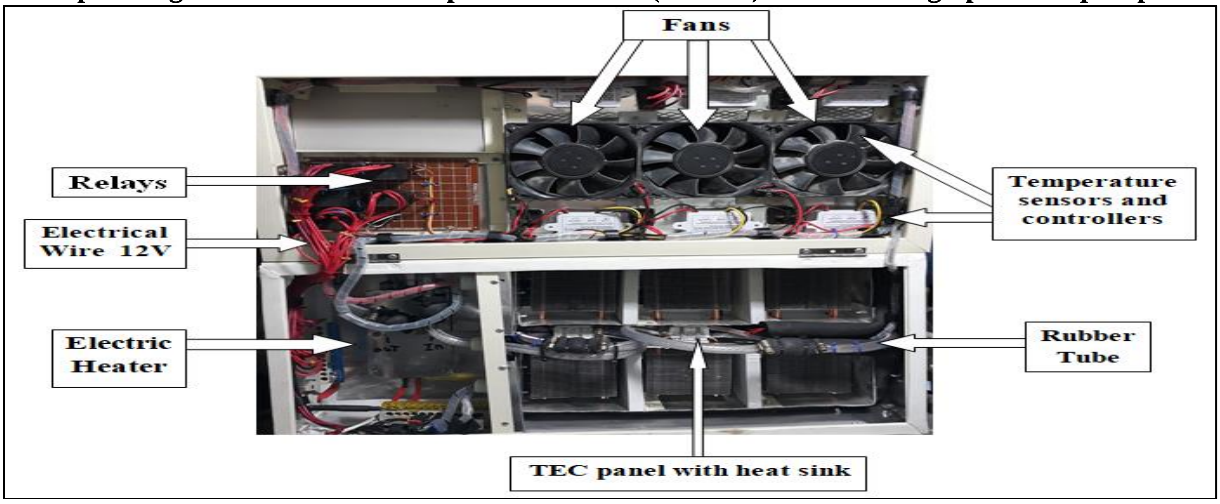

Fig 4. Pictures of Actual prototype Model shows the thermoelectric system from the inside.

TEST PROCEDURE

The ambient temperature and atmospheric pressure in the laboratory were recorded, the fuel tank was filled with diesel fuel and the engine was run for (20-25) minutes until reaching the stability of engine temperature. Initially the fuel temperature fixed on (50 °C) by thermoelectric system and engine run at (1200 rpm), and all data were taken, which includes. Fuel consumed (50ml) was calculated by using a graduated cylinder (burette) and stop watch (1,4), then measuring the Exhaust Gas Temperature (EGT) by a sensor located at the beginning of the exhaust pipe. (NOx) and (PM) emission concentration in the exhaust pipe where misheard by AirRex - HG540 and Texa gas box for exhaust opacity device. All above operations were repeated for three times and all data were taken after the engine works at full load with maintaining fuel temperature at (50℃). All above steps were repeated for (60,70℃). After that the engine maintain at (1500 rpm) and repeated all above steps for different for fuel temperature (50,60,70℃) that controlled by (TEC) device, the specific fuel consumption and thermal efficiency measured by the equation used by (10, 13).

RESULTS AND DISCUSSION

1-Effect of fuel temperature and speed on BSFC: Figure (5) illustrated the effect of fuel temperature and speed on (BSFC) when tested engine loaded at full load with two levels of engine speeds. It can be seen from the figure that fuel temperature (50°C) detected a reduction in the value of (BSFC) which reached (0.267kg/kW.hr), compared to the (BSFC) for fuel temperature of (60,70 °C) which pointed an increase in the (BSFC) by (0.275, 0.287 kg/kW.hr) respectively, the reason may be due to the variation in the density values of the fuel at selected temperature, which requires more fuel pressure to compensate for the difference in the amount of fuel injected into the engine, This results agree with results obtained by (12) while the engine speed (1500 rpm) recorded a reduction in (BSFC) than (1200 rpm) by (10.28%), the reason may be due to the increase in the amount of power produced by the engine. These results agree with results obtained by (6, 10).

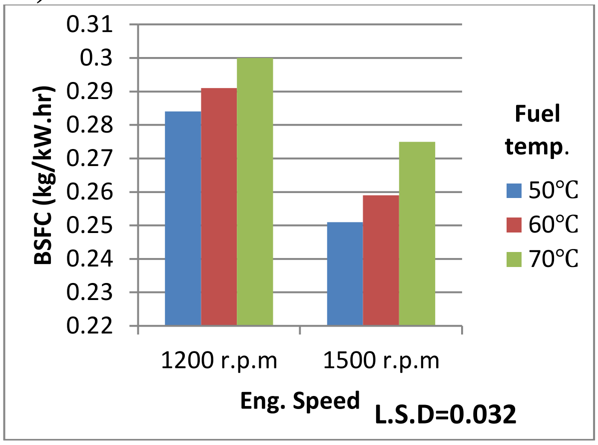

Fig 5. The Effect of Fuel Temperature Engine Speed on (BSFC)

2- Effect of fuel temperature and speed on BTE:

Fig (6) illustrates the effect of fuel temperature and speed on (BTE) of a tested engine. It can be noted from the figure that fuel temperature (50°C) showed an increase in the value of (BTE) which recorded (29.829%), then the fuel temperature (60,70°C) showed a reduction in (BTE) which reached (28.979,27.702 %) respectively. The reason may be due to the difference in engine temperature and the amount of brake power generated by the engine. These results agree with results gained by (17), and from the exact figure, it can be seen that the levels of (BTE) have been affected by engine speed; as the engine speed increase, the (BTE) increase by (10.35 %) the reason may be due to the more amount of burning fuel. These results agree with results gained by (13,16).

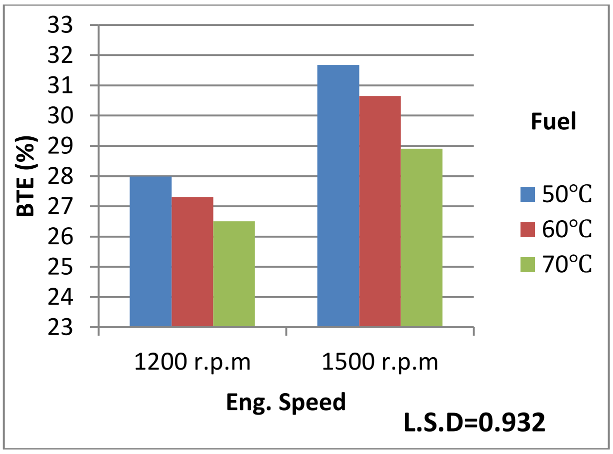

Fig 6. The Effect of Fuel Temperature And Engine Speed on (BTE)

3- Effect of fuel temperature and speed on EGT: Fig (7) illustrate the effect of fuel temperature and speed on (EGT), It can be noted from the figure that fuel temperature (50°C) recorded the lower rate of EGT and was (259.2°C).while fuel temperature (60,70°C) recorded the highest rate of EGT was (266.3,272.8°C), respectively. The reason may be due to the reduction in the value density and viscosity of diesel fuel which effects on the fuel spray angles and the remaining gases resulting from the previous power stroke, this results agree with results gained by (10) and from the same figure it can be seen that the (EGT) has been effected by engine speed ,as engine speed increase the levels of (EGT) an increase by (27.74 %) the reason may be due to the increase the numbers of power strokes. These results agree with results gained by(17).

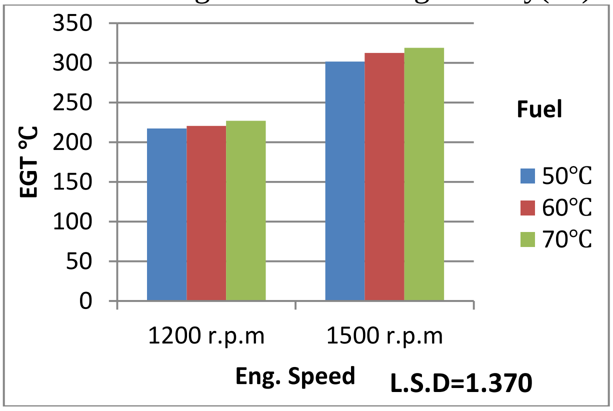

Fig 7. The Effect of Fuel Temperature and Engine Speed On (EGT)

4- Effect of Fuel Temperature and speed on NO_x Emissions: The effect of fuel temperature and speed on exhaust emitted (NO_x) can be illustrated in figure (8). It can be seen that fuel temperature at (50°C) was recorded; the lowest value of (NOx) was

(443.7 ppm).While fuel temperature (60,70°C) represented the highest value of (NO_x) emitted by the engine was (456.3,481)(ppm), respectively. The reason may be due to the high temperature in the cylinder in combustion and exhaust gases. This result is similar to the results gained by (5). From the same figure it can be seen that the levels of emitted (NO_x) have been affected by engine speed. As engine speed increase; from (1200) to (1500) rpm, the levels of (NO_x) rise by (26.35 %). The reason may be an increase of amount of fuel injected into the cylinder and the shortage in the amount of oxygen. These results agree with results gained by (15).

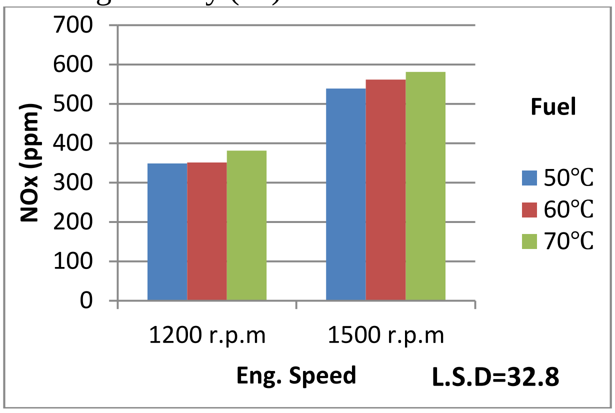

Fig 8. Effect of fuel temperature and Engine Speed on(NO_x)

5- Effect of Fuel Temperature and speed on PM Emissions

The effect of fuel temperature and speed on exhaust emitted (PM) can be illustrated in figure (9). It can be seen that fuel temperature (50°C) record the lowest value of (PM) was (0.043 ppm).While fuel temperature (60,70°C) recorded the highest value of (PM) emitted by the engine was (0.055,0.080) (ppm), respectively, and the reason of reduction in the concentration of (PM) at fuel temperature (50°C) may be due is to the good combustion of the fuel. This result is similar to the results gained by (9). From the same figure it can be seen that the levels of emitted (PM) has been effected by engine speed ,as engine speed (1500 rpm) registered an increase in the levels of (PM) by (68 %). and the reason for the increase in the concentration of (PM) is due to the low efficiency of the combustion process and the non-combustion of all the fuel injected into the cylinder. this result is similar to the results gained by (5).

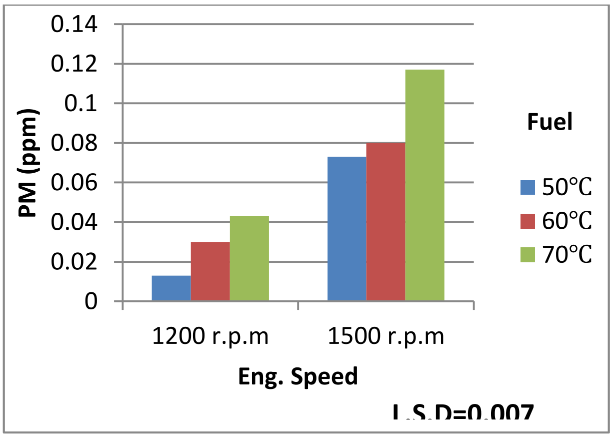

Fig 9. Effect of fuel temperature and Engine Speed on(PM)

Conclusions

1- Increasing the fuel temperature from (50°C) to (60°C) and then (70°C) increased the (BSFC)and (EGT) also emissions of exhaust gases (NO_x , PM) and reduced the (BTE) .

2- Using fuel within a temperature of (50 °C) gives the best performance indicators for the engine and the lowest emissions of exhaust gases.

3- Increasing the speed from 1200 rpm to 1500 rpm increased the BTE and EGT and the emissions of (NO_x and PM), while the (BSFC) decreased

Recommendation: The recommendations can be summarized as follows:

1- Maintaining the diesel fuel temperature within 50°C to obtain the best performance indicators for the engine and the lowest emissions of exhaust gases.

2- Conducting new tests to measure engine performance and emissions, within degrees not exceeding 50 °C.

REFERENCES

1. Al-Aani, F. S., 2024. Technical and economical parameters influencing the performance and feasibility of armatrac tractor to perform primary tillage and planting operation in silty clay loam soil. Iraqi Journal of Agricultural Sciences, 55(3):1239-1250. https://doi.org/10.36103/ea480m26

2. Al-Aani, F. S. and O. H. Sadoon, 2023. Modern GPS diagnostic technique to determine and map soil hardpan for enhancing agricultural operation management. Journal of Aridland Agriculture, v.9, :58-62. doi.org/10.25081/jaa.2023.v9.8511

3. Al-Sammarraie, M. A. J.; F.Al-Aani, and S. A. Al-Mashhadany, 2023. Determine, predict and map soil ph level by fiber optic sensor. in

iop conference series: Earth and Environmental Science, v.1225, p.012104. https://doi.org/10.1088/1755-1315/1225/1/012104
4. Alwash,A.A. and F.S. Al-Aani, 2023. Performance evaluation of seed drill- fertilizer under two different farming systems and tractor practical speeds. Iraqi Journal of Agricultural Sciences, 54(4): 1155–1162. https://doi.org/10.36103/ijas.v54i4.1809
5. Al-Shemmeri, T. T., and S. Oberweis, 2011. Correlation of the NOx emission and exhaust gas temperature for biodiesel. Applied Thermal Engineering, 31(10), 1682–1688. https://doi.org/10.1016/j.applthermaleng.2011.02.010
6. Bennett, J. 2014. Advanced fuel additives for modern internal combustion engines. Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance: Towards Zero Carbon Transportation, 165–194. DOI: 10.1533/9780857097422.1.165
7. Bilgin, A., O. Durgun, and Z. Sahin, 2002. The effects of diesel-ethanol blends on diesel engine performance. Energy Sources, 24(5), 431–440. DOI: 10.1080/00908310252889933
8. Chaichan, M. T. 2018. Performance and emission characteristics of CIE using hydrogen, biodiesel, and massive EGR. International Journal of Hydrogen Energy, 43(10), 5415–5435. DOI: 10.1016/j.ijhydene.2017.09.072
9. Chen, G. 2009. Study of fuel temperature effects on fuel injection, combustion, and emissions of direct-injection diesel engines. Journal of Engineering for Gas Turbines and Power, 131(2). DOI: 10.1115/1.3019006
10. Chyo, T., P. Kanefsky, C. Armesto, A. Shah, and D. Schoen, 2011. Cooling System And Control Strategy.
11. Dumra, N., K. Rolania, L.K. Khalaf, S.S. Yadav, S. Mandhania, Y.K. Sharma, U. Kumar, A.M. Ahmed, S.M. Popescu, and A. Choudhary 2024. Comparative evaluation of sublethal doses of different insecticides on the ovipositional behavior of whitefly (*Bemisia tabaci*) in Brinjal. Journal of King Saud University-Science, 36(2), 103070. doi.org/10.1016/j.jksus.2023.103070
12. Ganesan, V. 2012. Internal Combustion Engines (4th Edition). Tata McGraw Hill Education Private Limited.
13. Jasem, R. R., T. K. Ibrahim, I. T. Nazal, and H. S.Hamood, 2008. The Effect Of Skulduggery In Fuel Of Diesel Engines On The Performance Of Ic Engine. Tikrit Journal of Engineering Sciences, 15(3), 26–39.
14. Kibbey, T. C. G., L. Chen, L. D. Do, and D. A. Sabatini, 2014. Predicting the temperature-dependent viscosity of vegetable oil/diesel reverse microemulsion fuels. Fuel, 116, 432–437. https://doi.org/10.1016/j.fuel.2013.08.021
15. Knothe, G., C. A.Sharp, and T. W. Ryan, 2006. Exhaust Emissions of Biodiesel, Petrodiesel, Neat Methyl Esters, and Alkanes in a New Technology Engine. Energy & Fuels, 20(1), 403–408.
16. Leach, F., R. Ismail, and M. Davy, 2018. Engine-out emissions from a modern high speed diesel engine–The importance of Nozzle Tip Protrusion. Applied Energy, 226, 340–352. DOI: 10.1016/j.apenergy.2018.05.117
17. Mamat, R. 2010. Performance and emission characteristics of an automotive diesel engine using biodiesel fuel with the influence of air intake variables. University of Birmingham.
18. Raut, M. S., and P. V. Walke, 2012. Thermoelectric air cooling for cars. International Journal of Engineering Science and Technology (IJEST), 4(5), 2381–2394.
19. Sial, M. U., T. Farooq, L. K. Khalaf, S. Rahman, M. Asad, and B. A. Paray 2023. Two-step method for rapid isolation of genomic DNA and validation of R81T insecticide resistance mutation in Myzus persicae. Saudi Journal of Biological Sciences, 30(11), p.103791. doi.org/10.1016/j.sjbs.2023.103791
20. Tekeste, M. Z., L. R. Balvanz, F.S. Al-Aani, A. Boesenberg, and J. L. Hatfield. .2022. Hardened edges effects on wear characteristics of cultivator sweeps using circular soil bin test. Journal of Tribology, 144(2), 024501. https://doi.org/10.1115/1.4050805