

The Effect of Operating Factors on the Pollutants Emission from a Constant Pressure Burner

Dr. Abdul Al-Kadhim M. Hasan

Mechanical Engineering Department, University of Technology/Baghdad

Dr. Abdul Sattar Jawad M. Hasan

Mechanical Engineering Department, University of Technology/Baghdad

Riyadh Salman Radhi

Mechanical Engineering Department, University of Technology/Baghdad

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ABSTRACT

This paper presents the effect of varying operating conditions on pollutants emission (carbon monoxide [CO], unburned hydrocarbon [UHC], and Soot) from constant pressure burner. In this research a liquid fuel used are gas oil and kerosene. The operating conditions which taken in account are atomization pressure, inlet air temperature, equivalence ratio, as well as type of fuel.

It is found that the Carbon monoxide and Unburned hydrocarbon are inversely proportional to inlet air temperature with maximum decrease of (95%, 43%) respectively. In contrast, soot is directly proportional to inlet air temperature as the maximum increase in soot emission is 170%. Carbon monoxide, Unburned hydrocarbon, and Soot are inversely proportional to Atomization pressure as the maximum decrease in Carbon monoxide, Unburned hydrocarbon, and soot emissions are (56.5%, 37.4%, 76%) respectively. The relation between Carbon monoxide, Unburned hydrocarbon, and soot with equivalence ratio is directly proportional as maximum increase in Carbon monoxide, and Unburned hydrocarbon emissions are (130%, 81 %) respectively, while soot emissions is 190 %. Emissions from a constant pressure burner depend on the physical and chemical properties of fuel used, such as (viscosity, surface tension, volatility, the ratio of hydrogen atoms number to carbon atoms number (H/C), and lower heating value). it is found that the maximum increase in Carbon monoxide, Unburned hydrocarbon, soot emissions from gas oil are generally higher than those from kerosene fuel by (72%, 17.5%, 38%) respectively.

Key word: Pollution, Emissions, Continuous Combustion Chamber.

تأثير العوامل التشغيلية على انبعاث الملوثات من حارقة ثابتة الضغط

الخلاصة

البحث يظهر تغيراً لعوامل التشغيلية على انبعاث الملوثات (احادي اوكسيد الكربون, الهيدروكربونات الغير محترقة, والسخام) من حارقة ثابتة الضغط. الوقود السائل المستخدم هو

زيت الغاز و الكيروسين . العوامل التشغيلية التي اخذت بنظر الاعتبار هي ضغط التذرية , درجة حرارة الهواء الداخل الى غرفة الاحتراق, النسبة المكافئة بالاضافة الى نوع الوقود. وجد بأن احادي اوكسيد الكربون , و الهيدروكربونات الغير محترقة تتناسب عكسيا مع درجة حرارة الهواء الداخل الى غرفة الاحتراق بحيث اقصى نقصان في انبعاث احادي اوكسيد الكربون , و الهيدروكربونات الغير محترقة هي (95%, 43%) على التوالي . على العكس بالنسبة للسخام فإنه يتناسب طرديا مع درجة حرارة الهواء الداخل الى غرفة الاحتراق بحيث اقصى زيادة في انبعاث السخام هي 170%. احادي اوكسيد الكربون , الهيدروكربونات الغير محترقة , والسخام يتناسب عكسيا مع ضغط التذرية بحيث اقصى نقصان في انبعاث احادي اوكسيد الكربون , الهيدروكربونات الغير محترقة , والسخام هي (56.5%, 37.4%, 76%) على التوالي . العلاقة بين احادي اوكسيد الكربون , الهيدروكربونات الغير محترقة , والسخام مع النسبة المكافئة هي تناسب طرديا بحيث اقصى زيادة في احادي اوكسيد الكربون , و الهيدروكربونات الغير محترقة هي (130%, 81%) على التوالي, بينما اقصى زيادة في السخام هي 190%. انبعاث الملوثات من حارقه ثابتة الضغط يعتمد على الخصائص الكيميائية والفيزيائية للوقود المستخدم مثل (اللزوجة و الشد السطحي , الطيارية , نسبة عدد ذرات الهيدروجين الى عدد ذرات الكربون في الوقود (H/C), و القيمة الحرارية الصغرى للوقود). بصورة عامة وجد ان اقصى زيادة في انبعاث احادي اوكسيد الكربون , الهيدروكربونات الغير محترقة , والسخام من زيت الغاز هي اعلى من انبعاث الملوثات من وقود الكيروسين بمقدار (72%, 17.5%, 38%) على التوالي .

INTRODUCTION

Fossil fuels are the main source of energy for domestic power generation while the other energy sources, such as solar energy, wind energy and nuclear energy are still account for less than 20 percent of total energy consumption .Therefore, combustion of fossil fuels being humanity's oldest technology. That remains a key technology for today and foreseeable future. It is well known that combustion not only generates heat, which can be converted into power, but also produces pollutants, such as soot, carbon monoxide (CO), and Unburned hydrocarbon (UHC) .

The effort is now focusing on studying the key parameters that affects concentration levels of pollutant in exhaust gases. The main parameters expected to influence these emissions are atomization pressure, inlet air temperature, equivalence ratio, and fuel type. The increase in inlet air temperature improved the completeness of the chemical reaction, and then Carbon monoxide and Unburned hydrocarbon emission indices decreased [1]. In contrast, soot emissions will be increased with increasing inlet air temperature [2, 3]. Many researchers found that increasing the atomization pressure in air assisted atomizers generally decreasing the emissions. On the other hand, the increasing fuel injection pressure in fuel injecting systems results in formation of more homogenous fuel /air mixture ratios [4]. Air blast atomization increases the liquid breakup, generates more homogenous air/fuel mixture ratios and consequently lowers Carbon monoxide, Unburned hydrocarbon, and soot emissions. The concentrations of CO and UHC decrease with an increase of the Atomization air-fuel mass ratio. This is an indication that the burning process becomes more efficient as the Atomization air-fuel mass ratio increases [5].

The equivalence ratio when raised up to stoichiometric will decrease Carbon monoxide and Unburned hydrocarbon emissions, and after that increasing equivalence ratio at rich condition always results in increasing Carbon monoxide

and Unburned hydrocarbon emissions. But with respect to soot, the increase in equivalence ratio, increasing soot emissions [6]. Also it was found that the emissions from continuous combustion chambers depending on physical and chemical properties of fuel, such as viscosity, surface tension, the ratio of hydrogen atoms number to carbon atoms number (H/C), and volatility [2, 7, 8]. Soot concentration increased significantly as the flame temperature increased, the increase in soot with fuels of lower H/C ratio was much stronger than could be attributed to associated increases in the flame temperature [3].

EXPERIMENTAL WORK

Figure (1) shows schematic diagram of the rig that is completely manufactured and used in this study. The liquid fuel is stored in fuel tank and forced in fuel injection system by compressed air, which is supplied by reciprocating compressor. Compressed air is also used to atomize the liquid fuel in order to generate very small size droplets .The liquid fuel is directly sprayed into burner via the four-point air blast atomizer and measured by using liquid flow meter. The main air flow from the blower is forced through nine holes surround the atomizer as shown in Figure(2) and measured by using differential pressure method (orifice plate). Before the main air passed through atomizer hole its temperature raised by heaters and measured by a Digital thermo-meter. The size of fuel droplets in the spray can be reduced by increasing the atomization pressure of air supplied to the air blast. The amount of air used in atomization is measured by using air flow meter, and its pressure measured by Borden gauge. From knowing the amount of air and fuel which participated in combustion process may be calculated equivalence ratio as show in appendix (A). A small (10 mm base diameter) air-LPG pilot flame which is continuously sustained, and serves as an igniter source for the main fuel-air spray mixture as show in Figure (3). Carbon monoxide and unburned hydrocarbon emissions are measured by using exhaust gas analyzer as shown in Figure (4-A), while soot emission is measured by using smoke –meter as shown in Figure (4-B).

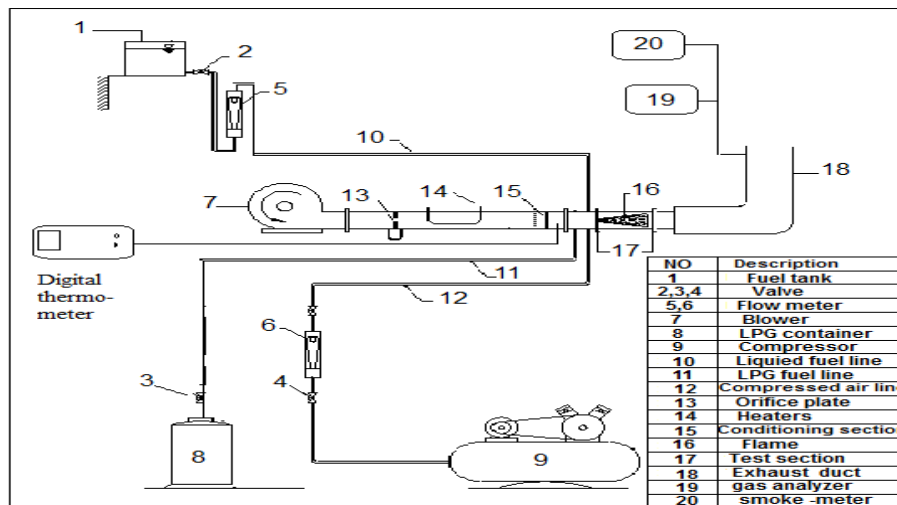


Figure (1) schematic diagram of the test rig.

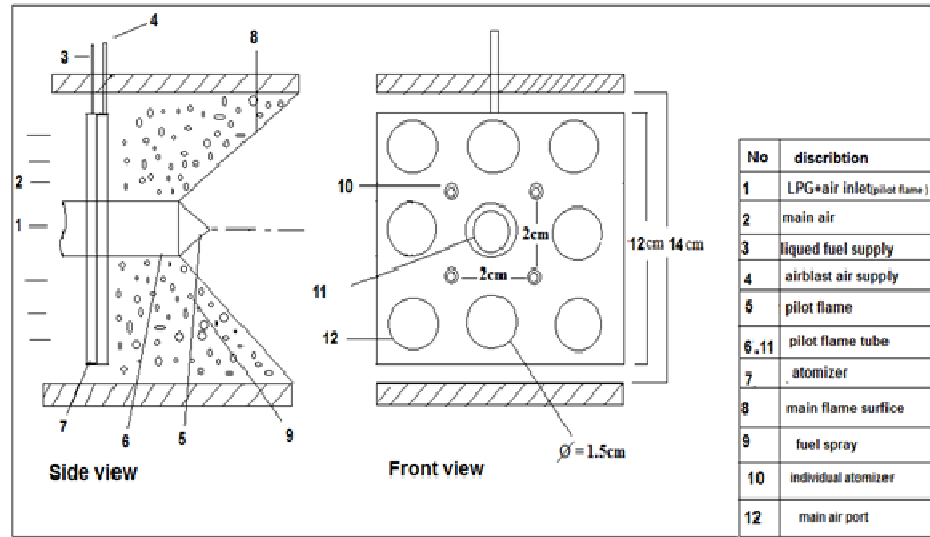


Figure (2) Schematic diagram of Flame holder.



Figure (3) test rig.

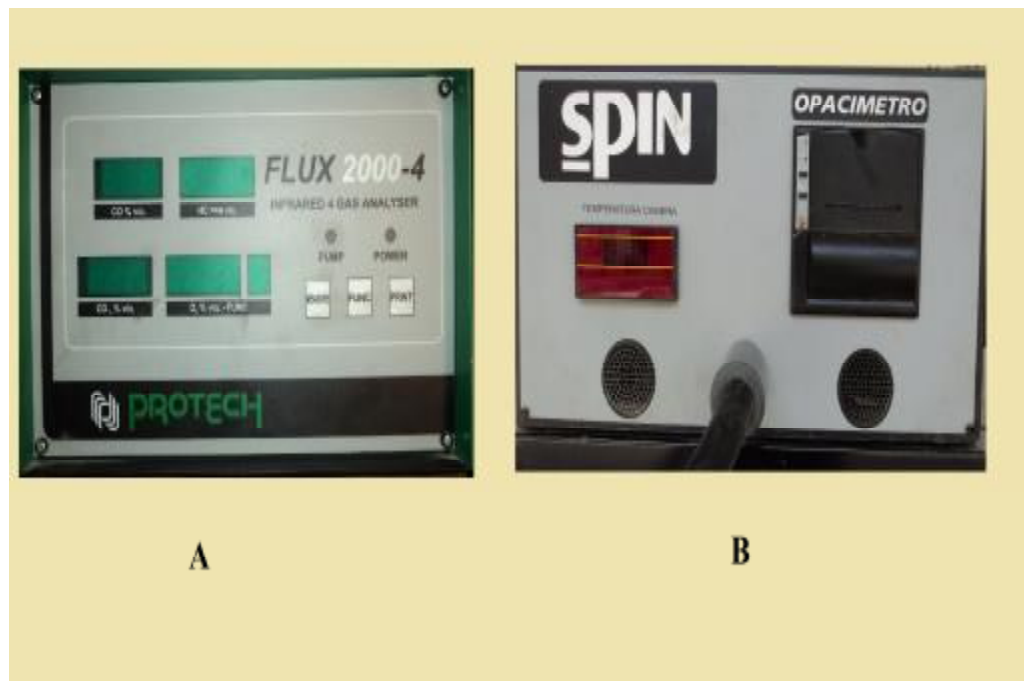


Figure (4) gas analyser and smoke meter devices.

RESULTS AND DISCUSSION

Experiments were conducted on two types of liquid fuels namely, gas oil and kerosene. The operating conditions of the constant pressure burners were investigated and graphically shown here under.

ATOMIZATION PRESSURE

As atomization pressure is increased, then the concentration of Carbon monoxide, unburned hydrocarbon, and soot emissions are decreased because when atomization pressure is low, it produces coarse spray and the evaporation is slow. Thus, a major portion of the liquid fuel will burn in droplet combustion or fuel rich pockets where the flame temperature is relatively low and insufficient oxygen surrounded the droplet to complete the oxidation of Carbon monoxide, Unburned hydrocarbon, and soot emissions, and that produce high Carbon monoxide, Unburned hydrocarbon, and soot levels. With increasing the atomization pressure, a fine atomization results in smaller droplets and good dispersion. The evaporation rate is increased with better mixing with air, and both of which are essential in the formation of homogenous mixture. The flame temperature is now higher than the flame temperature of fuel rich pockets. The higher flame temperature for this type of homogenous mixture will increase the reaction rate for the oxidation of Carbon monoxide, unburned hydrocarbon, and soot, and then decreasing Carbon monoxide, unburned hydrocarbon, and soot emissions.

Figure (2) shows that for gas oil fuel when the atomization pressure increases from 1 bar to 5 bar, the corresponding decrease in Carbon monoxide emissions by

56.5%, at $\Phi=1.01015$. But, as equivalence ratio has risen to 1.6465, the increase from 1bar to 5 bar will have the value of 29.5%. Figure (3) depicts that for gas oil fuel when atomization pressure increases from 1bar to 5 bar the corresponding decrease in Unburned hydrocarbon emissions by 37.4%, at $\Phi= 1.01015$. But, as equivalence ratio has risen to 1.6465, the increase from 1 bar to 5 bars will have the value of 19 %. While, Figure (4) illustrates that as atomization pressure has increased from 1bar to 5 bar at $\Phi=0.8$, the corresponding decrease in soot emissions was about 76% .Nevertheless , when equivalence ratio raised to 1.6965, the decrease in soot emissions will be 58% at corresponding increase from 1bar to 5 bar .

INLET AIR TEMPERATURE

It was found that increasing inlet air temperature decrease Carbon monoxide and Unburned hydrocarbon emissions, because increasing inlet air temperature accelerates the chemical reaction rates, so that combustion is initiated earlier and a large proportion of the fuel is burned in the fuel-richer region adjacent to the spray which increase flame temperature. That is suitable for the oxidation of Carbon monoxide and unburned hydrocarbon and then decreases Carbon monoxide and unburned hydrocarbon. Figure(5) shows that for gas oil fuel when inlet air temperature increases from 30 °C to 70 °C, the corresponding decrease in Carbon monoxide emissions by 95% at $\Phi=1.01015$. But, as equivalence ratio has raised to 1.6465, the increase from 30 °C to 70 °C will have the value of 22.6%. whereas, Figure (6) shows that for gas oil fuel when inlet air temperature increases from 30 °C to 70 °C, the corresponding decrease in Unburned hydrocarbon emissions by 43% ,at $\Phi=1.01015$. But, as equivalence ratio has risen to 1.6465, the increase from 30°C to 70°C will have the value of 19%. In contrast, soot emissions increases with increasing inlet air temperature because it accelerates the chemical reaction rates, so that combustion is initiated earlier in higher flame temperature with insufficient oxygen that increases soot emission. Figure (7) manifests as inlet air temperature has increased from 30°C to 70°C at $\Phi=0.8$, the corresponding rise in soot emissions by 170% .Nevertheless , when equivalence ratio raised to 1.6965, the rise in soot emissions will be 135% at corresponding increase from 30°C to 70°C.

EQUIVALENCE RATIO

As equivalence ratio is increased, then Carbon monoxide ,and Unburned hydrocarbon emissions will be increased , because the increase of equivalence ratios make the mixture very rich with insufficient oxygen for oxidation of Carbon monoxide ,and Unburned hydrocarbon emissions. Figure (8) shows that for gas oil when equivalence ratio increases from 0.8 to 1.6465, the corresponding rise in Carbon monoxide emissions by 130% at inlet air temperature 70°C. But, as inlet air temperature has decreased to 30 °C, the increase from 0.8 to 1.6465 will have the value of 63%.while, Figure (9) shows that for gas oil fuel when equivalence ratio increases from 0.8 to 1.6465, the corresponding rise in Unburned hydrocarbon emissions by 81%, at inlet air temperature 70°C. But, as inlet air temperature has decreased to 30°C, the increase from 0.8 to 1.6465 will have the value of 49%. With respect to soot, the increase in equivalence ratio, increases soot emissions also. This behavior may be attributed to the more fuel present that leads to a richer

flame with a higher flame temperature. Figure (10) depicts that as equivalence ratio has increased from 0.8 to 1.6465 at inlet air temperature 70°C, the corresponding rise in soot emissions by 148% .nevertheless .When inlet air temperature decreased to 30°C, the rise in soot emissions will be 190% at corresponding increase equivalence ratio from 0.8 to 1.6465.

FUEL TYPE

Emissions from kerosene fuel are lower than those obtained from gas oil fuel due to different fuel properties (as shown in Appendix (B)) that influence Carbon monoxide, unburned hydrocarbon, and soot production. Larger droplet size for gas oil fuel is due to the influence of higher viscosity and surface tension values compared to kerosene fuel. This situation will affect the evaporation rate, and thus results in Carbon monoxide, unburned hydrocarbon and soot emissions for kerosene fuel are lower than for gas oil fuel. Kerosene fuel is more volatile and has lower flash point value compared to gas oil fuel, hence, the droplet evaporation occurs in relatively shorter time scale due to higher dispersion rate and smaller droplet size. Then, this decreases Carbon monoxide, unburned hydrocarbon, and soot emissions. Kerosene fuel has higher lower heating value(LHV) as compared to the gas oil fuel, hence, the flame temperature is higher, and thus flame temperature for kerosene fuel is higher than gas oil fuel .therefore, Carbon monoxide ,Unburned hydrocarbon, and soot emissions for kerosene fuel are lower than those for gas oil fuel. Gas oil fuel has lower H/C ratio than kerosene fuel, thus, soot tendency in gas oil fuel is higher than Kerosene fuel because of difference in molecular structure.

Figure (11) shows that changing kerosene fuel with gas oil fuel the average increase in CO emissions was about 72 % when changing inlet air temperature from 30°C to 70°C. While, Figure (12) reveals that using gas oil fuel instead of kerosene fuel the average increase in Carbon monoxide emissions was about 16.28 % when changing atomization pressure from 1bar to 5bar. Figure (13) illustrates replacing kerosene fuel with gas oil fuel the average increase in Carbon monoxide emissions was about 18.8 % when changing equivalence ratio from 0.8 to 1.6965.

Figure (14) shows that changing kerosene fuel with gas oil fuel the average increase in unburned hydrocarbon emissions was about 17% when changing inlet air temperature from 30°C to 70°C. While, Figure (15) exhibits that using gas oil fuel instead of kerosene the average increase in unburned hydrocarbon emissions was about 23% when changing atomization pressure from 1bar to 5bar. Figure (16) shows that changing kerosene fuel with gas oil fuel the average unburned

hydrocarbon emission will increase by 17.5% when changing equivalence ratio from 0.8 to 1.6965. Figure (17) indicates that changing kerosene fuel with gas oil fuel the average increase in soot emissions was about 11% when changing inlet air temperature from 30°C to 70°C. While, Figure (18) manifests that replacing kerosene fuel with gas oil fuel the average increases in soot emissions was about 38% when changing atomization pressure from 1bar to 5bar. Figure (19) shows that using gas oil fuel instead of kerosene fuel the average increases in soot emissions will be about 10.22% when changing equivalence ratio from 0.8 to 1.6965.

CONCLUSIONS

The emissions from constant pressure burner have been studied for liquid hydrocarbon fuels. An air blast atomizer is designed and manufactured along with a complete system of ducts and auxiliaries to achieve the aim of the study.

According to the results obtained through the experiments, the following conclusions can be drawn:

1. Increasing inlet air temperature from 30°C to 70°C , the corresponding maximum decrease in Carbon monoxide and Unburned hydrocarbon emissions was by (95%, 43%) respectively. In contrast, soot emissions will increase with increasing inlet air temperature by 170%, All of them are at atomization pressure 2bar, and equivalence ratio $\Phi = 1.01015$.
2. Increasing atomization pressure from 1 bar to 5 bar, will lead to a corresponding maximum decreasing in Carbon monoxide, Unburned hydrocarbon , and soot emissions of (56.5%, 37.4%, 76%) respectively, at $\Phi = 1.01015$, and $T_{inlet} = 30^\circ\text{C}$.
3. Increasing equivalence ratio from 0.8 to 1.6465 results in maximum increase in Carbon monoxide, and Unburned hydrocarbon emissions by (130%, 81 %,) respectively, at $T_{inlet} = 70^\circ\text{C}$, and atomization pressure 2 bar, and soot emissions by 190 %, at $T_{inlet} = 30^\circ\text{C}$, and atomization pressure 2 bar.
4. The emissions from continuous combustion chambers depending on physical and chemical properties of the type of liquid fuel used. Increasing viscosity and surface tension produced more (Carbon monoxide, Unburned hydrocarbon, and soot) emissions. Also increase the volatility will decrease Carbon monoxide, Unburned hydrocarbon, and soot emissions. Decreasing H/C ratio will increase soot emissions. When changing kerosene fuel with gas oil fuel, the maximum increase in Carbon monoxide, Unburned hydrocarbon, and soot emissions are (72%, 17.5%, 38%) respectively.

REFERENCE

- [1].A L Heyes, D Jelereie and J H Whitelaw, " Experiments in a small gas-turbine combustor with gas and liquid fuels ", "Thermo fluids Section, Mechanical Engineering Department, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England, 1998.
- [2]. Zahmatkesh and M. Mohican, I. "Effect of liquid fuel droplet size on soot emission from turbulent spray flames ", Iranian Journal of Science & Technology, vol. 30, pp.339-351, No. B3, Faculty of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, I. R. of Iran, Email: Zahmatkh@shirazu.ac.ir, June 2006.
- [3].David W. Naegeli, Lee G. Dooge and Clifford A.Moses, "Effects of flame temperature and fuel combustion on soot formation in gas turbine combustor", Southwest Research Institute ,P.O, Drawer 28510, san Antonio ,Texas 78284, Combustion Science and Technology, VOL. 35, PP.117-131,1983.
- [4]. Chigier , N. W. Bachalo, R. Reitz, J. Bellan, and M. Herrmann , "Spray control for maximizing energy efficiency and reducing emission in combustion engines " , Atomization and Sprays, Volume X, pp.1-17, Number X, 2012.
- [5].Douglas L Allaire, "A Physics-Based Emissions Model for Aircraft Gas Turbine Combustors", M.Sc Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, May 26, 2006.

- [6].Edgar P. Paz , Joao A. Carvalho Jr. , Luiz R. Carrocci1, Ely V. Cortez ,and Marco A. Ferreira , " Comparative Study between Diesel Fuel and Hydrated Ethanol in Direct Burning ", Department of Energy, Sao Paulo State University, Campus of Guaratingueta, Guaratingueta, Brazil. Combustion and Propulsion Associate Laboratory, National Space Research Institute, Cachoeira Paulista, Brazil, 2009.
- [7].Chenn Zhou, Sanford Fleeter, Elias N. Houstis, and Rice, John R., "Gas Turbine Spray Dynamics and Combustion Simulation Design", Computer Science Technical Reports, Paper 1454, <http://docs.lib.purdue.edu/cstech/1454>, (1999).
- [8].Cheng Tung Chong and Simone Hochgreb "spray combustion characteristics of palm biodiesel", Faculty of Mechanical Engineering, University Technology Malaysia 81310 Skudai, Johor, Malaysia. Hopkinson Lab, Department of Engineering, University of Cambridge, Trumpington Street, CB2 1PZ Cambridge, UK, Email: ctc31@cam.ac.uk , 2011.

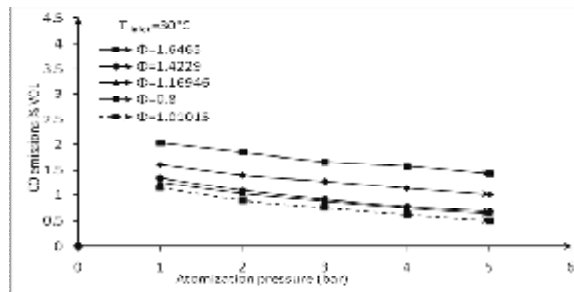


Figure (5) CO emissions from gas oil fuel Versus atomization pressure.

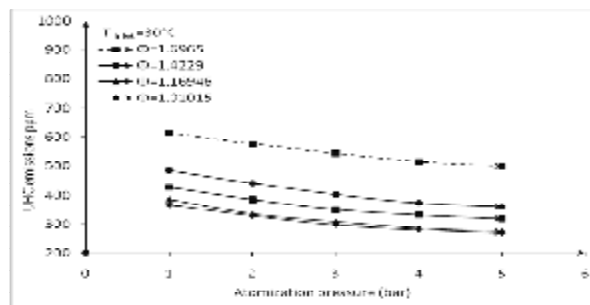


Figure (6) UHC emissions from gas oil fuel Versus atomization pressure .

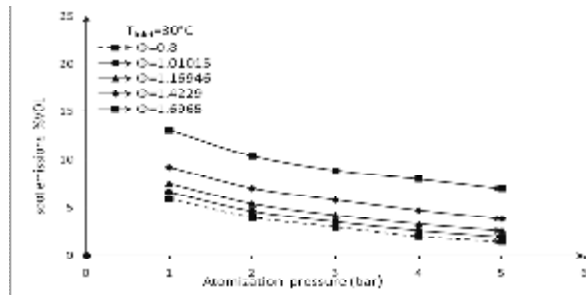


Figure (7) soot emissions from gas oil fuel Versus atomization pressure.

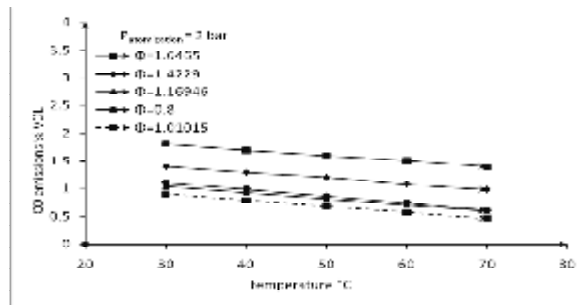


Figure (8) CO emissions from gas oil fuel Versus inlet air temperature.

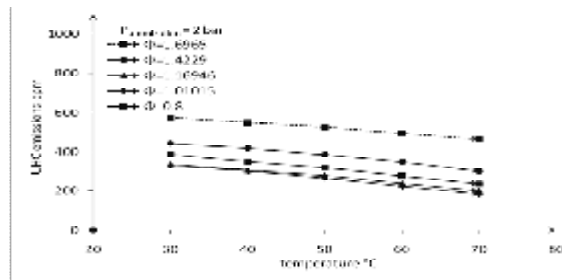


Figure (9) UHC emissions from gas oil fuel Versus inlet air temperature.

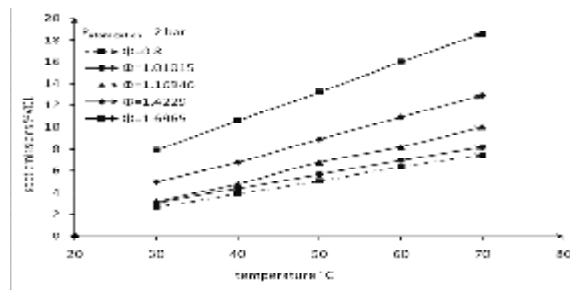


Figure (10) soot emissions from gas oil fuel Versus inlet air temperature.

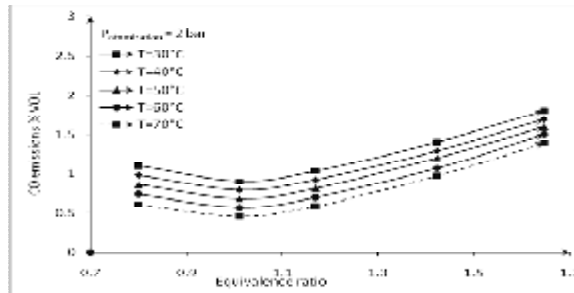


Figure (11) CO emissions from gas oil fuel Versus Equivalence Ratio.

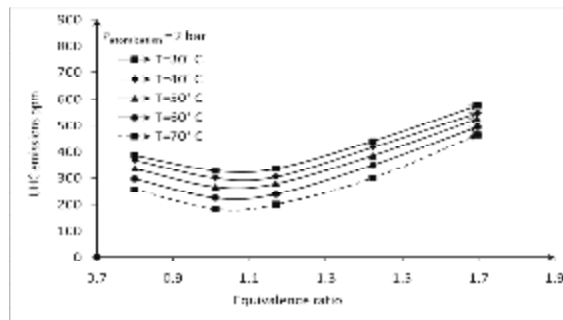


Figure (12) CO emissions from gas oil fuel Versus Equivalence Ratio.

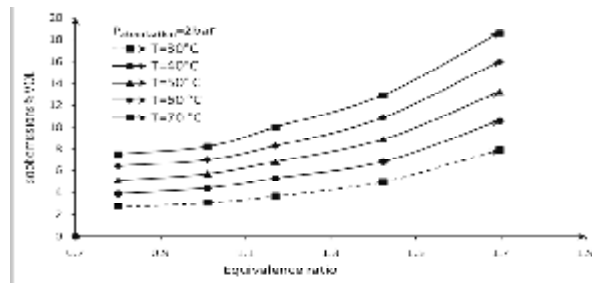


Figure (13) soot emissions from gasoil fuel Versus Equivalence Ratio.

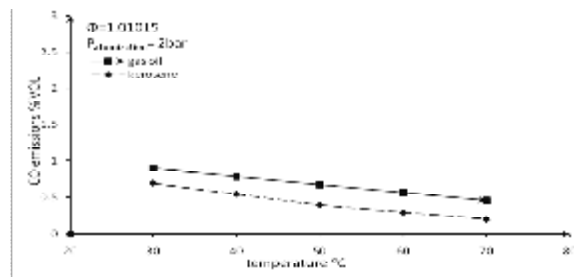


Figure (14) CO emission versus inlet Air temperature.

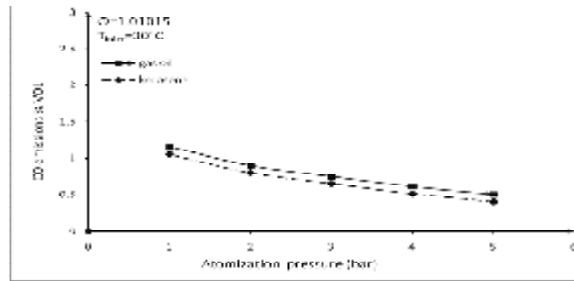


Figure (15) CO emission versus Atomization pressure.

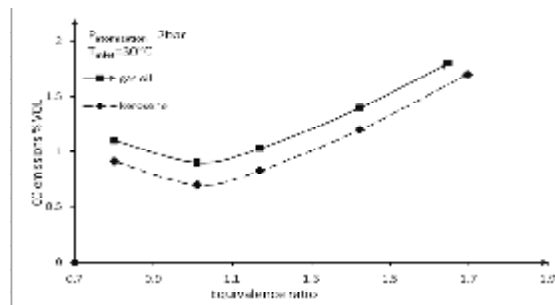


Figure (16) CO emission versus Equivalence ratio.

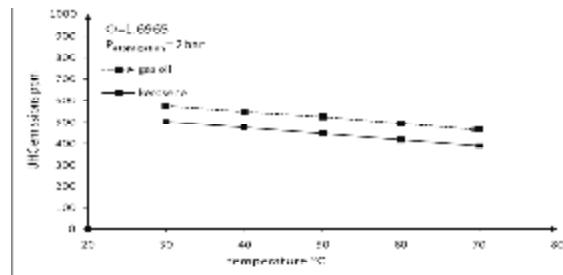


Figure (17) UHC emission versus inlet Air temperature.

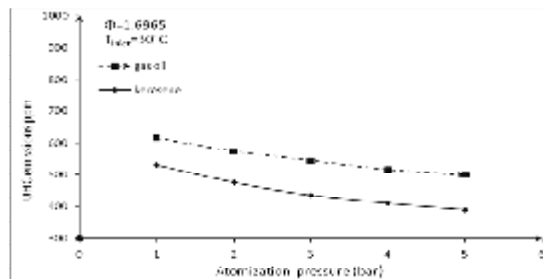


Figure (18) UHC emission versus Atomization pressure.

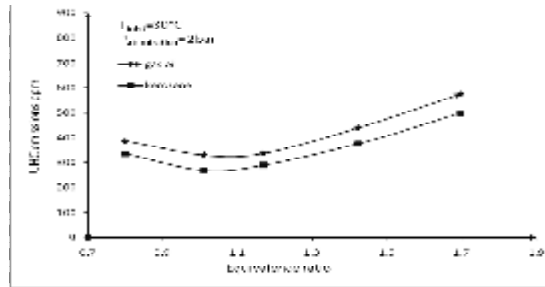


Figure (19) UHC emission versus Equivalence ratio.

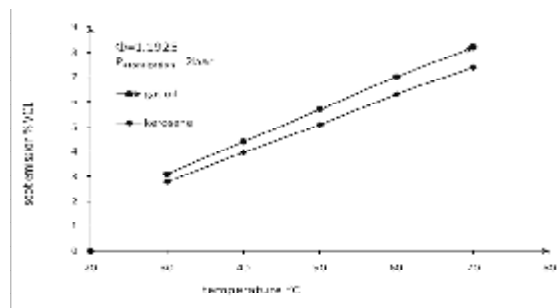


Figure (20) soot emission versus inlet Air temperature.

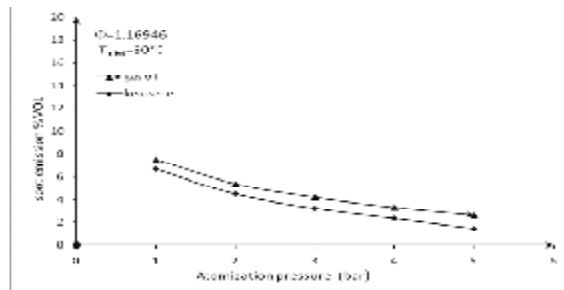


Figure (21) soot emission versus Atomization pressure.

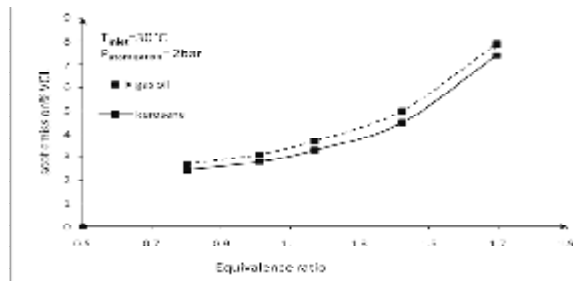
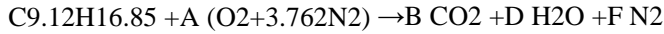


Figure (22) soot emission equivalence ratio.

APPENDIX (A)

Procedure of calculation the equivalence ratio for gas oil and kerosene fuels:

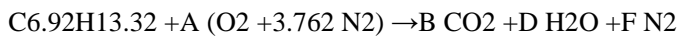
1. A- Calculation of theoretical A/F for gas oil fuel.



- Balance for carbon
Hence, B=9.12
- Balance for hydrogen
Hence, D=8.425
- Balance for oxygen
Hence, A=13.3325
- Balance for N₂
Hence, F=50.15

$$A/F)_{\text{stoich}} = \frac{13.33(32+3.762*28)}{12*9.12+16.85} = 14.4986$$

B- Calculation of theoretical A/F for kerosene fuel.



- Balance for carbon
Hence, B=6.92
- Balance for hydrogen
Hence, D =6.66
- Balance for oxygen
Hence, A =6.92+3.33=10.25
- Balance for N₂
Hence, F=38.56

$$A/F)_{\text{stoich}} = \frac{10.25(32+3.762*28)}{6.92*12+13.32*1} = 14.608$$

2. Calculation of the amount of the main air:

The amount of the main air is calculated from the following equation:

Where: K=constant = 0.021, and h=monometer reading in mmH₂O

$$\text{At } h = 0.3 \text{ mm H}_2\text{O} \rightarrow V = 0.021*(0.3)^{0.5} = 0.0115$$

Either with respect to the mass of air

$$m = \rho \times V$$

$$\text{At main air} = 0.3 \text{ mmH}_2\text{O} \rightarrow m = 1.19 \times 0.0115 = 0.013685 \text{ Kg/sec}$$

1. Calculation of air which used in atomization:

$$\text{At scale flow meter} = 1 \rightarrow m_{\text{ab}} = 1.19 \times 4 \times \frac{10^{-3}}{60} = 7.93 \times 10^{-5} \text{ Kg/sec}$$

The Table of the ratio of atomization air to the main air

Main air	Atomization air	7.93×10^{-5}	1.19×10^{-4}	1.58×10^{-4}	1.98×10^{-4}
0.013685		5.8×10^{-3}	8.695×10^{-3}	0.0116	0.0145
0.01666		4.7599×10^{-3}	7.14×10^{-3}	9.53×10^{-3}	0.0119
0.019278		4.11×10^{-3}	6.172×10^{-3}	8.24×10^{-3}	0.0103

The maximum ratio of air used in the atomization to the main air is
 Air ratio=0.0145

Hence, the air used in the atomization may be neglected

4- Calculation of the amount of gas oil fuel:

At fuel scale = 2 → $m_f = 840 \times 0.042 \times 10^{-3} \times 60^{-1} = 5.8 \times 10^{-4}$
 Kg/sec

5- Calculation the amount of kerosene fuel:

$M_f = \rho \cdot V_f$

At fuel scale = 2 → $m_f = 800 \times 0.04 \times 0.001 \times 60^{-1} = 5.333 \times 10^{-4}$ Kg/sec

6- Calculation of equivalences ratio:

$$\Phi = \frac{A/F)_{stioch}}{A/F)_{actual}}$$

A- Calculation of equivalence ratio for gas oil fuel:

For example at $m_f = 5.8 \times 10^{-4}$ kg/sec and $m_{air} = 0.013685$ kg/sec

$\Phi = 0.5675$

B- Calculation of equivalence ratio for kerosene fuel:

For example at $m_f = 5.333 \times 10^{-4}$ kg/sec and $m_{air} = 0.013685$ kg/sec

$\Phi = 0.5675$

Appendix (B)

Properties of the fuels used in this study (marketing specification of Iraqi petroleum products and Al Dora Refinery).

Fuel properties	Fuel type	
	Gas oil	Kerosene
Equivalent Chemical formula	$C_{9.12}H_{16.85}$	$C_{6.92}H_{13.32}$
Surface tension (s) kg/s ²	0.0267	0.026
H/C ratio	1.84	1.92
Specific gravity @15.4°C(max)	0.85	0.801
Flash point (abel) °C (min)	54	38
Viscosity Cst @40°C (max)	5.6	-
Calorific value Kcal/kg (gross)EST	10800	10900
Nitrogen content	-	-
Sulphur content	1%W(max)	0.2%V(max)