Experimental Study of The Effect of Fuel Spray Angle on Emissions of pollutants from a continuous Combustion Process

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Abstract: *Combustion processes are the primary sources of air pollution. Measures are taken to reduce emissions from combustion processes. This paper is an experimental study of the effect of spray angles on the emission of pollutants from a continuous combustion chamber using the liquid fuels (gas oil). The angles of spraying studied are 30°, 45°, and 60°. The pollutants CO, SOOT, and NOx are measured. The results showed that the emissions at 45° were less than that at 30° at the corner of 30°. This reduction in emitted pollutants was due to the decrease in droplet diameter associated with the increase of the spray's angle. Better atomization and mixing in this case improved and the mixture is more homogeneous. However, this caused higher temperatures leading to increased rates of emission of SOOT and NOx. The greater the angle of the spray displays, droplets diameters decreased, and the amount of evaporation increased producing higher combustion temperature*

Experimental Study of The Effect of Fuel Spray Angle on Emissions of …..

Noora Saleh Ekaab

Issue No. 41/2017

and decreased emission of CO. However, this caused an increase in SOOT and NOx emissions.

Keywords: Fossil fuels, Pollution, Emissions, Continuous combustion chamber, Angles of spraying.

Introduction

Now a day's, one of the most important problems in the world is the air pollution, especially which comes from combustion processes [1]. Optimization of this process includes improving combustion efficiency and decreasing the fuel consumption [2]. Environmental conservation and decreasing in the pollutants should be taken into consideration. Many air pollutants emitted into the atmosphere are due to fuel combustion. Liquid fuel is used extensively in boilers, furnaces, gas turbines, combustion systems, and automobiles [3]. Carbon monoxide, sulfur oxide, soot, and nitrogen oxides are the major pollutants emitted from the flames of liquid fuels. NO_X are harmful to human beings. They also cause the formation of acid rains, chemical fume fogs, destroying the ozone layer, etc. [4]. Negative effects of pollutants on the environment have made researchers look for the perfect combustion equipment [5]. Stated that hydrocarbon combustion can usually be characterized as a two-step process: first, the fuel is broken down to carbon monoxide, and then, the carbon monoxide is oxidized to carbon dioxide [6]. Soot is mainly composed of carbon (90 %), and hydrogen (10 %). Soot is formed via many steps starting with the formation of the first aromatic ring. The aromatic rings are then reacted to large polyaromatic hydrocarbons. These polyaromatic hydrocarbons then react and form soot particles [7]. The spray angle is defined as "the angle between the two tangent lines which delineate the approximate spray boundaries at half of the tip penetration from the discharge orifice" [8]. The spray combustion is a combination of premixed and non-premixed combustion. A spray flame has a wide range of fuel-air ratio and thus temperature distribution across the front. The primary physical processes involved in spray combustion are atomization, fuel vaporization

Experimental Study of The Effect of Fuel Spray Angle on Emissions of …..

Noora Saleh Ekaab

Issue No. 41/2017

[9]. The area covered by the spray in the effective images that can be employed to reflect the quality of fuel–air mixing is called the spray area [10]. The diameter of the droplet which its volume-to-surface area ratio is equal to that of the spray as stated is called the Sauter mean diameter (SMD) [11].

Abrishamchi [12] used liquid fuel to study the emission of NOX and CO produced from a cylindrical furnace of 0.24kW power. Various angles and patterns of fuel spray were studied through the experimental method. Pollutants measurement has been done for fuel spray angles of 45°, 60°, and 80° for spray pattern of a hollow and solid cone. The author found that increasing the spray angle caused a decrease in CO emission and an increase in NO_X. When the spray angle increases, the diameter of the fuel particles exhausted from the nozzle decrease, which results in increasing the contact between fuel droplets and the air molecules, and as a result, the air-fuel mixing will also increase. Better air-fuel mixing will create a homogenous mixture that increases combustion efficiency and hence, increasing combustion temperature. By so, it will increase NO_X.

DeCorso [13] studied the effect of ambient pressure on the spray drop size. The study was conducted for a swirl nozzle, and the fuel pressure differences (Δp's) of 25 and 100 psi while the studied gas pressures were 0.5, 14.5, and 114.5 psi. The tested fuel was diesel fuel; the nozzle capacity was 45 gal. /hr. at a pressure difference of 100 psi, and the nominal spray angle, 80. The authors used the photographic method in which the drop size was determined. The study focused on the spatial variation in fuel flow rate, spray-stream velocity, and drop size. The effects of large drop size and velocity variations across the spray stream were important, as well as, for the total nozzle output. An increase in the drop size was noticed as the ambient pressure goes from 14.5 to 114.5 psi. When the spray angle increased, the droplet diameter was decreased, which led to CO reduction. While the combustion temperature was increased, an increment NOx and Soot emission rates were observed.

Nejati [14] studied the emitted NO_X pollutant in a cylindrical furnace when liquid fuel was used. The study was conducted

Experimental Study of The Effect of
Fuel Spray Angle on Emissions of …..

Noora Saleh Ekaab

Issue No. 41/2017

experimentally and numerically for various angles and patterns of the fuel spray. The emitted pollutants were measured for fuel spray angles of 45°, 60°, and 80°, spray pattern of a hollow and robust cone. The study result revealed that when the spray angle increased, the diameter of exhausted fuel particles from nozzle decreased.

Khazraii [15] simulated NO_X emissions numerically in a turbulent liquid fuel spray flames using thermal and fuel models. The study investigated the influence of fuel spray angle (45°, 60°, and 80°) and the inlet air temperature on the emitted nitric oxides. They found that with increasing in spray angle, NO_X emission increased.

Nezhad [16] conducted an experimental work using a cylindrical laboratory furnace with fuel spray cone angles 30°, 45°, and 60°. Soot concentration in combustor was measured by filter paper method. The soot concentration was modeled using soot particle number density and mass density based acetylene concentration. An increase in spray enhances the evaporating rate and peak temperature near the nozzle, although peak soot concentration increased with increased spray angle. The maximum temperature of the flame was enhancing with spray angle. The maximum soot volume fraction and they found that increased soot concentration with spray cone angle increased.

This study aims to evaluate practically the effect of various injection angles of a liquid fuel on the emitted emissions resulted from a continuous combustion chamber. Three primary pollutants will be measured (CO, NO_X, and soot).

Experimental Setup

Figure (1) shows a schematic diagram of the manufactured test rig that was used in this study. The liquid fuel (gas oil) is stored in the fuel tank and forced in fuel injection system by compressed air supplied by a reciprocating compressor. Compressed air is also used to atomize the liquid fuel to generate minuscule size droplets. The liquid fuel is directly sprayed into the combustion chamber via the four-point air blast atomizer and measured by using a fluid flow meter. The main air flow from the blower is forced through nine

Experimental Study of The Effect of
Fuel Spray Angle on Emissions of …..

Noora Saleh Ekaab

Issue No. 41/2017

holes surround the atomizer and measured by using differential pressure method (orifice plate).

Table 1: The used gas oil

Fuel Properties	Gas oil
Equivalent Chemical formula	$C_{9.12}H_{16.85}$
Surface tension (σ) kg/s^2	0.0266
H/C ratio	1.83
Specific gravity15.4°C(max)	0.85
Flash point (abel) °C (min)	53
Viscosity Cst @40°C (max)	5.4
Sulphur content	1%W(max)
Calorific value Kcal/kg (gross)EST	10800

An air flow meter used to measure the amount of the atomization air while the air pressure was measured by a Borden gauge. The equivalence ratio calculated by knowing the amount of air and fuel participated in the combustion process. A small (10 mm base diameter) air-LPG pilot flame continuously sustained served as an igniter source for the main fuel-air spray mixture.

In this work, the pollutants resulting from combustion process were measured using a gas analyzer shown in (Figure 2) to measure CO and NOx levels. A smoke meter was used to measure soot emission (Figure 3). The used equivalence ratio was limited between (0.85-1.7).

The droplet size measurement system consists of a light source, lenses, and camera. The measuring of the droplet sizes (SMD) was achieved by rapid photographing of group droplets. The quick shooting was done by a quick camera type power shot from G5 Canon Digital Camera. The exposure time of the camera ranges from 15 to 1/2000 s. The size of the droplets was made

bigger by using lenses fixed to the camera. The group of the droplets was put under the light by the high-intensity light source. The two flashers work only during the short period needed to photographing. The picture was obtained, and the diameters of the droplets found in the picture were measured by comparing with the diameter of the wire that was also discovered in the same picture [11].

In this work change of spray cone angle 30°, 45° and 60°, was done by changing the nozzles' distance from the face of the burner because the nozzles are flexible and capable of movement forward or backward of the face of the burner.

1-LPG Liquid
2- Air flow meter
3- Gas fuel valve
4- Manometer
5- Blower
6- Digital thermometer
7- Orifice plate
8- Air compressor
9- Air line
10- Condition section
11- Test section
12- Exhaust duct
13- Fuel tank
14- Fuel flow valve
15- Fuel flow meter
16- Gas analyzer
17- Smoke meter

Figure (1) The Test Rig.

Figure (2) Gas Analyzer.

Figure (3) Smoke Meter Devices.

Results

Figure (4) shows the effect of spray angle on the CO emission. By increasing the spray cone zone, the mixing rate between fuel droplets and oxidant increases. The CO concentrations reduce with increasing the nozzles spray angles. The figure reveals that the minimum CO concentration is at a 60° spray angle because increasing the spray angle produces lower fuel droplet diameter. Increasing the mixing rates between fuel and air drops resulted in a homogenous mixture which increased flame temperature.
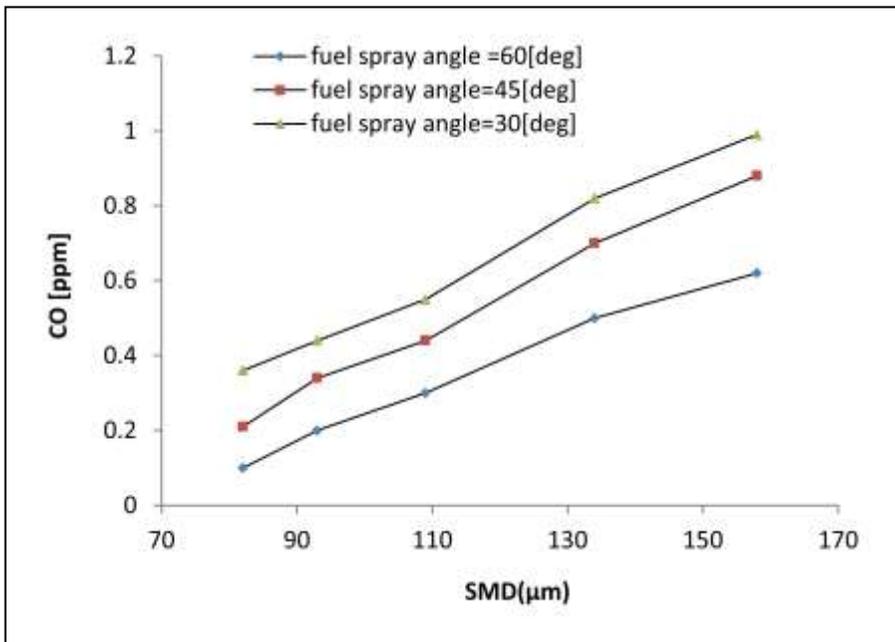
Figure (4) Effect of fuel spray angle on the CO concentration emission.

Figure (5) indicates the effect of spray angle on the SOOT emission. The increase of the spray angle increases the evaporating rate and peak temperature near the nozzle. The soot concentrations increase with increasing spray angle. The comparison between the three spray angles effect of the resulted soot clarifies that an increase in the spray cone angle increases the soot volume fraction levels near the nozzle. It can be seen that the maximum soot concentration is at spray angle of 60°.
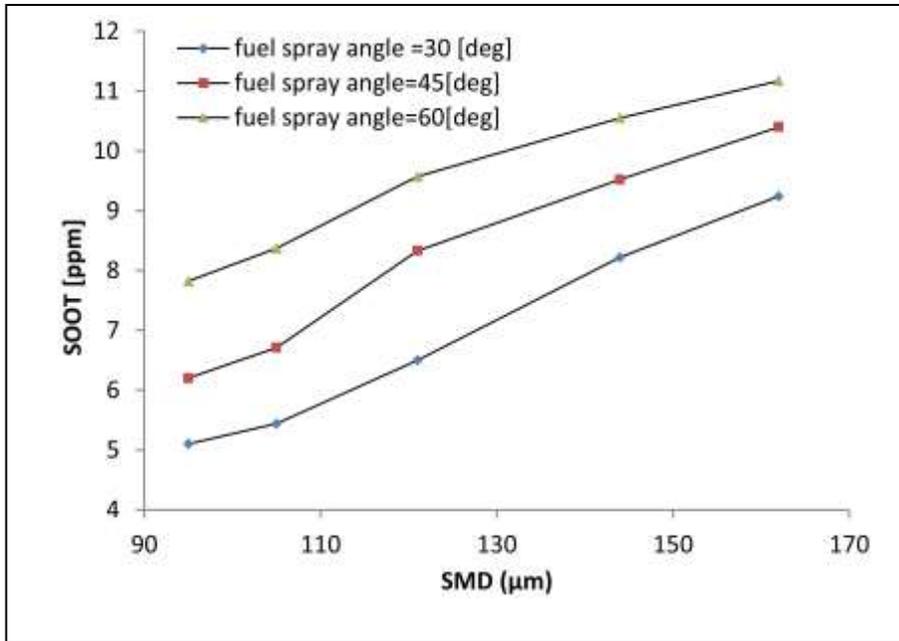
Figure (5) Effect of fuel spray angle on the soot concentration emission.

Figure (6) manifests the effect of spray angle on the NOx emission. Increasing the fuel spray angle caused an increase in emitted NOx. NOx profile strongly depends on the flame temperature. By increasing angle of spraying, the fuel particles diameter in the output nozzle becomes smaller resulting in increases the contact surface between fuel and air and also the better mixture between them. Thus increasing the spray angle means a complete combustion with higher maximum flame temperature. Three spraying angles comparison showed with increasing the angle of spraying, NOx concentration is increased near the fuel nozzle.
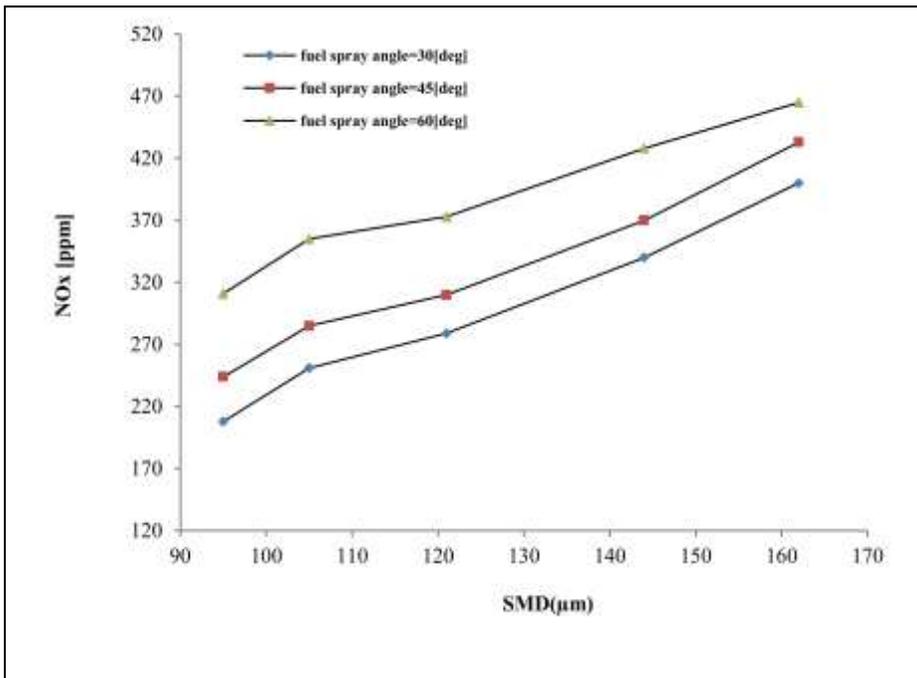
Figure (6) Effect of fuel spray angle on the NOx concentration emission.

Conclusions

In this paper, the production and emission of CO, soot and NOx pollutants in air-blast burners liquid fuel (gas oil) for various angles (30°, 45°, and 60°) and patterns of fuel spray was studied experimentally. The results showed that increasing in spray angles decreases CO and increases in NOx emission and Soot. It can be concluded that when the spray angle increases, the diameter of droplet size decreases, which as a result increases the contact between fuel and air and also, the air-fuel mixing increases. Increases in spray angle enhance the evaporating rate and peak temperature near the nozzle. Increasing the fuel spray angle by intervals of (30°, 45°, and 60°), decreased the emitted CO, but increased soot and NOx concentrations, as the flame temperature increased.

Experimental Study of The Effect of
Fuel Spray Angle on Emissions of …..

Noora Saleh Ekaab

Issue No. 41/2017

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Experimental Study of The Effect of
Fuel Spray Angle on Emissions of …..

Noora Saleh Ekaab

Issue No. 41/2017

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دراسة عملية لتأثير زوايا رش الوقود على انبعاث الملوثات من عملية الاحتراق المستمر

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المستخلص

عملية الاحتراق هي المصدر الرئيسي لملوثات الهواء. تؤخذ القياسات لتقليل الانبعاثات من عملية الاحتراق. في هذا البحث دراسة عملية لتأثير زوايا الرش على انبعاث الملوثات من غرفة الاحتراق المستمر باستخدام الوقود السائل (الكاز). تمت دراسة زوايا الرش 30، 45، 60 درجة. وكانت الانبعاثات المقاسة (CO, Soot, NOx). بينت النتائج المعروضة ان الملوثات المنبعثة عند زاوية 45° كانت اقل من تلك الناتجة عند زاوية 30° أذ ان زيادة زاوية الرش يقلل من قطر القطيرة، وتتحسن التذرية والخلط في هذة الحالة ويصبح الخليط اكثر تجانسا . كما ان هذة الحالة تسبب ازدياد درجات حرارة الاحتراق مما يؤدي الى زيادة معدلات انبعاث الدخان وNOx. أظهرت الدراسة ان كلما زاد عرض زاوية الرش يقل قطر القطيرة وتزداد كمية التبخر مما يؤدي الى ارتفاع درجة حرارة الاحتراق وتقليل انبعاث CO وكذلك تسبب زيادة NOx و Soot.

الكلمات الرئيسية: الوقود الاحفوري، انبعاث، الملوثات، غرفة الاحتراق المستمر، زوايا الرش.