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Experimental investigation of the geometry effects of furnace on the pollution emissions in a liquid fuel combustion

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ABSTRACT: One of the main parameters which affects the combustion behavior of a furnace (pollutant emission, temperature distribution, etc.) is the geometry of the furnace. In the current work, the pollutant emissions and combustion efficiency of two different cylindrical furnaces, having the same length-to-diameter ratio, are experimentally investigated. The experiments are performed in three different flow rates of gas oil, as the fuel of the furnaces. The TESTO-350XL gas analyzer is used for measuring the temperature and the combustion species. It is also recognized that the increase in the fuel flow rate results in an increase in the amount of NOx formation in both case but has a greater influence on the smaller furnace (furnace A). The variation of CO concentration with respect to fuel flow rate shows that there is an optimum flow rate in both furnaces which represents the minimum amount of CO emission.. The results show that the increase in the flow rate results in a decrease in the efficiency and an increase in the exhaust temperature in both furnaces.

Keywords: Furnace geometry, experimental investigation, pollutant emission, Efficiency.

INTRODUCTION

It is well known that, apart from generating heat and power, combustion produces pollutants such as oxides of nitrogen, soot and unburnt hydrocarbons (HC) [1]. Furthermore, inevitable emissions of CO2 are known to be a reason of global warming. CO which is produced in incomplete combustions due to low temperature flames or excess air, is known as a toxic gas which can easily combine with blood cells and results in death [2]. These emissions will be reduced by improving the efficiency of the combustion process, thereby increasing fuel economy. Hence in the last two decades great deals of attentions are dedicated to optimize the combustion systems. Great deals of studies have been performed to recognize the mechanism of NOx formation as one of the most important pollutants. According to the Zeldovich researches, thermal mechanism is known as the principle reason of the NOx formation. In thermal mechanism, for temperatures above 1800K, the NOx concentration is related to temperature exponentially [3]. Roslyakov et al showed that there is an exponential correlation that can be used to calculate the amount of NOx emission with respect to temperature variation in active combustion zone. In 2007, Hirotatso et al investigated the temperature distribution and its effects on NOx emission by varying the way that air entered the chamber through the nozzles, the number of the nozzles and their diameters. They concluded that smaller size of nozzles yielded an increase in the inlet air velocity and improved the mixing of the air and the fuel. As a result, the high temperature zone extended to the end of the chamber. According to their results, increase in inlet nozzle diameter can increase NOx emission greatly, because of its dependence on temperature and high temperature zone. They demonstrated that the longer the products remained in the high temperature zone, the more NOx produced in the exhaust gas [4]. In another research, Hirotatso et al studied the effect of using baffles in the combustion chamber, on the maximum temperature and the pollutants emission.

Flame temperature is known as one of the most important parameters in combustion [5]. Hence the exact flame temperature analysis and high temperature prediction can be useful to decrease the NOx emission. Furthermore, well predicting the maximum temperature can help us to choose proper material for combustion chamber walls [6].

Moghiman performed an experimental and numerical investigation on the pollutants formation in cylindrical furnaces. He understood that the length of the furnace had a significant effect on pollutant emission, i.e. an increase in furnace length results in reduction in mole fractions of carbon monoxide and ash and a sharp increase in NOx concentration. Decrease in temperature due to conduction and radiation heat losses from the furnace walls in addition the vortex flow of the burned gas formed at the cold end of the furnace account for reduction of NOx in long furnaces [7].

The main goal of this research is determining the best relevance between combustion chamber dimensions and type of industrial burners to obtain more efficiency and less pollutant emission for different industries such as cement industries, power plants and etc. that need to change burners because of changes in fuels. For this purpose the temperature distribution and NOx emission have been investigated experimentally by use of an industrial burner for two kinds of combustion chamber.

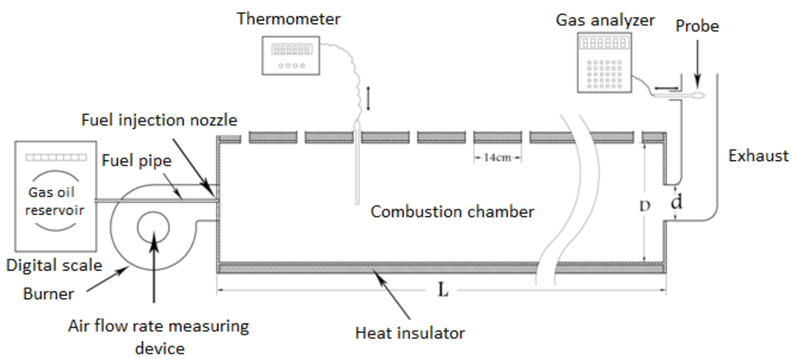
EXPERIMENTAL APPARATUS

The effects of furnace geometry and the fuel flow rates on the combustion behavior are studied experimentally in two furnaces with the same length-to-diameter ratio (L/D =5.375). The dimensions of these furnaces are tabulated in table 1. A 100000 kcal/hr burner is used in both furnaces and fed with gas oil and 57% excess air. The capacity and the injection angle of the nozzle in both furnaces are 0.85 gph and 60°, respectively.

Table 1: The geometry specifications of the furnaces

Furnace	Length (L) (mm)	Diameter (D) (mm)	Chimney length (mm)
A	1700	316	1050
B	2150	400	1050

The experimental setup is illustrated in figure 1. Some probes are devised every 14cm along the furnaces walls in order to measure the physical quantities, such as temperature. The furnaces walls are made up of ANSI 316 steel which is high-temperatures resistant and are covered by a 5cm insulator. The inlet air is controlled by a valve on the burner and the mixing is achieved by inlet air swirl. An S-type thermocouple with a ceramic cover is used to measure the temperature and is directly connected to a digital screen to show temperature in degrees of Celsius scale.



(a)

(b)

Figure 1. Experimental setup

Gas analyzing is performed by a TESTO-350XL gas analyzer which its probe has a filter that is capable for temperatures up to 700˚C. The Tests have been done for three different fuel flow rates. To confirm the accuracy of the experiments, the tests has been run several times and the average value of the results for each quantity is reported. All the measuring equipments are calibrated according to the standards. Investigations revealed that after about an hour the furnaces reach their steady state. Having great influence on the equivalence ratio, the ambient temperature is kept constant at 40°C within ±3˚C tolerance.

RESULT

The experiments are done according to the above mentioned experiment setup. The measuring devices and gas analyzer results for the small furnace (furnace A) are tabulated in Table 2.

Table 2 : Measuring devices results for furnace A

Measured quantity	Unit	Flow rate (lit/hr)		
		2.8	3.5	4.1
O2	%	7.66	7.65	7.55
CO	PPM	127	115	122
NOX	PPM	66	78	89
CO2	%	9.93	9.96	10.08
H2	PPM	62	114	153
EAIR	%	57.6	57.3	57.4
FT	oC	367	460.5	482.3
EFF	%	79.7	74.7	73.8
AT	oC	38.3	41.1	43.9

Axial distribution of temperature in furnace A is shown for three different fuel flow rates in figure 2. As seen, the temperature increases to its maximum value, approximately 60cm away from the furnace inlet, and then decreases gently. Because of similarity between this furnace and the one used by Moghiman [8], axial temperature distribution has been compared by those were obtain by Moghiman and the results are satisfactory and difference between reported maximum temperatures is 4%.

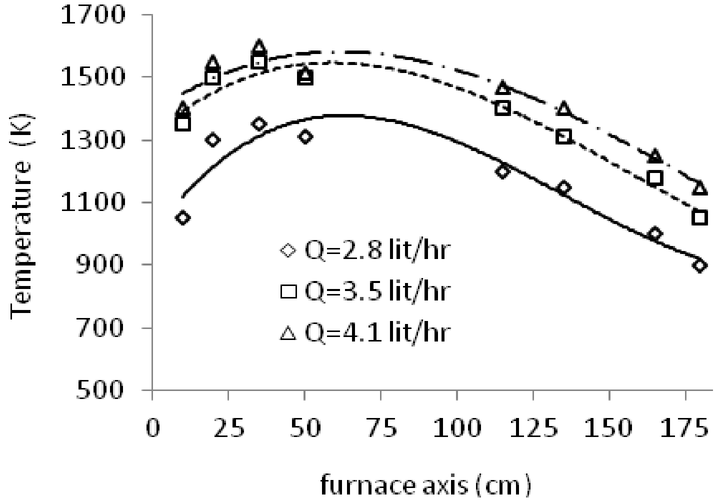


Figure 2. Axial temperature distribution of furnace (A) for three different flow rates Q1=2.8, Q2= 3.5, Q3=4.1 (lit/hr)

The concentration of NO emission for three different flow rates of fuel is compared in figure 3. Since NOx emission is related to temperature distribution, especially in high temperature zone, as expected, it is seen that NOx formation in the small furnace is more than the biggest one. According to experimental results, increase in fuel flow rate increases NO emission extremely.

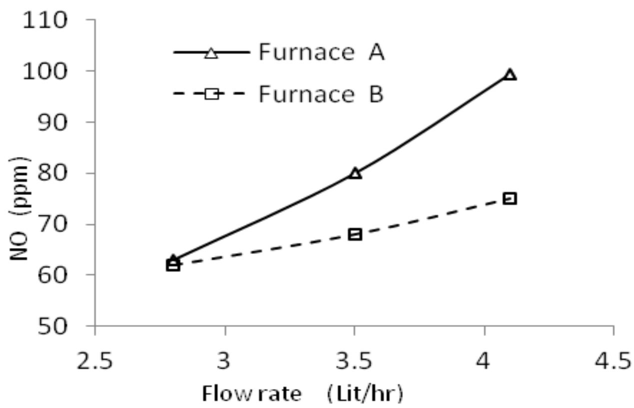


Figure 3. Comparison of NOx concentration with fuel flow rate in furnaces A and B

In figure 4, the NOx concentration at the maximum temperature is compared in two furnaces. As seen, increase in the maximum temperature yields an increase in the NOx formation. This trend is more considerable in the smaller furnace.

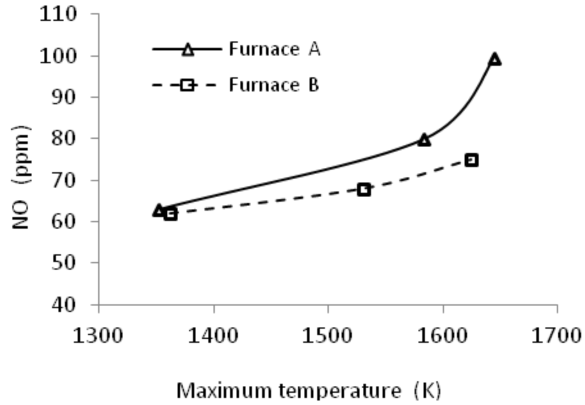


Figure4: Exhaust temperature and maximum temperature variation against NO emission

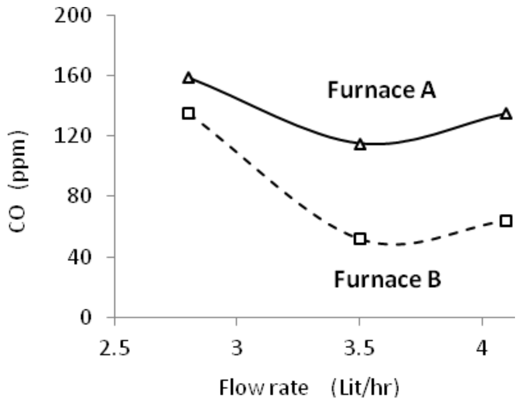


Figure 5- CO emission of three different flow rates for two kinds of furnaces

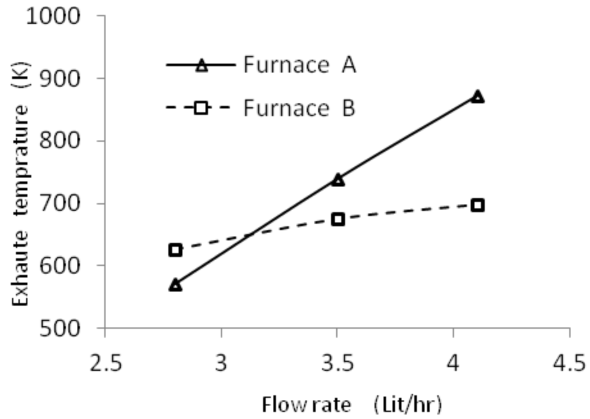


Figure 6. comparison of exhaust temperatures for three different flow rates

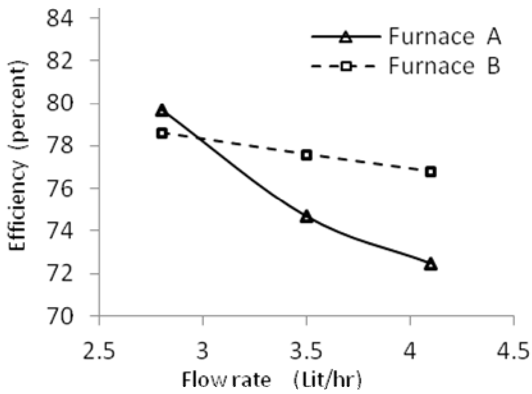


Figure 7. Efficiency of the furnaces against the flow rate

Figure 5 shows the amount of CO emission against flow rate for the two furnaces. It is seen that there is an optimum flow rate in which the amount of CO become minimized. Noticed that the CO emission depends on the exhaust gas temperature and excess air. Figure 6 illustrates the variation of the exhaust temperature with flow rates in both furnaces. Both furnaces show the same increasing trend. The effect of fuel flow rate on the efficiency of both furnaces is shown in figure 7. It is recognized that the increase in flow rate results in a decrease in the efficiency. However, the rate of reduction in the efficiency in the small furnace is more than the big one.

CONCLUSION

For constant capacity of industrial burner, reduction in furnace dimensions yields an increase in NOx and CO emissions, due to the temperature increase. Also a good design for furnace, which has been done according to industrial burner specification, can reduce CO emission extremely. Results show that the efficiency reduction for small furnace (A) is greater than big furnace (B), so it is not efficient to use industrial burners with capacities higher than the furnace capacity.

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