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Experimental Investigation of Combustion Chamber Dimensions Effects on Pollutant Emission and Combustion Efficiency

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***Abstract*—**The combustion chamber dimensions have important effects on pollutant emission in furnaces as a direct result of temperature distribution and maximum temperature value. In this paper the pollutant emission and the temperature distribution in two cylindrical furnaces with different dimensions (with similar length to diameter ratio) in similar condition have been investigated experimentally. The furnace fuel is gas oil that is used with three different flow rates. The results show that in these two cases the temperature increases to its maximum value quickly, and then decreases slowly. The results also show that increase in fuel flow rate cause to increase in NOx emission in each case, but this increase is greater in small furnace. With increase in fuel flow rate, CO emission decreases firstly, and then it increases. Combustion efficiency reduces with increase in fuel flow rate but the rate of reduction in small furnace is greater than large furnace. The results of axial temperature distribution have been compared with those have been obtained numerically and experimentally by Moghiman.

***Keywords*—**Furnace dimensions, Oxides of Nitrogen, Carbon monoxide, Efficiency.

I. INTRODUCTION

BECAUSE of increase in pollutant emission such as NOx, SOx and other greenhouse gases such as CO, through the last two decades the researches have been focused on power systems optimization to obtain high performance systems with less pollutant emission. The CO2, as one of main combustion products, was known as a harmless gas before, but new researches revealed that it is one of most important reasons of the greenhouse effect. The well-known produced pollutants of combustion are: SO_x, NO_x, CO, CO_2, unburned hydrocarbons, soot, dust and ash [1]. The carbon monoxide, as a toxic gas that is produced by burning fuels including Carbon can combine with blood cells easily and cause to death [2]. The CO can be produced by incomplete combustion; low temperature flames and combustions with exceed air.

Despite a wide range of researches about NOx minimization, it is one of most interesting fields of combustor designing. And the main goal is to design power systems with less pollutant emission. Researches show that the maximum amount of NOx emission is due to thermal mechanism (Zeldovich). In this mechanism, for temperatures that are higher than 1800 K, the amount of NOx emission has been 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 changing the way that air was entering the chamber through the nozzles, number of nozzles and their diameters for a furnace that was 420mm in length and 38mm in diameter. They showed that decrease in nozzles diameter cause to an increase in air velocity and fuel-air mixing. As a result, the high temperature zone extended and got away from end of 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 showed that there is a direct relation between number of NOx moles in exhaust gas and the duration that combustion products remain in high temperature zone [4]. In another research, Hirotatso et al installed a blade in a combustion chamber and investigated the effects of its position and type on maximum temperature value and amount of NO_x emission. The results showed that by increase in space between blade and furnace inlet, the value of maximum temperature a little increases but the area of high temperature zone decreases and as a result, NOx emission decreases.

It is obvious that the flame temperature is one of the most important parameters in combustion [5]. So the exact flame temperature analysis and high temperature prediction can be useful to decrease the NOx emission. In addition, the maximum temperature prediction can help us to choose proper material for combustion chamber walls [6].

Moghiman has investigated the production and emission of pollutant in tunnel furnaces for a cylindrical furnace, which was 4.25m in length and 0.8m in diameter, experimentally and numerically. The results show that the length of tunnel furnace has a significant effect on pollutant emission and increase in furnace length cause to reduction in mole fractions of carbon monoxide and ash. The results also show that the density of NOx increases suddenly at first, and then a little reduces. It seems that the reason of reduction in mole fractions of carbon monoxide and ash is due to this fact that increase in furnace length provide more time for these substances to burn

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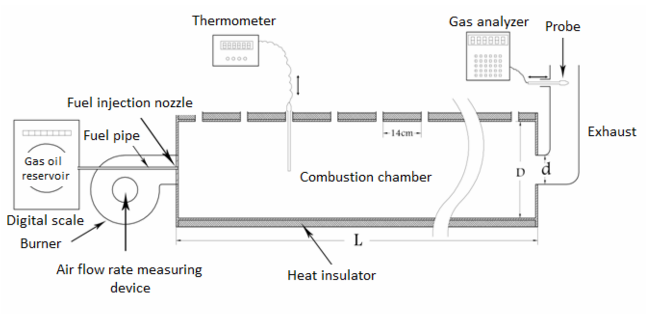
completely, and the first jump of NO_x density is due to increase in pressure losses, reduction of burned gas velocity and increase in fuel stay in combustion chamber. These parameters cause to complete combustion and increase in temperature that is an important reason for thermal NOx production. Reduction in temperature due to increase in heat transfer through the walls conduction, radiation and also inverse flows of cold gas at the end of furnace because of vortex flows of burned gas are reasons of reduction in NOx emission in long furnaces [7].

According to new researches, the consistency between industrial burner and combustion chamber is an important parameter that affects temperature distribution and pollutant emission. And since changing the fuel for each furnace is not possible without changing burner, choosing a proper burner is necessary, otherwise, not only the efficiency reduces greatly, but also the pollutant emission increases.

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 NO_x emission have been investigated experimentally by use of an industrial burner for two kinds of combustion chambers.



(a)

(b)

Fig. 1 (a) schematic of furnace (b) The test bed for small furnace

II. Furnaces Structure and Measuring Equipments

High capacity cylindrical furnaces that are used widely in industries such as cement industries have a great effect on pollutant emission. One of most important principles of experimental furnaces designing is similarity between these models and real cases and it is considered during designing the used furnace in this research. The dimensions of used furnace are mentioned in Table I. As shown in Fig. 1, for measuring quantities through the furnaces, some holes are devised. The distance between holes is 14 centimeter. In Fig. 1, the test bed and a schematic of used furnaces are illustrated. The used material for furnaces wall is steel with AISI 316 Standard that has high resistance to high temperature. To decrease heat losses, the furnace body is covered by insulator, with 5 cm thickness. The insulator is coated by incombustible stuff. The maximum capacity of burner is 100000 kcal/hr and fuel is injected by a nozzle. The specifications of burner and furnace have been mentioned in Table I. The amount of feeding air is adjustable by air valve of burner. Mixing of fuel and air is done by feeding air swirl. Temperature measuring is done by an S type thermocouple that has high resistance to high temperatures. This device has been connected to a digital screen directly and shows temperature in Celsius scale. Thermocouple has been calibrated before and it is protected by a ceramic casing. Gas analyzing is done by a gas analyzer system type TESTO 350 XL; its probe has a filter that is capable for temperatures up to 700˚C. This gas analyzer is able to measure mentioned quantities in Table II. The tests have been done for three different fuel flow rates. To reduce the errors, every test has been repeated many times and the average value of results for each quantity is reported. The amount of exceed air is considered to be fixed during the tests, because, for used value of exceed air; the CO emission is the lowest. Investigations revealed that the combustor reaches to a steady state after about one hour and after this period of time, measuring will be valid. The ambient temperature has been fixed around 40˚C, because it affects on equivalence ratio greatly. To eliminate the effect of combustion chamber walls heat flux on ambient temperature, a ventilator was used to balance ambient temperature, and the ambient temperature variation had tolerance of ±3˚C.

TABLE I
FURNACES AND INDUSTRIAL BURNER SPECIFICATIONS

Fuel	Exceed air	Nozzle injection angle	Nozzle capacity (gph)	burner capacity $\frac{kcal}{hr}$	Chimney length cm	Diameter D (cm)	Length L (cm)	Furnace type
Gas oil	57%	60	0.85	100000	105	32	170	small
Gas oil	57%	60	0.85	100000	105	40	215	large

III. RESULTS

To investigate the effects of combustion chamber dimensions on temperature distribution and pollutant production, measuring was done and the results are illustrated in Figs. 2 and 3. As mentioned, the results have been obtained for three different flow rates of fuel. As shown, the results show that increase in fuel flow rate cause to increase in furnace temperature. Temperature measuring through the central axis of chamber shows that the temperature distribution has a maximum near inlet and then reduces mildly. 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 percentage of difference between reported maximum temperatures is 4%.

TABLE II
POLLUTANT EMISSION OF THREE DIFFERENT FUEL FLOW RATES FOR SMALL FURNACE

Fragment	Unit	Q1=3.17 (l/min)	Q2=3.5 (l/min)	Q3=3.7 (l/min)
O_2	%	7.66	7.65	7.55
CO	PPM	127	115	122
NO_X	PPM	66	78	89
CO_2	%	9.93	9,96	10.08
H_2	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	0C	38.3	41.1	43.9

The amount of NO emission for three different flow rates of fuel is compared in Fig. 4. Since NO_x emission is related to Temperature distribution, especially in high temperature zone, it is obvious that NOx emission in small furnace is more and according to presented temperature distribution (Figs. 2, 3), it is justifiable. According to experimental data, increase in fuel flow rate increases NO emission extremely.

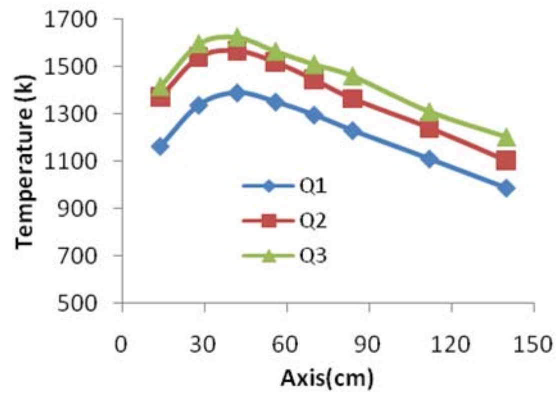


Fig. 2 Temperature distribution of small furnace for three different flow rates Q_1=3.17, Q_2= 3.5, Q_3=3.7(liter/min)

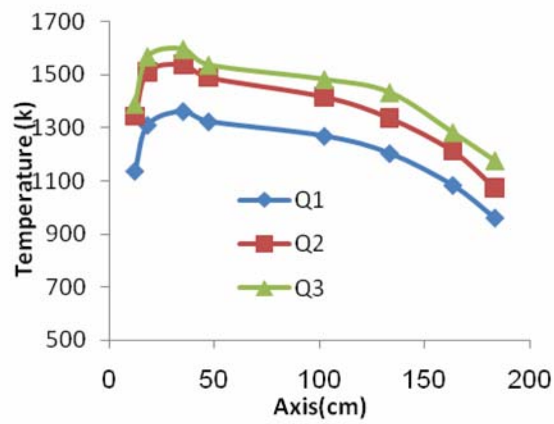


Fig. 3 Temperature distribution of small furnace for three different flow rates Q_1=3.17, Q_2= 3.5, Q_3=3.7(liter/min)

In Fig. 5, relevance of NO emission, exhaust temperature and Maximum temperature is illustrated. As shown, Maximum temperature and exhaust temperature have similar behavior and it is clear that increase in temperature lead to increase in NO emission.

Fig. 6 shows amount of CO emission for two kinds of furnaces. The curve has a negative slope up to its minimum and, when flow rate became maximum, it changes to positive values. CO emissions are dependent on exhaust gas temperature and exceed air in combustion.

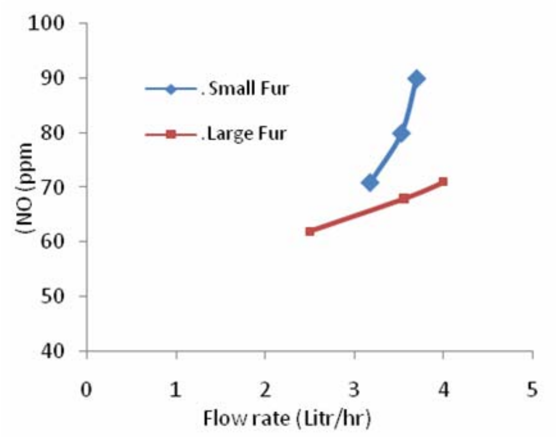


Fig. 4 NO emission against fuel flow rates for two kinds of furnaces

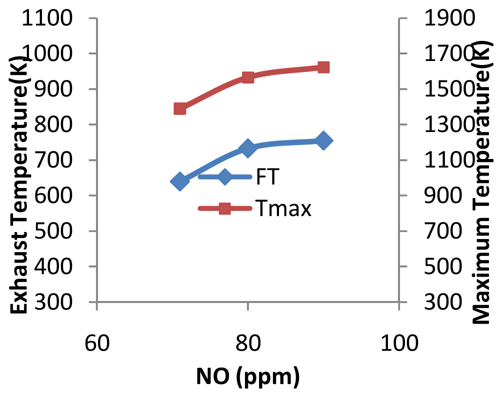


Fig. 5 Exhaust temperature and maximum temperature variation against NO emission

In Fig. 7, exhaust temperature changes against flow rate changes are illustrated. The curves for each case are straight lines but slope of small furnace curve, is higher than large one.

And finally, for each furnace, the effect of fuel flow rate on combustion efficiency is illustrated in Fig. 8. As shown increase in fuel flow rate, cause to reduction in furnace efficiency. But the rate of reduction for small furnace is more than large furnace rate of efficiency reduction.

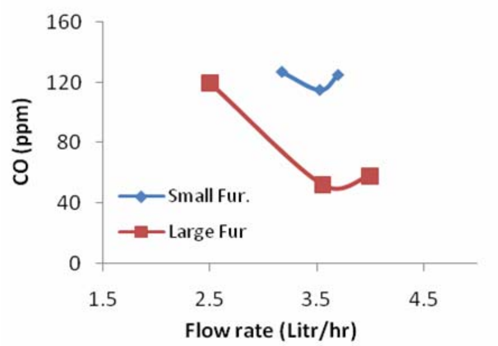


Fig. 6 CO emission of three different flow rates for two kinds of furnaces

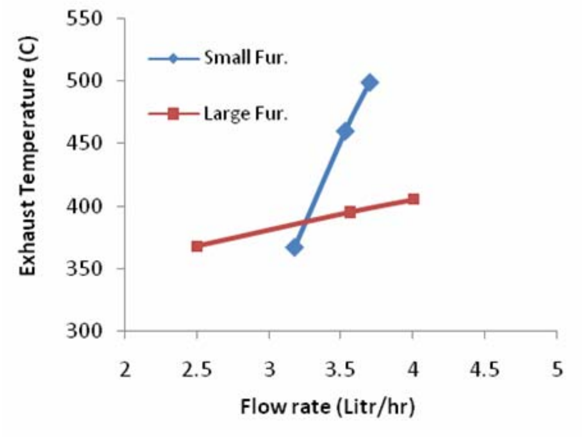


Fig. 7 Comparison of exhaust temperatures for three different flow rates

IV. RESULTS AND DISCUSSION

-For constant capacity of industrial burner, reduction in furnace dimensions, due to increase in temperature, cause to increase in NOx and CO emission.

-A good design for furnace, which has been done according to industrial burner specification, can reduce CO emission extremely.

-The efficiency reduction for small furnace is greater than large furnace, so it is not efficient to use industrial burners with capacities that are higher than furnace capacity.

REFERENCES

[1] W. Licht, "Air pollution control engineering", 2th edition, Marcell Dikkers , 1988.
[2] M. Ghiaseddin, “Air pollution, resources and effects of control”, Tehran university press, 2006 (book).
[3] P.V.Roslyakov, I.A.Zakirov,” Nonstoichiometric Burning of Natural Gas and Boiler Oil on Power Plants”, Moscow, MEI. 2001. (Book).
[4] H. Wanatabe, Y. Suwa, Y. Matsushita, Y. Morozomi, “Numerical investigation of spray combustion in jet mixing type combustor for low NOX emission”, Energy conversion and management, Vol. 49, pp. 1530-1537, 2008.
[5] H. Wanatabe , Y. Suwa, Y. Matsushita, Y. Morozom, “spray combustion simulation including soot and NO formation”, Energy conversion and management, Vol. 48, pp. 2077-2089, 2007
[6] J.Li,s.k,Chou,W.M.Yang,z.w.li, “A numerical study on premixed micro –combustion of CH4-air mixture: effect of combustion size, geometry and boundary conditions on flame temperature”, Chemical engineering journal, Vol. 150, pp. 213-222, 2009.
[7] M. Moghiman, “Production and emission of pollutants in liquid fuel fired tunnel furnace”, Journal of engineering, Ferdowsi University of Mashhad, Vol. 13, pp. 71-84, 2002.
[8] M. Moghiman, K. Bashinezhad, I. Zahmatkesh, "An investigation of soot formation and combustion in turbulent spray flame", Kuwait journal of science and engineering, pp 183-202, Vol.34, No.1, 2007.