AmirKabir University of Technology
(Tehran Polytechnic)

AmirKabir Jounrnal of Science & Research
Mechanical Engineering - ASJR-ME

Vol. 48, No. 1, Spring 2016, pp. 13-16

Experimental Investigation on Effect of Dilution and Air Stream Swirl on NO_x Emission in Premixed C_3H_8-Air Flame

M. Mahmoodi Arya[1*], A. Fahimi Rad[2], P. Bazyar[3], H. M. Heravi[4]

1- M.Sc. of Mechanical Engineering, Islamic Azad University, Mashhad Branch
2- M.Sc. of Mechanical Engineering, R&D Center, Iran Heavy Diesel Mfg. Co. (DESA), Amol
3- M.Sc. of Mechanical Engineering, FZA University of Applied Science and Technology, Amol
4- Assistant professor, Islamic Azad University, Mashhad Branch

(Received March 03, 2012, Accepted March 15, 2015)

ABSTRACT

The reaction of thermal NO is highly sensitive to temperature and if a technique can reduce the flame temperature, it would be effective to reduce NO_x formation. The dilution of the fuel and also producing swirling flows can reduce the flame temperature and as a result, decrease the rate of NO_x formation. In the present study, the effect of dilution and the swirling flow on NO_x emission in the premixed propane-air mixture is investigated experimentally. The experiments were carried out in an axially symmetric cylindrical furnace for an equivalence ratio of 0.7 to 1.3 and (0.0-1.0) dilution ratios. The swirling is achieved by a swirler with 45-degree angle corresponding to the swirl number of 0.7. The results show that by increasing the dilution ratio, the flame temperature and as the result, the NO_x emissions are decreased. The results also reveal that the swirler causes better mixing of the fuel, air and the diluents and parts of combustion products are returned to the reaction zone and since the present species have high heat capacities, they absorb the heat of combustion, which in turn decreases the temperature of the furnace and consequently decreases the NO_x emissions. The experimental results are in a good agreement with the results reported by other researchers.

KEYWORDS:

Dilution, Premixed, Equivalence ratio, Dilution ratio, Swirling number, NO_x.

[*] Corresponding Author, Email: m.mahmoodi.arya@gmail.com

1- INTRODUCTION

Combustion of fossil fuels leads to significant pollution and is probably the major contributing factor in global warming. When fossil fuels (such as natural gas and oil) and their derivative compounds burn with air, oxidation products, like CO, CO_2 and H_2O, are formed. In addition, nitrogen molecules in the air react with some oxygen molecules and form nitrogen oxides [1]. Nitrogen oxides include nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O), of which NO and NO_2 are known as NO_x [2]. Dilution, as a way of reducing NO_x is considered in many experiments since it shifts the combustion to the lean condition, (φ<1.0), and reduces the formation of nitrogen oxides [3]. In this study, a diluent with a high heat capacity is added to increase the total heat capacity of the fuel-air-diluent mixture and, as a result, the mixture absorbs more heat during the combustion and reduces the temperature of the combustion chamber. This leads to the reduction of NO_x emission production which is related to the temperature decrease [4]. Also a swirler is used to enhance mixing of the fuel, air and diluents. In addition, it returns the diluents and parts of the combustion with high heat capacities to the reaction zone to decrease the temperature of the furnace and consequently the NOx emissions.

2- EXPERIMENTAL

In order to investigate the effect of fuel dilution and swirling flow on the formation of pollutants NO_x, a furnace was designed and constructed. Figure 1 shows the schematic of the designed furnace and its accessories.

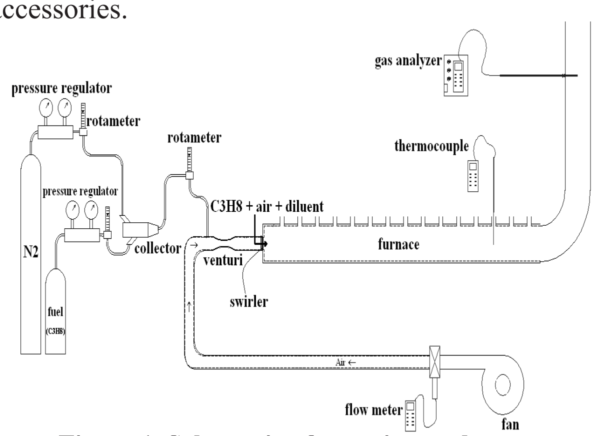

Figure 1. Schematic of experimental set up

3- RESULTS

The experimental study was conducted over a wide range of dilution and equivalence ratios (0.7<φ<1.3). The dilution ratio (β) and swirl number ($S.N$) are computed from:

$$\beta = \frac{n_{\text{Diluent}}}{n_{\text{Fuel}}} \tag{1}$$

$$S.N. = \frac{2\tan\theta}{3} \times \frac{1-\sigma_r^3}{1-\sigma_r^2} \tag{2}$$

Where $n_{Diluent}$ and n_{Fuel} are the number of diluent moles and fuel moles and $S.N.$ = 0.7.

The effect of dilution and swirling on the temperature and NO_x formation are represented in the Figures 1 and 2:

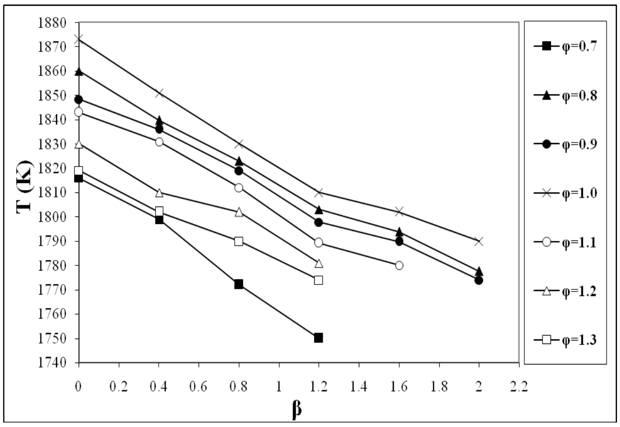

Figure 2. Effect of dilution on temperature

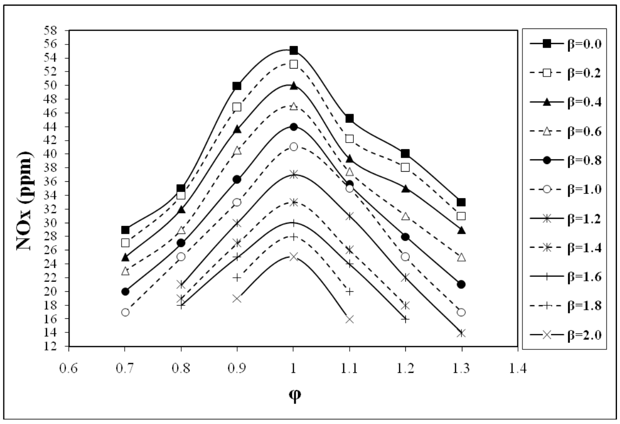

Figure 3. Effect of dilution on NO_x

As it can be seen from the figures by adding the diluent to combustion chamber, the temperature of the combustion chamber was decreased. Also it was observed that at equivalence ratio of nearly 1.0, the temperature of combustion chamber was higher than the others, this is because of the existence of required oxygen for complete combustion. Also as it can be seen from the Figure 3 the level of NO_x increases from the equivalence ratio of 0.7 up to stoichiometric, reaching a maximum value and then starts decreasing in a rich combustion (φ>1.0) zone. This is because of the temperature of the furnace, concentration of

Table 1. Extinction limits and NO_x reduction at different φ

φ	Extinction limits	NOx reduction (%)
0.7	1.1	41*
0.8	1.8	49*
0.9	-	60
1.0	-	55
1.1	-	66
1.2	1.8	53*
1.3	1.4	58*

*Extinction

oxygen in the inlet air and the short residence time due to increase of inlet velocity. In the lean zone although the mole fraction of oxygen decreases but because of increasing temperature, NO_x increases. In the lean zone with increasing the equivalence ratio, the concentrations of oxygen and nitrogen at the inlet decrease but the combustion tends to stoichiometric which is the main factor of increasing the flame temperature. In addition in the lean condition, the oxidation of nitrogen is very slow and the increase of temperature causes the emission of NO_x to increase. At near stoichiometric NO_x emission reaches its maximum because of presence of oxygen for the complete combustion. By passing the stoichiometric condition towards the rich zone because of reducing the concentrations of oxygen and nitrogen and also the temperature, the NO_x emissions decrease.

Two calibrated sensors were used for taking the samples. In the case of observing differences between the data, sampling was repeated with another sensor in order to prevent any error.

The NO_x measurements taken at three different points, at the end of furnace and exhaust pipe were nearly the same and a small difference is due to the oxidation of nitric oxide to nitrogen dioxide because of oxygen presence.

According to Table 1, because the mole fraction of fuel at lean condition is low with addition of diluents, the mole fraction of fuel in the mixture is less than required amount of fuel for the combustion and therefore the flame extinguishes. It is also observed in the rich condition because of deficiency of air for the combustion the flame extinguishes. Also the

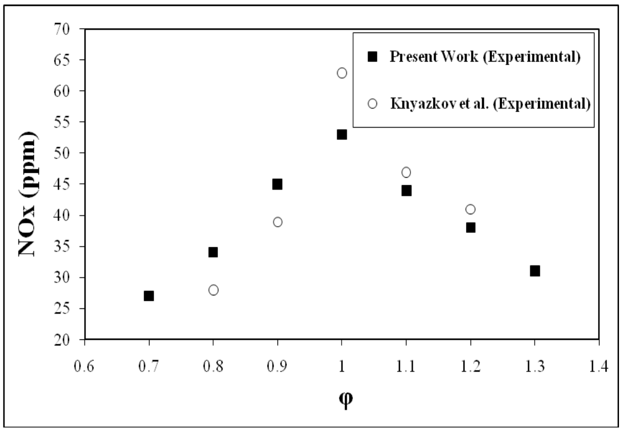

Figure 4. Comparison with the Knyazkov results [5]

maximum reduced values of NO_x with dilution at different equivalence ratios are observed.

Figure 4 shows the effect of equivalence ratio on NO_x emission and a comparison with the other researchers.

4- REFRENCES

[1] Schefer R.W., Wicksall D.M., Aggarwal K., "Combustion of Hydrogen-Enriched Methane in A Lean Premixed Swirl Stabilized Burner", Proceeding of the Combustion Institute, Vol. 29, pp. 843- 851, 2002.

[2] Hill S.C., Smoot, L.D., "Modeling of Nitrogen Oxides Formation and Destruction in Combustion System", Progress Energy combustion science, Vol. 26, No. 4, pp. 417- 458, 2000.

[3] Ghoniem A.F., Annaswamy A., Park S., and Sobhani Z. C., "Stability and Emissions Control Using Air Injection and H2 Addition in Premixed Combustion", Proceedings of the Combustion Institute, Vol. 30, pp. 1765- 1773, 2005

[4] Kim H.K., and Kim Y., "NO Reduction in 0.03-0.2 MW Oxy-Fuel Combustor Using Flue Gas Recirculation technology", Proceedings of the Combustion Institute, Vol. 31, pp. 3377- 3387, 2007.

[5] Knyazkov D.A., Shmakov A.G., Dyakov I., Korobeinichev O.P., De Ruyck J., and Konnov A.A., "Formation and Destruction of Nitric Oxide in Methane Flames Doped With NO at Atmospheric Pressure", Proceedings of the Combustion Institute, Vol. 32, pp. 327- 334, 2009.