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Thermal and Performance Analysis Flameless Combustion Process in a High Temperature Industrial Furnace Using Computational Fluid Dynamics

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Abstract

Heat treatment furnaces play an important role in refinery and petrochemical systems. The emission of a huge amount of environmental pollutants such as nitrogen oxides (NOx) and carbon dioxide (CO_2), along with the cost of repairs and periodic overhauls have given more attention to the optimization of the furnaces. Flameless combustion as a newly emerging process, with features such as reducing emissions of pollutant gases, uniform distribution of temperature profile along with reducing thermal stresses, and noise pollution in the torch, promising to change the conventional combustion systems and move them toward emission, operational, and maintenance cost reduction. In this study, the burner made by Sholeh-Sanat Company was investigated using the computational fluid dynamics under pre-heating conditions and oxygen concentrations of 3 and 6%. The furnace performance was considered in steady flameless conditions with eddy-dissipation concept (EDC). Flameless combustion characteristics were obtained in the torch and compared to conventional combustion; moreover, the temperature peaks were eliminated, and the temperature profile became more uniform. Also, in the 6% state, the mass fraction of nitrogen oxides and carbon dioxide compounds were observed to be about 400 and 3000 times decreasing respectively. Working under 3% mode, more uniform temperature profile and less nitrogen oxides were observed.

Keywords: Flameless Combustion, Nitrogen Oxide Reduction, Computational Fluid Dynamics (CFD), Eddy Dissipation Concept (EDC)

Introduction

High temperature gradients as a result of conventional flame distribution in furnace parts reduce the mechanical structure strength and made overhauls shorter and impose economic problems to the process. Despite of common way of fuel and oxidant injection method into reaction zone with low momentum, flameless combustion occurs with very high momentum directly injection of fuel and air while having temperature upper than fuel auto ignition point in the reaction zone [1]. In order to establish flameless combustion (Figure 1) it is required to use separate jets to inject fuel and oxidant to reaction zone while oxygen concentration in oxidant stream has to be lower than 15% [2]. Lifted or hot flame regime would be possible in condition of higher oxygen level that causes flame instability, so it have to be avoided [3]. In addition, colder exhaust gas recirculation to better turbulency along with using fuels with long-ignition delay time is recommended [4].

Simulation

Model Geometry and conditions

In this study, an imaginary furnace consisted of a real burner made by SSECO, a stack and a fire-box have been analyzed. The geometry is depicted on Figure 2. Fuel and oxidant stream are injected separately. Pure methane (CH_4) are used as the fuel. In conventional mode air (21% O_2, 79% N_2) are used as oxidant. Because of steady state assumption, the simulation is done in wall temperature constant condition. At first, conventional combustion simulated then by changing conditions to flameless mode, the results were achieved. In order to study flameless combustion, the O_2 concentration is decreased to 3 and 6%. Also, the diluted air temperature set to 1300K. Boundary condition Temperatures used in conventional and flameless mode are shown in Tables 1 and Table 2; respectively. In pre-processing, step a combination of one million structural and unstructured meshes were drawn. For mesh checking step, it is better to test system in cold flow mode to reduce calculation iteration time. In this study, combustion regimes have been simulated simulated using EDC combustion model, P1 radiation model, standard k-ε turbulence model and PISO numerical calculation algorithm.

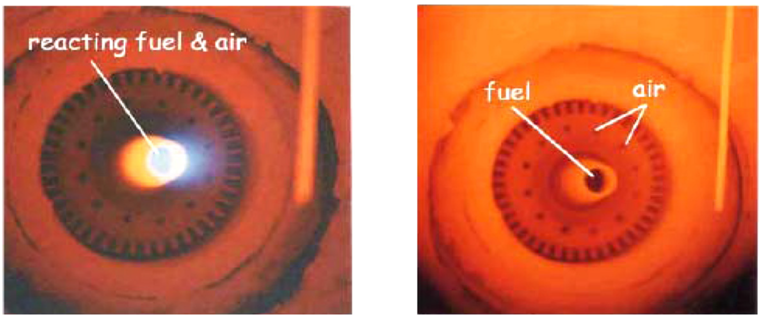

Figure 1: Flame mode (left) – flameless mode (right) [4].

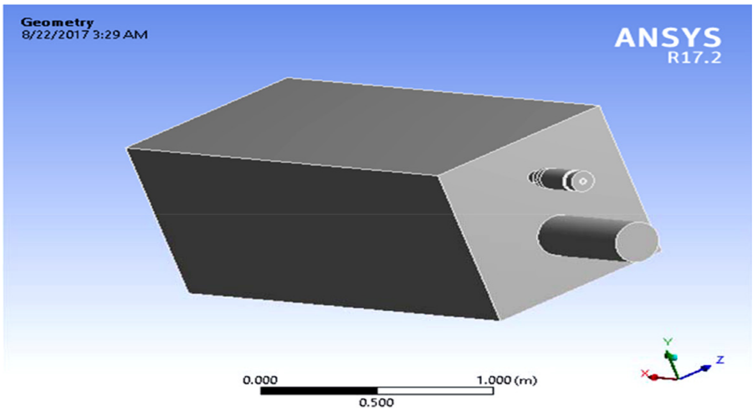

Figure 2: The model geometry.

Table 1: Boundary condition Temperatures used in conventional mode.

Boundary Condition	Temperature (K)	Boundary Condition	Temperature (K)
Right side wall	1400	Air inlet	500
End wall	1400	Fuel inlet	300
Connection wall	1400	Stack	1200
Burner wall	Adiabatic	Bottom wall	1400
Stack wall	1400	Right side wall	1400

Table 2: Boundary condition Temperatures used in flameless mode.

Boundary Condition	Temp. (K)	Boundary Condition	Temp. (K)
Right side wall	1027	Air inlet	1300
End wall	1027	Fuel inlet	300
Connection wall	1027	Stack	1027
Burner wall	Adiabatic	Bottom wall	1027
Stack wall	1027	Right side wall	1027

Discussion and Results

Temperature Gradient

As shown in Fig. 3, the temperature profile in flameless modes (3 and 6%) is very uniform, especially in 3% concentration of O_2, in comparison with conventional mode (flame). These drawn points in each mode, start from the temperature of inlet then due to combustion, the temperature is rising in all of them.

The result of this figure is calculated by a line parallel with furnace length which passes from central axis of the burner. It is significant that the temperature peaks in 3 and 6% are eliminated as a result of flameless combustion conditions. For example, due to simulated result, the temperature peak is decreased from 2350K to 2100K 1900K in 6 and 3% mode; respectively. Also Figure 3 shows the full uniform temperature distribution in burner in flameless mode in comparison with conventional combustion that is the main characteristics of this form of combustion.

Pollutants Reduction

Another important aspects of flameless combustion is decreased production of NOx and CO_2, which exerts an encouraging influence on industries to use this technology.

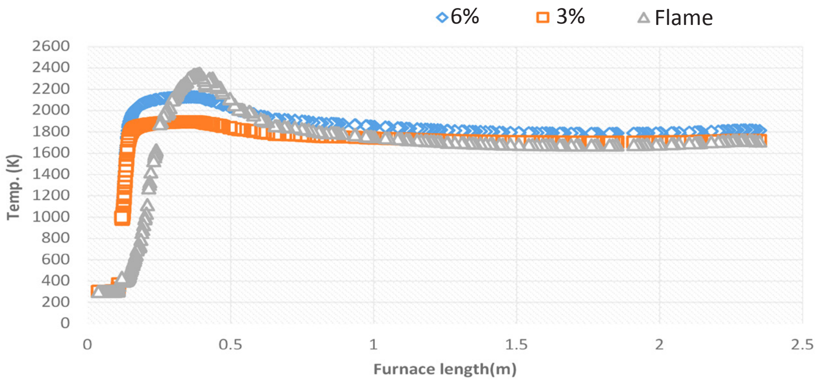

Figure 3: Temperature distribution in furnace.

Because of high differences between produced NOx in flameless and flame mode, they depicted separately, Fig.4 and Fig.5 separately.

These figures also are calculated by a line parallel with furnace length which passes from central axis of the burner to the end of fire box. Produced NOx mostly is consisted of NO, therefore, the result is illustrated by NO mass fraction. As it is obvious in Figures 4 and Figure 5, the produced NO in 6% and 3% is 400 and 3000 times lower than flame mode data, respectively.

In Figure 6, there is a comparison between produced CO_2 mass fraction in flame and flameless modes. The result did not show a noticeable difference between 3% and 6% mode; however, their average amount (0.0375) is lower than flame mode (0.115).

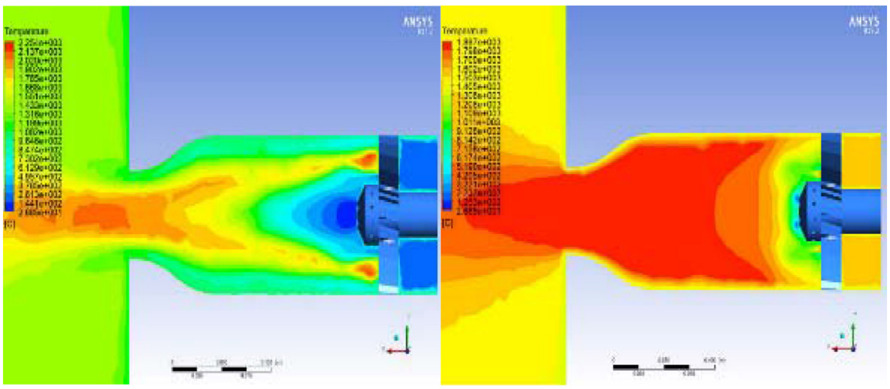

Figure 4: The burner temperature profile conventional mode (left side) and flameless mode (right side).

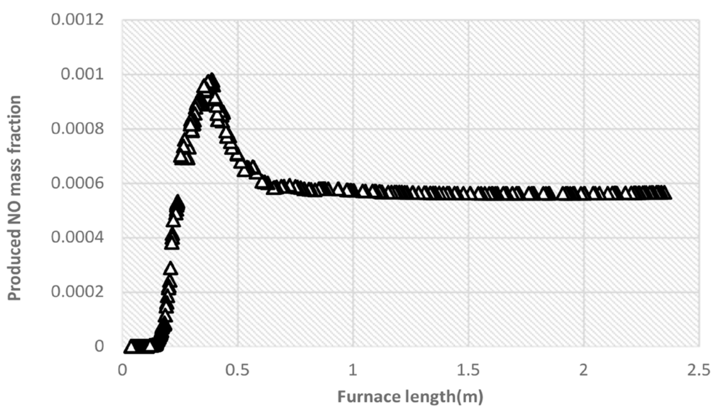

Figure 5: Produced NO mass fraction in flame mode.

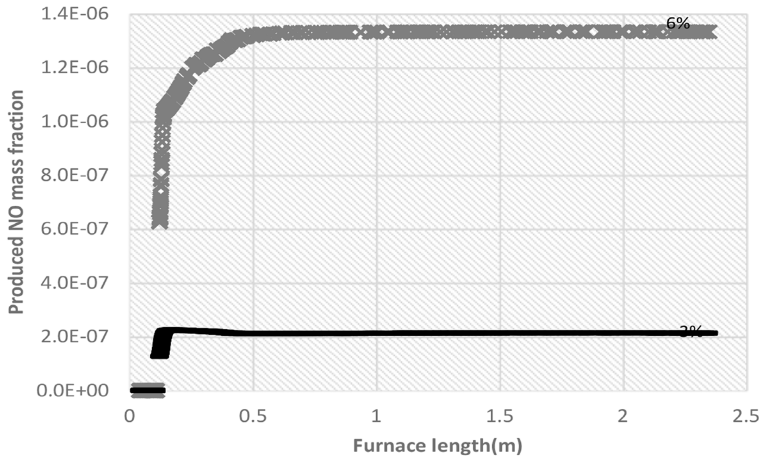

Figure 6: Produced NO mass fraction in 3% and 6% flameless modes.

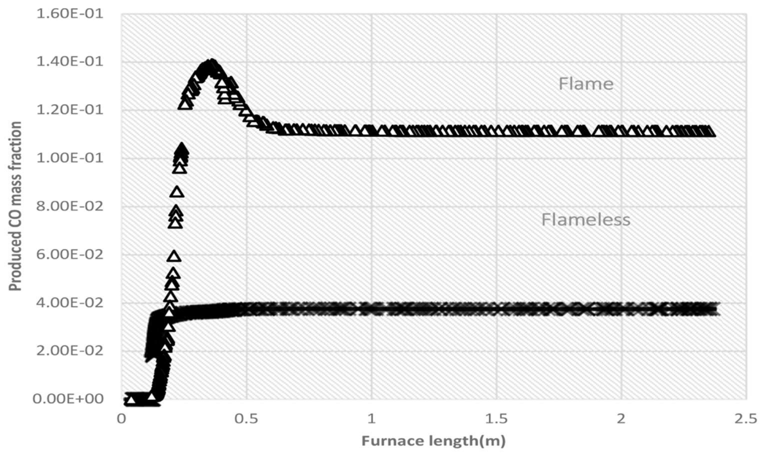

Figure 7: Produced CO mass fraction in flame and Produced CO mass fraction in flame and flameless modes

Conclusions

In this study, using a novel technology: flameless combustion, causing a decrease in temperature gradients in comparison with conventional combustion, has made temperature profile uniform. In the other word, the range of temperature changes in flame mode is decreased from 600 degree to 300 and 150 degree in 6% and 3%, respectively. The simulated result of NOx formation showed a sharp drop in produced NO in flameless modes. In 3% mode with lowest amount reached to 0.2 ppm and in 6% reached to 1.4 ppm. The CO mass fraction decreased 3 times after using flameless modes; however, the oxygen modes had no effect in result.

The results show the importance of using flameless combustion. However, the burner is well manufactured by Sholeh-Sanat Co, the furnace is not designed yet, therefore there is no real data to compare the results effectively. This study is a pre-step to estimate the conditions that should be applied in the laboratory conditions. Of course, the reduced level of pollutants in the entire furnace and the burner performance model with the applied conditions, promising a flameless mode inside the combustion chamber.

References

[1]. Bradley D., Lau A. and Lawes M., "*Flame stretch rate as a determinant of turbulent burning velocity*," DOI: 10.1098/rsta.1992.0012, Vol. 338, issue 1650, February 15, 1992.

[2]. Delacroix F., “*THE flameless oxidation mode*,” ADEME (French Agency for energy and environment management) pp. 1-18, 2005.

[3]. He Y., “*Flameless combustion of natural gas in the SJ/WJ furnace*,” Thesis for Doctor of Philosophy Queen’s University, pp. 1-172, 2008. 2008.

[4]. Wuenning J. G., “*FLOX - flameless combustion*,” in : Thermprocess Symposium, June, 2003.