Numerical Investigation of Effective Parameters in Radiant Heat Transfer of Oxyfuel Combustion Process of Swirling Gas Furnaces

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ABSTRACT

In gas furnaces based on oxyfuel combustion, radiative heat transfer is an important part of the heat flux and plays an important role in the flame temperature distribution. Different parameters affect the radiant heat transfer of furnaces. In this study, the effect of wall emissivity coefficient, oxidizer compound, and inlet flow swirl number in a Harwell gas furnace was investigated. k-ε standard, discrete ordinate and eddy dissipation model were utilized to model turbulence, radiation and combustion process, respectively. The radiative properties of the gaseous medium were determined using weighted-sum-of-gray-gases model. The results showed that with increasing the swirl number, the maximum flame temperature moves upwards and approaches the inlet. This causes the heat flux of the walls to increase and the axial heat flux to decrease. By changing the oxidizer composition, the radiant activity of the gaseous medium changes. This causes a change in the temperature distribution in the whole field and axial and the wall heat fluxes. The use of nitrogen in the oxidizer causes the maximum temperature to move towards the walls, while the use of carbon dioxide causes the flame to concentrate in the central axis, although the increase of the mass percentage of oxygen in the oxidizer improves flame diffusion. Increasing the wall emissivity coefficient causes the flame to become more concentrated and its maximum temperature to move upwards.

KEYWORDS

Combustion, Gas furnace, Oxidyfuel, radiation, Swirl number

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1- Introduction

Carbon dioxide released from the combustion of fossil fuels is a major cause of global warming. Oxyfuel combustion can be considered a promising technology for carbon capture and storage. Radiation heat transfer is a major part of heat transfer in combustion systems, also plays an important role in flame stability [1]. Computational fluid dynamics simulations have been widely used by many researchers for modeling swirl flames in the combustion chamber [2], estimating capsule heat transfer in return to the atmosphere [3], optimizing problem design parameters of blowing jets [4], suction [5] and examining the effect of the performance of variable parameters on the suction [6]. Swirl is an aerodynamic mechanism that increases flame stability and effectively enhances fuel-air mixing. In their work, Yang et al. [7] investigated the effect of flow swirl number on turbulence interaction and heat transfer in oxygen furnaces. In our study, the impact of the swirl number, the type of oxidizer, and the radiation coefficient of the walls was pursued. The main innovation of this research is the study of the effect of the radiation coefficient of walls in swirl gas furnaces, which has received less attention by researchers.

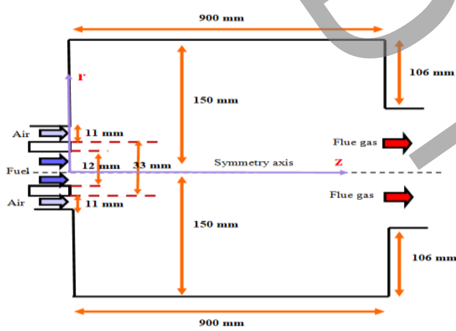

Fig. 1. Schematic of the gas furnace in this study

2- Methodology

In this research, a gas furnace has been investigated, which is called a Harrow furnace. This furnace produces swirl and turbulent flames and its fuel is natural gas. The dimensional details of which are shown in Fig.1.

2-1- Numerical method

In this research, simulation has been done in two dimensions and steady. The pressure-based algorithm was used to solve the equations and the simple algorithm was utilized to separate the pressure-velocity coupling. The standard k-ε model was employed to model the Reynolds stress. The species transfer model and eddy dissipation model were applied to transfer different species to each other and to simulate the combustion process in the furnace, respectively. The discrete orientation model was used to model the radiation heat transfer term.

2-2- Computational domain

The generated grid is a structure type with rectangular elements. Due to the choice of the standard k-ε for modeling turbulence, the first layer of the grid is considered in such a way that y+ is approximately equal to 30. Fig. 2 shows the grid and the density of cells near the inlet and outlet boundaries.

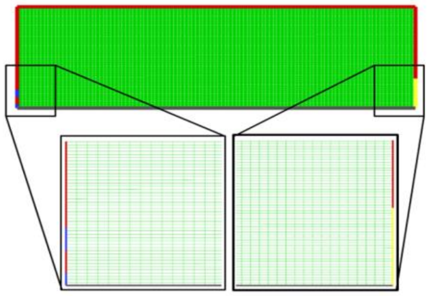

Fig. 2. Computational domain and its boundaries

2-3- Grid independence and validation

To investigate the independence of numerical solution from the grid size, three grids with 20,000, 40,000, and 80,000 elements were constructed and the results of temperature distribution in the axial direction of r=0 were examined. The results showed that the mesh with 40,000 cells was sufficient. The results of this study are shown in Fig.3. In order to validate, the simulation results were compared with experimental and numerical results of other researchers. Fig. 4 shows that the present simulation is more consistent with the experimental results.

3- Result and Discussion

To investigate the combined effect of the parameters, wall emissivity coefficients of 0.4 and 0.8 were considered and impact of two different swirl numbers of 0.4 and 0.8 on the composition of different gases were investigated. The results of this study have presented in Fig. 5. It can be seen that by placing a larger swirl number in the nitrogen oxidizer, the maximum axial temperature has increased, but in carbon oxidizers, it decreases. In each type of oxidizer, a similar trend is observed to change the radiation coefficient and the swirl number, which indicates that the general trend of the graph is determined by the type of oxidizer. With increasing emissivity coefficient, the axial temperature in all oxidizers reduced for all swirl numbers. As the swirl number increases, the maximum axial temperature occurs at closer distances from the inlet. Generally, with the simultaneous increase of the swirl number and the radiation coefficient, the high-temperature zone of the flame is closer to the inlet and the temperature value of this zone has also decreased.

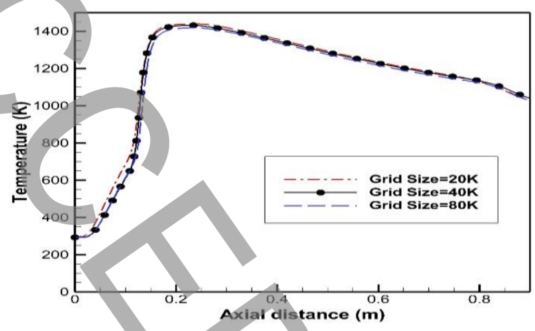

Fig. 3. The effect of grid size on the simulation

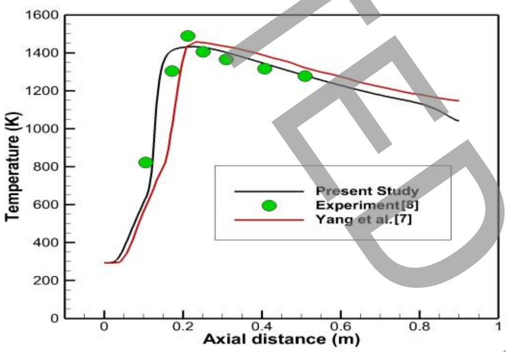

Fig 4. Simulation validation

4- Conclusions

In this study, the effective parameters of the combustion and heat transfer process of swirl gas furnaces were investigated. The results showed that with increasing the wall emissivity coefficients, the wall heat flux increases. By changing the oxidizing compound from carbon monoxide to nitrogen, the combustion gases resulting from the reaction of methane with nitrogen become more radiation active. As the mass percentage of oxygen relative to carbon dioxide in the oxygen oxidizer increases, the amount of water vapor leaving the combustion process increases and the environment becomes more suitable for radiation heat transfer, consequently, the heat flux of the walls increases. As the swirl number increases, the fluid tends to move perpendicular to the axis. This causes the maximum flame temperature to occur near the walls and the inlet. So, it reduces the axial diffusion and enhances the diffusion perpendicular to the axis.

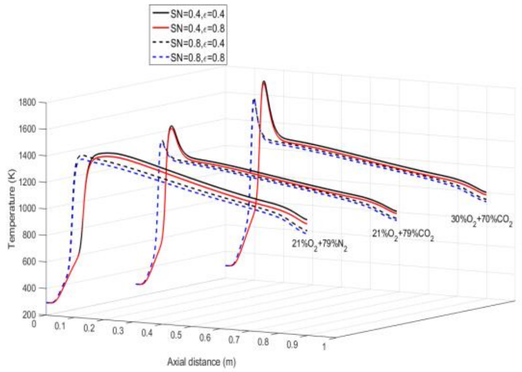

Fig. 5. Effect of combining parameters

5- References

[1] N. Gascoin, Q. Yang, K. Chetehouna, Thermal effects of CO2 on the NOx formation behavior in the CH4 diffusion combustion system, Applied Thermal Engineering, 110 (2017) 144-149.

[2] A.C. Benim, S. Iqbal, W. Meier, F. Joos, A. Wiedermann, Numerical investigation of turbulent swirling flames with validation in a gas turbine model combustor, Applied thermal engineering, 110 (2017) 202-212.

[3] V. Tahmasbi, S. Noori, Extending Inverse Heat Conduction Method to Estimate Flight Trajectory of a Reentry Capsule, AUT Journal of Mechanical Engineering, 4(4) (2020) 7-7.

[4] M. Tadjfar, S. Kasmaiee, S. Noori, Optimization of NACA 0012 Airfoil Performance in Dynamics Stall Using Continuous Suction Jet, Fluids Engineering Division Summer Meeting, (2020).

[5] M. Tadjfar, S. Kasmaiee, S. Noori, Continuous Blowing Jet Flow Control Optimization in Dynamic Stall of NACA0012 Airfoil, Fluids Engineering Division Summer Meeting, (2020).

[6] S. kasmaiee, M. Tadjfar, S. kasmaiee, Investigation of Suction Jet Parameters in Flow Control of Dynamic Stall, Journal of Applied and Computational Sciences in Mechanics, 32(2) (2021) 181-200.

[7] X. Yang, Z. He, Q. Niu, S. Dong, H. Tan, Numerical analysis of turbulence radiation interaction effect on radiative heat transfer in a swirling oxyfuel furnace, International Journal of Heat and Mass Transfer, 141 (2019) 1227-1237.

[8] N. Wilkes, P. Guilbert, C. Shepherd, S. Simcox, The application of Harwell-Flow 3D to combustion models, Atomic Energy Authority Report, Harwell, UK, Paper No. AERE-R13508, (1989).