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Numerical Study on the Enhancement of the Thermal Efficiency of a Household Gas Water Heater and Verification with Experimental Results

M. T. Shervani-Tabar*, Sh. Kashani Asl, M. Yari, S. Baheri Eslami

Department of Mechanical Engineering, University of Tabriz, Tabriz, Iran

ABSTRACT: In this research for the aim of optimizing the gas consumption, increasing the thermal efficiency of a household gas water heater has been investigated numerically. The optimal design and configuration of the baffles in the middle tube of the gas water heater prevents the quick exit of the exhaust gases and consequently increases the retention time of the hot gases inside the middle tube and reduces the wasting of their thermal energy. The combustion process in the gas water heater is a chain process and completing this process occurs along its path in the middle tube. Therefore for obtaining the maximum thermal efficiency, the numerical analysis of the combustion process and designing and configuration of the baffles inside the middle tube have been carried out and conducted simultaneously. The Ansys Fluent computational fluid dynamics code has been employed for the computational simulation of the combustion of the gas, the heat transfer from the contents of the middle tube into the water tank and distribution of the velocity of the exhaust gases along their path inside the middle tube and around the baffles. Computational simulation of the problem under investigation has been carried out by considering different geometries and configurations of the baffles along the path of the exhaust gases. Numerical results show that the mass fraction of the methane gas and the carbon dioxide in the exhaust gases is negligible and consequently all of the methane gas has been consumed. The numerical results have been verified by the experimental results.

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1- Introduction

Due to the extensive consumption of gas throughout the country, every attempt for enhancement of the thermal efficiency of the gas water heaters results in a reduction of energy consumption [1]. In small residential units under 60 square meters, due to national building, regular household gas water heater is suggested to be used [3]. Recent researches show that by using baffles in the middle tube of a household gas water heater prevents the quick exit of the exhaust gases and consequently reduces wasting of their thermal energy [2-4]. In the present research effects of different baffles with different size and geometry in the middle tube of a household, gas water heater have been investigated numerically. The numerical results have been verified by the experimental results of the problem under investigation.

2- Methodology

The computational simulation of the processes of combustion and heat transfer in the middles tube of a household gas water heater has been carried out by the method of finite volume. The conservation equations of mass, momentum and energy have been employed as the main governing equations of the numerical simulation of combustion and flow of the exhaust gases in the middle tube of the household gas water heater as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0, \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_i}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i+F_i, \tag{2}$$

$$\frac{\partial}{\partial t}(\rho E)+\frac{\partial}{\partial x_i}(u_i(\rho E+p))=\frac{\partial}{\partial x_i}(k_{eff}\frac{\partial T}{\partial x_i}+u_j(\tau_{ij})_{eff})\,. \tag{3}$$

The stress tensor is defined as

$$\tau_{ij}=\left[\mu_{eff}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]-\frac{2}{3}\mu_{eff}\frac{\partial u_l}{\partial x_l}\delta_{ij} \tag{4}$$

*Corresponding author's email: msherv@tabrizu.ac.ir

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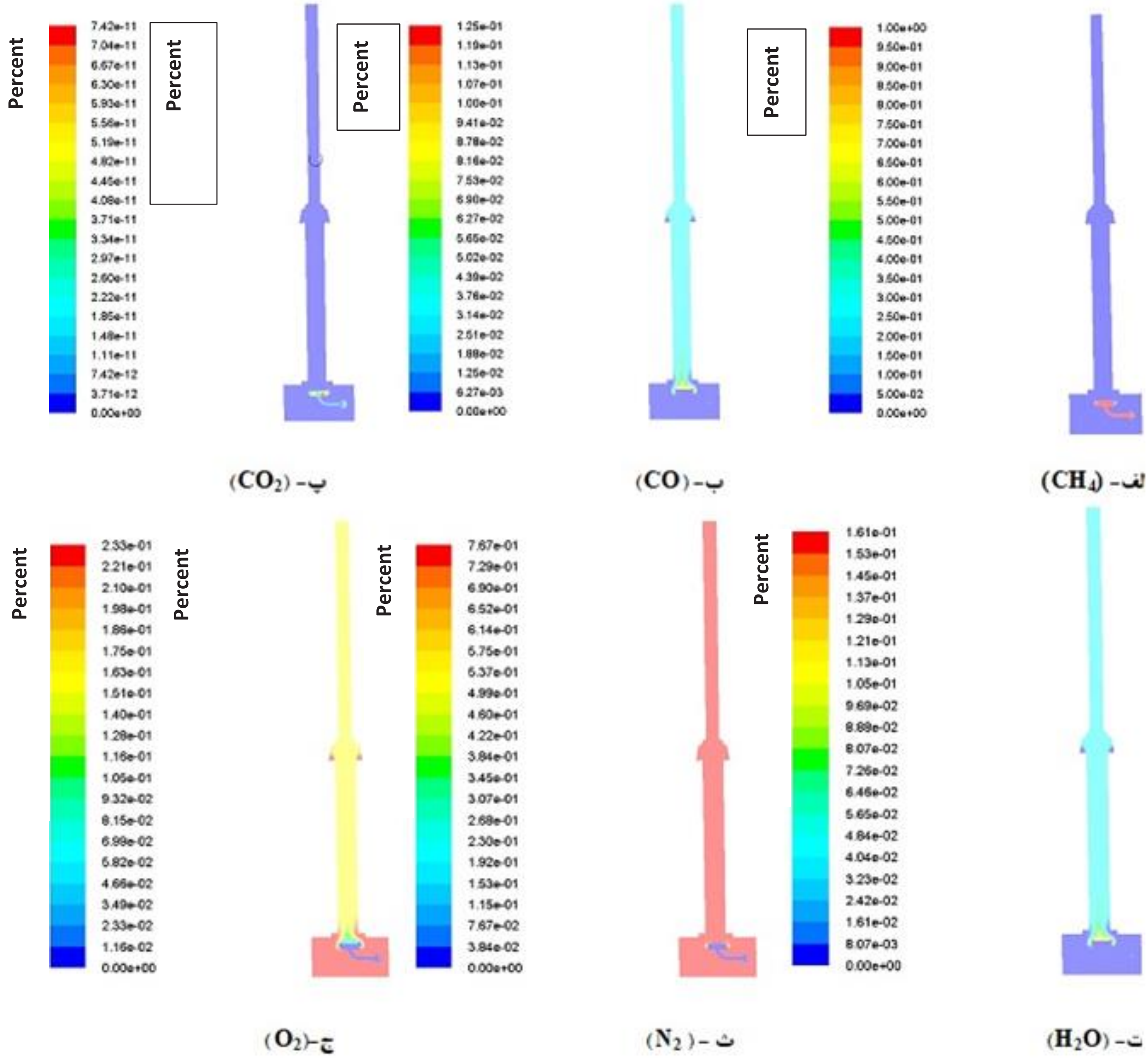

Fig. 1. Distribution of species contours of CH_4, CO, CO_2, H_2O, N_2, and O_2 (%)

The effective viscosity is the sum of the molecular and turbulent viscosity coefficients which is given as

$$\mu_{eff} = \mu + \mu_t \, . \tag{5}$$

The effective conduction coefficient is the sum of the conduction and turbulent conduction coefficients and is given as

$$K_{eff} = K + K_t = K + \frac{C_P \mu_t}{\Pr_t} \, . \tag{6}$$

It should be noted that conduction, diffusion of species, and dispersion of viscosity have been considered for balance and conservation of energy in the computational simulation of the problem. It should also be noted that combustion includes releasing of thermal energy due to the conversion of the chemical species to one another.

The model of Eddy-Dissipation has been used in computational simulation of the combustion process. In this model, the reaction rate is controlled by turbulence. Also, the k-ε turbulence model has been employed for the computational simulation of the turbulent flow of the exhaust gas [5].

Table1. Mass fractions of species in the optimized final model

Species	Mass fraction (Percent)
Methane (CH_4)	4.61E-16
Oxygen (O_2)	0.1705
Carbon dioxide (CO_2)	1.87e-12
Carbon monoxide (CO)	0.0337
Water (H_2O)	0.0434
Nitrogen (N_2)	0.7522

3- Results and Discussion

Table 1 presents the mass fraction of different species of the exhaust gas at the downstream of the adjustable warhead and Fig. 1 illustrates the contours of these species.

Numerical results indicate that the mass fractions of the methane gas and the carbon dioxide in the exhaust gas are negligible. This means that all of the methane gas has been consumed. The numerical results have been verified by the experimental results.

4- Conclusions

In this research for obtaining the maximum thermal efficiency of a household gas water heater, both the combustion characteristics and geometry and size of the baffles have been considered simultaneously.

Numerical results show that all of the methane gas has been consumed and the thermal efficiency of the household gas water heater has been increased to 82.5%.

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