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Numerical Investigation of Temperature Distribution in a Fire Resistance Test Furnace

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Abstract

Fire is one of the most important securities of life issue in crowded life spaces. In order to determine whether the construction materials provide the necessities in the standard, conditions during a fire incident should be simulated and materials need to be tested in this simulated environment. Fire resistance test furnaces are used in determining the fire resistance of a material. In this study, according to the general rules for fire resistance experiments defined in TS EN 1363-1 standard, a fire resistance test furnace is designed three dimensionally and computational fluid dynamics analysis of the fire test furnace is done with ANSYS Fluent program in order to evaluate and determine the temperature distribution inside the fire test furnace. The governing equations for mass, momentum and energy were solved for the three dimensional unsteady incompressible flow, with radiative heat transfer and turbulence model. It was found that temperature distribution inside furnace plays crucial role on volume mean temperature of furnace.

Key words: Fire Resistance Test Furnace, CFD, Temperature Distribution

1. Introduction

Fire security measures are one of the trending topics in security sector. Fire security measures are not only focused on fire extinguishing but they should also provide enough time for people to get away from the fire. The most important element in these studies are obviously construction materials. The specifications of construction materials, which are key elements in fire resistance, are defined in Fire Materials Directive, under the headline of "Security during Fire" [1]. In order to determine whether construction materials comply with this standard or not, fire conditions must be simulated in an environment. This environment which fire conditions are created is called as fire resistance test furnace. TS EN 1363-1 defines the rules for fire resistance experiments [2]. A schematic of a fire resistance test furnace is shown in Fig. 1.

Fire resistance test furnace was designed in respect of TS EN 1363-1. A temperature curve, namely ISO 834 curve was the main basis in design studies. This curve is named as inside furnace mean temperature in TS EN 1363-1 standard. ISO 834 curve is shown in Fig. 1.

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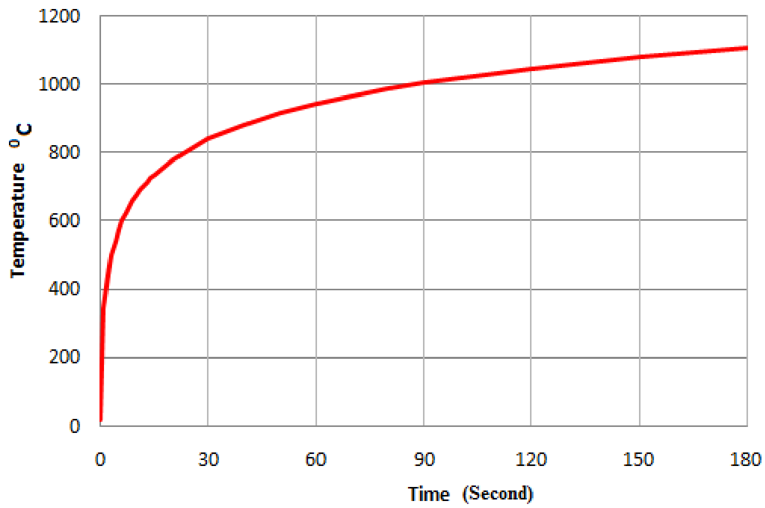

Fig. 1 ISO 834 curve

Welch and Rubini made the first full scale CFD (Computational Fluid Dynamics) study in fire resistance test furnaces [3]. In their study, a computer code namely SOFIE (Simulation Of Fires In Enclosures) was used. As a result of their work, inside furnace mean temperature was found 200 K higher then ISO 834 curve.

The study of Jansson and Anderson involves a different computer code named FDS (Fire Dynamic Simulator) [4]. Their research includes both experimental and numerical studies. In the study, it was observed that numerical and experimental results are not in a good agreement but the code provides a good approach.

Piloto et. al. modelled a 1 m^3 fire resistance test furnace according to ISO 834 curve and used ANSYS Fluent computer program for CFD analysis [5]. It was stated that S2S (Surface to Surface) radiation model was used and adiabatic conditions were assumed in this study. It was stated that numerical results agree well with experimental results.

In this study, a 1 m^3 cubic fire resistance test furnace with four burners and one exhaust was designed. Propane ($C_3H_8$9 was considered as fuel and air was used as oxidizer. CFD analysis was made in order to determine the temperature distribution inside the fire resistant test furnace. Gathered data was compared with ISO 834 curve.

2. Computational Fluid Dynamics Analyses

For CFD analysis, ANSYS Fluent computer program was used. Finite Volume Method was selected as discretization method. Governing equations of mass, momentum and energy was calculated in second order in Fluent. The pressured based solver was used with unsteady and first order implicit formulation. In calculations, adiabatic conditions were assumed. As turbulence model, "realizable k- ε" was used. In heat transfer, heat transfer with radiation was also taken into consideration since the temperature is rising up to 1000 ^{O}C. Thus, P-1 radiation model was selected as radiation model. Also, some gases like CO_2, CO, $H_2O_{(g)}$, SO_2 contribute to heat transfer [6]. The weighted-sum of gray gases model is adopted in order to calculate the absorption coefficients and rate of radiation emitted by the gases as a function of temperature with gray gas assumption [7]. The generalized Eddy Dissipation Model was used to simulate the combustion of propane-air mixture.

For inlet conditions, temperatures of the gases were selected as room temperature. Inlet velocities of propane and air were determined from the study of Welch and Rubini(1997) and Karabaş (2015) [3,8]. The transient calculation was made under 0,01 second time step. A total number of 1032361 nod point was used in the mesh which can be observed in Fig. 2.

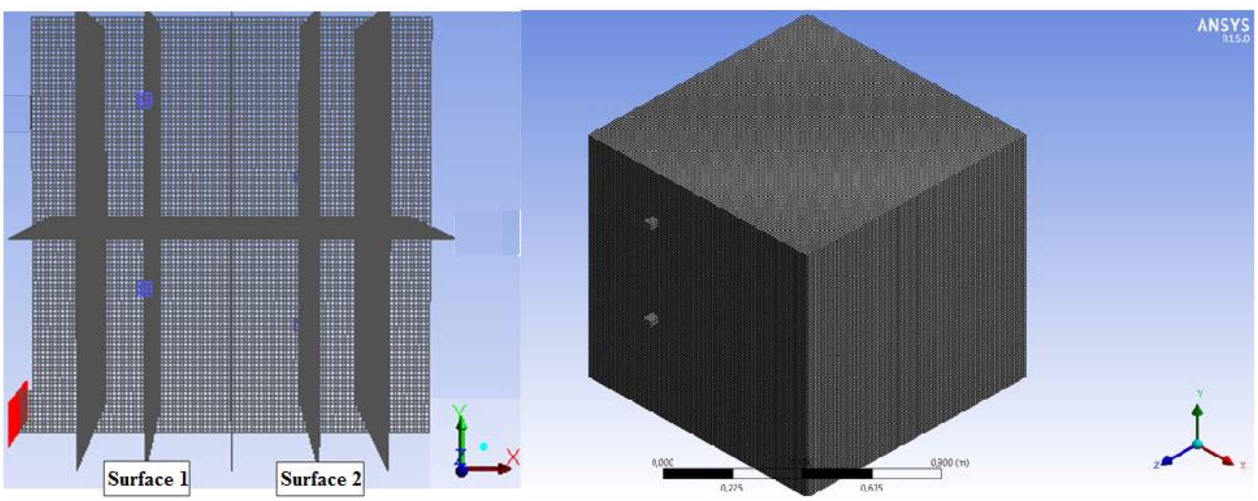

Fig. 2 Geometry, mesh and surfaces of the modelled fire resistance test furnace

3. Results

Temperature distributions on the Surface 1 and Surface 2, which is shown in Fig. 2, can be found in Fig. 3, Fig. 4, Fig. 5 and Fig. 6.

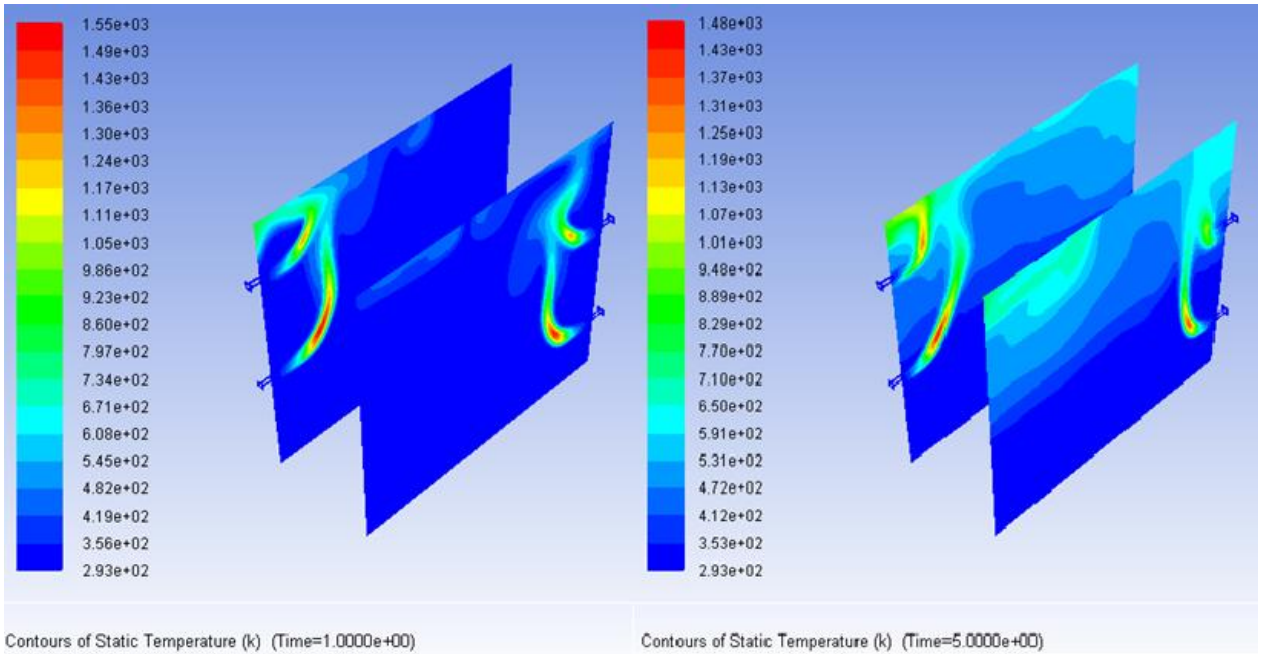

Fig. 3. Temperature distributions of Surface 1 and Surface 2 on 1st (Left) and 5th (Right) seconds

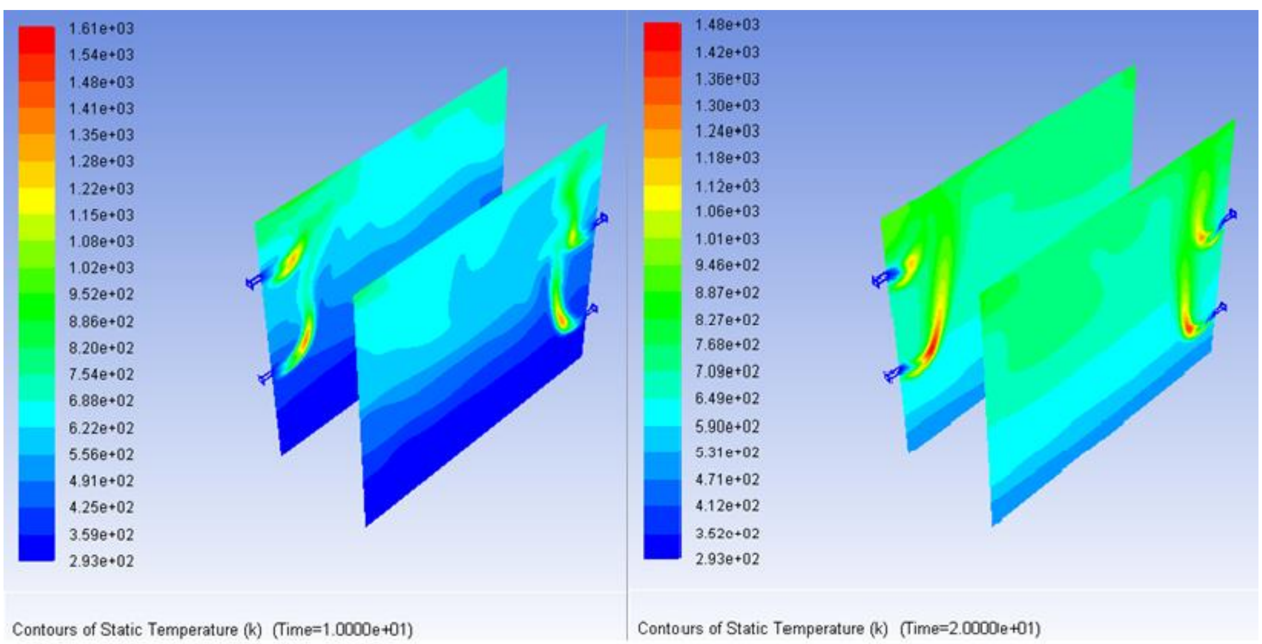

Fig. 4. Temperature distributions of Surface 1 and Surface 2 on 10th (Left) and 20th (Right) seconds

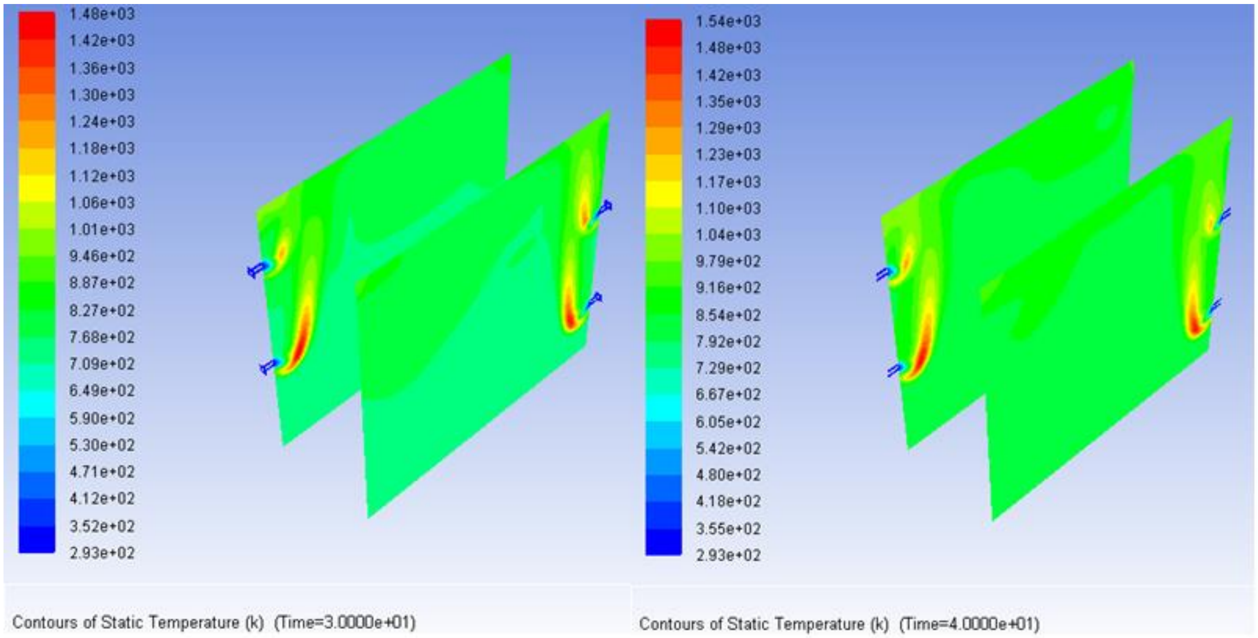

Fig. 5. Temperature distributions of Surface 1 and Surface 2 on 30th (Left) and 40th (Right) seconds

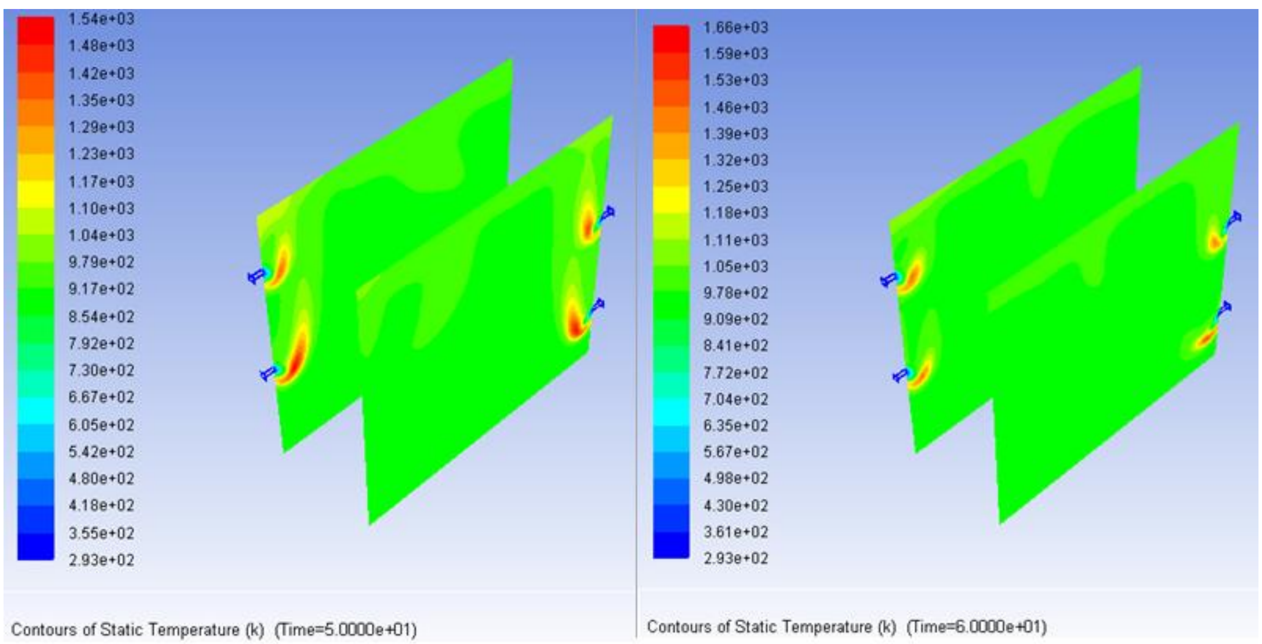

Fig. 6. Temperature distributions of Surface 1 and Surface 2 on 50th (Left) and 60th (Right) seconds

When the propane and air mixture were introduced to fire resistance test furnace, fire starts only in front of the burners in Fig. 3. In 5th second, Fig. 4, temperature starts to increase at the top surface of the furnace. Since the temperature increase starts at the top surface, exhaust location was selected at the bottom of the furnace which can be observed in red in Fig. 2. At the 30th second in Fig. 5, temperature distribution starts to get homogenized and at the 50th second in Fig. 6, a homogeny distribution of temperature inside the furnace can be observed.

4. Discussion

Volume mean temperature graph was drawn in order to determine the relationship between ISO 834 curve which can be found on Fig. 7.

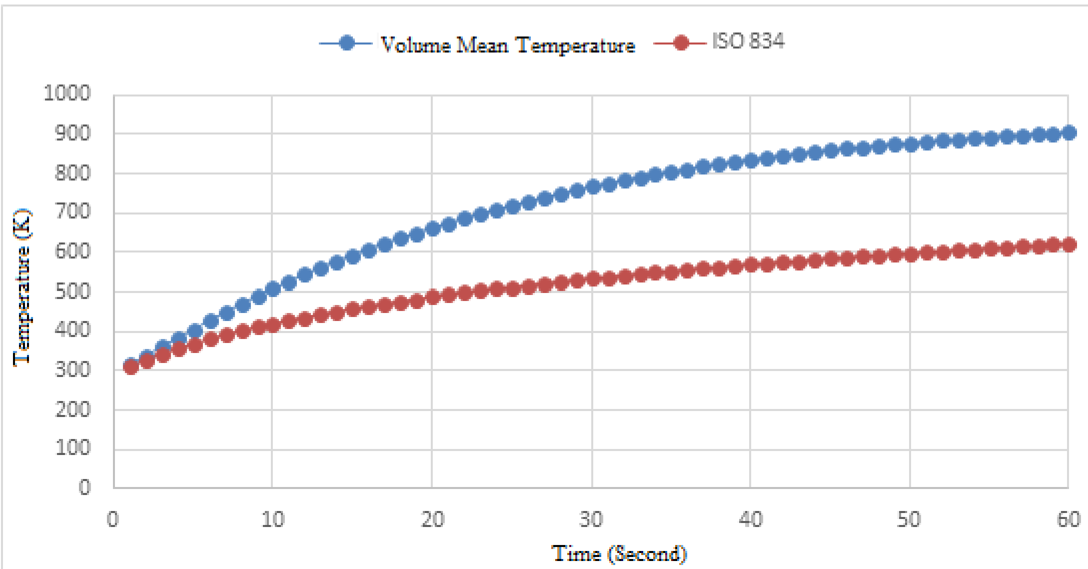

Fig. 7. Graph of Volume mean temperature vs ISO 834 curve

As time passes, the difference between volume mean temperature of the furnace and ISO 834 curve increases. Volume mean temperature was appearing to be higher than ISO 834 curve during the 60 second period. The reason of this difference between volume mean temperature and ISO 834 was investigated and it was figured out that there were much more energy inside the furnace then it was supposed to be. Then, exhaust gas temperature was examined and exhaust gas vs ISO 834 curve was drawn, in Fig. 8. In the first 21 seconds, exhaust gas temperature was below ISO 834 curve and that caused combustion products to leave more energy inside the furnace. That more energy caused volume exhaust temperature values to result higher then ISO 834 curve.

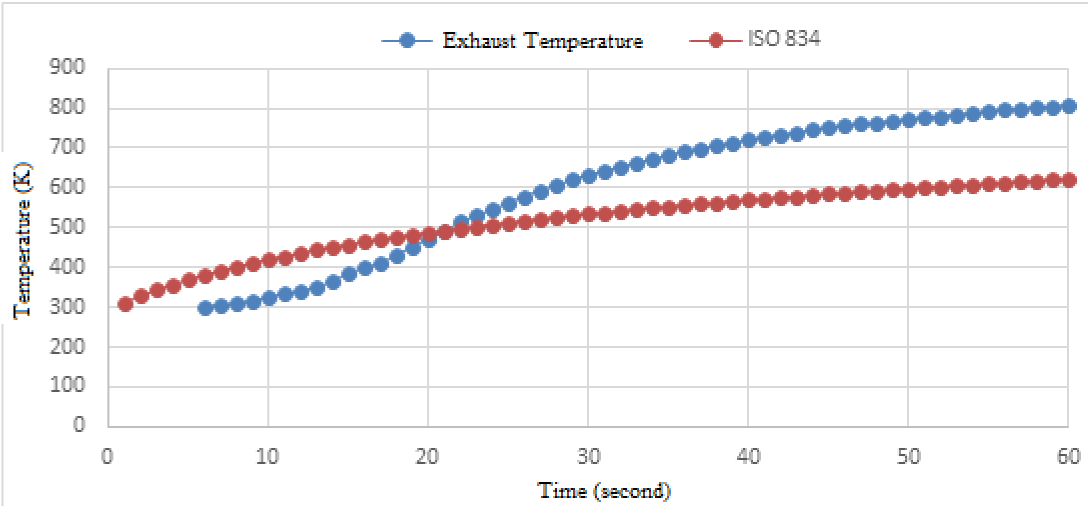

Fig. 8. Graph of Volume mean temperature vs Exhaust temperature

Conclusions

In this study, a fire test resistance furnace with 1 m^3 cubic structure was designed. A CFD analyses was done in order to investigate the temperature distribution inside the furnace. According to the gathered data, volume mean temperature was higher than ISO 834 curve. When the reason of that situation investigated, it was determined that for the first 21 seconds, exhaust gases have lower temperature than ISO 834 curve. That caused combustion products to leave more energy inside the furnace. This more energy resulted with higher volume mean temperature than ISO 834.

The non-uniform distribution of temperature during the first 21 second, which can be observed in Fig. 3 and Fig. 4, caused combustion products to leave the furnace with lower temperature than ISO 834. This situation caused volume mean temperature to get higher than ISO 834 curve.

More studies should be conducted for temperature distribution in a fire resistance test furnace with different geometries and burner-exhaust types.

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