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SEMI-SPHERICAL CERAMIC FOAM BURNERS AND BURNING SIMULATION (PART II)

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ABSTRACT
In this study, a semi-spherical ceramic foam burner for a small capacity boiler was developed. For the burning simulation, the solid model of the semi-spherical foam burner was constituted and the mathematical model related to the system was made.The programmes PrePDF, GAMBIT and FLUENT 6.0 were used to get the simulation. The burning simulation in mixture was done for the static pressure distribution, the velocity distribution, and the temperature distribution.The turbulence ratio is 95%, and the inlet velocity is 10 m/s for the uniform temperature on the surface of the semi-spherical ceramic foam burner.
Keywords: Ceramic foam, Ceramic burner, Burning simulation

1. INTRODUCTION
In this study, a simulation of the burning process of a semi-spherical ceramic foam burner was set up. In this field, Jones and Mcguirk [1] developed the mathematical model for combustion chamber in gas turbine. They applied this model to the combustion chamber with two and three dimensions and also compared with the experimental studies done by Owen [2]. Gafletti, Belli and Bruno [3] compared the two different turbulent models and they saw that difference between two models decreased at high pressures. Günter and Lenze [4] obtained the variation coefficients for the heat, momentum and the mass in their turbulence calculation. Markatos and Moult [5] developed a new calculation technics for turbulent and incompressible flows in an axial symmetric combustion chamber. This technics covered the chemical reaction and radiation. Nikjooy, So and Peck [6] used the chemical models and examined the differences between the models. Khalil, Spalding and Whitelaw [7] examined the flow in two dimensinoal axis. Torii and etc. [8] did the laminarisation of heated gas flow in a circular pipe. They used the numeric analysis by means of the k-ε model. Nagona and Kim [9] obtained the two dimensional heat transfer models by considering the sliding tension for flows in the wall. Torii [10] found the constant of the transport equations by using the k-ε model and simulated the flow field of fluid. Magnussen [11] developed the mathematical model during sooty burning. Bird and etc [12] obtained the correlation for density and viscosity in a control volume by considering the thermal specifications. Altınışık and etc [13] developed the solid model of the semi-spherical foam burner was constituted and the mathematical model.

2. MATHEMATICAL MODEL
In order to obtain the mathematical model of the system, the densities for the incompressible and the compressible flows in ideal gases were written. The densities for the mixture for the unideal gases, the compressible and the incompressible flows were given respectively [14]. The viscosity of the gas depending on the temperature and the Sutherland's viscosity law were written [15].

2.1 Physical Models

The conservation's law of the mass can be given in the following form

$$\frac{\partial P}{\partial T} + \frac{\partial}{\partial x_i}(\rho . u_i) = 0 \tag{1}$$

The continuity equation for compressible flow in transient regime is

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho . u) + \frac{\partial}{\partial r}(\rho . v) + \frac{\rho . v}{r} = 0 \tag{2}$$

Here, x is the axial coordinate, r is radial coordinate, u and v are velocities in axial and radial directions, t is the variation of time and ρ is fluid density. The conservation equation of momentum for compressible flow in transient regime can be expressed as follows [16] ,

$$\frac{\partial \rho}{\partial t}(\rho . u_i) + \frac{\partial}{\partial x_j}(\rho . u_i u_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i + F_i \tag{3}$$

Here, $\rho . g_i$ shows the gravitation acceleration, F_i is the external force and P is the static pressure. τ_{ij} is the sliding tension and it can be given in the following form,

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

Here, μ is the molecular viscosity.

The conservation equation of the momentum for the two dimensional asymmetric geometries in radial and axial direction can be written in the following form [16],

$$\frac{\partial}{\partial t}(\rho . u) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho . uu) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho . uv) = -\frac{\partial P}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu \left(2\frac{\partial u}{\partial x} - \frac{2}{3}(\nabla . \vec{\upsilon}) \right) + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu \left(2\frac{\partial u}{\partial r} - \frac{\partial v}{\partial x} \right) \right] + F_x \right] \tag{5}$$

$$\frac{\partial}{\partial t}(\rho v) + \frac{1}{r}\frac{\partial}{\partial x}(r\rho . uv) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho vv) = -\frac{\partial P}{\partial r} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu \left(2\frac{\partial v}{\partial x} + \frac{\partial u}{\partial r} \right) \right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu \left(2\frac{\partial v}{\partial r} - \frac{2}{3}(\nabla . \vec{\upsilon}) \right) \right] - 2\mu \frac{V}{r^2} + \frac{2}{3}\frac{\mu}{r}(\nabla . \vec{\upsilon}) + \rho \frac{w^2}{r} + F_r \tag{6}$$

Here, the value of the $\nabla . \vec{\upsilon}$ is,

$$\nabla . \vec{\upsilon} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial r} + \frac{v}{r} \tag{7}$$

The conservation statement of the energy is

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}[u_i(\rho E + P)] = \frac{\partial}{\partial x_i}\left[k_{eff} \frac{\partial T}{\partial x_i} - \sum_{j=1}^{N} h_j j_j + u_j (\tau_{ij})_{eff} \right] + S_h \tag{8}$$

Here, k_{eff} is the effective conduction coefficient, j_j is the diffusion flux of the addition of the j element to the mixture, $k_{eff}\frac{\partial T}{\partial x_i}$ is the heat transfer by conduction, $\sum_{j=1}^{N} h_j j_j$ is particle diffusion, $u_j(\tau_{ij})_{eff}$ is the viscosity distribution and S_h is given up the heat at the end of the chemical reaction.

2.2 Turbulent Model

By means of the Reynolds analogy, the equation given by [11] for heat and mass transfer can be expressed in the following form [17],

$$\frac{\partial}{\partial t}(\rho E) + \frac{\partial}{\partial x_i}[u_i(\rho E + P)] = \frac{\partial}{\partial x_i}\left[\left(k + \frac{C_p \mu_t}{\Pr t} \right) \frac{\partial T}{\partial x_i} + u_j (\tau_{ij})_{eff} \right] + S_h \tag{9}$$

Here, $(\tau_{ij})_{eff}$ is the effective sliding tension and it can be expressed as follows,

$$(\tau_{ij})_{eff} = \mu_{eff} \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) - \frac{2}{3}\mu_{eff} \frac{\partial u_i}{\partial x_i} \delta_{ij} \tag{10}$$

Here, k is the turbulent kinetic energy, ε is the distribution rate. The transport equations of the $k-\varepsilon$ turbulent model [18] are

$$\rho \frac{Dk}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho\varepsilon - Y_M \tag{11}$$

$$\rho \frac{D\varepsilon}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_i} \right] + C_1 \varepsilon + \frac{\varepsilon}{k}(G_k + C_3 \varepsilon G_b) - C_2 \varepsilon \rho \frac{\varepsilon^2}{k} \tag{12}$$

Here, G_k is the turbulent kinetic energy production depending on the velocity gradient of the gas, G_b is the turbulent kinetic energy production depending on buoyancy of the gas, Y_M is the total distribution ratio of the flow expansion for the compressible turbulent flow, σ_k is the turbulent Prandtl number for $\sigma\varepsilon$, k ve ε, $C_1\varepsilon$, $C_2\varepsilon$ and $C_3\varepsilon$ are the model constants [17].

The turbulence viscosity is

$$\mu_t = \rho . C_\mu \frac{k^2}{\varepsilon} \tag{13}$$

Here, C_μ is the model constant and it was calculated by Torii (8). C_μ is 0,09 for the low Reynolds number of k and ε values.In order to complete the mathematical model, it is necessary to write the boundary conditions, the radiation model [17], the chemical equilibrium equations and the decomposition equations.

3. BURNING SIMULATION

PrePDF, GAMBIT and FLUENT 6.0 programs were used for the burning simulation. The figure 1 shows the simulatioın of turbulent kinetic energy of the air-fuel mixture and its graphs is given in Figure 2.

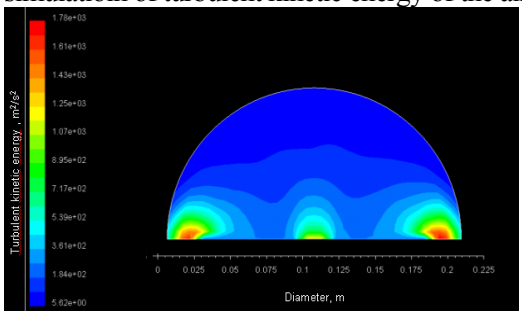

Figure 1. Simulatioın of turbulent kineticenergy

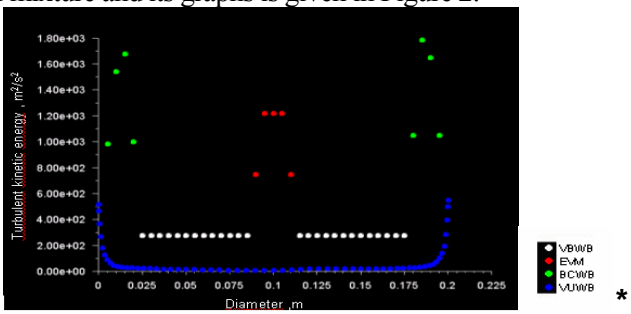

Figure 2. Graph of turbulent kinetic energy

The simulation of mass ratio of CO_2 in mixture and the simulations of mass ratio of N_2 in mixture and their graphs were given in figure 3, 4, 5 and 6 respectively.

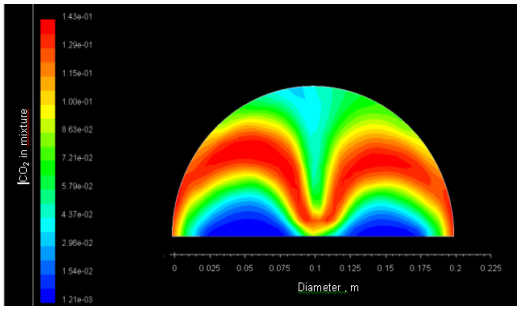

Figure 3. Simulatioin of mass ratio of CO2 in mixture

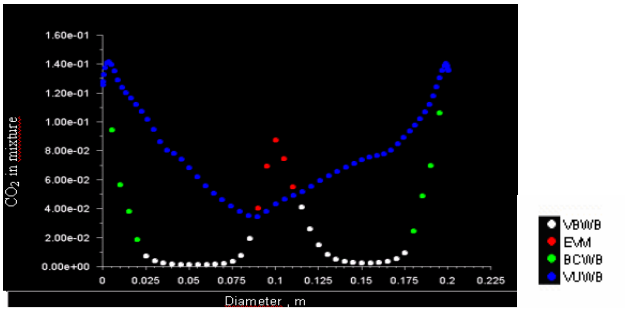

Figure 4. Graph of mass ratio of CO2 in mixture

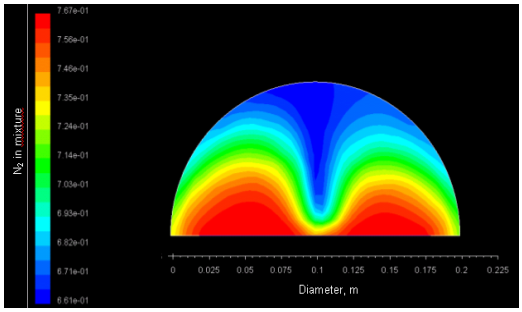

Figure 5. Simulatioin of mass ratio of N2 in mixture

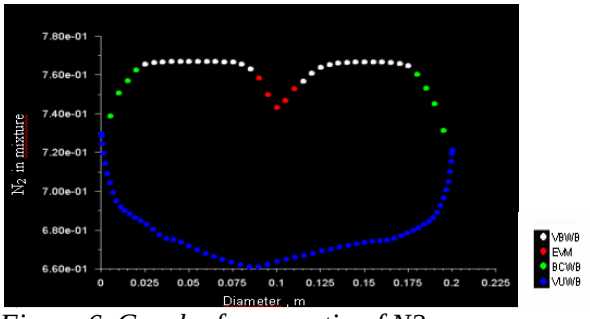

Figure 6. Graph of mass ratio of N2 in mixture

*** *(EVM)*** *The entering values of the mixture*
(BCWB) *The values of bottom corner wall of burner*
(VBWB) *The values of bottom wall of burner*
(VUWB) *The values of upper wall of burner*

4. RESULTS AND DISCUSION

As seen in Figure 1, The total energy is great in the region having the excess density. The value of the total energy is very small in the upper wall of the burner. Because the velocity is zero in the wall. The decreasing of the velocity value affects the decreases of turbulent kinetic energy. For this reason, the total energy decreases (in Figure 2).

The incerases or decreases of the velocity affects on the turbulent kinetic energy. If the velocity is zero in the wall, the kinetic energy is also zero. Figure 3 shows the simulation of the mass ratio of CO_2 . The mass ratio of CO_2 is much in the central of the burner, but it is small in the bottom of the burner. The variation of the mass ratio of CO_2 according to the diameter of burner in mixture is shown in Figure 4. As seen figure, there is a tarnsition region between two regions. These regions are under and upper zones of the semi-sphere. In order to improve the burning, the amount of CO_2 and the height of the condensing point of the water vapour in chimney gas have to remain in desired value. If the fuels containing C aren't burned in ideal conditions and CO gives out insead of CO_2 . Figures 5 show the simulations of N_2 . Figure 6 gives the its graph. The molecular N_2 affects to the invironment, but its compounds affect to the environment too. The formation equilibrium of CO and NOx have to adjust the perfect. Till the necessary time for burning provides, N_2 remains in the bottom region of the burner. The reason of the decrease of N_2 amount in wall, is the push force occuring by the blowing. As known, N_2 exists different ratios in the air.

The ratio of turbulent is 95% and the inlet velocity is 10 m/s for the uniform temperature on the surface of the semi-spherical ceramic foam burner.

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