Natural Convection Study of Air between Heated Walls

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Abstract

Natural convection of air was computationally analyzed for differentially heated walls enclosure. The investigated walls were kept at 34.7 °C and 15.1 °C. The temperature variations between hot wall and cold wall are examined at different heights with turbulence model k-ω SST.

Keywords: Natural convection, k-ω SST

Nomenclature

k	Turbulent kinetic energy
SST	Shear Stress Transport
SIMPLE	Semi Implicit Method for Pressure Linked Equation
u	Fluid velocity
m	Molar weight
G	Generation of k
S	Source term
c_p	Specific heat capacity
Pr	Prandtl number
i, j, k	Indices

Greek Symbols

ω	Specific dissipation
ρ	Density
μ	Dynamic viscosity
μ_T	Turbulence viscosity or, Eddy viscosity

Notations

$\partial/\partial t$	Partial time derivative
$\partial/\partial x$	Partial positional derivative

1. Introduction

Natural convection is a type of heat transfer phenomenon, in which the fluid motion is generated only due to density differences that occurs because of temperature gradients in the fluid. Enclosed natural convection has many practical applications ranging from furnace to electronic cooling system.

This report includes the analysis of natural convection concerning temperature variations at different heights and its validation with the experimental data.

2. Problem Definition and Numerical Technique

blockMesh utility of OpenFOAM was used to create geometry and mesh. Simulation and post-processing were carried out in *buoyantSimpleFoam* solver and *Paraview* with *Sigma Plot* respectively. A 3D model of enclosed heated walls case was studied using *k-ω SST* turbulence model. The dimensions of the model = 2.18 m × 0.076 m × 0.52 m. The final results are considered for validation with the experimental results [1]. *SIMPLE* algorithm was used for pressure-velocity coupling [2]. The convective and turbulent terms were solved by *bounded Gauss limitedLinear* scheme [2]. The computational domain is shown in the Fig. 1.

Number of cells in the model = *90,688*

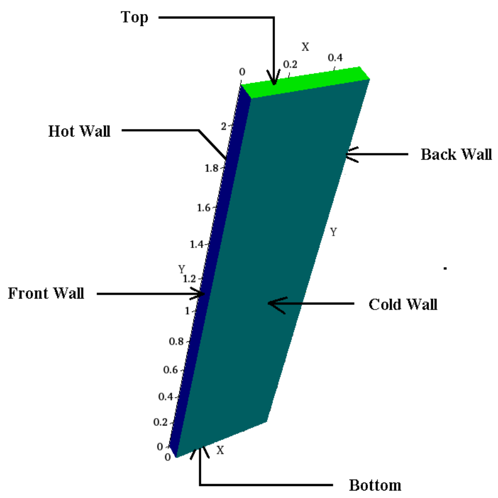

Fig. 1. Computational domain

Table 1. Simulation Parameters

Parameter	***Value***
ρ	1.225 kg/m^3
μ	1.831e-05 Pa.sec
m	28.96 g/mol
Pr	0.704
c_p	1005 J/kgK
Cold Wall Temperature	15.1 °C
Hot Wall Temperature	34.7 °C
Velocity at Walls	0 m/sec

3. Turbulence Equation: *SST* $k-\omega$

$$\rho\frac{\partial k}{\partial t}+\rho u_i\frac{\partial k}{\partial x_i}=\overset{\approx}{P}_k-\beta^*\rho k\omega+\frac{\partial}{\partial x_i}\left[(\mu+\sigma_k\mu_T)\frac{\partial k}{\partial x_i}\right]\qquad(1)$$

Eq. (1) is the k transport equation of SST $k-\omega$ model

$$\rho\frac{\partial \omega}{\partial t}+\rho u_i\frac{\partial \omega}{\partial x_i}=\alpha\rho S^2-\beta\rho\omega^2+\frac{\partial}{\partial x_i}\left[(\mu+\sigma_\omega\mu_T)\frac{\partial \omega}{\partial x_i}\right]$$
$$+2(1-F_1)\rho\sigma\omega_2\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i}\qquad(2)$$

Eq. (2) is the ω transport equation of SST $k-\omega$ model

The blending function F_1 is,

$$F_1=\tanh\left\{\left\{\min\left[\max\left(\frac{\sqrt{k}}{\beta^*\omega y},\frac{500\mu}{y^2\omega}\right),\frac{4\rho\sigma_{\omega 2}k}{CD_{k\omega}y^2}\right]\right\}^4\right\}$$

Where,

$$CD_{k\omega}=\max\left(2\rho\sigma_{\omega 2}\frac{1}{\omega}\frac{\partial k}{\partial x_i}\frac{\partial \omega}{\partial x_i},10^{-10}\right)$$

Another blending function F_2 is,

$$F_2=\tanh\left[\left[\max\left(\frac{2\sqrt{k}}{\beta^*\omega y},\frac{500\mu}{y^2\omega}\right)\right]^2\right]$$

The turbulence viscosity will be,

$$\mu_t=\frac{a_1 k}{\max(a_1\omega,SF_2)}$$

The production limiter used to prevent the build-up of turbulence in the stagnation region which is,

$$P_k=\mu_T\frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$$

And,

$$\overset{\approx}{P}_k=\min(P_k,10\beta^*\rho k\omega)$$

The SST model constants are,

$$\alpha_1=\frac{5}{9},\beta^*=0.09,\beta_1=\frac{3}{40},\alpha_{k1}=0.85,\alpha_2=0.44,$$

$$\beta_2=0.0828,\alpha_{k2}=1,\alpha_{w2}=0.856$$

4. Results

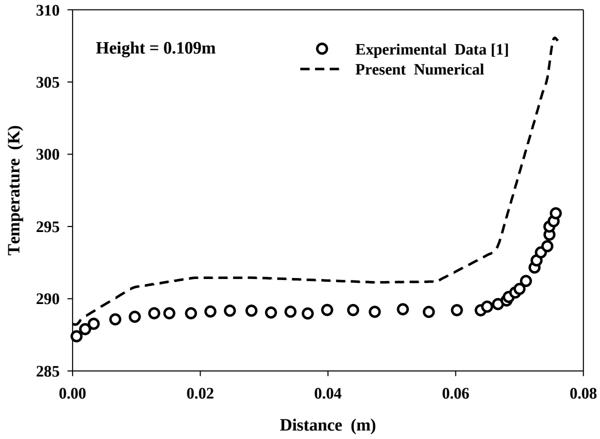

Fig. 2. Temperature distribution at Height = 0.109m

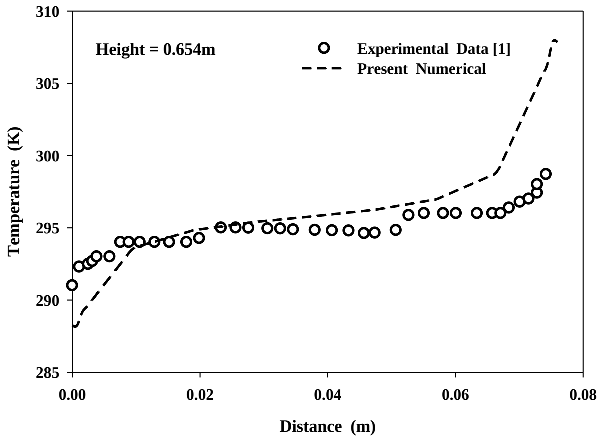

Fig. 3. Temperature distribution at Height = 0.654m

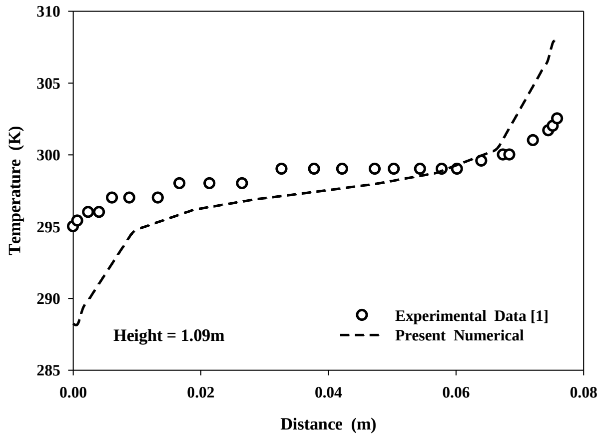

Fig. 4. Temperature distribution at Height = 1.09m

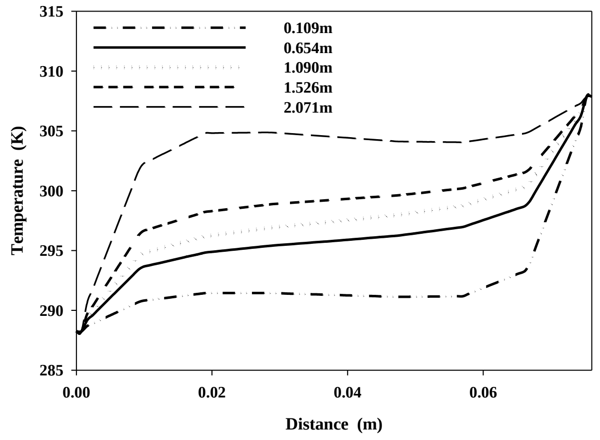

Fig. 7. Comparison of Temperature distribution at different heights

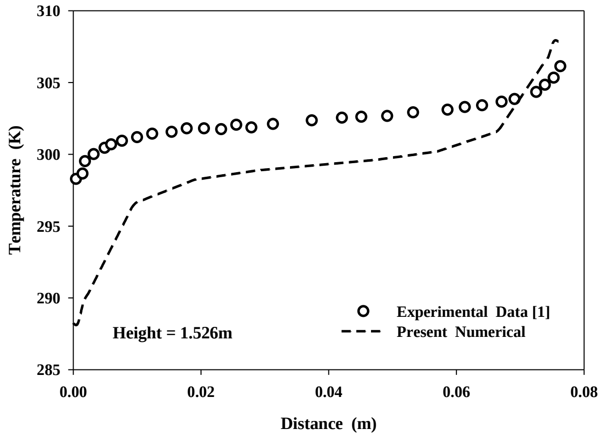

Fig. 5. Temperature distribution at Height = 1.526m

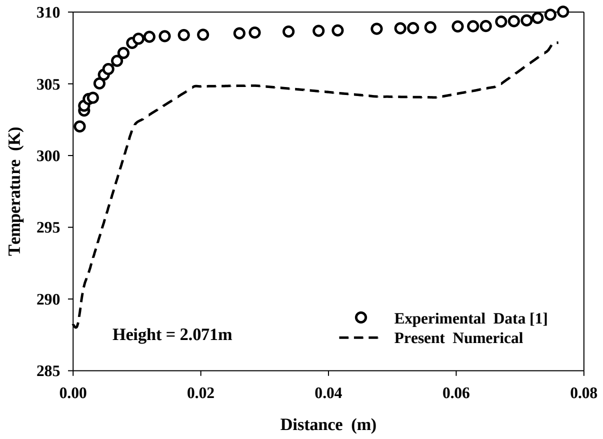

Fig. 6. Temperature distribution at Height =2.071m

The solver underpredicts the temperature distribution at lowest height = 0.109m. As height goes beyond 0.109m, the numerical results start crossing their corresponding experimental results. Thus, overpredicted outcomes can be noticed at the peak heights. Again, the temperature profiles are highly anti-symmetry at the top and bottom.

5. Contours

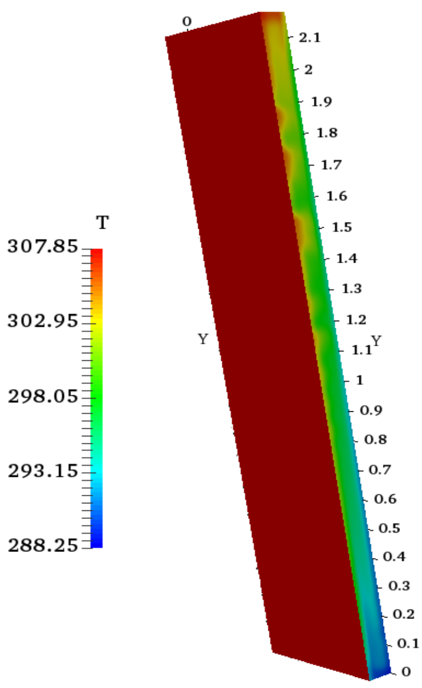

Fig. 8. Temperature contour from the sight of Hot Wall

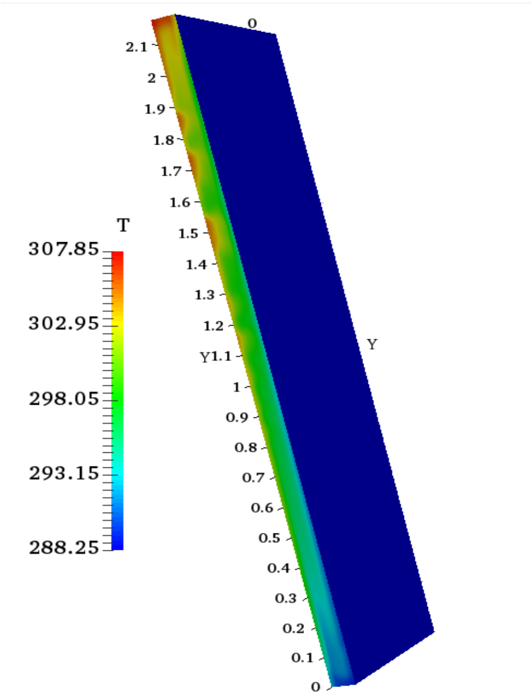

Fig. 9. Temperature contour from the sight of Cold Wall

References

[1] Betts P.L., Bokhari I.H., ”Experiments on turbulent natural convection in an enclosed tall cavity”, International Journal of Heat and Fluid Flow 21 (2000) 675-683

[2] OpenFOAM User Guide version 6.0 (2018)