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Investigation of Thermo-Mechanical Properties of Flue Gases Using CFD in Thermal Regenerator

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Abstract

In-depth computational fluid dynamics (CFD) research on transient flow inside a thermal regenerator is the goal of this paper. The regenerator is heated to 100 °C at the beginning of the CFD simulation cycle. CATIA is used to create the computational/FEA model of the regenerator. The goal is to accurately simulate how gas flow will behave under various regenerator operation and design conditions. For CFD simulation, ANSYS Fluent software is employed.

Keywords: FEA, ANSYS, Regenerator, CFD

1. Introduction

Today there is a lot of focus on solar energy and its production. The major hindrance in using solar energy is that it is not available at all time and the power demand of system (industry or Civil) is time dependent [1-3]. In order to overcome thus drawable of computing solar power various emery storage devices are being developed since last 20 years [2-4]. One of the important Energy storages is thermal heat regenerators [5]. The basic working principal of a thermal regenerator is that its traps the heat from waste gases and the provides this trapped heat when required [6-9]. The process of transforming heat form flue gas to ambient air using regenerator is called charging and discharging of regenerator [10].

The Process diagram in fig. 1 shows the Basic Working of Regenerator Below [11-13]

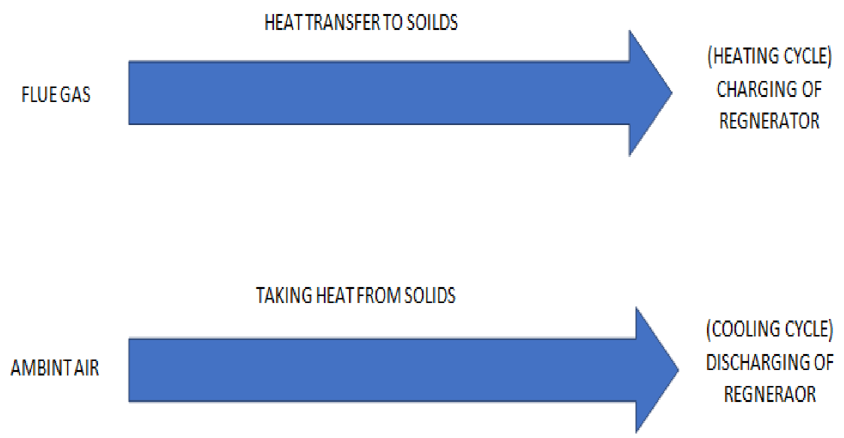


Figure 1. *Heating and Cooling Cycles*

Nomenclature	
A	area of heat exchange between soil and gas, m^2
c	specific heat at constant pressure, $J\,kg^{-1}K^{-1}$
D	diameter of solids, m
C_2	resistance factor. m^{-1}
h	heat transfer coefficient by convection, $w\,m^{-2}\,K^{-1}$
k	thermal conductivity, $w\,m^{-1}\,K^{-1}$
p	pressure, Pa
t	time, s
u	velocity components, ms^{-1}
Subscript	
s	solid phase
f	fluid phase
Greek Symbols	
ρ	density, $kg\,m^{-3}$
μ	viscosity of gas, $kg\,m^{-1}\,s^{-1}$
μ_t	turbulent viscosity, $kg\,m^{-1}\,s^{-1}$
ø	porosity
ε	solid emissivity

Figure 2. *shows the CATIA model of thermal heat Regenerator.*

1.1 Finite Element Model

In Order to simulate the behavior of Thermal Heat Regenerator physical model of regenerator is prepared on CATIA Software [14]. The Dimension of the Regenerator are as follows

1. Length of Regenerator – 100 cm
2. Diameter of Regenerator- 20 cm

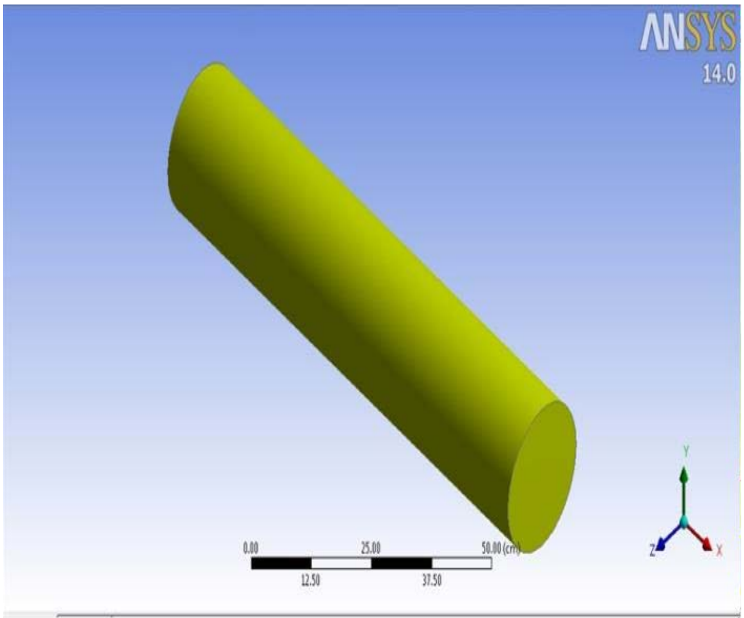


Figure 2. *CATIA Model*

CATIA model is then converted into FEA Model for CFD simulation. The complete domain of regenerator is converted into fluid zone in Ansys [15] so that the flue gases & air can pass through it. Fig 3 shows the FEA Model used for the simulation.

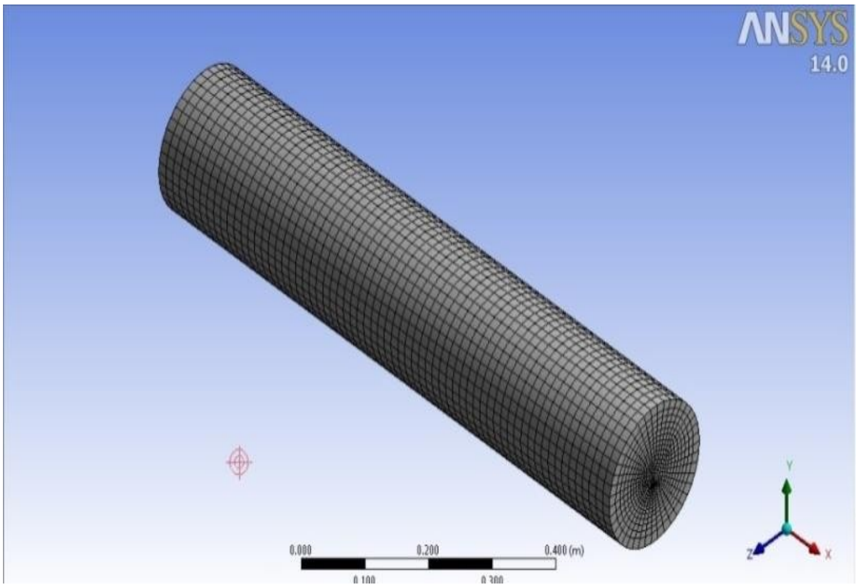


Figure 3. *FEA Model*

2. Literature Review

Kuldeep Panwar et.al. (2015) conducted the comparison of packed-bed thermal regenerator experimental and CFD analysis. The findings of the simulations of the CFD and the recently reported experimental studies of regenerators with D/dp > 15 are contrasted in the current work. In all flow regimes, there is a very strong agreement between the two results. For the analysis, commercial Ansys Fluent software is employed.

Guangyi Pu et.al. (2021) proposed that Numerical modelling techniques were used to examine the efficiency of heat transfer in a three-canister regenerative thermal oxidizer for the treatment of volatile organic compounds. A simple model was created to account for the physical features that changed due to temperature. The findings indicate that as running time rises, the preheating temperature and departure temperature tend to remain steady. Under steady-state conditions, the equipment's heat transfer efficiency was influenced by a number of factors, including incoming gas flow and temperature, valve switch time, combustion temperature, regeneration medium materials & porosity, and packing height. The increase in heat transfer efficiency that results from raising the packing cross-sectional area and packing height is accompanied by a rise in the cost of the requisite machinery. In a similar vein, the heat transfer efficiency can be increased without impairing the operation of any machinery by increasing the density of the regenerative medium batteries as well as shortening the valve switch time.

Aja Ogboo Chikere et.al. (2012) investigated that the diffuser's output without the distribution vanes will resemble a heat jet rather than the even dispersion it is designed to offer. In response to an experimental issue with directing turbulent, high-temperature flue-gas through a big angle diffuser, the idea of guiding vanes for diffusers was developed. It was discovered that the jet diffused at a rate of 1:2, from inlet to exit, as opposed to a fairly uniform discharge issuing from the diffuser. The hot flue gas is concentrated in the centre of the outlet, which has an effect on the insulation and the experimental result. In order to solve this issue, a CFD simulation was used to examine the process and modify the system in a way that would improve performance.

3. Mathematical Model

Mathematical Model of regenerator is developed considering following assumptions [16]-

1. The medium of Fluid flow is considered as porous medium with porosity of 0.6.
2. Flue gas is incompressible
3. The properties of flue gases & solids are function of temperature only.

3.1 Governing Equations

For CFD simulations following governing equations are applied to analyze the Turbulent Flow Field in Ansys.

3.1.1 Continuity Equations [17]

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

3.1.2 Momentum Equation

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial}{\partial x_i}\left(p + \frac{2}{3}\rho k\right) + \frac{\partial}{\partial x_j}\left((\mu + \mu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_l}{\partial x_l}\right)\right) + S_i \qquad (2)$$

$$\alpha = \frac{D^2}{203}\frac{\phi^3}{(1-\phi)^2} \qquad (3)$$

$$C_2 = \frac{3.9}{D}\frac{(1-\phi)}{\phi^3} \qquad (4)$$

3.1.3 Energy Balance Equation

$$u_f \rho_f c_f \frac{\partial t}{\partial x} + \rho_s c_s (1-\varepsilon)\frac{\partial t}{\partial \tau} = k_s \frac{\partial^2 t}{\partial x^2} \qquad (5)$$

3.1.4 Boundary Conditions

at, x=0

$$v_F \rho_f c_f (t_{fi} - t) = -k_s \frac{\partial^2 t}{\partial x^2} \qquad (6)$$

at τ=0

$t = t_{amb}$ (7)

3.1.5 Energy Balance for Solid

$$S_{fr}(1-\varepsilon)\rho_s c_s \frac{\partial t_s}{\partial \tau} = hA(t_f - t_s) \qquad (8)$$

3.1.6 Initial & Boundary Conditions

$$\text{at}\ \tau=0$$

$$t=t_s=t_0 \qquad (9)$$

$$\text{at}\ \tau>0 \quad x=0 \quad t_f=t_{fi}$$

$$x = 0 \quad (_s \quad _0 \quad _{fi} \quad \left(\frac{\tau hA}{S_s \rho_s c_s}\right) + t_{fi} \qquad (10)$$

Table 1. *Boundary Conditions*

S. No	Modeled Equation	Velocity	Flow	Temp.
1.	Inlet	5 m/s	K=constant ε=constant	373K
2.	Outlet	Outflow	Extrapolate from interior of domain wall functions	Extrapolate from interior of domain q= constant
3.	Porous (ø = 0.6)	No slip		

4. Results & Discussions

CFD simulations with charging of regenerator. The initial thermal pressure and flow conditions of flue gas is shown in table 1. The mathematical model is solved using density-based transit solver in Ansys fluent software to get the results. The time duration of compilation heating cycle is 60 seconds

Figure 4 and figure 5 show the variation in velocity and pressure in the porous medium of regenerator. The contour shows the increase in velocity of flues gases with decrease in pressure along the flow path.

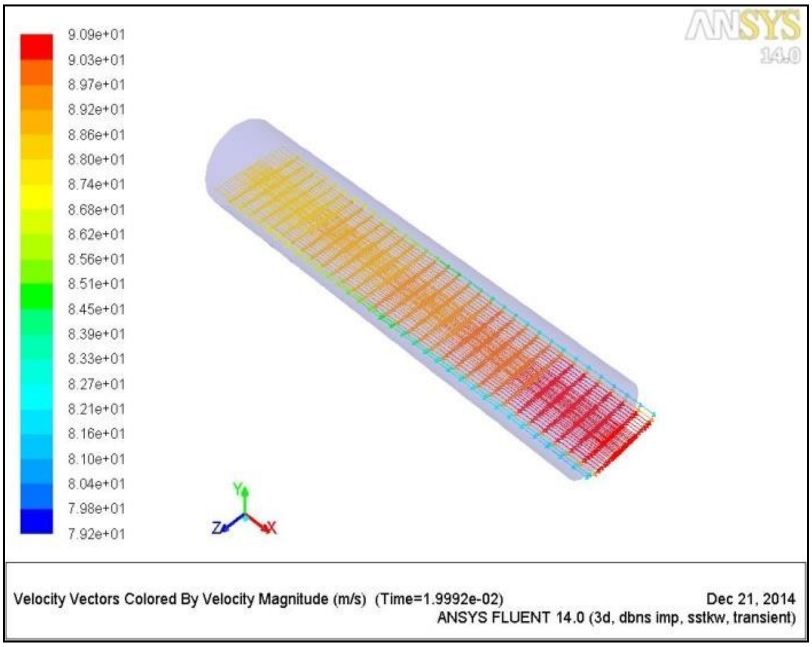


Figure 4. *Velocity Contour along Flue Gases Flow*

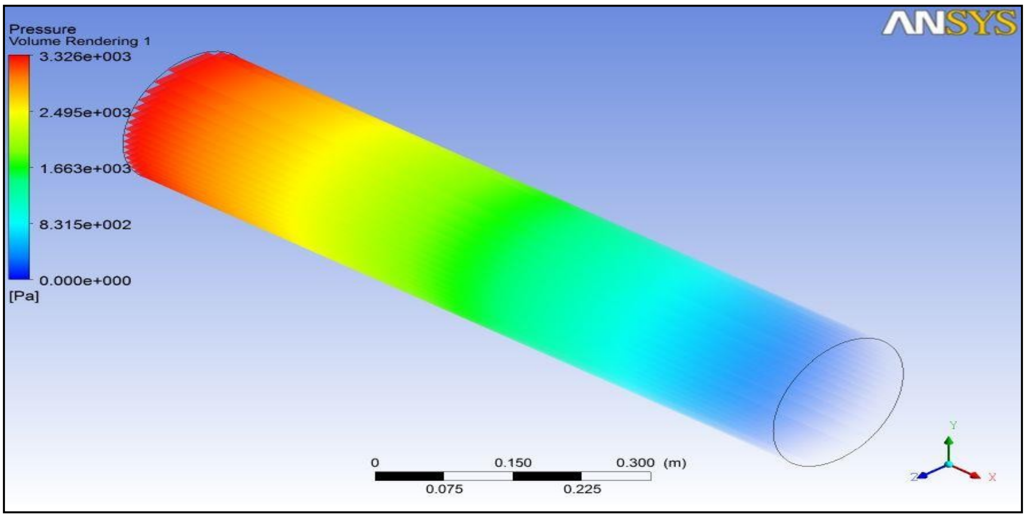


Figure 5. *Pressure Contour along Flue Gases Flow*

Figures 6, 7, 8 & 9 represent the temperature variation of flue gases in the regenerator during the heating cycle of 60 seconds. The results shows the heat being transformed to the regenerator bed from the flue gases by decrease in temperature of flue gases from inlet to outlet.

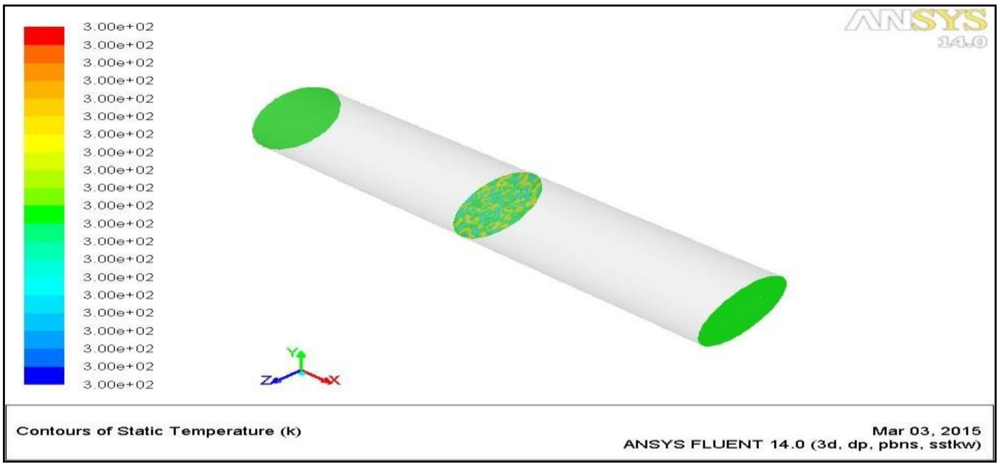


Figure 6. *Flue Gases Temperature Contour along length of regenerator at t= 0*

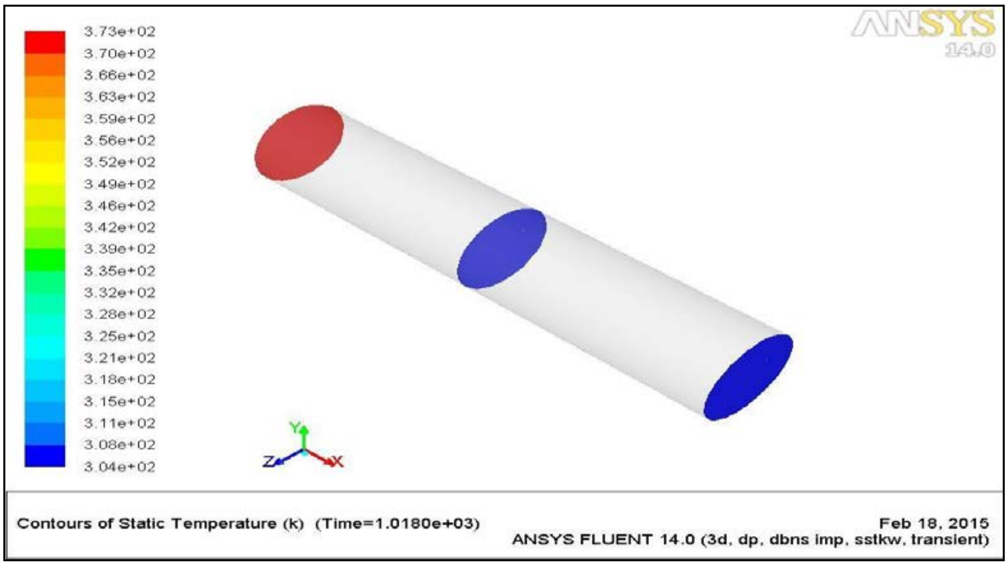


Figure 7. *Flue Gases Temperature Contour along length of regenerator t = 2e-3*

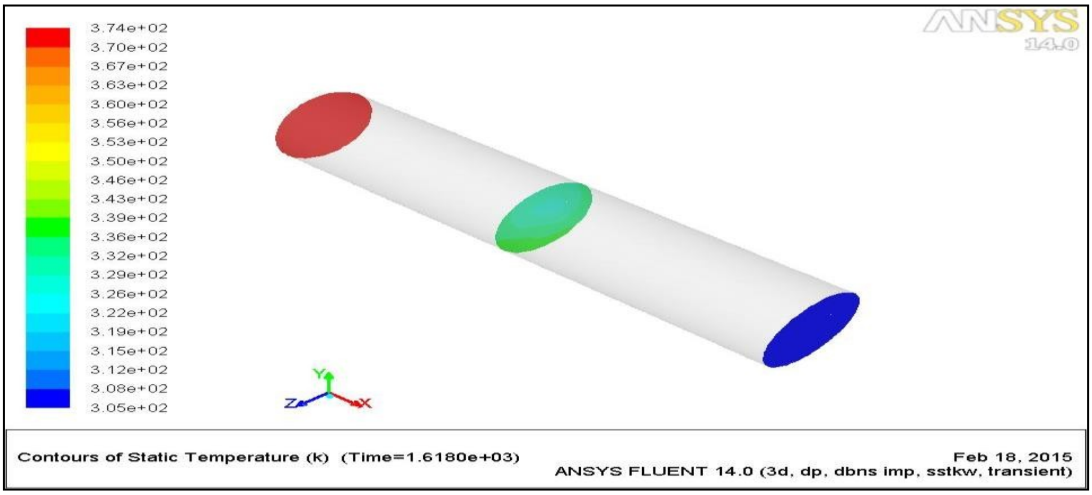


Figure 8. *Flue Gases Temperature Contour along length of regenerator t = 1e-3*

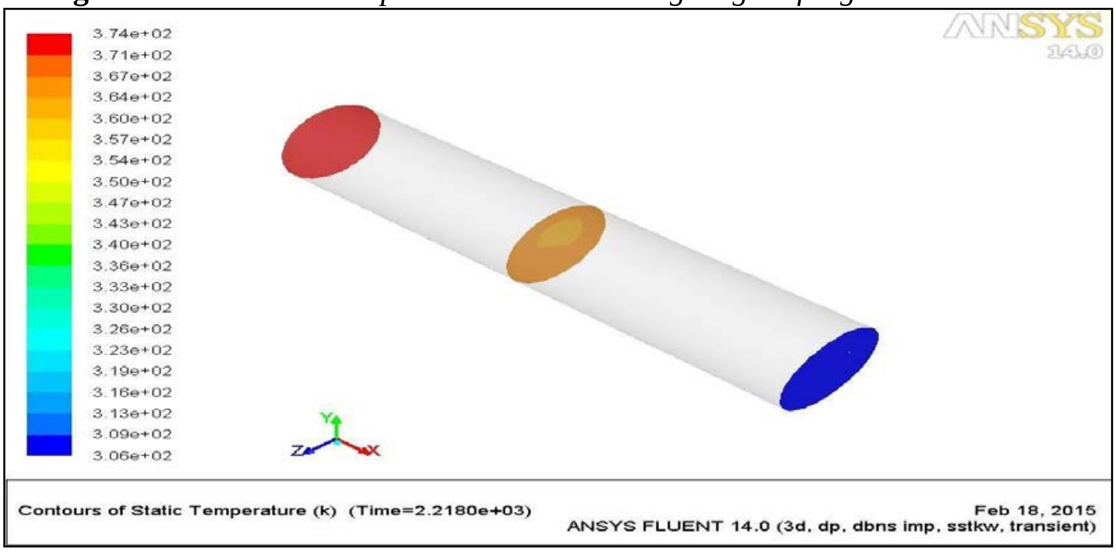


Figure 9. *Flue Gases Temperature Contour along length of regenerator t = 1.15e-3*

Figure 10, 11, 12 & 13 represents thermal profile of regenerator during heating cycle. It is very clear from the thermal plots of the regenerator that it is about 50 % charged during the Heating Cycle by flue gases and now the charged regenerator can transfer this heat to ambient air for any Required purpose.

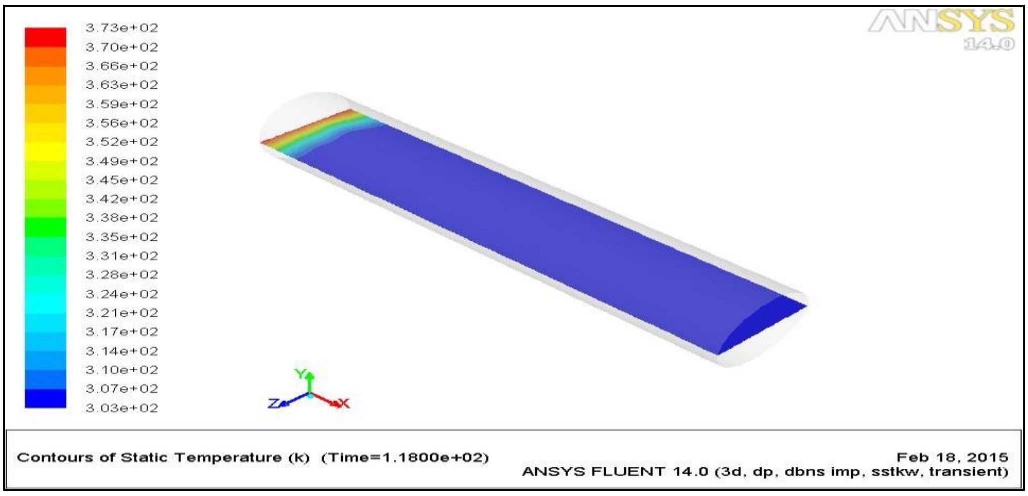


Figure 10. *Regenerator Temperature Contour along length of regenerator at t= 0*

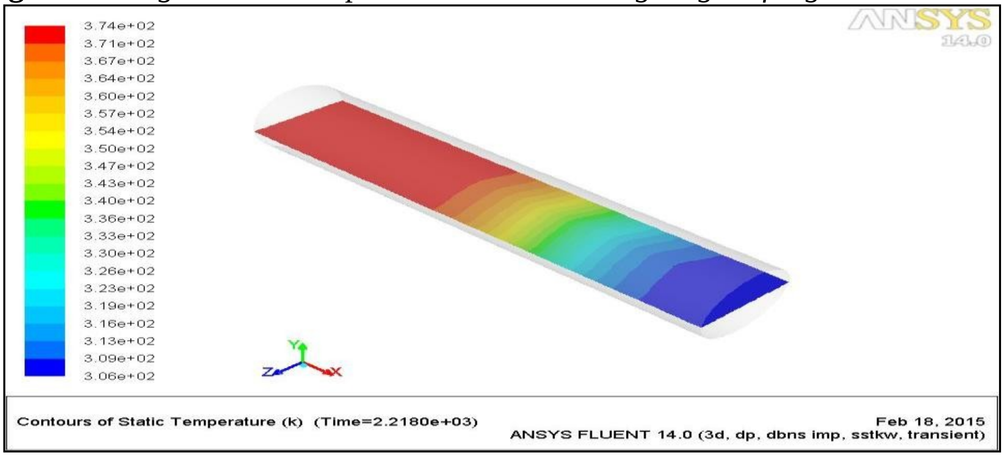


Figure 11. *Regenerator Temperature Contour along length of regenerator at t= 2e-3*

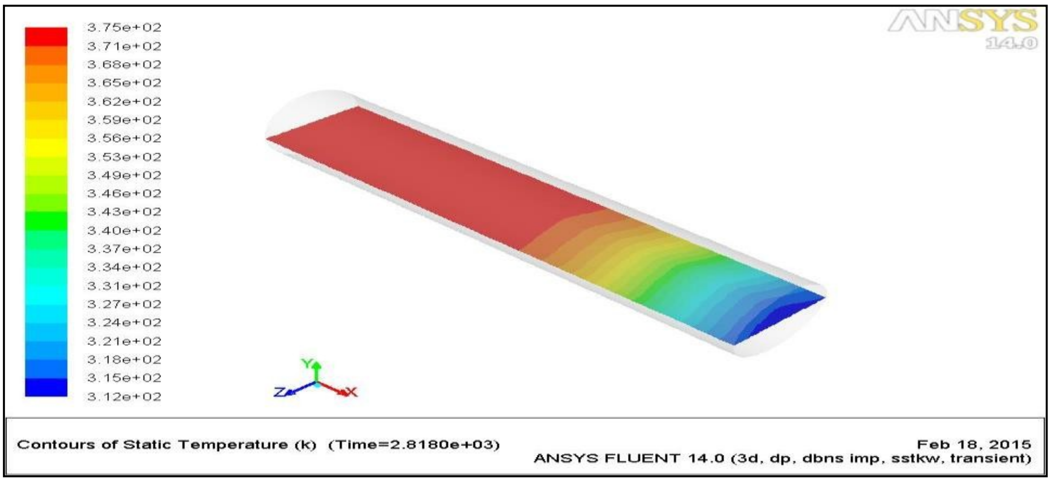


Figure 12. *Regenerator Temperature Contour along length of regenerator at t= 1e-3*

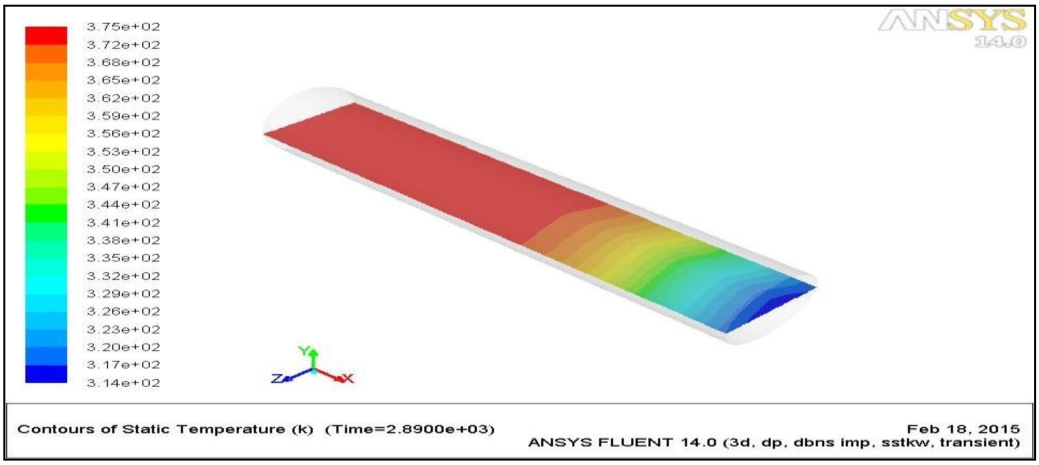
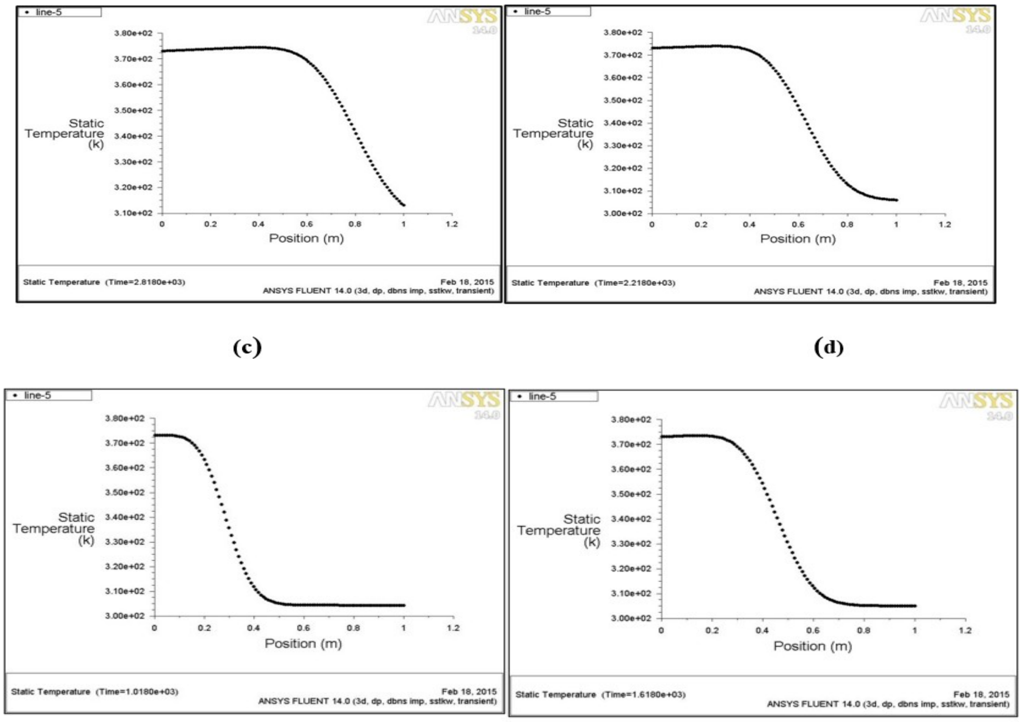


Figure 13. *Regenerator Temperature Contour along length of regenerator at t= 1.15e-3*

Fig 14 (a, b, c, d) represents the flue temp. Variation across the regenerator length during heating cycle of 60 sec. at four different time points.



(c) (d)

(a) (b)

Figure14. *Regenerator heating cycle temperature variation along Y=0 plane at (a) t = 0 min (b) t = 2e-3 min (c) t = 1e-3 min (d) t = 1.15e-3 min*

Conclusion

CFD Analysis of regeneration during transit flow was carried out using Ansus Fluent software. Flue gas was forced to cycle through the regenerator for 60 seconds at 100° C or 373 K following are the conclusions of the analysis-

- Velocity and pressure contours predict the correct behavior of the flue gases in the porous medium. Along the flow pressure decreases while velocity increase.

- Temperature contour of flue gases shows at the almost all the heat of flue gasses in lost to the regenerator.
- Temperature contour of regenerator shows that by the heating cycle of 60 secs of flue gases the regenerator is almost 50% Charged.

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