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Unsteady CFD Analysis of Regenerator

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Abstract— The paper aims to study the thermal characteristics of the regenerator and investigate the effects of various factors on the thermal characteristics of the fixed bed regenerator. In the present work various factors affecting the thermal characteristics of the regenerator such as, bed height/length, regenerator diameter, particle diameter, heat storage capacity, switching time, residence time, and gases flow direction are numerically investigated. CFD analysis is done to understand the temperature and fluid flow variations in the thermal regenerator. Commercial Ansys Fluent software is used for the analysis.

Index Terms— CFD, unsteady, regenerator, thermal characteristic, Ansys Fluent

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1 INTRODUCTION

Thermal heat regenerator is a type of heat exchanger which is filled with solids (metals or ceramics) of different shapes called bed of regenerator that have high volumetric heat capacity i.e, it can absorb and store relatively large amounts of heat. The complete working of thermal regenerator consists of two cycles, namely heating cycle and cooling cycle. During the heating cycle hot gases that can be exhaust/flue gases of any manufacturing industry such as glass manufacturing industry is made to pass through the regenerator. The heat from the flue gases is transferred to the solids and flue gases at lower temperature exist from regenerator. After the completion of heating cycle cooling cycle starts with cold air entering the same regenerator bed. The solids now transfer the heat to the cold air and cold air gets heated up. On the other hand in recuperators, the fluid between which the heat has to be transferred is separated by a wall through which heat is transferred. In recuperators there s no mixing of fluids between which the heat is to be transferred. Thus the heat in storage type heat exchanger (thermal regenerator) is not transferred through the wall as in recuperators but it is stored and rejected by solids. Figure 1 shows a parallel heat regenerator which is required for continuous flow of heated air **[1]**.

2 REVIEW OF LITERATURE

The pressure drop inside the regenerator in case of a fully developed flow is given by Ergun's equation given by **Ergun [2]**. The limitation of this equation is that it holds good for large D/dp ratio (>15), where condition of uniformity in void fraction prevails.
The Ergun's equation is:

(1)

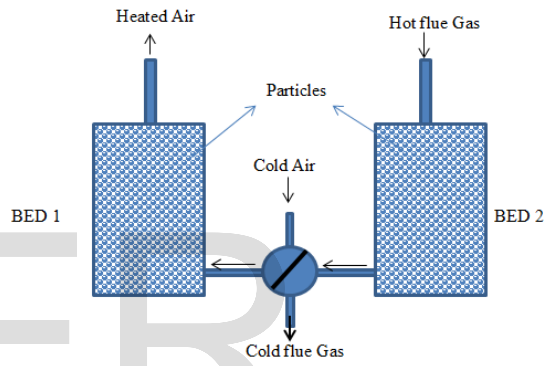

Fig. 1. Fixed bed Parallel heat regenerator [1]

The coefficients of Ergun's equation in Eq. 1 i.e., 150 and 1.75 are universally disputed and controversial. **Hicks [3]** has also given an equation for pressure drop in fixed bed regenerator with spherical particle but the coefficients in his equation are not constant but are the function of Reynolds number. In another research conducted by **Handly and Heggs [4]** it was found that Ergun's equation was unable to predict the pressure in irregular packed bed regenerator. Another equation for pressure drop in fixed bed regenerator is given by **MacDonald [5]** as:

(2)

All the above mentioned pressure equation are for fixed bed regenerator with D/d_p greater than 15. Since the regenerators with D/d > 15 are considered having uniformity in void fraction in the bed, the flow complexities is very low in these cases. The complete review of wall effects in regenerator done by **Einsfeld and Schnitzlein [6]** concluded that correlation for pressure drop by **Reichelt [7]** is most promising one.
The detailed understanding of flow structure in spaces near the particles in these beds can only be gathered by highly sophisticated flow analysis tool like Ansys Fluent.

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The one of the objectives of the present thesis is focused on studying the flow complexity with in the regenerator with different operating conditions and calculating the pressure drop and temperature variation for fixed bed regenerator with the help of CFD simulations.

3 CFD ANALYSIS

Computational Fluid Dynamics (CFD) is used to solve the complex problems in fluid mechanics and heat transfer. In cases where the geometries are very complex to predict the flow and temperature distribution CFD have been proved to be a very handy, useful and efficient. In experimental work lot of labor is required to decide the appropriate condition for stratification, which can be easily done with the help of CFD for the regenerators **[8].**

Ansys fluent is a state of art computer software which is used to model the heat transfer and fluid flow process complex engineering situations.

The computational model for the current study was made in Ansys-Design Modular and meshing was done in ICEM of Ansys Fluent. 5499 hexahedral cells comprising 6160 nodes were used for meshing to capture the effect of stratification accurately with in the regenerator. ICEM view of different mesh is shown in Fig. 2.

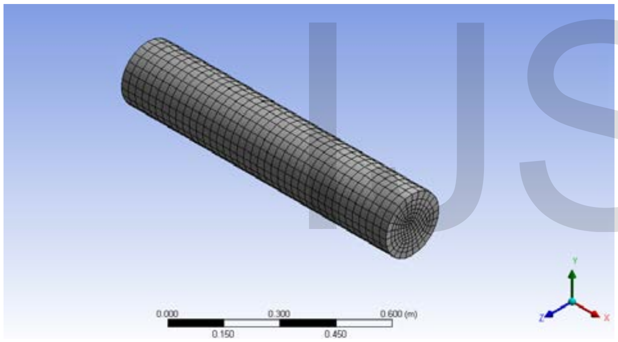

Fig. 2. ICEM view of surface meshing

3.1 Governing Equations

The governing equations with which the physical phenomenon of flow through porous medium can be governed are as follows **Panwar & Murthy [9]**:

Continuty Equation :

$$\nabla.\left(\varepsilon\rho\vec{v}\right)=0 \tag{3.19}$$

Momentum Equation :

$$\frac{\partial}{\partial t}\left(\varepsilon\rho\vec{v}\right)+\nabla.\left(\varepsilon\rho v\vec{v}\right)=-\varepsilon\nabla p+\nabla.\left(\varepsilon\vec{\tau}\right)+$$

$$\varepsilon\vec{B}f-\left(\frac{\mu}{\alpha}+\frac{C_2\rho}{2}\left|\vec{v}\right|\right)\vec{v} \tag{3.20}$$

$$\left\{\begin{matrix}\text{Rate change}\\ \text{of momentum}\\ \text{per unit}\\ \text{volume}\end{matrix}\right\}+\left\{\begin{matrix}\text{Net rate of}\\ \text{momentum}\\ \text{flux due to}\\ \text{convection}\end{matrix}\right\}=\left\{\begin{matrix}\text{Pressure}\\ \text{force}\end{matrix}\right\}+\left\{\begin{matrix}\text{Viscous}\\ \text{force}\end{matrix}\right\}+\left\{\text{Body force}\right\}-\left\{\begin{matrix}\text{viscous \& inertial}\\ \text{drag force by}\\ \text{the pore wall}\\ \text{on the fluid}\end{matrix}\right\}$$

The viscous loss coefficient and the inertial loss coefficients of the porous zone are calculated with the help of following equations:

$$\alpha=\frac{\left(d_p{}^2\times\varepsilon^3\right)}{203\times(1-\varepsilon)^2} \tag{3.21}$$

where,

dp is the diameter of solid particle (alumina)

ε is the porosity of the regenerator bed

α is the permeability

Viscous loss coefficient in each component direction = 1/α

$$C_2=\frac{3.9(1-\varepsilon)}{d_p\times\varepsilon^3} \tag{3.23}$$

where,

d_p is the diameter of solid particle (alumina)

ε is the porosity of the regenerator bed

C_2 is the inertial loss coefficient

3 RESULTS & DISCUSSION

For transient CFD simulation the regenerator was modelled in Ansys fluent. The simulation is started by making the flue gases at high temperature (473 K) to enter the regenerator bed for cycle time of 60 sec. Once the heating cycle is over the cooling cycle starts with ambient at 300 K entering the regenerator in counter flow direction for the cycle time of 60 sec.

This alternate flow of flue gases in heating cycle and ambient air in cooling cycle is continued till the steady state in temperature flow is reached. Fig. 3 & Fig. 4 shows the temperature contours along the regenerator bed length during heating and cooling cycle at plane y = 0 at time 1 and 2 min respectively.

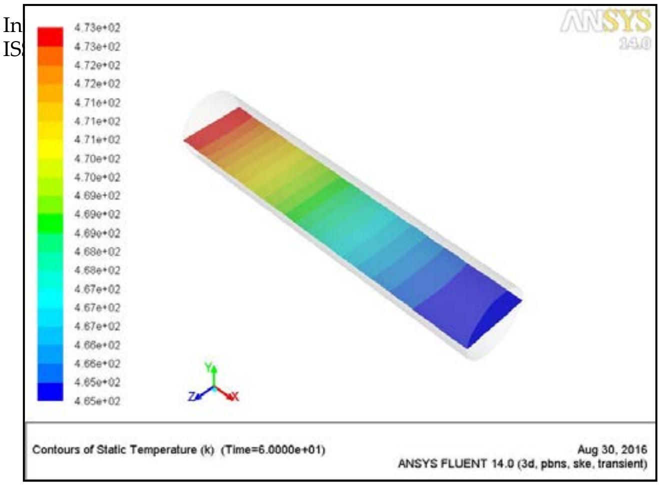

Fig. 3. Temperature variation along regenerator length at plane y=0 for heating cycle at t= 1 min

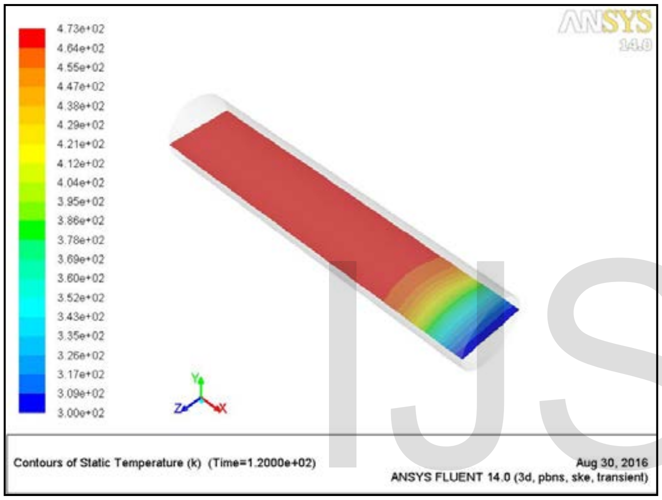

Fig. 4. Temperature variation along regenerator length at plane y=0 for cooling cycle at t= 2 min

Whereas, Fig. 5 & Fig. 6 shows the temperature contours along the regenerator bed length during heating and cooling cycle at plane y = 0 at time when steady state is reached i.e. the rate of cooling and heating is now constant. During the heating cycle the temperature at inlet flue gases entering the regenerator bed was decreases because of heat energy being absorbed by the solids and for cooling cycle the temperature was raised due to heat energy being released by the solids and transferred to the ambient air.

Figure 7 and Figure 8 shows the variation of simulated temperature of Flue gas and air during heating and cooling cycle. During the heating cycle the temperature of the flue gas is transferred to the solids in the regenerator-bed due to which the temperature of flus gases decreases as it passes through the regenerator. After 60 sec of heating period heating cycle is a discontinued and cooling cycle start with air entering the regenerator at 300 K from counter flow direction.

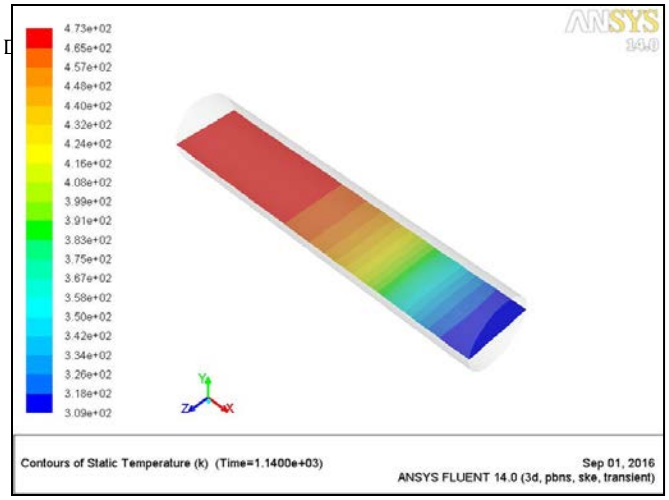

Fig. 5. Temperature variation along regenerator length at plane y=0 for heating cycle at t= 19 min

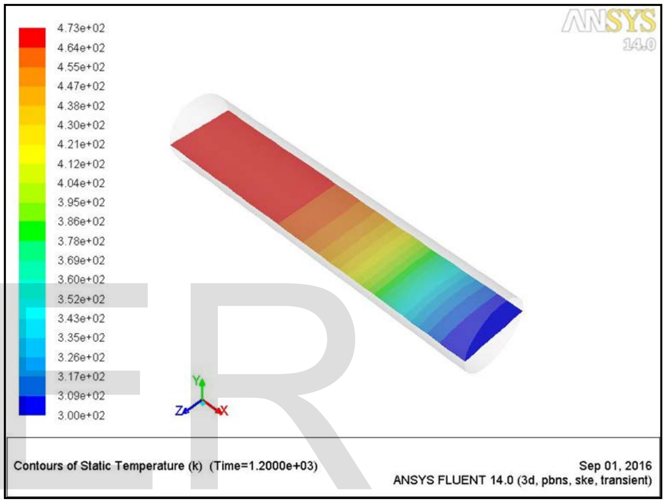

Fig. 6. Temperature variation along regenerator length at plane y=0 for cooling cycle at t= 20 min

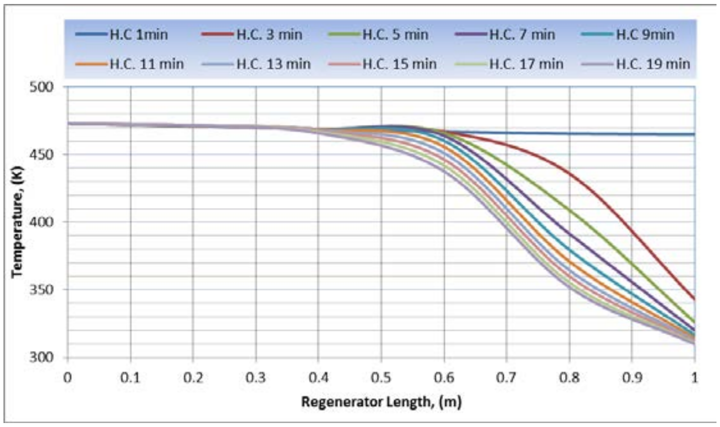

Fig. 7. Variation of temperature with regenerator length during heating cycle

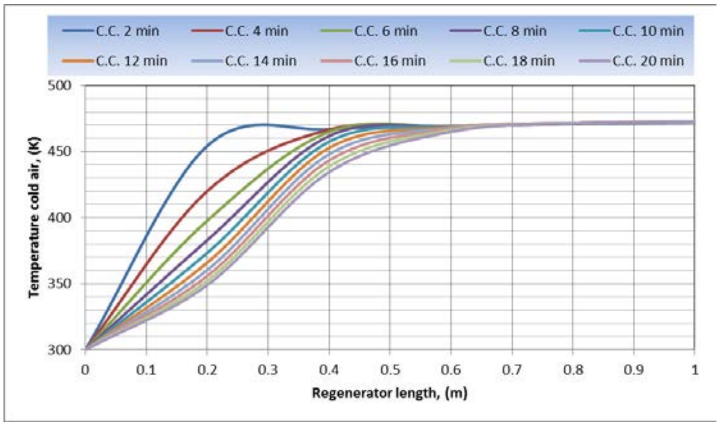

Fig. 8. Variation of temperature with regenerator length during cooling cycle

4 CONCLUSION

The thermal characteristics of regenerator were studied and effect of various factors such as regenerator height, D/dp ratio, and porosity was studied. With the help of Ansys Fluent, contours of pressure and temperature were studied for regenerator with different length.

Regenerator was modelled in Fluent and simulations were carried out to study the variation of temperature along the regenerator length. The exit flue gas temperature was calculated from the results of simulations and with the help of it the effectiveness of regenerator was calculated as a function of exit flue gas temperature.

At last the transient CFD models of regenerator with D/dp> 15 was modelled and solved in fluent. The simulation results of each time cycle (heating and cooling cycle) were analysed and efficiency for each regenerator was calculated. This transient model of regenerator can be used for other applications of thermal regenerators

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