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Packed-Bed Thermal Heat Regenerators Transient Flow Regime CFD Analysis using ANSYS Fluent

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Abstract In this study, the Pebble bed regenerator will be analyzed using computational fluid dynamics (CFD). The transitory flow produced by a solar air heater will power the Pebble bed regenerator. When hot air with a temperature of 1000 °C enters the regenerator at one end, a piece of commercial software known as Ansys Fluent conducts an analysis. The quantity of heat that is absorbed by the pebbles is calculated using this methodology. To be able to assess the regenerator's performance accurately under circumstances with variable flow, a physical model of the regenerator must be created. The performance of the regenerator is simulated under a variety of different operating and design conditions using the aforementioned model. The conventional k-e turbulent model and the common wall function are frequently used together when attempting to simulate the flow of gas.

Index Terms - Ansys Fluent, CFD, Regenerator, solar air heater, transient flow

PAGE LAYOUT

Solar power provides a variety of benefits, but the fact that it is an intermittent source of energy is one of the most significant disadvantages of using solar energy. In a similar vein, the requirements for energy that different applications have change throughout time, but they do so in a number of different ways and stages that are reliant on the supply of solar energy. In light of this, it is of the highest necessity to integrate the solar system in order to bring supply and demand together in a temporal domain. This may be accomplished by integrating the solar system. Because of the sporadic character of the energy that is generated by solar thermal systems, thermal storage systems constitute a substantial obstacle to the broad adoption of these types of systems. This is due to the nature of the energy that is produced by these systems. Solids have the ability to function as an efficient mediator in the process of transferring heat from one gas to another due to their increased volume. They are able to participate in the transfer of heat from one gas to another because to this property. Two distinct processes, the charging phase and the discharging phase, can be used to describe the process of transferring heat from one gas to another through the medium of solids. The heating of the particles by the hot gas is the first step of the process, while the heating of the other gas constitutes the second stage. The study and analysis that was done by Pinel et al. on a number of different methods for the storage of thermal energy.

A research that was carried out by Wei and his colleagues found that the regenerator is made up of a matrix for storing heat that is referred to as a pebble bed. The findings of this study were presented at a conference. This matrix has a significant capacity for the storage of heat in addition to its strong flow resistance and great temperature resistance. It also has a high resistance to the passage of fluids. A number of cycles, each of which consists simply of alternating phases of heating and cooling the surroundings, may be used to model the operation of the regenerator. This can be done through the utilization of a number of different cycles. Hot air is sent from the solar air heater to the regenerator during the heating cycle, where it helps to heat the matrix overall. This happens when the heating cycle is running.This takes place while the heating cycle is in progress. This incident takes place while the heating cycle is in the process of taking place. When a certain period of time has elapsed, the solar air heater will cease the process of releasing hot gases into the atmosphere, and it will then begin the process of cooling down the air. The heat from the matrix is transmitted from the regenerator to the cold air whenever the cold air travels through the regenerator in the opposite direction of the hot air. The function of the regenerator that is responsible for regeneration has been the subject of investigation in a number of publications that have been produced in an effort to comprehend its operation. Yu et al. and Panwar et al. developed one-dimensional models of heat transmission using transient mathematics for the solid and liquid phases of regenerators. These models were designed for heat transfer in regenerators. These iterations were designed specifically for use as heat conductors in regenerators. The transient transfer of heat via a regenerator that included spherical particles was modeled using a one-dimensional model of two-phase fluid dynamics that was established by Park et al. This model was constructed by Park et al. Zong et al. have presented a mathematical model that is three-dimensional, and it depicts the transient behavior of heat transfer in the regenerator matrix. Rafldi and his fellow colleagues developed a honeycomb regenerator with a two-dimensional structure. In the course of his inquiry, Levenspiel looked at the movement of the temperature front inside of a fixed bed regenerator. Once hot gas has been supplied, the temperature front of the gas will fall across the bed of solids and travel in the opposite direction. There are three primary occurrences that are responsible for the propagation of the hot fronts: first, a separation of the flow of gas in the packed bed from that of the plug flow; second, the resistance of the fluid to the transfer of heat between solid and gas; and third, the resistance of the packed bed's particles to the flow of heat into them. The interaction of these three processes is the primary contributor to the propagation of the hot fronts, and it is responsible for the majority of their effects. Liu et al. conducted a three-dimensional investigation of the heat transfer and gas flow in a regenerator that contained aluminum balls for their study, which can be found here.

PHYSICAL MODEL

This is done in order to carry out an investigation into the results of the simulated operation of the heat storage system (Regenerator). When recent advancements in high-performance computer hardware are taken into account, as well as the enhanced analytic capabilities of commercial CFD software, This is done in order to assess whether or not the treatment that has been suggested is, in fact, successful.

Instead of being separated into the three distinct zones that would ordinarily be expected in an arrangement of this kind, the space that is filled by the storage tank is regarded as a single fluid zone. This is because the tank occupies the whole region. This is due to the fact that the tank consumes the whole space. Figure 1 provides a diagrammatic illustration of a regenerator's internal workings. This particular kind has a length of one hundred centimeters and a diameter of twenty centimeters. A computational grid that is based on ICME Fluent and includes hexahedral cells that are dispersed equally throughout each zone can be seen in Figure 2. This grid was created by our team. The following list of presumptions serves as the foundation for the mathematical modeling of the regenerator:

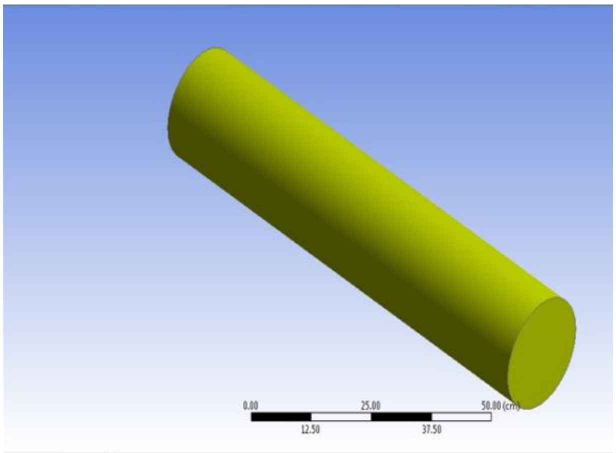


FIGURE 1:

PHYSICAL MODEL OF REGENERATOR

- It is hypothesized that the gas moves in a laminar pattern through a porous medium as it passes through the pebble bed of the regenerator. This hypothesis is based on the observation that the gas moves in this manner.
- Let's proceed with the understanding that the regenerator is unable to cause the gas to become more compressed.
- The only factor that has a significant influence on any of the thermophysical characteristics of a substance, including those of liquids, gases, and solids, is temperature. Temperature is the only component that can be controlled.

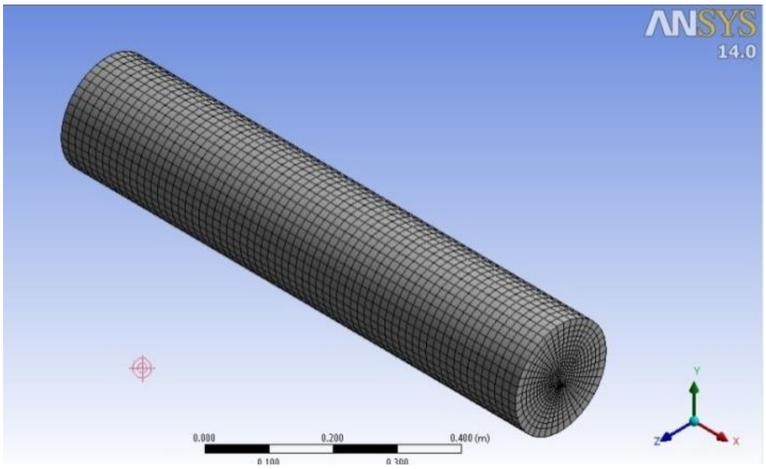


FIGURE 2

COMPUTATIONAL MODEL OF REGENERATOR

GOVERNING EQUATIONS

In the computation of the turbulent flow field that may be found in the regenerator, the standard k-turbulence model is utilized. This matter has been brought to our attention previously. 1.2.1 The equation describing continuity is as follows:

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

1.2.2 Momentum Equation:

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

In order to examine the impacts of pressure drop and drag coefficient in fixed bed regenerators, Si. Reddy and Joshi carried out a computational fluid dynamics (CFD) simulation as the source term for the ith moment equation. This was done so that they may investigate the ways in which these two elements interact with one another.

Huang offered both an equation for permeability and an inertial resistance factor for gas flow in the axial direction in his work modelling the mechanism of heat transfer within a regenerator. These two elements concern the movement of gas. This was done as part of his modeling efforts. These two considerations are relevant to the movement of the gas. This was a part of the work that he was performing at the time. The rate of heat transport could be calculated with the assistance of this equation, which was very helpful. You can figure out which of the two options is preferable by applying the following equations to the situation:

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

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

Energy Balance Equation:

$$\underset{\text{Heat carried by fluid}}{u_f \rho_f c_f \frac{\partial t}{\partial x}} + \underset{\text{Heat stored in solid}}{\rho_s c_s (1-\varepsilon) \frac{\partial t}{\partial \tau}} = \underset{\text{Heat transfered by solid}}{k_s \frac{\partial^2 t}{\partial x^2}} \quad (5)$$

Boundary Condition:

at x=0

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

at τ=0

$t=t_{amb}$ (7)

Energy Balance for Solid:

$$\underset{\text{Heat stored in solids}}{S_{fr} (1-\varepsilon) \rho_s c_s \frac{\partial t_s}{\partial \tau}} = \underset{\text{Heat transfered by Fluid to Solids}}{hA(t_f - t_s)} \quad (8)$$

Initial and boundary conditions:

at τ=0

$t=t_s=t_0$ (9)

at τ>0 x=0 $t_f=t_{fi}$

x=0 $$t_s = (t_0 - t_{fi}) \exp\left(\frac{\tau h A}{S_s \rho_s c_s} \right) + t_{fi} \quad (10)$$

TABLE 1

BOUNDARY CONDITIONS

S. No	Modeled Equation	Velocity	Flow	Temperature
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

RESULTS & DISCUSSIONS

The calculation will begin in earnest when the heating cycle is over. While the air entering from the air heater is heated to 373K before being used, the regenerator is maintained at a temperature of 300K. The pressure leaving the regenerator will start off at zero when it is first switched on. Table 1 may be found here, and it lists the boundary conditions. A thermal regenerator's mathematical modeling may be handled via the computational fluid dynamics (CFD) program Ansys Fluent.

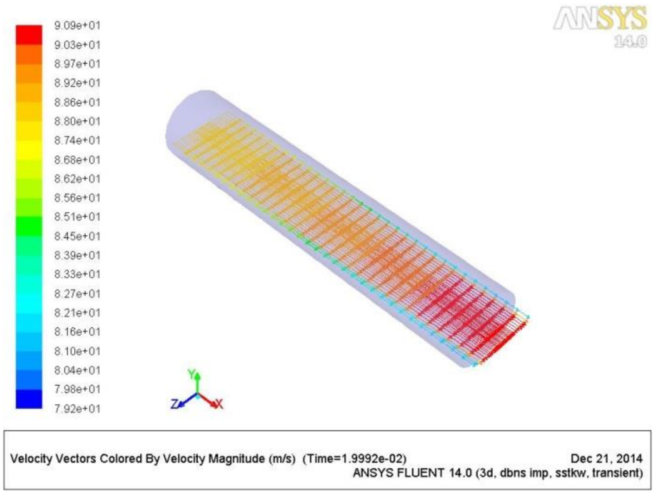


FIGURE 3

VELOCITY VARIATION ALONG REGENERATOR DURING HEATING CYCLE

In order to successfully manage the domain, the team has decided to put into action a density-based transient solution. This will be the strategy they use. In order to solve the equations, the control volume approach is utilized first to discretize the governing equations into implicit form. This allows the equations to then be solved. Following this step, techniques based on COUPLES are utilized in order to solve the equations. Following a heating cycle that lasts one minute and ten seconds, the results are analyzed before being shown to the user.

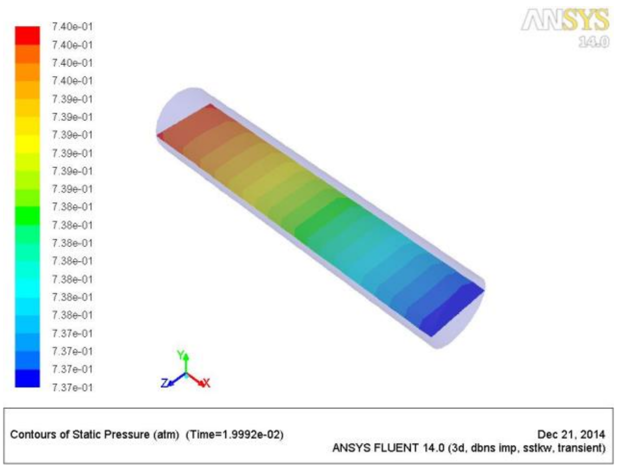


FIGURE 4

PRESSURE VARIATION ALONG REGENERATOR DURING HEATING CYCLE

Figure 4, which may be seen by clicking this link, provides a visual representation of the pressure variation along the line y=o. When evaluating the performance of the regenerator, the change in pressure is a factor that is quite significant and should be taken into consideration. The graph makes it abundantly evident that there is a consistent decrease in pressure in the direction that the gas is going, which is true for both the flow and pressure directions. This is illustrated by the fact that the pressure decreases as the flow decreases. This is true for travel in either direction. The end of the heating cycle is signaled by the release of the gas into the environment at a pressure of 7469 pascals, at which point one may claim that the cycle is complete. As the pressure in the system drops, you can see in Figure 3 that the regenerator's flow rises in the opposite direction of the pressure drop. This causes the flow's velocity to increase.

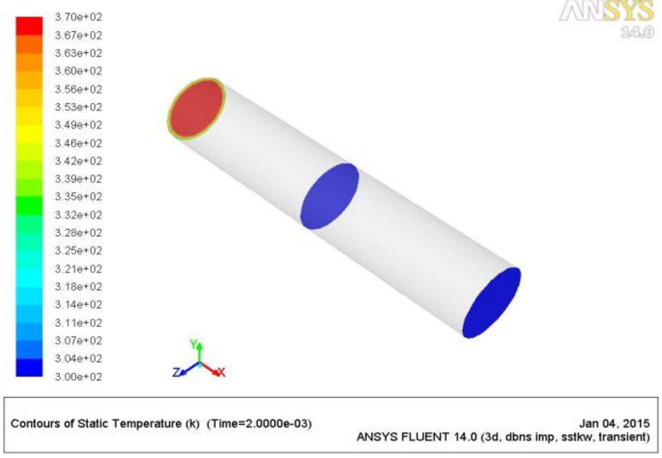


FIGURE 5

GAS TEMPERATURE VARIATION ALONG X=0, X=0.5 AND X=1M PLANE AT T = $2X10^{-3}$

The temperature variation that happens in the porous medium over the course of time as the heating cycle progresses is depicted in Figures (5), (6), (7), and (8), respectively, and may be seen at planes x=0, x=0.5, and x=1m, depending on the figure. These planes were chosen because of the constant distance that separated each one from the next. In the beginning, the temperature of the porous medium is kept at 300 degrees Celsius while hot gas that has been heated to 373 degrees Celsius is fed to the input of the regenerator.

The Y-axis will continue to trend higher in the direction of increasing temperature as the temperature continues to climb. The average temperatures of the intake and outflow were 370 and 300 degrees Celsius, respectively, at time step 1.02x10-1; however, these temperatures will continue to rise during the remainder of the experiment.

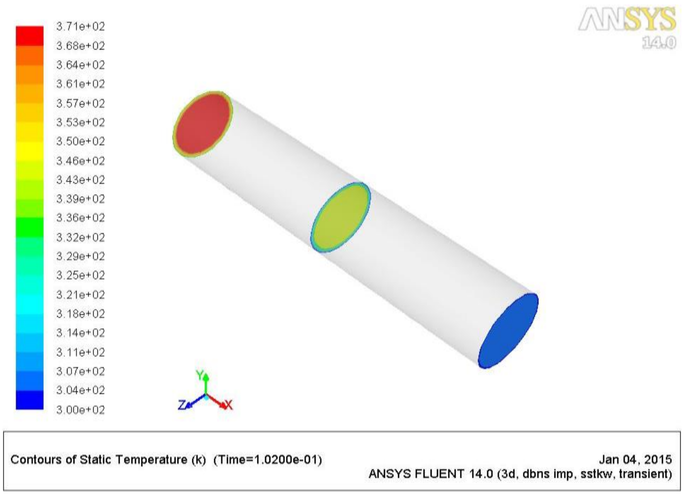


FIGURE 6

GAS TEMPERATURE VARIATION ALONG X=0, X=0.5 AND X=1M PLANE AT T=$1.02X10^{-3}$

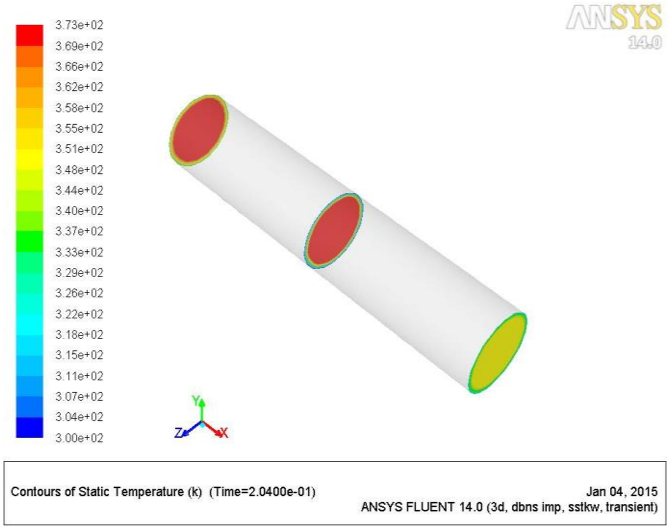


FIGURE 7

GAS TEMPERATURE VARIATION ALONG X=0, X=0.5 AND X=1M PLANE AT T=1.15X 10^{-1}

The figure numbered (9), (10), (11), and (12) represent, correspondingly, the transient temperature changes of the regenerator bed, which is also referred to as the pebble bed. These temperature variations occur during the heating cycle. These graphs illustrate the variations in temperature that occurred at a range of different time step settings. Temperature variation that takes place along the plane in which Y=0 is defined likewise takes place in the same manner as temperature variation that takes place along the plane in which x is defined. The regenerator is able to boost the temperature of its bed by drawing heat from the hot air that is present in the surrounding region while the heating cycle continues to run.

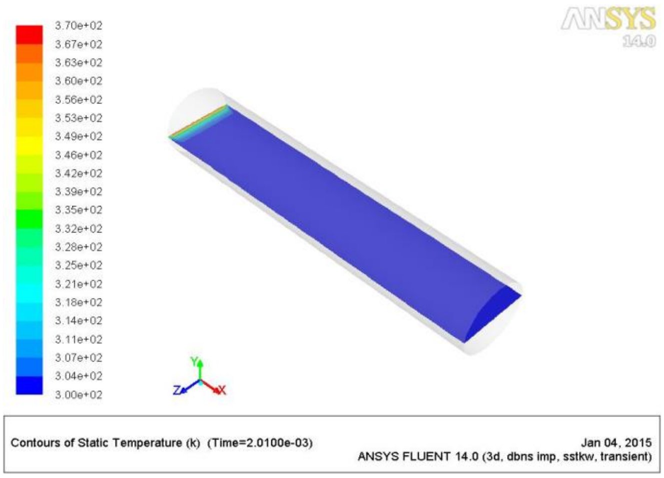


FIGURE 9

PEBBLE BED TEMPERATURE VARIATION ALONG Y=0 PLANE AT T=2X10^{-3}

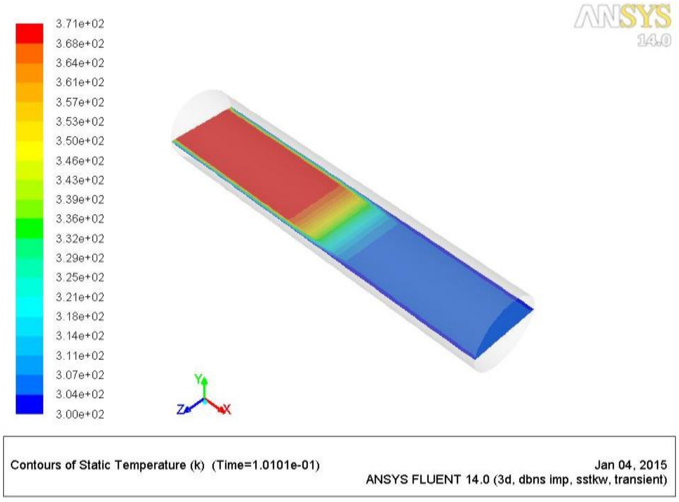
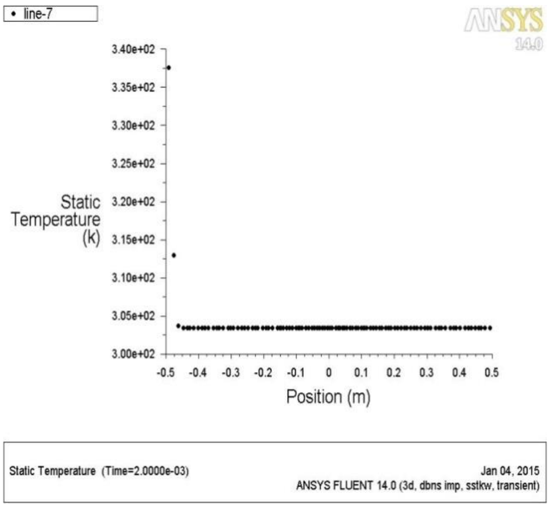


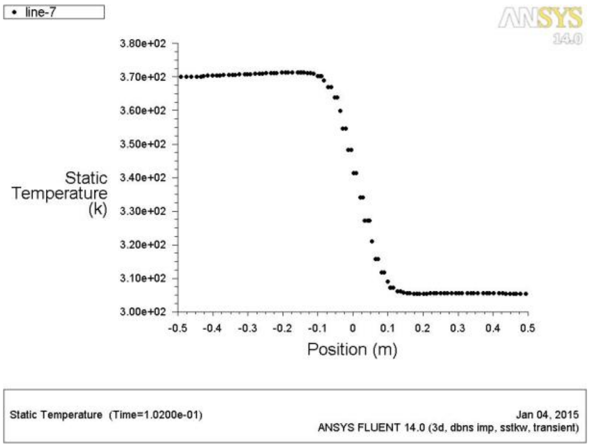
FIGURE 10

PEBBLE BED TEMPERATURE VARIATION ALONG Y=0 PLANE AT $T=1.01X10^{-1}$

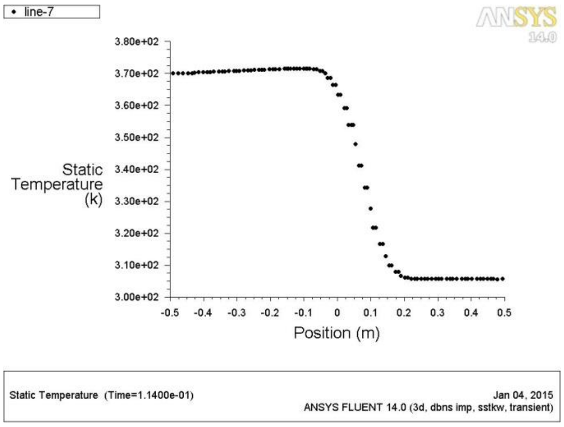
The temperature change that occurs along the axis of the pebble bed regenerator may be viewed graphically in Fig. 13(a), (b), (c), and (d), respectively. Each of these figures represents the temperature change in a different way (d). The progression of the temperature front inside the regenerator is seen in Figures 13(b), 13(c), and 13(d) show several situations.as it travels from one area to another. It is possible that one, two, or all three of the following variables are responsible for this progression: Because to the fact that some fluid particles travel at a faster speed than others, the usual flow of hot gas through the porous medium is disrupted. This is caused by the fact that certain fluid particles travel more quickly than other fluid particles. (i) an abnormality in the migration of a hot gas plug through a porous medium as compared to its usual movement. (ii) Because there is fluid present in the system, heat cannot go from a gas to a solid as it would ordinarily do; this is the opposite of what would typically occur. It's likely that beds made of coarse materials will have a much smaller area and heat transfer coefficient compared to beds composed of tiny grains. This is because coarse materials have a larger surface area. This is because the coarse solid particles have greatly increased in size, which has led to the current situation. (iii) There is a barrier that stops heat from entering the particle, and it takes very long for large solid particles to reach a temperature where they may be heated. This makes it difficult to heat large solid particles.



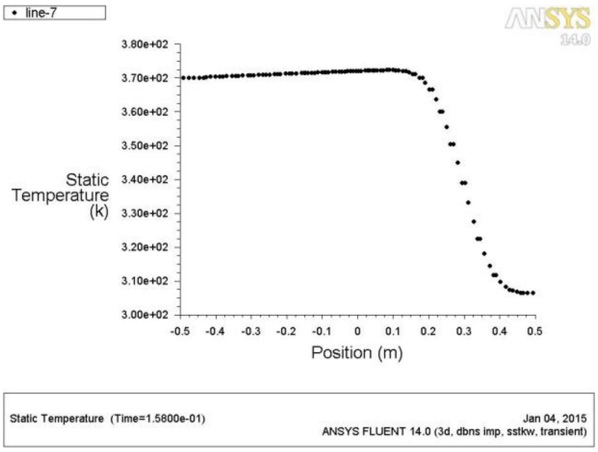
(a)



(b)



(c)



(d)

FIGUGE 13

REGENERATOR TEMPERATURE VARIATION ALONG Y=0 PLANE AT (A) T=2X10-3, (B) T=1.02X 10-1, (C) T=1.15X 10-1, (D) T=2.04X 10^{-1}

CONCLUSION

The unpredictability of solar power's energy production is one of its most major drawbacks; however, this shortcoming may be somewhat overcome by the utilization of thermal storage devices. Regenerators generate high temperatures that are used in a range of locations, including households and commercial institutions. These temperatures are ideal for use in a variety of environments. In order to evaluate the efficiency of regenerators, a three-dimensional transient (unsteady) mathematical model was constructed. This model's goal was to determine how well regenerator's function. Fluent was used since it was the most effective method for solving the problem. The audience was given a presentation that detailed the findings of a research into fluctuations in temperature, velocity, and pressure. The presentation was given in front of the audience. The following choices and conclusions were arrived at after consideration and deliberation:

I. The movement of a gas along a certain path result in a steady decrease in pressure in that direction. This phenomenon is known as the pressure gradient. The gas has an out pressure of 7469 pa after the heating cycle is complete, and the flow velocity through the regenerator has increased from 5 meters per second to 9 meters per second. Previously, the flow velocity was just 5 meters per second. At the beginning of the process, the gas was pumped into the system at a rate of five meters per second.

II. The temperature of the porous medium is kept at 300K throughout the operation, while hot gas with a temperature of 373K is fed into the regenerator at the beginning of the procedure. Along the Y-axis, the temperature will continue to rise to ever-higher and more extreme levels. The average temperatures of the intake and outflow were 370 and 300 degrees Celsius, respectively, at time step 1.02x10-1; however, these temperatures will continue to rise during the remainder of the experiment.

III. As the heating cycle continues, the temperature of the bed continues to rise as a direct result of the regenerator drawing heat from the hot air and then transferring that heat to the bed. This process occurs while the bed is in contact with the regenerator.

IV. As the temperature front travels through the regenerator, it is easy to observe that it is expanding as it moves through the device. This is due to three separate phenomena: hot gas flowing away from the plug in a porous media; fluid that resists both heat movement into and out of solids and between gases particles that resists heat transfer between gas and solid. Hot gas moving away from the plug in a porous material. It is possible to watch the expansion of the temperature front as it moves through the regenerator. This may be seen as an increase in temperature.

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