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DESIGN AND CFD ANALYSIS OF THERMAL ENERGY STORAGE SYSTEM IN APPLICATION TO SOLAR COOKER

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ABSTRACT

LPG cooking stoves to cook the food in most houses.In India, 20Crores families are spending Rs 1.5 lakh Crores for LPG every year.In India, the solar energy is available abundantly for 9-10 months in a year. At present, solar cookers are to be placed in a open area for heating purposes. The cooking can be done only when there is hot sun.The thermal energy storage systems are used in the solar thermal power plants to preserve energy by using phase change materials which are are very costly. Hence there is a need to design and develop a low cost thermal energy storage system in combination with parabolic solar dish collectors for usage of energy at all times.

In this work, a solar parabolic dish collector with thermal energy storage system is designed to reduce the initial cost, and to improve the rate of heat energy storage and retrieval capacities by using a specially designed carbon bricks. The analysis of the thermal energy storage system is carried out using the ANSYS-CFX Software.

The CFD –Analysis is carried out for hot fluid i,e for heating the bricks and cold fluid i.e, for cooling the brick. The results shows that the heat transfer co-efficient is around 15 to 20

w/m^2/°k for hot fluid and 25 to 40 w/m^2/°k for cold fluid. The hot fluid heat transfer co-efficient is less because of its low density and cold fluid heat transfer co-efficient is more because of high density of air, the overall heat transfer co-efficient for heating the thermal energy storage system and retrieving the heat will be in between 20 to 25 w/m^2/°k.

KEYWORDS:BRICKS,HEAT TRANSFER COEFFICIENT, THERMAL ENERGY STORAGE

1.INTRODUCTION

Most households use LPG, biogas or wood for cooking purpose. In very few houses the solar cooking stoves are used for cooking purpose. The major draw back of usage of solar energy is availability between 9am to 4pm only and takes more for cooking. At the same time solar cooking stoves are taking plenty of time and it is not possible cooking 2 to 3 vessels at a time like 2 to 3 burners LPG stoves.

Even though, solar energy is abundantly available, we are not in a position to use the solar energy for cooking purpose. Solar energy is used for heating water using flat plate collector which can be stored in a tank at 70°C and can be used next day morning. Because of the storage system, the solar water heaters are little bit more popular than solar cooking stoves. So, there is a emergency need to develop the solar based cooking stove with high temperature thermal energy storage system. In this work, an efficient and low cost thermal energy storage system is designed using carbon bricks coated with clay.

1.1 SOLAR COOKING STOVE WITH THERMAL ENERGY STORAGE SYSTEM:

It consists of a solar concentrating collector, high temperature thermal energy storage system, heat exchange based cooking stove and working fluid circulating system. In this system, the heat collector receives the heat at the parabolic dish collector is trapped and stored in the high temperature thermal energy storage system. By circulating the air between receiver and thermal energy storage system. The thermal energy storage system consists of carbon bricks coated with clay and an Aluminum pipe heat exchanger. The heat stored in the bricks is transferred to the aluminum heat exchanger by circulating the air between bricks and heat exchanger. The heat stored in the bricks is in the range of 300°C to 600°C.

The heat received in the aluminum heat exchanger located in thermal energy storage system is transformed to the cooking stove heat exchanger by circulating the terminal 66 liquid. This liquid can withstand up to 300°C. The terminal liquid will be heated the thermal energy storage heat aluminum exchanger up to 280°C maximum. The maximum cooking temperature required in oil frying is 180°C. Therefore the terminal 66 liquid can liberate the heat by coming down from 280°C to 200° C. The thermal energy storage system will be designed to store the heat energy sufficient for 3 days cooking needs. Because of this reason we can use the solar cooking stove in combination with thermal energy storage system just like LPG cooking stove. Even though little bit investment of solar cooking stove is more compare with LPG cooking stove. But their own be operating cost. The rough estimations of solar cooking stove with thermal energy storage system is Rs.25,000. The maximum payback period is 2 to 3 years and the balance lifetime of 13 years can be utilized with only operating cost.

2. LITERATURE REVIEW:

PankajSainiet.al [1] presented a paper on thermal energy storage unit based parabolic dish collector for indoor cooking applications. He used acetanilide as PCM in thermal energy storage system. The cooking performance was satisfactory.PiaPiroschkaotte [2] studied the usage of solar cooking technology in India and Burkina Faso, based in social and cultural aspects.
Iris Chu et.al [3] designed and developed a PCM based thermal energy storage system integrated with concentrated solar collector to cook the food after sunset.AbhishekSaxena [4] studied the different Phase Change Materials usage in the thermal energy storage system indicated with concentrated solar collector for cooking Applications. He found that stearic acid is a good PCM for cooking applications. He tested experimentally using a simple box type solar cooker. Gavisiddeshaet.al [5] developed a parabolied concentrator solar cooker and evaluated it performance by using a 3liter pressure cooker with various food materials cook. Ashok kundapuret.al [6] studied the various aspects of testing, aesthetics, cost related to solar cooker for standardizing the solar cookers.

3. ENERGY STORAGE SYSTEM WITH INSULATION:

The thermal energy storage system in a solar cooker is designed. The capacity of thermal energy storage system is designed to use for 3 days by a family consisting of 5 members. The maximum temperature of thermal energy storage system can reach upto 600°C. The minimum temperature maintained in the thermal energy storage system is 300°C. The thermal energy storage system is made of carbon bricks and coated with thin clay to avoid compression of Carbon. It is assumed that the thickness of clay and its effect on heating and cooking is negligible. The insulation provided surrounding the thermal energy storage system is Vacuum. The design calculations of the thermal energy storage system is given below.

3.1 THEORITICAL CALCULATIONS:

Family size = 5 members

Average quantity of food for person = 1 kg/day

Cooking will be 5kgs at maximum,

Total heat required to cooked the food ($m\ Cp\Delta t$) = 5kgs × 4.2 ×100˚c

= 2000 KJ

Loss of water vapor = 1kg

Latent heat = 2200 KJ

Expected losses to be atmosphere from the cooking vessel = ½ kg

Heat loss from cooking vessel and pipes = 2000KJ

Storage system for 3days:

Total required heat for 3days = 3(2000+2200+2000)

=18,600KJ

Quantity of thermal energy storage material = 250kgs (approximately)

Specific heat of brick = 1KJ

Range of temperature energy can be stored = 300˚C to 500˚C

Total heat that can be stored in the thermal energy system = $m.Cp.\Delta t$

= 250 × 1 × 200

= 50,000 KJ

Density of brick = 2 kg/liter

The volume of brick = 250/2 = 125 liters

Volume of air gap between the bricks = 125 liters

Total volume of thermal energy system = 250 liters

Vacuum insulation flask = 100 liters

Total volume of thermal energy system = 250 + 100 = 350 liters

Height of tank = 2 meters

Tank shape is Cylindrical (Vertically)

Tank volume = 350× 100 Cm^2

$$\frac{\pi}{4}d^2h = 350 \times 100$$

$$d^2 = 2229.29$$

$$d = 47.21 \text{ Cm}$$

Surface Area (A) = (π.d.l) + $2(\frac{\pi}{4}d^2)$

A= (3.14 × 47.21 × 200) + $2(\frac{\pi}{4}(47.21)^2)$

A = 3.3147 m^2

Q = h A Δt T

$$h = \frac{Q}{A.\Delta t.T}$$

$$= \frac{32000}{3.3147 \times 400 \times 259200}$$

= 0.0000931131 KJ/ m^2/°C/Sec

h = 0.0931131 j/m^2 /°C/Sec

Where

Q=32000 KJ,

A=3.3147 $m^{2,}$

Δt=400˚c,

T= 3600 × 24 × 3

=259200 sec.

Thermal Conductivity of Vacuum Insulation = 0.007 W/m.K

$$0.093 = \frac{0.007 \times 1000}{x}$$

$$x = \frac{0.007 \times 1000}{0.093}$$

x =75.26 mm

Diameter (d) =47.21 cm

Diameter of the storage tank with insulation flask = 47.21+20

= 67.21 cm

Bricks weight = 375 Kgs Approximately

Maximum temperature of air entering into the thermal energy storage system = 550°C

Minimum temperature of the bricks to be maintain = 250°C

Time required to be heat this thermal energy storage system = 5 hours

Heat capacity of thermal energy storage system (Q) = m.Cp.Δt

$= 375 \times 1 \times (550 - 250)$

= 93,750 KJ

Heat absorption rate per second(Q) = $\frac{93,750}{5 \times 3600}$

Q= 5. 208 KJ

Quantity of air to be supplied per second (Q) = m.Cp.Δt

= 5.208 KJ

Mass of air (m) = $\frac{Q}{Cp.\Delta t}$

$= \frac{5.208}{1 \times 50}$

= 0.010416 kg/ sec

Where

Cp = 1KJ

Δt = 50 sec

Volume of air at 550°C = $\frac{M.R.T}{P}$

$= \frac{0.1 \times 343 \times (550 + 273)}{1 \times 10^5}$

= 0.282289

= 0.28 m^3 air/second

Area of Brick and Air Domain:

In brick domain: Length of brick domain = 1 Cm

Width of brick domain = 20 Cm

Area of brick domain = 1×20

= 20 Cm^2

In air domain: $A = 6 \times (20 (\frac{1}{2}(2.0 \times 3.5)) + (1 \times 20))$

$A = 6 \times 90\ Cm^2$

$= 0.54\ Cm^2$

Velocity of air (V) = A.v = 0.28 m^2/ sec

$= \frac{0.28}{0.54} = 5.185 m/s$

$= 5.185\ m/s$

Surface of area(A) = $((20 \times 4.03) + (4\times3.5)) \times 200\ Cm^2$

$= (80.6 + 14) \times 200\ Cm^2$

$= 94.6 \times 200\ Cm^2$

$= 18{,}920\ Cm^2$

$A = 1.892\ Cm^2$

$Q = h.A.\Delta t$

$h = \frac{Q}{A\times\Delta t}$

$= \frac{5.208}{(1.892 \times 50)}$

= 0.05505 KJ/m^2/◦c

= 55.05 J/m^2/◦c

h = 55.05 j/m^2/◦c

4. METHODOLOGY

4.1 Modeling and CFD analysis of Solar Thermal Energy Storage System:

The basic steps involved in solving any CFD problem are as follows:

- Identification of flow domain.
- Geometry construction or Component Modeling.
- Grid generation.
- Specification of boundary conditions and initial conditions.
- Selection of solver parameters and convergence criteria.
- Results and post processing.

The Solar Thermal Energy Storage System is modeled and analysis is carried out by following above steps. CFX-14 For Analysis of pre solver and post, ICEM-14 for Grid generation of brick and air.

The work inthis paper is limited to heat transfer between air and brick for the FIRST stage using solid works, grid generation of each domains and analysis of using CFX. The flow domain of the Brick and air is modeled in SOLIDWORKS from the 2D drawings as shown in Figure.1 and exported into ICEM CFD to generate the mesh. It is a Semi-automated meshing module which represent the rapid generation of multi-block structured or unstructured hexahedral volume meshes. Blocks can be interactively adjusted by splitting it to the underlying CAD geometry and fitted internal can be generated by the system automatically.

4.1.1. MODELING:

The "2D Sketch" data file contains the brick "profile" in Cartesian or cylindrical form. The 2D points are listed, line-by-line, in free in a closed loop surrounding the brick.

A minimum of two brick profiles are required, one which lies exactly on cold surface and one which lies exactly on the hot surface. The profiles must be listed in the geometries are handled by placing multiple domain definitions.

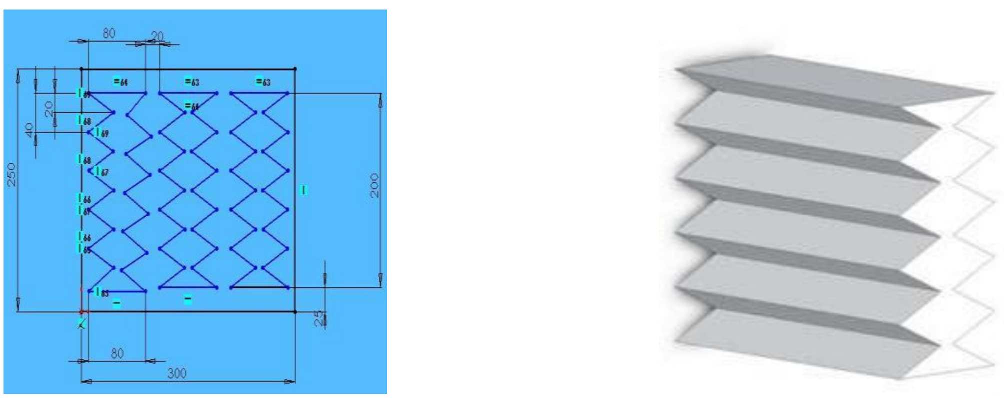

Figure1 2D Sketch and 3D model of solar thermal energy storage fluid domain

4.2. GRID GENERATION

ICEM CFD grid is designed for the creation of high quality computational meshes for periodic air and brick geometries as shown in Figure.2. Pre-defined grid templates are used to minimize grid set-up time and mesh for the given application.

Steps involved in creating grid

1. Select a ICEM CFD topology suitable for the application.
2. Import the hub, shroud and blade geometry as well as blade count and axis of machine rotation.
3. Select the appropriate, inlet, outlet and tip clearance toggles in ICEM CFD grid.
4. Review and adjust node distributions.
5. Review and adjust node counts/mesh size.
6. Creates the mesh.
7. Review the mesh.
8. Repeat the steps 4, 5 or 6 as required.

Inflow and outflow regions etc. Meridional view shows the number of profiles from air and brick which defines the shape and location of the grid near the side edge. The final step improves the grid quality by checking the skew angle that is depends on number of elements as shown in Table.1 Meshing of storage system like stay air and brick is very simple and easy by using ICEM CFD grid.

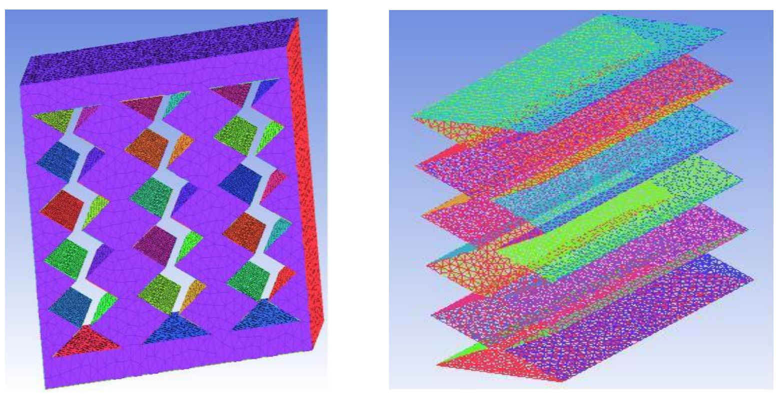

Figure.2 Grid Generation of Brick and Air domain

Table 1: Tetrahedral elements meshing of air fluid domain

Domain	Nodes	Elements
Air	118542	601446
Cold	29601	139940
All Domains	148143	741386

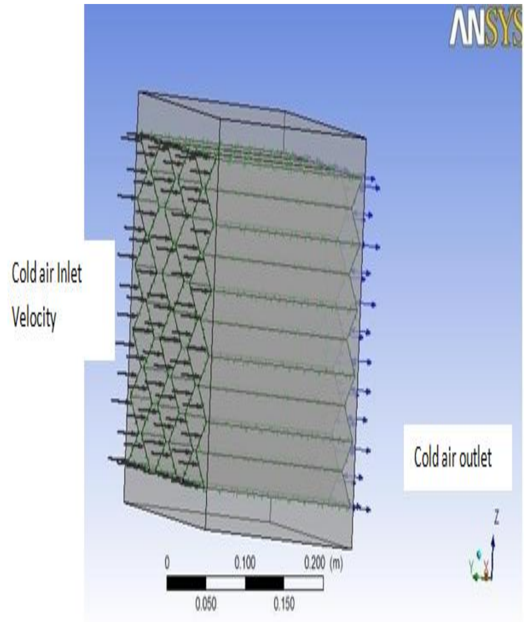

Figure. 3 Define Cold and hot air and brick (assembly) Domain boundary conditions

4.3. IDENTIFICATION OF FLOW DOMAIN:

Before constructing the grid, it is required to understand the exact flow domain properly. The flow domain in this case is air. It is therefore required that before going ahead with 3D modeling and grid generation, the common interfaces should be clearly defined. The software that is used is decided later based on nature and complexity of the geometry. For air, obtained from 2D drawing and subsequently grids are generated using ICEM CFD, so that realistic boundary conditions as shown in Figure.3 can be given at the inlet and outlet surfaces.

The boundary wall is the region where no slip condition exists and the velocity gradually increases and reaches to mainstream velocities. That means, velocity gradient exists there and that region close to the boundary wall should have fine grids.

4.4 ANALYSIS (CFX-14):

The analysis of existing 1st stage of pressure has been done using CFX software.

1. Importing already created Turbo grid Mesh.

2. Defining the Domains.
3. Defining the boundary conditions like mass flow rate at the inlet, fluid properties at the inlet, outlet etc.
4. Defining the interfaces.
5. Write definition file.
6. Start run.

4.5 CFD -ANALYSIS OF A STORAGE ENERGY SYSTEM:

CFD analysis was made to understand the flow through the storage system. ANSYS CFX-14 software tool was used for analysis purpose.

Specification of boundary conditions and initial conditions:-This part of simulation is done in CFX-Preprocessing **.** The files with the extensions: **".grd", ".gci", ".bcf"** of air and brick, also the files without having any extension of seals of a utility storage energy are copied into a new folders separately and this grid file are read into pre-processing model of CFX-14 software.

4.7. PHYSICS DEFINITION :

Physics definition involves defining the physical parameters such as, temperature, velocity, etc. and other boundary conditions relevant for the problem. Preprocessing involves the following steps. The software used was CFX PRE 14.

I. DEFINING THE DOMAIN AND BOUNDARIES :

The stage i.e., the air and brick along regions like inlet and outlet are defined. The air, brick of both assemblies was treated as walls. The interface between the air and brick is defined as stage. The boundary conditions were applied at inlet and outlet.

II. INITIAL CONDITIONS :

The initial condition for the pressure field should be the average of the value of pressure specified on any of the outlet boundaries and the lowest value of pressure specified on any of the Inlet boundaries. A sensible initial guess for the temperature field is an average of the boundary condition temperatures.

THE STRUCTURE OF ANSYS CFX :

ANSYS CFX consists of four software modules that take a geometry and mesh and pass the information required to perform a CFD analysis.

5. RESULT AND DISSCUSIONS:

The CFD –Analysis is carried out for hot fluid i,e for heating the bricks. The results shows that the heat transfer co-efficient is around 15 to 20 $w/m^2/^{c}k$. the cold fluid CFD-Analysis i,e for cooling the bricks.As per above Figure 4, Figure 5, Figure 6 shows that (heat transfer coefficient wall, heat flux, temperature, and velocity) getting good range of results compare to theoretical results.

The results shown in Table.2 that the heat transfer co-efficient is varying from 25 to 40 $w/m^2/^{c}k$. the hot fluid heat transfer co-efficient is less because of its low density and cold fluid heat transfer co-efficient is more because of high density of air, the overall heat transfer co-efficient for heating the thermal energy storage system and retrieving the heat will be in between 20 to 25 $w/m^2/^{c}k$.

Table 2: Results of domains in cold fluid and hot fluid

S.No.	Properties of fluid	In Cold air	In Hotair
1	Wall heat Transfer Coefficient(W/m^2K)	30.6	21.4
2	Temperature (K)	921.3	1075.0
3	Wall Heat Flux (w/m^2)	29630	30201
4.	Velocity (m/s)	5.18	5.18

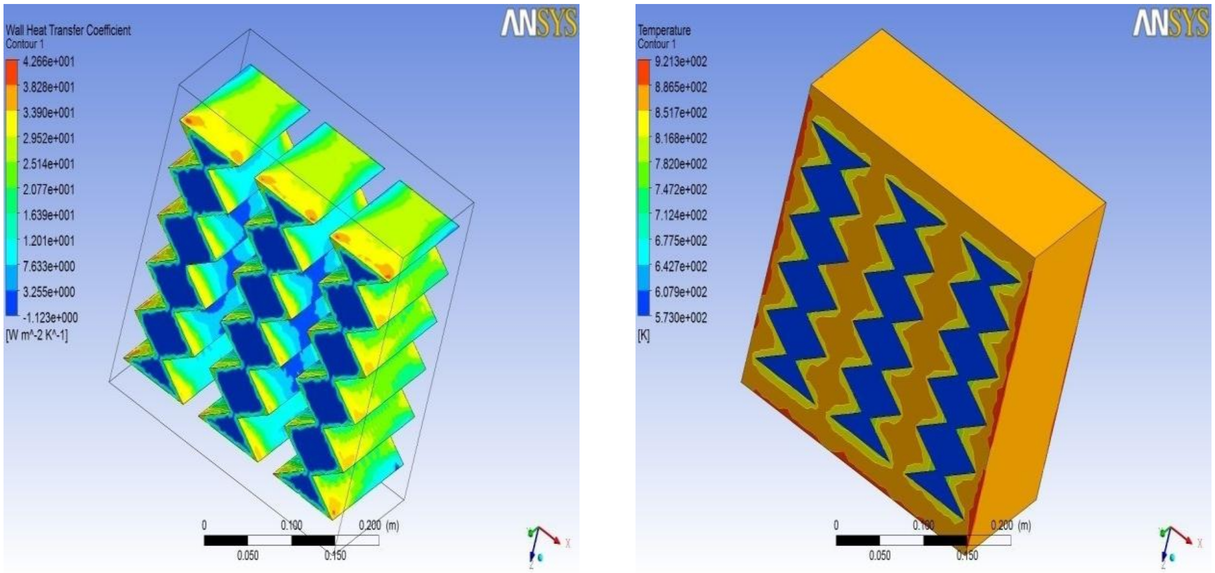

Figure.4 Wall heat transfer coefficient and Temperature in cold fluid region

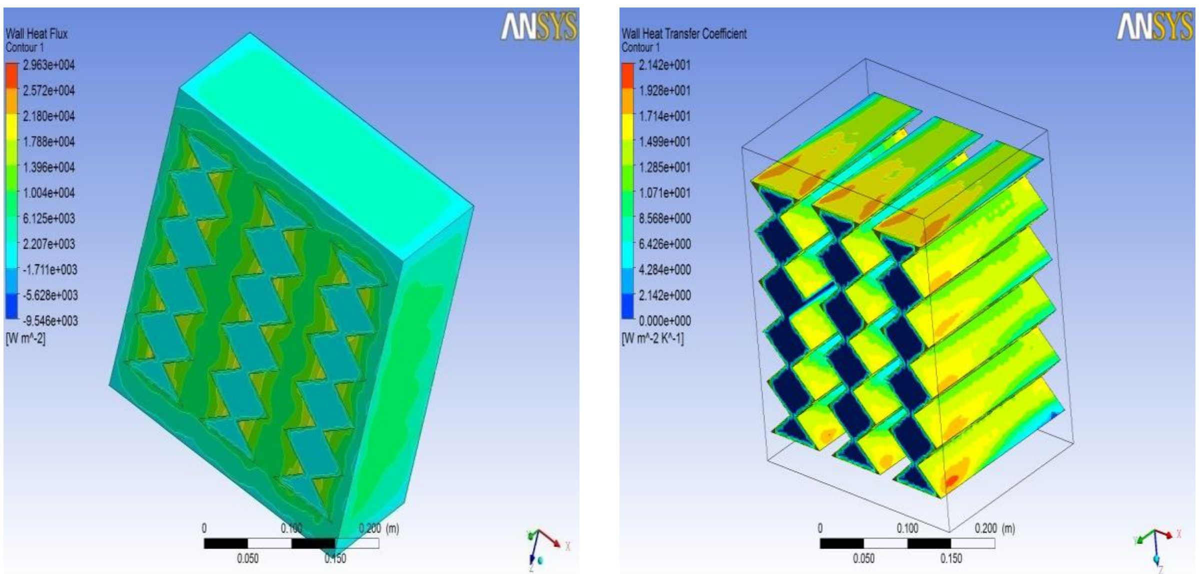

Figure. 5 Wall heat flux and wall heat transfer coefficient in hot fluid region

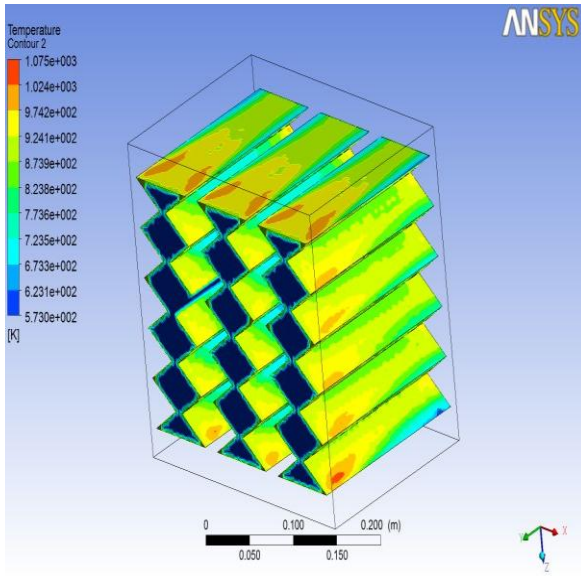

Figure. 6 Temperature in hot fluid region

6. CONCLUSION:

Solar energy is abundantly available. In India, people are not using for cooking purpose much because of available of energy is time dependent. In this work, a thermal energy storage system using carbon bricks with holes is designed. The insulation system is vacuum chamber surrounding in the brick container. The capacity of thermal energy storage system is designed for 3days usage for family of 5 members.

The CFD –Analysis is carried out for the fluid (heating and cooling of the bricks). The results shows that the heat transfer co-efficient is around 15 to 20 w/m^2/°k while energy is stored in the bricks. The results shows that the heat transfer co-efficient is varying from 25 to 40 w/m^2/°k while the heat is recovered from the bricks.The hot fluid heat transfer co-efficient is less because of its low density and cold fluid heat transfer co-efficient is more because of high density of air and the overall heat transfer co-efficient for heating the thermal energy storage system and retrieving the heat will be in between 20 to 25 w/m^2/°k.

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