CFD Analysis of forced convection through flat plate solar collectors

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Abstract - *Solar flat plate collectors which utilizes sun rays to produce energy are commonly used for domestic and industrial purposes and have the largest commercial application amongst the various solar collectors. This is mainly due to simple design as well as low maintenance cost. An attempt is made to analyze the solar collector using the Computational Fluid Dynamics (CFD) to simulate the solar collector for better understanding of the heat transfer capabilities of the collector. In the present work, Fluid flow and heat transfer in the collector panel due to the solar radiation are studied. The conjugate heat transfer phenomenon between collector and water is modeled using ANSYS CFX software. The geometric model and fluid domain for CFD analysis is generated using ANSYS Design Modeler software. Grid generation is accomplished by ANSYS Meshing Software. The effect of important parameters such as mass flow rate, absorber material has also been investigated.*

Key Words: CFD,

1.INTRODUCTION:

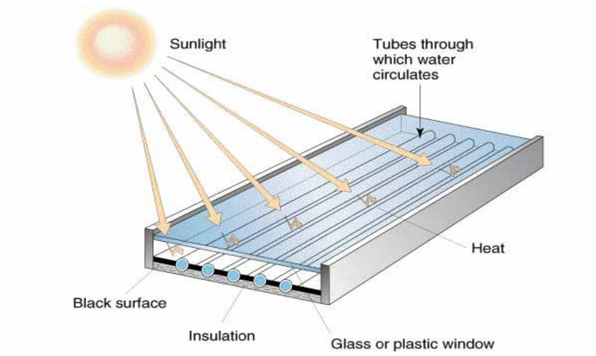
The solar energy is the energy received from the sun that sustains life on earth. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar powerand solar water heating to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties.

In this age a power hungry India is locking towards a renewable energy for its need. Extensive researches are going on in this field. So it would be ideal to invest in solar collectors as well as photovoltaic cells.

The Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere.[5] Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses.

1.1 Solar Flat Plate Collector

A typical flat-plate collector is a metal box with a glass or plastic cover (called glazing) on top and a dark-colored absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss.



Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to liquid passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal—typically copper or aluminum—because the metal is a good heat conductor. Copper is more expensive, but is a better conductor and less prone to corrosion than aluminum. In locations with average available solar energy, flat plate collectors are sized approximately one-half- to one-square foot per gallon of one-day's hot water use**.**

1.2 Literature Survey

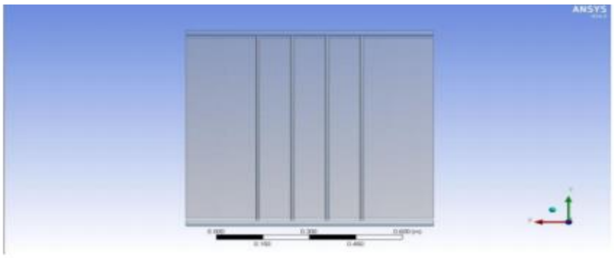
A numerical analysis of flat plate collector for circular pipe configuration by using cfd has been done by Ranjitha P et al.[1] In this study numerical and experimental investigation of flow and temperature was performed. The influence of tube shape in conventional collectors was investigated using CFD.

CFD analysis was done on flat plate solar collector by Fabio Struckmann [2]. His studies proved that the efficiency is a linear function of the three parameters defining the operating condition: Solar irradiance (I), Fluid inlet temperature (Ti) and Ambient air temperature (Ta).

Another study was carried out by Y. Raja Sekhar et al., [3] to study the theoretical and experimental analysis is performed on a flat plate collector with a single glass cover. The efficiency of FPC is found to increase with increasing ambient temperature. There is no significant impact of tilt angle on the top loss coefficient.

2. Geometrical Modelling

Geometric model and domain of the circular tube absorber is created using ANSYS CFD. The domain created for circular tube configuration is as shown in the figure.



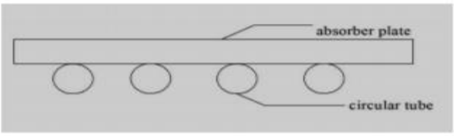


Fig 4.1 Modeling of circular tube- absorber configuration

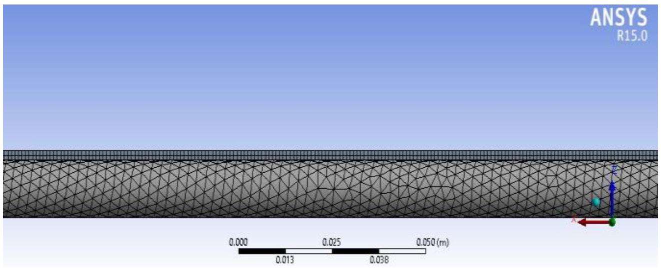
First the two header pipes (0. 0254m dia.) are modelled in the ZX plane.The distance between the two header pipes is maintained at 0.8m.The four riser pipes (0. 0127m dia.) are modelled in YZ plane, arranged in series and perpendicular to the header pipes. The distance between the riser pipes are maintained at 0. 11m. The absorber plate is designed to have its lower plane rest on the riser tubes.

Absorber plate dimension: 0.795m*0.8m*0.002m .Final geometry consists of two domains: Fluid domain (pipes) and Solid domain (absorber plate).

2.1 Meshing

In computational solutions of partial differential equations, meshing is a discrete representation of the geometry that is involved in the problem. Essentially, it partitions space into elements over which the equations can be approximated. Zone boundaries can be free to create computationally best shaped zones, or they can be fixed to represent internal or external boundaries within a model. Meshing is the process of dividing the Solid/Fluid part into number of infinitesimally small, but non-zero elements.

Meshing is the process of dividing the Solid/Fluid part into number of infinitesimally small, but non-zero elements. The solver preference was set as CFX for the model to be meshed. The relevance was maintained at -50 to get acceptable number of elements for the simulation to be carried out. A total of two elements have been maintained at the thickness of the plate to observe the change in properties. The body sizing is used on the fluid domain(pipes) with a element size of 0.0005m. The total number of elements obtained is 1600437 and the skewness is maintained at 0.79 which is acceptable.



3. Boundary Conditions And Assumptions

(i)Absorber side

Boundary Type: Wall
Heat Transfer: Heat Flux:1316.8W/m^2

(ii)Side Walls

Boundary Type: Wall
Heat Transfer: Adiabatic

Fluid

(i) Inlet

Boundary Type: Inlet
Flow Regime: Subsonic
Mass and Momentum: Mass flow rate: 0.025, 0.05, 0.075 kg/sec
Flow direction: Normal to boundary condition
Turbulence Intensity: Medium (5%)
Heat Transfer: Static Temperature:308.6K

(ii) Outlet

Boundary Type: Opening
Flow Regime: Subsonic
Mass and Momentum: Opening Pressure and Direction:0 Pa
Flow Direction: Normal to boundary condition
Turbulence Intensity: Medium (5%)
Opening Temperature: 301.5K

(iii) Fluid walls

Boundary Type: Walls
Mass and Momentum: No Slip Wall
Heat Transfer: Heat Transfer Coefficient:3000W/m^2K
Outside Temperature:303.5K

Interface

Plate pipe Interface
It is the interface between the absorber plate bottom and the fluid walls of riser pipe. Fluid-solid interface is used. GGI type mesh connection is used to connect meshes.

4. Material properties

The materials used for the simulation are Copper as the absorber plate and water as the working fluid

Properties	Copper	Water
Molar Mass(Kg/Kmol)	63.55	18.02
Density(Kg/m^3)	8933	997
Specific Heat(J/KgK)	385	4181.7
Dynamic Viscosity (Pa s)	-	0.0008899
Thermal Conductivity(W/mK)	401	0.6069

5. Efficiency equation

From the literature survey an analytical equation for the efficiency was obtained and this equation was used to compare different temperature values at the outlet.

$$\eta = \frac{actual\ useful\ energy\ collected}{solar\ energy\ incident\ on\ the\ collector}$$

$$\eta = \frac{Q_u}{I_t . A_c}$$

$$Q_u = \text{m}.C_p(T_o - T_i)$$

where:

m: mass flow rate in kg/s

C_p: specific heat of water = 4182 J/kg

T_o: outlet temperature

T_i:inlet temperature

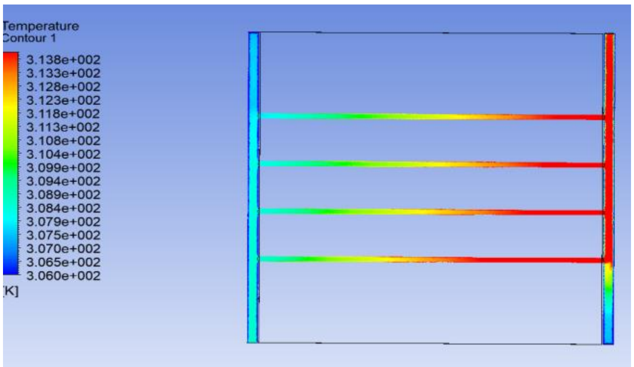
I_t: incident heat flux in W/m2 = 1316.8W/m2

collector plate area

6. Validation and result

The journal "numerical analysis of flat plate collector"by Ranjitha was used for validation.

The riser tube diameter was set at 0.0127m while the mass flow rate was set as 0.025kg/s.The simulation was carried out using CFX and the results was obtained are as follows

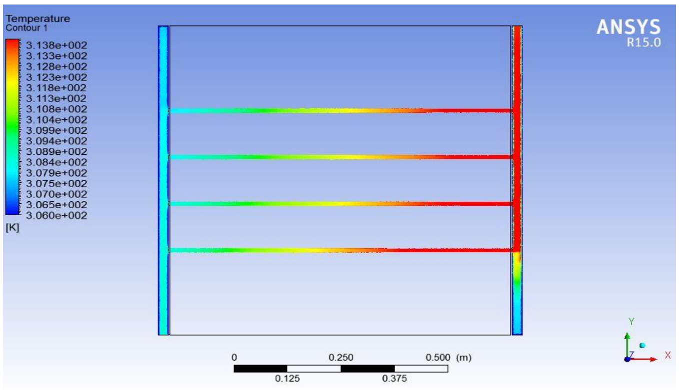


Experimental Results from journal	CFD Results
Inlet temperature: 308.6 K	Inlet temperature: 308.6 K
Outlet temperature: 312.8 K	Outlet temperature: 313.76 K

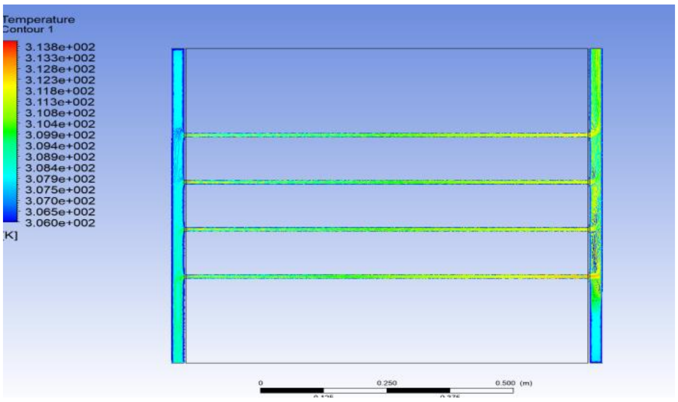
As the difference in outlet temperature between the experimental value in the journal and the simulation performed is less than 1K ,the validation is successful.

6.2 Other Cases

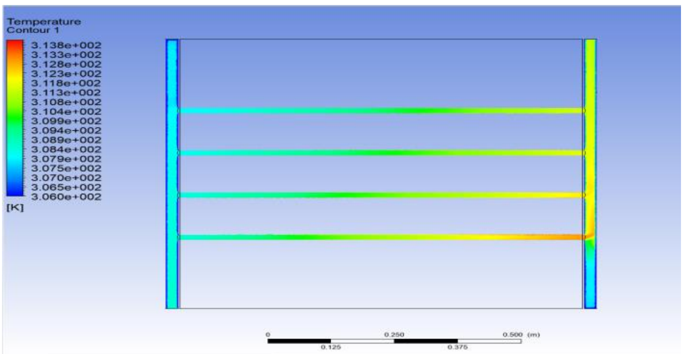
Case 1(a):
diameter_0.0106m , mass flow rate_0.025 kg/s



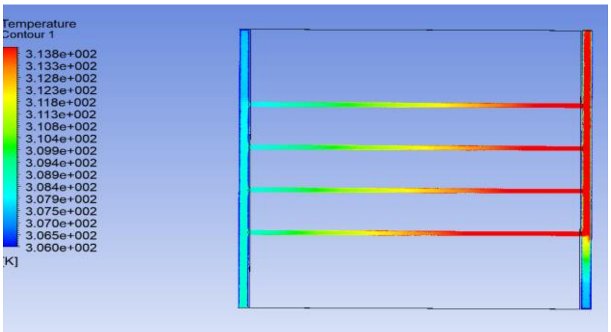
Case 1(b) : diameter_0.0106 m , mass flow rate_0.05 kg/s



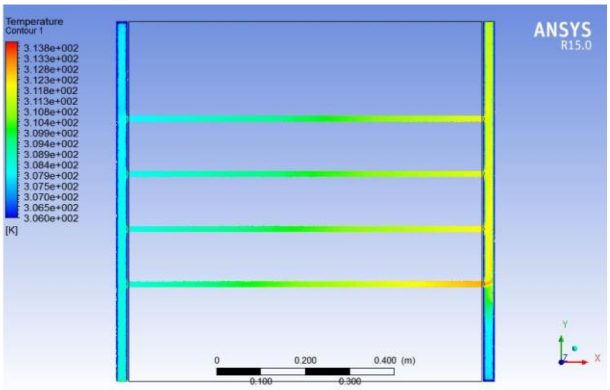
Case 1(c) : diameter_0.0106 m , mass flow rate_0.075 kg/s



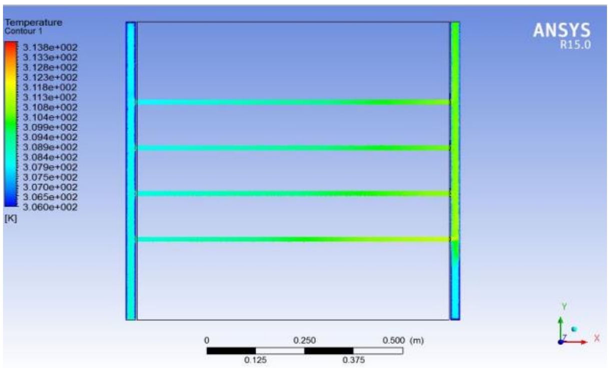
Case 2(a) : diameter_0.0127m , mass flow rate_0.025kg/s



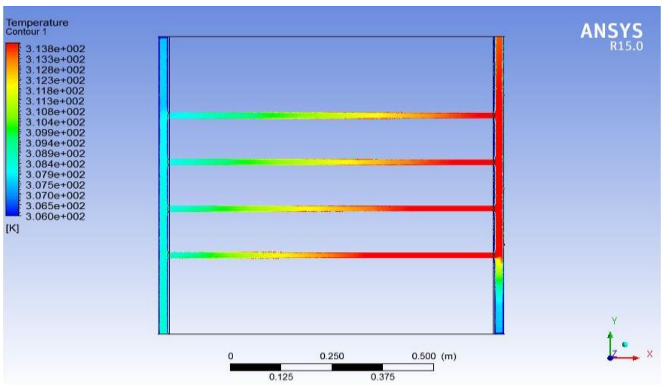
Case 2(b) : diameter_0.0127m , mass flow rate_0.05kg/s



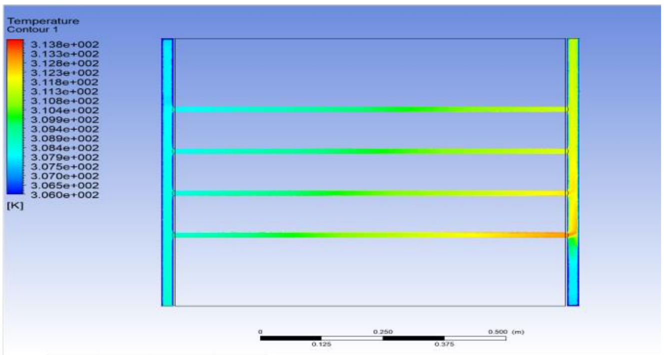
Case 2(c) : diameter_0.0127m, mass flow rate : 0.075 kg/s



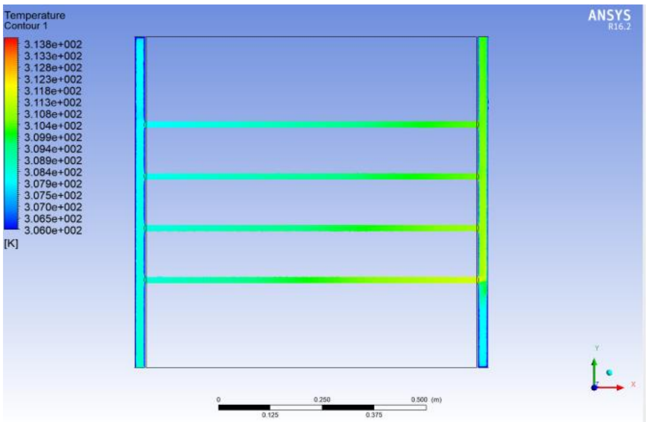
Case3(a):diameter_0.0152,massflow rate_0.025 kg/s



Case 3(b) : diameter_0.01524 , mass flow rate_0.05 kg/s



Case 3(c) : diameter_0.01524 , mass flow rate_0.075 kg/s



7. Results

The parameters considered for the flat plate collector for the determination of efficiency and thus its performance is inlet Temperature, ambient temperature, the outlet temperature, mass flow rate

Sl No.	Riser tube diameter (m)	Mass flow rate (kg/s)	Inlet temperature(K)	Outlet temperature (K)
1	0.01016	0.025	308.6	313.702
2	0.01016	0.050	308.6	311.093
3	0.01016	0.075	308.6	310.100
4	0.01270	0.025	308.6	313.760
5	0.01270	0.050	308.6	311.186
6	0.01270	0.075	308.6	310.164
7	0.01524	0.025	308.6	313.366
8	0.01524	0.050	308.6	311.096
9	0.01524	0.075	308.6	310.140

From the table it can be concluded that for afixed value of diameter as the mass flow rate increase the outlet temperature goes on decreasing .

8. Conclusion

At const. mass flow rate, it is observed that the outlet temperature and efficiency first increases, then decreases. The optimum value of riser tube diameter is 0.0127m.

At constant diameter , it is observed that the outlet temperature decreases with increase in mass flow rate.

By increasing the mass flow rate at constant diameter of the riser pipes, we observe that there is increase in pressure inside the pipe.Velocity of flow increases with increase in mass flow rate (at const. diameter) and decreases with increase in diameter (at const. mass flow rate).

Maximum efficiency is obtained at a mass flow rate 0.05 kg/s. The most optimum test case with the maximum efficiency was Case 2(b) :diameter_0.0127m , mass flow rate_0.05kg/s.

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REFERENCES

[1] Ranjitha P,Somachekar V,Jamuna A ,"Numerical analysis of solar plate collector for circular pipe configuration by using CFD"(IJERT/Volume 2/Issue 12/2013)

[2] Mohammed Saad Abbas,Dr Narsimhulu Sanke,"Performance analysis of flate plate collector with modified risers"(IJERT/VOLUME 5/Issue 9/2012)

[3] Vishal G Shelke,Prof Chinmay V Patil,"Analyze the effect of variations in shape of tubes for flat plate solar water heater"(IJSER/ VOLUME 3/Issue 4/2015)

[4] S P Sukhatme,J K Nayak third solar energy,"Principles of thermal collection and storage"(IJERT/VOLUME 3/Issue 7/2016)

[5] H.P.Garg,J.Prakash,"Solar energy fundamentals and applications"(2014