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THERMAL ANALYSIS OF SOLAR FLAT PLATE HARP TYPE AIR HEATER USING CFD

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Abstract - The use of solar energy has increased tremendously from the last two and half decades. Different appliances are developed to harness this energy; one of them is solar air heater. The uses of solar air heater have increased from clothes drying to drying of industrial products. Agricultural products such as food grains, fruits, etc. contain a substantial amount of moisture, which reduces their shelf life. Removal of moisture efficiently and in cost effective way would really help to enhance shelf life of such products and will in-turn uplift farmer community. Flat plate solar air heaters would be the promising source of hot air, which could be judiciously utilized for various low temperature heating needs like drying, room heating etc. This work aims at development of a cost effective solar air heater without compromising its efficiency. So, a CFD model of the solar collector with HARP type absorber was created by use of PRO-E software and is meshed with ICEM-CFD which is simulated using FLUENT.

Key Words: solar energy, solar air heater, drying, CFD model, ICEM-CFD, HARP absorber, FLUENT.

1.INTRODUCTION:

In this work an attempt has been made to use solar energy for heating air which can be used for different applications such as drying in food industry, in hotels for cloth drying, for auxiliary heating purposes such as room ventilation, night cooling, space heating, etc. CFD analysis with steady state and for turbulent flow was done using k-ε model. CFD simulation of was done in FLUENT 15.0.7 while the model was made in PRO-E software and different contours for pressure, velocity, temperature and for heat flux were obtained.

CFD heat transfer analysis was done by S.J.Arulanandam et al. [1] in Canada to find the effect of different non-dimensional parameters on the efficiency of collector. With the assumption of no wind conditions, they found out that the major effect or dominant effect is of Reynold's no. (Re), followed by plate porosity given by $\sigma = \frac{\pi D^2}{4P^2}$ and then t^* a non-dimensional plate thickness and at last on plate admittance A_d. While it was found that the Nusselt no. have negligible or no effect on the performance of the solar collector.

CFD modelling of a polymer solar collector was done by G. Martinopoulos et al. [2] to determine the average efficiency of the collector by experimentation and CFD simulation. They found similar flow patterns and temperature distribution patterns in both the cases and observed a good agreement between the results. They concluded that the CFD as a tool can be used for further enhancement of efficiency and optimization of the collector.

In a comparative study done by Manjunath M.S. et al. [3] for a solar collector with dimple plate has shown that with the surface enhancement of solar collector, high performance from the same collector can be got. They did the simulation for two different collector plate designs i.e. one with dimple on it (plate with semicircular grooves) and the other one a flat plate. The criterion for comparison was varying heat flux from 600 W/m^2 to 1000 W/m^2. The difference between the simulated results and experimental was of 5^{o}C for the absorber plate while it gave a difference of about 5.5^{o}C for the outlet temperature.

In a numerical analysis of solar flat plate collector done by Ranjitha P. et al. [4] using CFX as simulation tool found that a 5% deviation in results of simulation and experimental results. The CFX results showed that simulation can be used to increase the efficiency and performance of the solar collectors. In their results a maximum temperature of 329.6K was given by simulation results while the experimental results gave a value of 332.3K at 2 pm with the radiation heat flux of 1397 W/m^2 and an inlet temperature of 323K.

2. PROBLEM STATEMENT:

The use of solar energy has increased and with the advancement of technology the need to develop efficient drying devices has also been increased. The use of solar energy systems has grown in the past few years and also the improvement in the performance and efficiency of the solar collector has also seen a sign of growth. But with the overall performance being less as compared to the other thermal system extensive research is required to be done. The solar air heaters present today are very costly so the need to make cheap and easily available solar air heaters is increasing in a developing country like ours. So, this work aims to develop a cheaper solar air heater which can be used by all. A sincere effort has been made in this project to increase the overall efficiency of the solar collector. CFD simulation results of Harp absorber system was compared with the theoretical results for the temperature of absorber plate, outlet temperature of the fluid, Reynold's no., and surface heat transfer co-efficient. Results of pressure variation inside the tubes were also compared.

3. METHODOLOGY:

The design of the set-up was made in PRO-E software and was analyzed in ANSYS 15.0.7. The original set-up was simplified to be used in ANSYS so that the computational load can be decreased. The original geometry and simplification of it is as shown in figure:

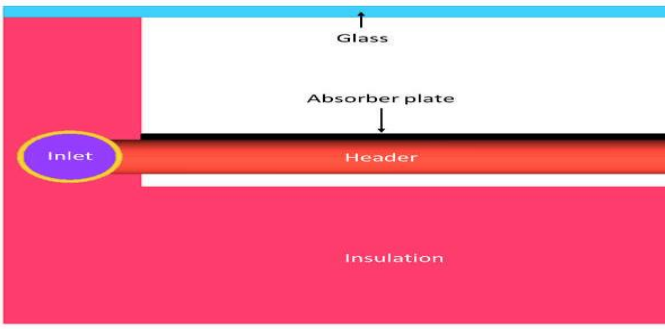

Figure 1 – Solar Collector Assembly

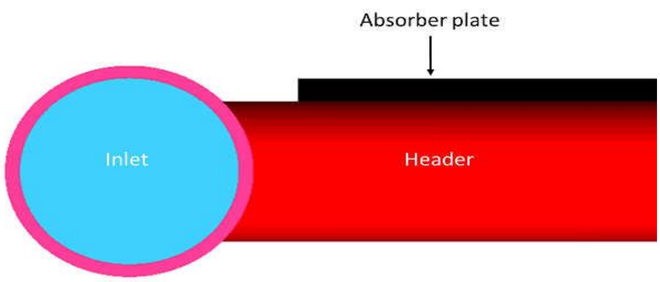

Figure 2 – Simplified geometry used in ANSYS

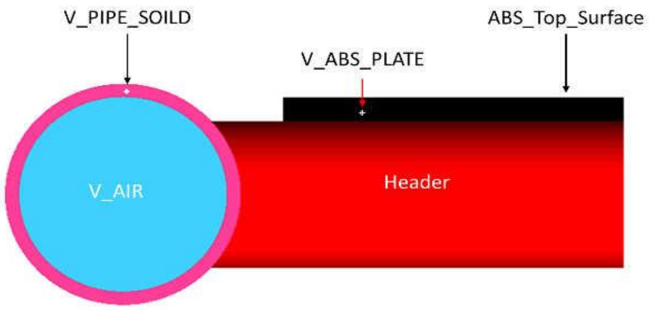

Figure 3 – Zones in the geometry

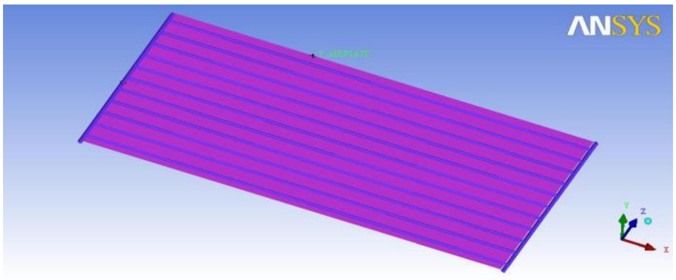

Figure 4 – Harp absorber with plate

Solar collector was analyzed for a mass flow rate of 0.089435 m^3/sec. in ANSYS 15.0.7. The header in harp-type absorber was of 19.05mm OD and 16.91mm ID. The plate with a thickness of 0.2mm and was of area 2m^2. The insulation at the bottom and side insulation was of glass wool. The antireflective glass cover used was 4mm thick. The air supplied to the solar collector was at atmospheric temperature of about 33ºC. In FLUENT a surface to surface (S2S) radiation model was considered to take the radiation effect also in consideration.

The materials used for the different components of the solar collector with their properties are:

Table 1: Material used with their properties.

Part	**Material**	**Density (Kg/m^3)**	**Thermal conductivity (W/m K) at 20ºC**	**Specific heat(KJ /KgK)**
Plate	Copper	8790	380	0.385
Header & riser tubes	Copper	8790	380	0.385
Insulation	Glass wool	130-150	0.040	0.69
Cover	Glass with antireflective coating	2900-5900	0.8	0.8

4. SIMULATION:

The actual setup was modeled in PRO-E and meshing was done using ICEM-CFD. Surface meshing was done using tri elements while the volume meshing was done using tetrahedron elements. Prism mesh was done for the wall i.e. tubes and plate with triangular base so that heat transfer rate across it can be known accurately.

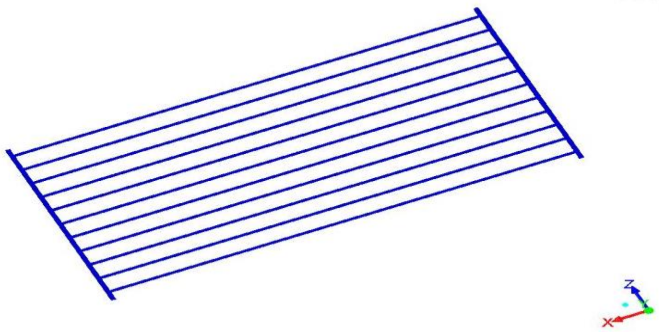

Figure 5 - Harp absorber meshed

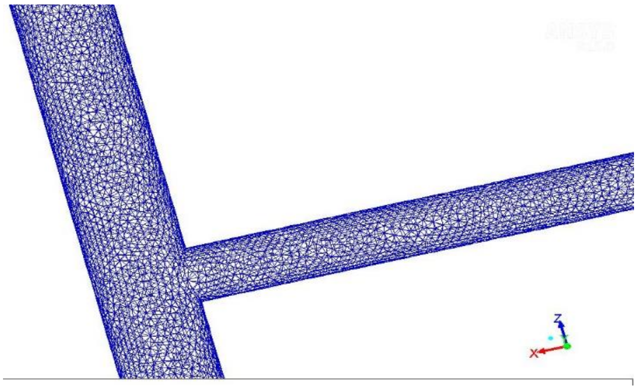

Figure 6 – Zoomed image of mesh

- Pre-Processor – ICEM CFD
- Solver – ANSYS FLUENT
- Post-Processor – ANSYS FLUENT
- Surface mesh – Triangular element
- Volume mesh – Tetra element
- Surface to Volume – Prism element
- Mesh count - 9 million for Harp absorber

Once the meshing was done the meshed file was imported to FLUENT 15.0.7. The boundary conditions were then applied to the meshed model and energy equation with continuity equation for flow was solved. For turbulence modelling k-ε model was used. The results were obtained when the solution got converged that is shown by the residual plot. The criterion for convergence of energy equation was kept at 10^{-8} while for the continuity equation it was kept at 10^{-5}. The results obtained were used for validation of the problem.

Table 3: Boundary condition

Sr. No.	Parts	Type of boundary condition
1	Inlet	Mass flow inlet
2	Outlet	Outflow
3	Plate	Wall
4	v_air	Interior
5	Pipe	Wall
6	v_pipe	Interior
7	Plate & Tubes	Surface to Surface radiation model with solar load

Mass Flow Rate	(kg/s)
inlet	0.01126
int_v_air	0.048691411
int_v_plate	0
outlet	-0.011260001
plate	0
top_surface	0
tubes	0
Net	-9.3132258e-10

Figure 7 – Mass flow rate of harp absorber

Total Heat Transfer Rate	(w)
inlet	117085.02
outlet	165210.2
plate	-8.7999142e+08
top_surface	8.7999456e+08
tubes	1.6577858e+08
Net	1.6606401e+08

Figure 8 – Heat transfer rate of harp absorber

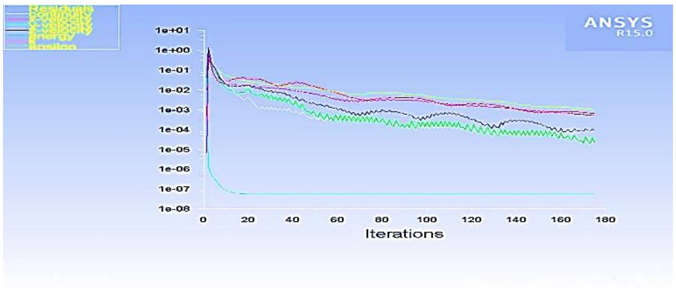

Figure 9 – Residual plot of Harp absorber

5. RESULTS:

The results of the simulation were compared with analytical results. It is found close agreement between them. A comparison of results for pressure, velocity, Reynold's no., heat transfer co-efficient is shown in below table:

Table 4 – Comparison of Analytical & Simulation results

Parameter							
Pressure difference (Pa)		Velocity (m/sec)		Surface Heat transfer co-efficient (W/m^2K)		Cell Reynold's no.	
Analytical	Simulation	Analytical	Simulation	Analytical	Simulation	Analytical	Simulation
198.81	160	0.011243	0.01	10.328	7.5	7.089	7

The pressure drop over a solar collector is an important parameter for system designing. It is becoming increasingly important as the focus on energy efficiency is getting stronger and the designer should minimize the energy needed for pumping yet maintaining flow rates that allows the collectors to operate efficiently.

Low velocity in the collector shows that the residence time of air in tubes is more which helps it to gain more heat as air has less thermal capacity than water so more residence helps in gaining more heat by conduction and radiation. In the below table efficiency of the solar air heater is found out and compared with the assumed efficiency and a close agreement was observed. Also a graph of efficiency versus $[(T_{fi} - T_a) / I_T]$ was plotted which gives $[F_R \times (\tau\alpha) \times A_p / A_c]$ on y- axis while slope of it gives $[F_R \times U_l \times A_p / A_c]$. The graph has negative slope.

Table 5 – Comparison of Efficiency of Harp absorber

Time of the day	I_T (W/m^2)	Outlet fluid temperature (K) from FLUENT	q_{Useful} for Harp AS (W/m^2)	η of Harp system
9 am	431.79	330	304.48	0.3525
10 am	653.58	348	497.63	0.3806
11 am	775.80	359	614.64	0.3961
12 pm	860.31	365	712.35	.4140
13 pm	854.77	370	733.94	0.4293
14 pm	783.95	370	733.94	0.4681
15 pm	671.32	355	565.79	0.4214
16 pm	507.56	338	374.92	0.3640
17 pm	333.71	323	209.04	0.3132

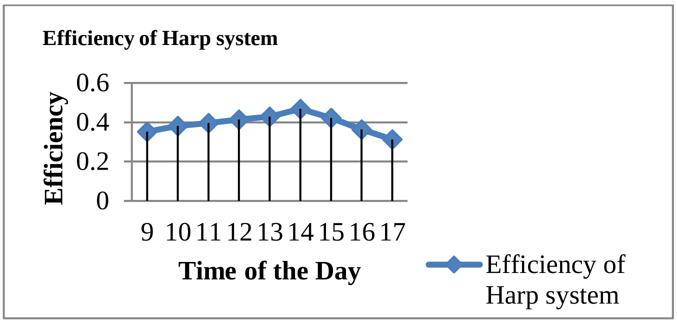

Figure 10 – Plot of Efficiency v/s Time of the day

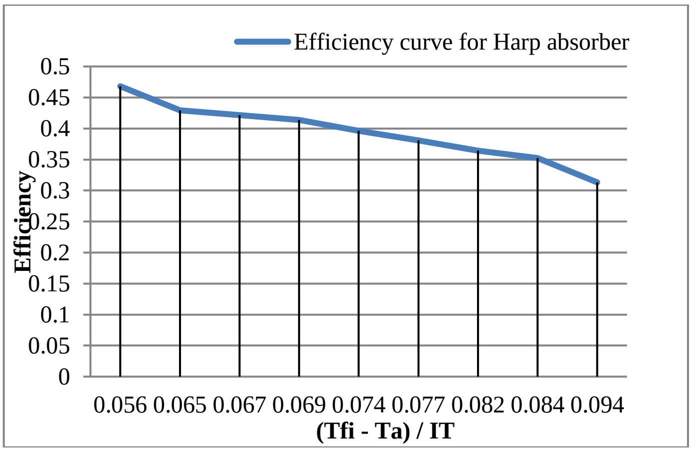

Figure 11 – Plot of Efficiency v/s $[(T_{fi} - T_a) / I_T]$ for F_R of Harp system

6. Conclusion:

Harp type solar collector model was analyzed for the operating conditions from morning 9am to 5pm. It was observed from the results that the highest efficiency in both absorbers was found at 2 pm which is mainly due to the fact that the absorber material has absorbed heat and the radiation intensity is on decrease. The heated air can be used for different industrial applications such as for pasteurization, for heat pump in the food industry, for heating of process water, for heat pump in fries industry for drying French fries, for washing process, for drying damp materials which are used for different process e.g. coal has to be dried before use because wet coal produces large ash and requires more heat which decreases the efficiency of the plant.

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