CFD ANALYSIS OF SOLAR FLAT PLATE COLLECTOR WITH SEMI CIRCULAR BAFFLES

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Abstract - The heat transfer enhancement is very important in many engineering applications to increase the efficiency of solar flat plate collectors. The active techniques require external power like surface vibrations, electrical fields etc. and the passive techniques are those which does not require any external power. Our research involves a solar flat plate collector setup whose risers were designed with two variants namely a riser without inserts and a riser with semicircular baffles. The major aim of the research is to create a turbulent flow of water in the riser so that more efficient heat transfer takes place thereby increasing the efficiency of the entire system by CFD analysis using ANSYS FLUENT. Post analysis, a significant rise in temperature was achieved thereby proving that an increase in turbulence has led to an increase in heat transfer rate of the system.

Index Terms - CFD, Solar flat plate collectors , Semicircular baffles , augmentation techniques.

I. INTRODUCTION

A solar flat-plate collector is a metal box with a glass or any other transparent cover (called glazing) on top and a dark-colored absorber plate at the bottom. The sides and bottom of the collector are insulated to minimize the heat loss. Sunlight passes through the cover and strikes the absorber plate, which then heats up, converting solar energy into heat energy. The heat is transferred to the water passing through the risers attached to the absorber plate. Absorber plates are most commonly painted with "selective coatings" which absorb and trap heat better than any other ordinary black paint. Absorber plates are usually made of metal—typically either copper or aluminum—because both of them are good heat conductors. Copper is the more expensive, but is better when it comes to resistance from corrosion. In locations with an average available solar energy, flat plate collectors are sized approximately at one-half- to one-square foot per gallon of one-day's hot water use.
In order to increase the heat transfer rate of the system, we can make use of different types of augmentation methods. Augmentation methods include active and passive methods with the latter being the most widely used. In our research we have made use of semicircular baffles which are evenly spaced in the riser tube. These baffles or turbulators convert laminar flow of water to turbulent flow which thereby contributes to an increase in efficiency of the entire system.

II. AUGMENTATION TECHNIQUES

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers.[1] Existing enhancement techniques can be broadly classified into three different categories:

1) Passive Technique
2) Active Technique
3) Compound Technique.

Passive Techniques generally uses surface or geometrical modification to the flow channel by incorporating inserts or additional devices.

They promote higher heat transfer coefficient by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop.[2]

Following methods are generally used

a) Inserts
b) Extended surface
c) Surface modification
d) Use of Additives

Active heat transfer techniques involves some external power input for the enhancement of heat transfer, Some examples of Active heat transfer techniques include pulsation by cams and reciprocating plunger, the use of magnetic field to disturb the seeded light particles in a flowing stream etc.

III. LITERATURE REVIEW

USE OF INSERTS

Inserts refers to an additional arrangement made as an obstacle in order to alter the flow pattern in a tube so as to achieve augmented heat transfer.

Different types of inserts include:

- Twisted tapes and wired coils
- Ribs and baffles

Twisted Tapes

Twisted tape increase the heat transfer Coefficient at a cost of rise in pressure drop. The Swirl inserts and tape twister technique are used to create a flow disturbance and the pressure drop losses are much higher as compared to the gain in the heat transfer coefficient.[3]

Fig. 1 Twisted tapes

Ribs and Baffles

Baffles are used in the riser to direct the fluid stream across the tubes and to increase the fluid velocity and finally improve the rate of transfer.

Differently shaped ribs and baffles also create bulk flow disturbance, but unlike tapes or swirls, ribs and baffles are discrete objects.

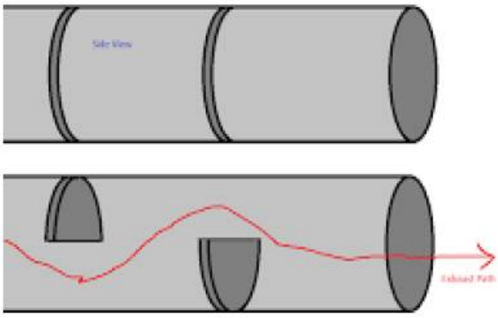

Fig. 2 Semi Circular Baffles

- M. Yahya investigated on the CFD analysis of solar hot water heater with integrated storage system. The performance of flat plate collector with different types insertion in riser tube is analyzed by CFD i.e. $\theta = 5^\circ, 10^\circ \& 15^\circ$

  The performance in two ways
  - Tilted dependence
  - Time dependence.[4]

- S. Vijayakumar has investigated the results of the heat transfer have been compared wellwith the available results. The heat transfer rate in the collector has been found to be increased by 18% to 70%. It has been observed that heat losses are reduced consequently increasing the thermal performance about 30% over the plain water[5]

IV. EXPERIMENTAL SETUP

The experimental setup is like any other solar water heater setup, with 6 riser tubes with 2 Cold water storage tanks and 1 Hot water storage tank. Different kinds of experiments can be carried out with the setup thus making it a valuable contributor to our research project.

Fig. 3 Experimental setup

V. RESEARCH METHODOLOGY

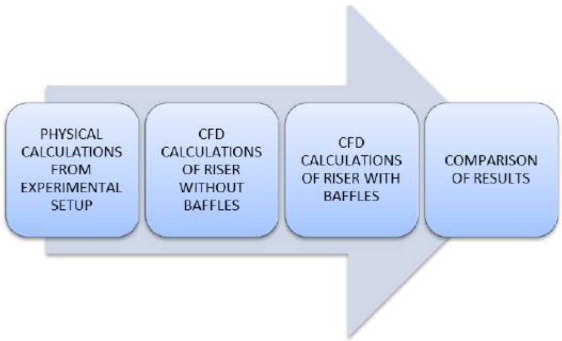

Fig. 4 Flow of Research

VI. CAD MODEL OF COLLECTOR ASSEMBLY

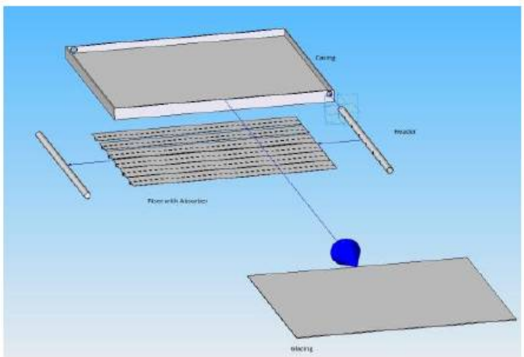

Fig. 5 CAD model of collector assembly

VII. PHYSICAL EXPERIMENTATION

Glossary

Symbols	Description	Values/Unit
U_L	Overall heat loss coefficient	W/m^{2}K
U_t	Top heat loss coefficient	W/m^{2}K
U_b	Back heat loss coefficient	W/m^{2}K
U_e	Edge heat loss coefficient	W/m^{2}K
N	Number of glass cover	1
B	Tilt angle of collector	60°
ε_p	Emissivity of absorbing plate	0.12
ε_g	Emissivity of glass cover	0.88
k_b	Conductivity of back insulation	0.04 W/mK
X_b	Back insulation thickness	0.05 m
A_e	Area of edge	0.32775 m^2
A_c	Area of collector	0.74115 m^2
I_t	Intensity of radiation falling on collector	W/m^2
τ_o	Transmissivity of absorbing plate	0.85
α_o	Absorptivity of absorbing plate	0.96
M	mass flow rate of water through the collector	0.0848 kg/s
C_p	Heat capacity of water	4180 J/kg°C
F_R	Heat Removal Factor	

Physical readings (For Intensity=830 W/m^2)

TIME (t, min)	AMBIENT TEMPERATURE (T_a, °C)	INLET WATER TEMPERATURE (T_{fi}, °C)	PLATE TEMPERATURE (T_p,°C)	OUTLET WATER TEMPERATURE (T_{fo},°C)
0	25	33.8	62.5	34.5
15	25	35	63.6	35.9
30	25	36.1	65.3	37.1
45	25	37.2	66.3	38.3
60	25	38.2	67.2	39.4

(a)

Physical Results

TIME (t, min)	OVERALL HEAT LOSS COEFFICIENT (U_L)	HEAT REMOVAL FACTOR (F_R)	EFFICIENCY η
0	1.154	0.5017	40.29
15	1.154	0.6465	51.79
30	1.154	0.7198	57.55
45	1.154	0.7934	63.31
60	1.154	0.8672	69.06

(b)

Formulae and Sample Calculations[6]

$$U_b = \frac{k_b}{x_b} \quad (1)$$

$$U_e = U_b\left(\frac{A_e}{A_c}\right) \quad (2)$$

$$U_t = \left\{\frac{\frac{1}{N}}{\frac{C}{T_p}\times\left[\frac{T_p - T_a}{N+f}\right]^{0.33} + \frac{1}{h_a}}\right\} + \left\{\frac{\sigma\times(T_p+T_a)\times(T_p^2+T_a^2)}{(\varepsilon_p + 0.05N(1-\varepsilon_p))^{-1} + \frac{2N+f-1}{\varepsilon_g} - N}\right\} \quad (3)$$

$$C = 365.9\times(1 - 0.00883\beta + 0.0001298\times\beta^2) \quad (4)$$

$$f = (1 + 0.04h_a - 0.0005h_a^2)\times(1 + 0.091N) \quad (5)$$

$$h_a = 5.7 + 3.8v \quad (6)$$

$$U_L = U_t + U_b + U_e$$
$$U_L = 1.2305 \quad (7)$$

$$F_R = \frac{\dot{m}C_p[T_{fo} - T_{fi}]}{A_c[I_t\tau_o\alpha_o - U_L(T_{fi} - T_a)]} \quad (8)$$
$$F_R = 0.7198$$

$$\eta = F_R\left[(\tau_o\alpha_o) - \frac{U_L(T_{fi} - T_a)}{I_t}\right] \quad (9)$$
$$\eta = 57.55$$

VIII. CFD ANALYSIS OF TUBE WITHOUT SEMICIRCULAR BAFFLES

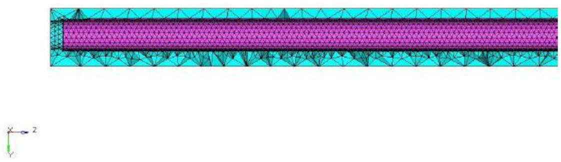

Fig. 6 Mesh diagram of riser tube (without baffles)

BOUNDARY CONDITIONS APPLIED

In this analysis, a mass flow rate of 0.01413 kg/s was applied for the riser inlet. A heat flux of 830 W/m^2 was applied to the top glazing thereby simulating a solar heat input. The heat flux is transferred to the risers through the air cavity between the glazing and the risers whose refractive index is 1.000293. The side and bottom walls of the system were treated as adiabatic.[7]

TEMPERATURE DISTRIBUTION PLOT

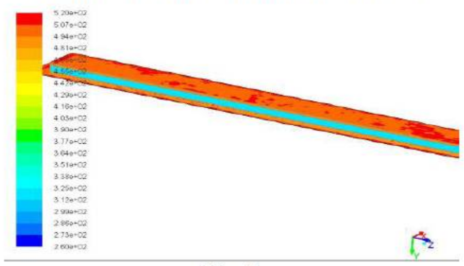

Fig. 7

The above contour plot gives us a glimpse of the temperature distribution post analysis on ANSYS Fluent.[7]

PRESSURE DISTRIBUTION PLOT

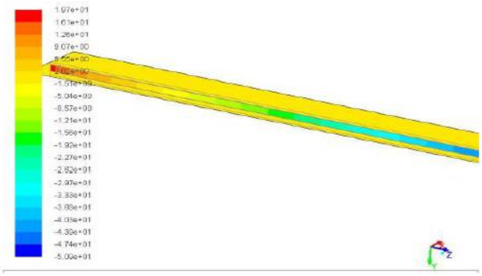

Fig. 8

IX. CFD ANALYSIS OF RISER TUBE WITH SEMICIRCULAR BAFFLES

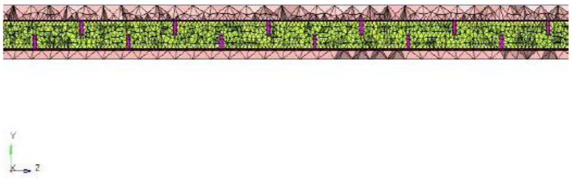

Fig. 9 CFD meshing of riser tube with baffles

BOUNDARY CONDITIONS APPLIED

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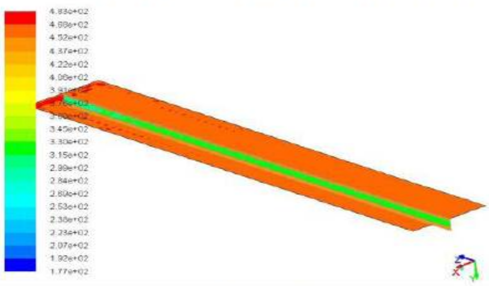


Fig. 10

PRESSURE DISTRIBUTION PLOT

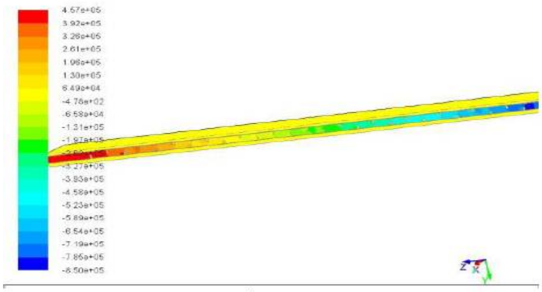
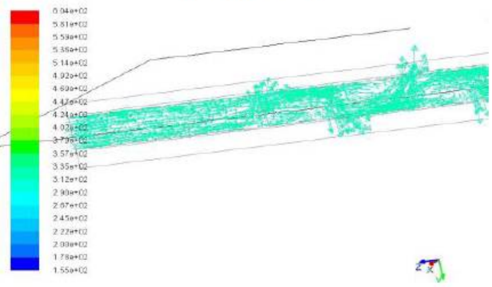


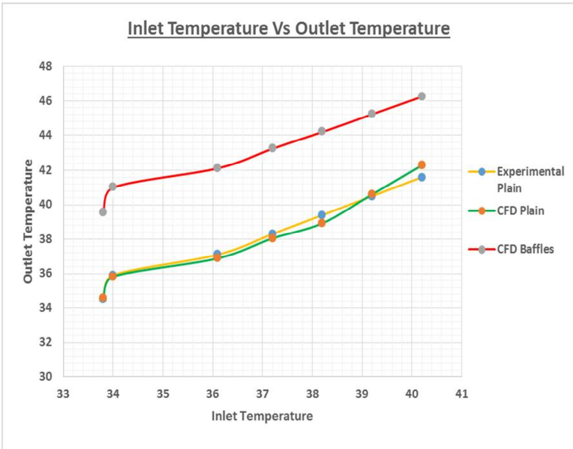
Fig. 11

VECTOR PLOT



X. RESULTS AND NUMERICAL VALIDATION

Experimental Plain		CFD Plain		CFD Baffles	
Inlet Temperature	Outlet Temperature	Inlet Temperature	Outlet Temperature	Inlet Temperature	Outlet Temperature
33.8	34.5	33.8	34.58	33.8	39.58
34	35.9	34	35.82	34	41.02
36.1	37.1	36.1	36.89	36.1	42.14
37.2	38.3	37.2	38.05	37.2	43.26
38.2	39.4	38.2	38.92	38.2	44.22
39.2	40.5	39.2	40.6	39.2	45.25
40.2	41.6	40.2	42.29	40.2	46.27



The above plot clearly shows a rise in outlet temperature when the semicircular baffles were introduced and this has been validated by CFD calculations.

CONCLUSION AND INFERENCE

1. The comparison of solar flat plat collector is made with respect to experimental setup and CFD numerical technique.
2. From the above results, it clearly shows that heat transfer for riser tube with baffles is more when compared to riser tube without baffles.
3. The baffles has been constructed with a pitch length of 52 mm so further variations has to be carried out in the future.

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