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Performance Investigation of Thermal Electric Generator Run On Solar Thermal Device: An Experimental and Simulation Study

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ABSTRACT

Investigating the impact of changing solar air design absorber plates applying CFD modeling software isthe goal of the current research article. This paper compares various velocity circumstances with an upgraded design of solar air heater after simulating a basic solar air heater for a whole year. This research also undergoes experimental validation. This study makes use of Ansys Fluent software. All field tests are carried out in Jaipur. Compared to a simple solar air heater, an improved design solar air heater exhibits a 20% efficiency improvement. Electrical energy is the most valuable product for human technical advancements in the modern period.

Keywords: Solar Energy, Solar air heater, CFD simulation, TEG simulation, Optimization, DOE

INTRODUCTION

Since 1970, solar energy has been used largely because of the escalating expense of power. It starts the water cycle, keeps the Earth's surface temperature higher than usual, and enables photosynthesis in plants.

Furthermore, the quantity of solar radiation that is available to the surface of the earth is far lower than that which is outside the atmosphere. Between 25-50% of sunlight is lost when it enters the earth's outer atmosphere. A large portion of the energy that is sent to the earth is reflected and absorbed by the greenhouse gases and water vapor.

Traditional energy sources have attracted a very high level of human curiosity. Solar radiation is the most abundant and sustainable energy source in the world. There are numerous places where solar energy is clearly utilized, including.

Heating industrial operations, producing electricity using photovoltaic and solar thermal power plants, heating swimming pools, heating greenhouses, heating hot water at home, and heating and cooling areas

LITERATURE SUMMARY

HikmetEsen [1, 2008] studied experimentally on a double flow solar air heater with metallic absorber plate obstructions. investigated experimentally on a twin flow solar air heater with obstacles made of metallic absorber plates. The main variable in his research study is expanding the absorber plate's heat transfer area using different techniques.

S. V Karmare and A.N. Tikekar [2, 2010] numerically investigated on roughened surface solar air heater. In his research paper 60 inclinations on absorber plate is made. The conclusion of this research work is that experimental and numerical works are in well agreement with each other. In this study project, rib and angle of attack optimization is also carried out.

Chii-Dong Ho and Ho-Ming Yeh [8, 2011] Logic-based observations have been made about how double-pass and external-recycle operations affect the solar air heaters that are performing well. Particularly while running at a lower air moving liquid rate, the item that gives better value increases as the reflex 3 relation increases. Additionally, a double-pass solar one air heater with additional equipment is preferable than a single-pass solar one air heater of the same size.

S. Aboul-Eneinet. Al. [13, 2011] To find the truth, research on the double pass-finned plate solar air heater was done both experimentally and probably (albeit not definitely). An air heater model that needed careful thought or in-depth research was displayed.

P. Promvongeet. al. [12, 2011]In this study, the impacts of linked ribs and delta-wiglet type vortex generators (DWs) on forced convection heat provide property in law and not in harmony loss behaviors for turbulent air flow through a solar air heater. The rectangular narrow method of point of view relation, AR=10, and the high level, H=30 mm, are used for measurements.

CAD Design of solar air heater:
The design of solar air heater is made in Ansys DM software having rectangular rib configuration in its design improvement research plan. Both designs are present in following figure (Figure 1 and Figure 2)

Figure 1 Simple solar air heater

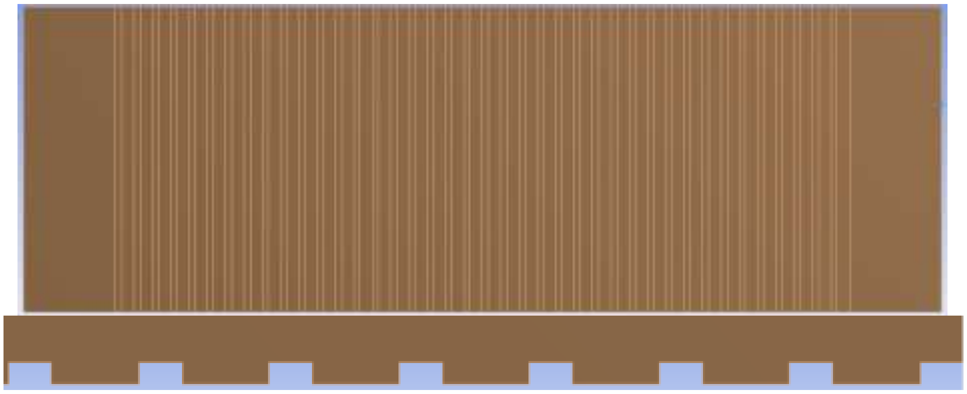

Figure 2 Improved design-I solar air heater

CFD Theory:
Computational fluid dynamics (CFD) is one branch of fluid dynamics.. It is a research tool that uses the numerical solution of the governing equation to replicate real flows in an economical manner. The Navier-stock equation for Newtonian fluids is the primary governing equation. Instead of using governing partial differential equations, the computational method used algebraic equations, which were then solved by a digital computer. Additionally, it offers testing conditions that cannot be measured experimentally or resolved analytically. CFD procedure steps:

- Partial differential modeling, or mathematical modeling
- The numerical approach (the technique of discretization and solution)
- Software (pre and post processing, solver)

Governing equation of fluid flow
Three fundamental governing equations are primarily employed in CFD. It is referred to as the Navier-stock equation, the continuity equation, and the energy equation. Every equation's physical foundation is unique.

Governing equation of mass conservation
Another name for this equation is the continuity equation. It symbolizes the conservation of mass. All fluids, including compressible, Newtonian, and non-Newtonian flows, are covered by the continuity equation. It asserts that the total mass flowing in and out per unit time per unit volume equals the change in mass due to a change in density per unit time per unit volume.

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

Compressed vector notation

$$\frac{\partial \rho}{\partial t} + div(\rho u) = 0$$

The equation for unsteady three-dimensional continuity is shown above. In fluid flow, every point in a fluid field needs to adhere to the explicit law of mass conservation.

Governing equation of conservation of momentum

The law of motion applies to all solid, liquid, and gaseous matter. One fluid layer will move with regard to another neighbouring fluid layer if shear stress is applied to the fluid particle. When the shear force is stopped, the original state is not restored, which leads to deformation. Therefore, distortions must be considered when analysing fluid particles.Newton's second rule of motion states that the rate of change of momentum is exactly proportional to the unbalanced force acting on it, in the direction of the force

Considerable useful forces that have an impact on fluid particles.

- Surface forces, such as viscous and pressure forces and
- Body forces, such as the electromagnetic, centrifugal, Carioles, and gravity forces

Navier (1823) used molecular considerations to obtain the expression of the motion equation for a viscous fluid. The motion equation for viscous fluids, Stokes, is also derived in a different way. Thus, the Navies-Stokes equation is the fundamental formula that controls fluid flow.

$$\rho \frac{Du}{Dt} = \frac{\partial(-p+\tau_{xx})}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{Mx}$$

The Navies-Stokes equation in the x-direction is shown above. The terminology for inertia and pressure, viscosity, and body force are displayed on the left and right, respectively. Fluid flow is slowed by pressure and viscosity.

In y and z direction

$$\rho \frac{Dv}{Dt} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial(-p+\tau_{yy})}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + S_{My}$$

$$\rho \frac{Dw}{Dt} = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial(-p+\tau_{zz})}{\partial z} + S_{Mz}$$

The governing equation for energy conservation

The energy equation is derived using the first law of thermodynamics. This law states that the net flux of heat into a fluid element plus the rate of work done on the fluid element as a result of surface and body forces equals the rate of change of energy inside the fluid element. The fluid's energy (E) is the sum of its internal energy (i), kinetic energy 1/2 (u2 + v2 + w2), and potential energy. Consequently, the energy equation is

$$\rho \frac{DE}{Dt} = -div(pu) + \left[\frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{xy})}{\partial y} + \frac{\partial(u\tau_{xz})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(w\tau_{zz})}{\partial z}\right] + div(K\,grad T) + S_E$$

E = i + 1/2 ($u^2 + v^2 + w^2$) in this case

CFD Modeling Steps:

In this step the general process applied in current research work is discussed. CFD simulation is performed using Ansys WB management software and all simulation is done on Ansys Fluent software. The possible main steps involved in CFD simulation is as present.

Step 1: Formulation of flow Problem

Figure 3 CFD Flow Issue

Step 2: Creation of the Grid

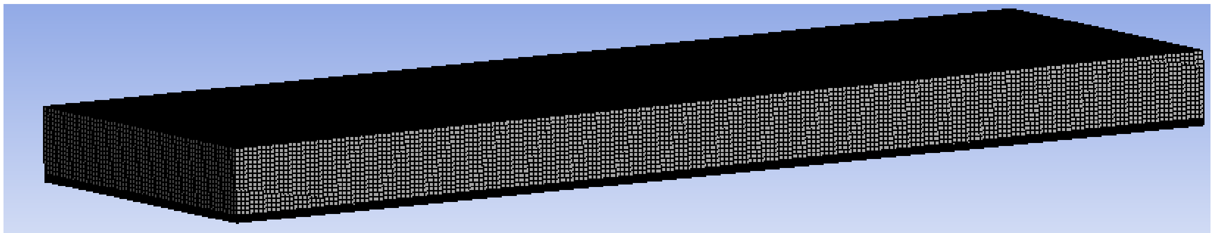

Figure 4 Cell skewness for CFD discretized domain

Step 3: Set up the CFD model

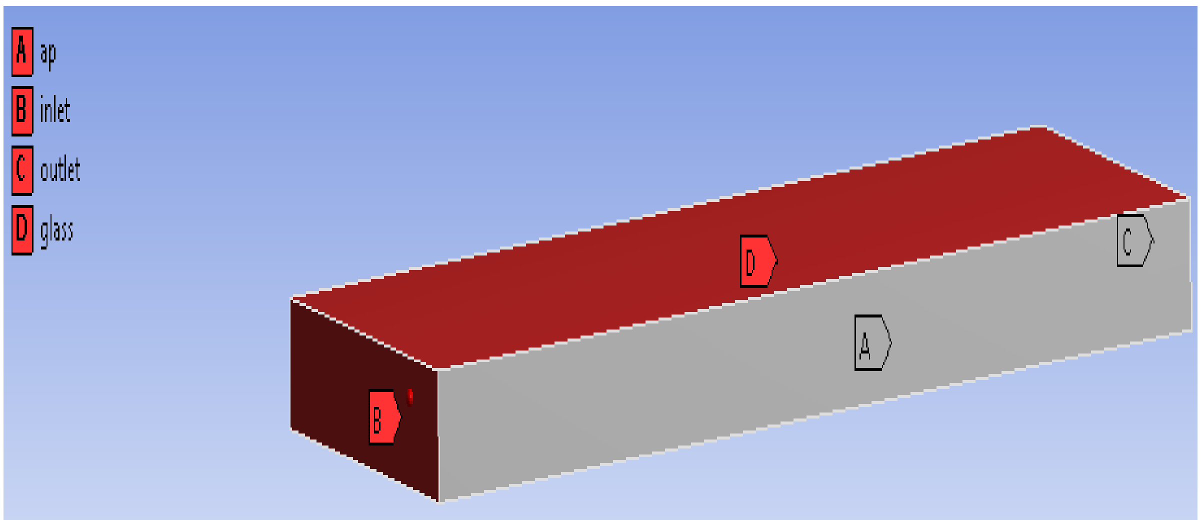

Figure 5 Boundary of Solar Air Heater

Step 4: Simulation Post Processing

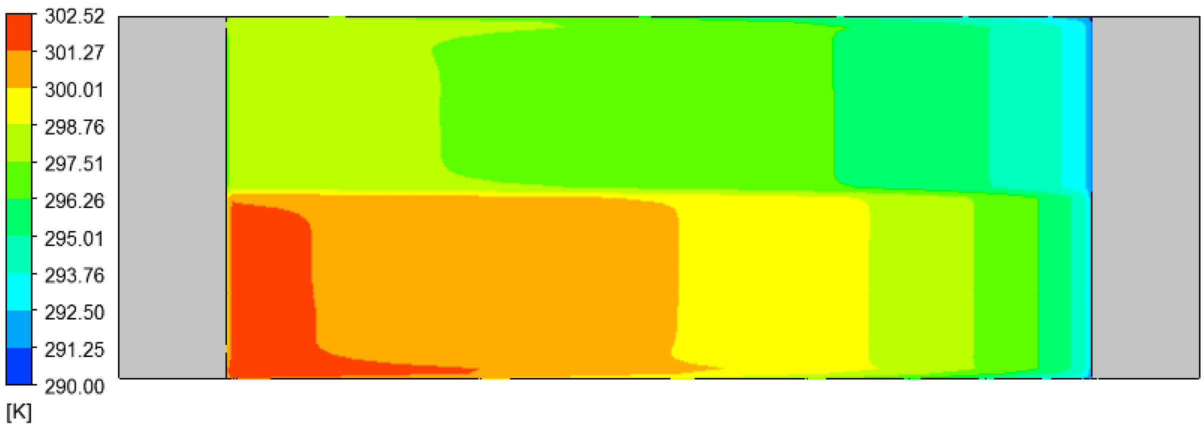

Figure 6 Contours for Solar air heater (Temperature Contour 12 AM January)

CFD Simulation validation:

In present study experimental validation is performed for approval of experimental results data. This experimental validation is performed for simple rectangular solar air heater having horizontal installation arrangement. Experimental results are present in table 1 for this condition and figure 7 show the validation of experimental data with co-relation equations.

Table 1 CFD Validation of Solar Air Duct for Nu Number

Velocity (m/s)	Tin	Tout	Re	Nu-CFD	Nu-DB	Nu-GC
0.35	298	330.70	1101	2.27	5.78	3.28
0.55	299	328.00	1730	3.72	8.30	5.59
0.75	299	326.50	2359	5.70	10.64	7.88
1.00	299	323.30	3145	8.07	13.39	10.57
1.20	299	321.20	3774	10.02	15.50	12.57
1.50	298	319.10	4718	13.27	18.53	15.59
1.75	299	318.54	5504	15.21	20.96	17.89
2.00	298	316.10	6290	16.88	23.32	20.16
2.25	298	315.23	7077	20.00	25.63	22.43
2.50	298	314.53	7863	22.55	27.88	24.61
3.00	299	313.10	9436	25.67	32.26	28.94

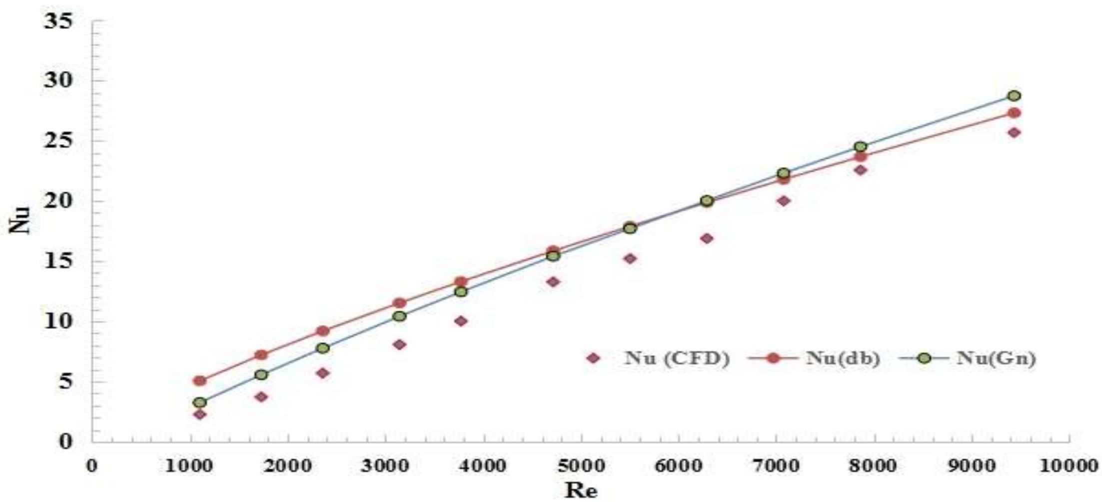

Figure 7 CFD Validation for Nu Number

RESULT & DISCUSSION

Heat transfer characteristics for simple solar air heater

This section presents a comprehensive and in-depth investigation of the seasonal impacts on the thermal performance of solar air heaters. Full year is selected on the basis of season for Jaipur city. The selected months are January, March, June and October for full day simulation results. All results are present in table 5.1 to table 5.4 for simple plate solar air heater. In these tables Nu number and outlet temperature Tout is presented and discussed for full day analysis.

Table 2 heat transfer characteristics for month January

Time	Velocity	Re	Tout	Nu
8 AM	3.00	27970	291.00	72.73
9 AM	3.00	27970	291.73	123.85
10 AM	3.00	27970	292.50	174.60
11 AM	3.00	27970	294.01	230.17
12 AM	3.00	27970	294.32	387.33
13 PM	3.00	27970	294.29	388.53
14 PM	3.00	27970	293.87	390.53
15 PM	3.00	27970	293.03	397.42

16 PM	3.00	27970	291.89	407.38
17 PM	3.00	27970	290.64	430.92

Table 3 heat transfer characteristics for month March

Time	Velocity	Re	Tout	Nu
8 AM	3.00	27970	292.01	394.61
9 AM	3.00	27970	293.44	387.60
10 AM	3.00	27970	294.60	384.36
11 AM	3.00	27970	295.35	384.19
12 AM	3.00	27970	295.68	384.68
13 PM	3.00	27970	295.64	384.60
14 PM	3.00	27970	295.21	386.13
15 PM	3.00	27970	294.36	387.16
16 PM	3.00	27970	293.12	395.21
17 PM	3.00	27970	291.67	406.73

Table 4 heat transfer characteristics for month June

Time	Velocity	Re	Tout	Nu
8 AM	3.00	27970	293.13	401.43
9 AM	3.00	27970	294.34	394.74
10 AM	3.00	27970	295.25	392.87
11 AM	3.00	27970	295.83	390.55
12 AM	3.00	27970	296.06	390.04
13 PM	3.00	27970	296.00	390.53
14 PM	3.00	27970	295.57	393.27
15 PM	3.00	27970	294.82	396.77
16 PM	3.00	27970	293.74	401.51
17 PM	3.00	27970	292.42	417.49

Table 5 heat transfer characteristics for month October

Time	Velocity	Re	Tout	Nu
8 AM	3.00	27970	292.16	398.40
9 AM	3.00	27970	293.48	389.89
10 AM	3.00	27970	294.48	387.40
11 AM	3.00	27970	295.07	386.92
12 AM	3.00	27970	295.20	387.36
13 PM	3.00	27970	295.06	387.76
14 PM	3.00	27970	294.46	389.31
15 PM	3.00	27970	293.46	395.32
16 PM	3.00	27970	292.14	407.17
17 PM	3.00	27970	290.75	428.98

Like these results rectangular rib results are present in this research work and present in table 6 for Re number ranged from 4000 to Re 28,000 for month June. As seen in this table it is clear that as Re increased NU is also increased but very less.

Heat transfer characteristics for Rectangular rib solar air heater

Table 6 heat transfer characteristics for month June

Time	Velocity	Re	Tout	Nu
12 AM	0.50	4662	307.06	97.69
12 AM	0.75	6992	301.34	145.10
12 AM	1.00	9323	298.56	145.56
12 AM	1.25	11654	296.97	137.79
12 AM	1.50	13985	295.81	136.66
12 AM	1.75	16316	295.04	131.67
12 AM	2.00	18646	294.48	123.92
12 AM	2.25	20977	294.00	134.58
12 AM	2.50	23308	293.64	138.17
12 AM	2.75	25639	293.38	134.42
12 AM	3.00	27970	293.26	134.74

CONCLUSION

In present study total four designs are simulated using CFD tool for year round results. All results are discussed in previous chapter in detail. A detailed experimental validation is also carried out for this study. Grid indecency test is also presented in study. Main conclusions of this study presented here:

1. A well defined experimental validation is done in study and according to validation results CFD and Experimental work show good agreement with each other.
2. Nu number analysis for all four designs for full year simulation is also discussed in previous chapter and it is found that season and design both can change thermal performance of SAH
3. Thermal efficiency analysis for all four designs is presented for this study. As per this analysis, design four is most efficient design for SAH device, and simple SAH is less effective device for SAH analysis.

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