

The Netherlands Press

Journal of Green Energy and Transition to Sustainability

Article

CFD ANALYSIS OF A FLAT PLATE SOLAR COLLECTOR TO IMPROVE HEAT TRANSFER CAPACITY

Dr Lelya Hilda

Associate Professor, Faculty of Chemical Engineering, Institute Agama Islam Negeri Padangsidimpuan, North Sumatera, Indonesia.

Orchid: 0000-0002-0607-1761

Email: lelyahilda@iain-psp.ac.id

Abstract. Low-level and medium-level solar heat systems typically use flat-panel solar heat collectors to absorb solar heat energy, convert it to heat, and then heat the liquid (usually water or air) flowing through them. Communicate. These systems are used in home and industrial applications such as water and heating. The purpose of this work is to provide numerical simulations of solar collectors built for a variety of purposes. To better understand the heat transfer capacity of solar collectors, the tool Computational Fluid Dynamics (CFD) was used in the current diploma treatise. In this paper ANSYS Workbench is used to build a 3D collector that included an air intake, a wavy textured absorption plate, a glass cover plate, and pebbles. ANSYS ICEM is used to build an unstructured grid. The results were obtained using the ANSYS FLUENT program.

Keywords: Solar collectors, Heat energy, Numerical simulations, Heat systems.

Journal of Green Energy and Transition to Sustainability Volume 1 Issue 1 Received Date 20 May 2022 Accepted Date 05 June 2022 Published Date 01 July 2022 Online at https://www.jgets.org/

1. Introduction

The most significant energy source in the planet is solar energy. In the absence of an atmospheric layer, the Sun, which has a diameter of 1.39×109 (m), emits 1353 (W / m2) on a surface perpendicular to light rays when it is 1.495×1011 (m) from Earth. 170 trillion (KW) of solar energy is received by the planet each year, of which 30% is reflected back into space, 47% is transformed to cold thermal energy, and 23% is used for the biosphere's cycle of evaporation and precipitation [1]. For the kinetic energy of wind, waves, and plant photosynthesis, 0.5 percent is employed.

There are several components in the solar energy system. The solar collector, which transmits heat from the sun to the absorber and from the absorber to the fluid, is the most crucial component of these systems. Solar panel modifications are frequently done to improve the efficiency of these systems [2]. The most popular solar collectors for solar space heating and solar hot water systems in homes are flat plate collectors. A standard flat collector is a metal box that is insulated, covered with glazing made of glass or plastic, and has a dark absorber inside. These collectors warm air or liquids to temperatures lower than 80°C.

2. Flat plate collector

Plate Collector, flat the comparatively straightforward flat plate collector has the broadest utility among the several solar collectors designs now under development. In comparison to other types of collectors, it is the simplest and least expensive to build, install, and operate, and its qualities are well recognised. Additionally, it is possible to employ diffuse and pyrheliometer. Flat plate collectors may produce heat at temperatures high enough to heat buildings, hot water, and swimming pools for both domestic and commercial usage [3]. A freezing unit can also be used, especially if reflectors help the sun's incidence. Temperatures between 40 and 100 °C may be reached with ease using the flat plate collector [4]. With a specific surface, reflectors to boost incident radiation, and a highly careful construction employing heat resistant materials, higher working temperatures may be attained.

In Figure 1.1, a typical flat plate collector is seen. A substantial portion of the solar energy that strikes the surface of a high absorption absorber after passing through a transparent cover is absorbed by the panel and transported to a transport medium in a liquid tube for use or storage. To minimise conduction loss, the casing side and the bottom of the absorber are adequately insulated. The liquid tube may be a separate component of the absorbent panel, or it may be welded to the panel. A header pipe with a significant diameter connects the liquid pipe at both ends.



Figure 1.1 A solar flat plate collector

The absorber plate, tubes or fins, thermal insulation, cover strip, glazing, container, or casing are the key parts of a flat plate solar collector.

2.1 Problem Statement

The dimensions of the solar collector used in this investigation are depicted below. The analysis makes advantage of a solar water heater's natural cycle. Each tube is 0.8 metres long, and the corrugated structure has an inner diameter of 0.0127 metres. A pipe with a diameter of 0.0254m and a length of 0.8m is created by gas welding together two pipes that are spaced apart by 0.11m. In order to insulate the area between the absorption tube array and the outer box, rock wool is placed there. The absorption tube array creates an inner box, which is subsequently joined to the outside box. These components are separated by aluminium foil, the box is coated with 0.004-mm transparent tempered glass, and there is a 0.035-mm air gap between the panel and the glass cover. The collector's total dimensions are $1.003 \times 0.503 \times 0.105$ m, and its effective glazing area is 0.5 m^2 .[5]

2.2 Geometry And Mesh

The final 3D design is meshed after the geometry is created in the 3D modeler. The completed mesh consisted of 64,000 elements and 68234 nodes. Figure 2.1 shows the completed mesh.



Figure 2.1 The final mesh.

2.3 Setup

Generally, for any analysis some settings need to be configured for the Ansys Fluent simulation process. The setup's solver is configured to be pressure-based, and the formulation for velocity is absolute. Gravity is in the geometry's negative Y-direction and steady time is considered. Figure 2.2 depicts the entire configuration [6].

Scale	Check	Report Quality
Display]	Units	
olver		
уре	Ve	locity Formulation
Pressure-Ba	ised	Absolute
O Density-Bas	ed 🤇	Relative
100		
lime		
Steady		
O Transienc		
Cravity		
ravitational Ac	celeration	
(m/s2) 0		•
(m/s2) -9.81		



Turn on the energy equation. Figure 2.3 shows the model constants used in a viable k-epsilon viscosity model (two equations).

The k-epsilon model was first used because it does not algebraically define a turbulent length scale for moderate to high complexity flows. Turbulent kinetic energy is the first quantity (k) transmitted. The rate at which turbulent kinetic energy dissipates is the second reported variable (epsilon).

Model	Model Constants	
() Inviscid	C2-Epsilon	
	1.9	
O Spalart-Allmaras (1 eqn)	TKE Prandtl Number	
k-epsilon (2 eqn)	1	
O k-omega (2 eqn)	TDR Prandtl Number	
Transition K-ki-omega (3 eqn)	1.2	
Iransition SST (4 eqn)	Energy Prandtl Number	
Crale Adaptive Simulation (SAS)	0.85	
Dotached Eddy Simulation (DES)	Wall Prandtl Number	
Large Eddy Simulation (LES)	0.85	
O carge cody samalation (ccs)		
k-epsilon Model		
🔘 Standard		
O RNG		
Realizable		
Near-Wall Treatment	User Defined Functions	
Standard Wall Functions	Turbulant Viscosity	
Scalable Wall Functions	none	
Non-Equilibrium Wall Functions	Departel Numbers	
Enhanced Wall Treatment	TVS Prandtl Numbers	
O Menter-Lechner	The Planut Number	
User-Defined Wall Functions	TDR Prandti Number	
Enhanced Wall Treatment Ontions	none	
Pressure Gradient Effects	Energy Prandtl Number	
✓ Thermal Effects	none	
	Wall Prandti Number	
opuons	1000	
Buoyancy Effects Only Turbulence Production *	inche .	
Viscous Heating		
Curvature Correction		
Production Limiter		

Figure 2.3 Viscous model

The Rosseland radiation model is applied, then solar ray tracing, as seen in Figure 2.4. Illumination parameters are computed using solar calculators. For the sake of this analysis, A place is required for its latitude and longitude positions.

Off Rosseland P1 Discrete Transfer (0 Surface to Surface (Discrete Ordinates (Monte Carlo (MC)	17RM) (525) DO)			
Solar Load				
Model	Sun Direction Vector			
O off	X -0.0899552 Y 0.9	55401 Z +0.028426		
Solar Ray Tracing Solar Irradiation	Vse Direction Computed fr	m Solar Calculator		
	Illumination Parameters			
Solar Calculator	Direct Solar Irradiation (w/m.	solar-calculator	٠	Edît
	Diffuse Solar Irradiation (w/m	solar-calculator		Edit
		and the second s	0.5	

Figure 2.4 Radiation model selection

Nobal P	osition			Me	esh Oriental	tion
Longit	ude (deg) 77.209				North	East
Lati	tude (deg) 28.6139			x	(1	X 0
Timezoi	ne (+-GMT) 5			Y	0	Y 0
				z	0	Z [1
Date an	d Time			So	lar Irradiati	ion Method
Day of	Year	Time of	Day) Theoretic	al Maximum
Day	21	Hour	12	2	Fair Weat	ther Conditions
Month	6 🇘	Minute	0	‡ Ор	tions	
				SI	unshine Facto	or 1

Figure 2.5 Solar calculator

Next step is to select the materials used in the flat plate collector. Generally, the materials used in the collector include copper and glass.

As glass is missing in the fluent data base, aluminium is selected as the material and replace the properties of aluminium with the properties of glass as shown in figure 2.6.

The next step is to set up the boundary conditions of distinct parts of the solar flat plate collector namely absorber plate, inlet, collector, and the glazing. For the analysis, the following boundary conditions are used:

liame	Material Type	Order Mater	tate by
gitee	sold	🖲 Name	
Chemical Formula	Fluent Solid Materials	Chemica	el Formula
glass	glass	(theory	natubase.
	Modare	- Filecon -	Para de la composition
	6ane -	GRANTA M	DS Database
		User Defin	ed Database
Properties			
Density (kg/m3)	constant	• Edit	
	233		
Cp (Specific Heal) (3/kg-k)	constant	* 6dit	
	759		
Thermal Conductivity (w/m-k)	constant	* fdit	
	1.15		

Figure 2.6: properties of glass

1. The absorber plate is of copper and the absorptivity is considered as 0.9 in both visible and infrared regions as shown in figure 2.7 A and figure 2.7 B

4 1							
1							
	Radiation	Species	399	Nutipiese	105	Fotential	Strutturg
	He Edt.	Heat Well Thick of Generation	Flax (w(n2) oess (m) g Rate (w(n3)	0	cler (lig	yer	· ·

Figure 2.7 Boundary conditions of absorber plate a) Radiation setup b) Thermal setup

2. The glazing is made of glass and considered as a semi-transparent substance involving in the solar ray tracing. The absorptivity is set as 0.1 in IR and visible regions and transmissivity is considered as 0.9. The image indicating these parameters is shown in figure 2.8.

Zone Name glazing Adjacent Cell Zone collector Momentum Thermal Radiation Species (2014 Multipliase (2015 Potential (3) BC Type	Inuntane
grazing Adjacent Cell Zone collector <u>Momentum Thermal Radiation Species (2014 Multipliase UDS Potential S</u> BC Type	Inuchane
Adjacent Cell Zone collector Momentum Thermal Radiation Species (2014 Multipliase UDS Potential S BC Type	tructure
Momentum Thermal Radiation Species DPM Multipliase UDS Potential S BC Type	Inurhane
ВС Туре	
semi-transparent	
Solar Boundary Conditions	
Perticipates in Solar Ray Tracing	
Absorptivity Transmissivity	
Direct Visible 0.1 + Direct Visible 0.9	.*
Direct IR 0.1 + Direct IR 0.9	
Diffuse Hemispherical 0.9	

Figure 2.8 Glazing boundary conditions

3. Setting up the inlet as a mass flow inlet followed by the selection of direction specification as "Normal to Boundary" and the mass flowrate as 0.05 kg/s at a temperature of 25°C as shown in the figure 2.9.

nlet							
Momentur	n Thermal	Radiation	Species	DPM	Multiphase	Potential	UDS
	Reference F	rame Absolu	te				
Mass Flo	w Specification M	ethod Mass F	low Rate				,
	Mass Flow	/ Rate (kg/s)	0.05				
Supersoni	c/Initial Gauge Pre	essure (pasca	Do				
Directi	on Specification M	ethod Norma	l to Boundary				
Tu	rbulence						
	Specification Me	thod Intensit	y and Viscosit	y Ratio			
	Turbulent Inte	ensity (%) 5					•
т	urbulent Viscosity	Ratio 10					

Figure 2.9 Boundary conditions of inlet.

- 4. Setting the outlet temperature as 25°C.
- Finally selecting the wall material as aluminium undergoing convection at free stream temperature of 25°C and with a heat transfer coefficient of 5 W/m²K. The entire parameter selection is shown in the figure 2.10

Adds and a set of the face of	alls djacent Cell Zone ollector								
djacent Cell Zone ollector Momentum Thermal Radiation Species DPM Multiphese UDS Potential Structure hermal Conditions 	djacent Cell Zone ollector								
Momentum Thermal Radiation Species DPM Multiphese UDS Potential Structure hermal Conditions Heat Flux Heat Transfer Coefficient (w/m2-k) 5 •									
Heat Flux Heat Transfer Coefficient (w/m2-k) 5 Temperature Free Stream Temperature (c) 25 Convection Wall Thickness (m) 0 Mixed Heat Generation Rate (w/m3) 0 via System Coupling Shell Conduction 1 Laver	Momentum	Thermal	Radiation	Species	DPM	Multiphase	UDS	Potential	Structure
Heat Flux Heat Transfer Coefficient (w/m2-k) 5 Temperature Free Stream Temperature (c) 25 Convection Wall Thickness (m) 0 Moxed Heat Generation Rate (w/m3) 0 Via System Coupling Shell Conduction 1 Laver	hermal Condition	15							
Temperature Free Stream Temperature (c) 25 Convection Wall Thickness (m) 0 Moxed Heat Generation Rate (w/m3) 0 Via Mapped Interface Shell Conduction 1 Laver	🔿 Heat Flux		He	at Transfer Coe	fficient (w/m2	!-k) 5			
Convection Wall Thickness (m) Radiation Wall Thickness (m) Mixed Heat Generation Rate (w/m3) via System Coupling Heat Generation Rate (w/m3) via Mopped Interface Shell Conduction	Temperature		Free	e Stream Tempe	rature (c) 25				
Moxed Heat Generation Rate (w/m3) 0 via System Coupling Heat Generation Rate (w/m3) 0 via Mopped Interface Shell Conduction 1 Laver	Radiation			Wall Th	ckness (m)				
via System Coupling Heat Generation Rate (w/m3) 0 via Mapped Interface Shell Conduction	Mixed			1100 110	Caness (m) 0				
vis Mapped Interface Shell Conduction 1 Layer Edit.	🔘 via System Ci	oupling		Heat Generatio	n Rate (w/m3	3) 0			*
	Wis Mapped B	nterface				Shell Cond	juction 1 La	iyer	Edit.
Material Name	Material Name								
aluminum + Edit	aluminum	*	Edit						

Figure 2.10 Boundary conditions of the wall.

The next step is to set the reference values and reference zones. The reference zone is considered as the collector and the values are computed from inlet (Figure 2.11)

compute from	
inlet	
Reference Values	
Area (m2)	(1
Density (kg/m3)	1.225
Enthalpy (j/kg)	83246.14
Length (m)	1
Pressure (pascal)	0
Temperature (c)	25
Velocity (m/s)	32.61456
Viscosity (kg/m-s)	1.7894e-05
Ratio of Specific Heats	1.4
Yplus for Heat Tran. Coef.	300
Reference Zone	
collector	

Figure 2.11 Reference values.

The next step includes the selection of the solution methods. For this analysis Green-Gauge node based gradient solver is used under SIMPLE scheme and setting all the values to be considered as second order for more accuracy in the results as displayed in figure 2.12.

Solution Methods	0	D
Pressure-Velocity Coupling		
Scheme		
SIMPLE		-
Spatial Discretization		
Green-Gauss Node Based	*	-
Pressure		
Second Order	*	1
Momentum		
Second Order Upwind	-	1
Turbulent Kinetic Energy		
Second Order Upwind	-	1
Turbulent Dissipation Rate		
Second Order Upwind	-	E.
Energy		
Second Order Upwind	•	-
Transient Formulation		
Non-Iterative Time Advancement		
Frozen Flux Formulation		
Warped-Face Gradient Correction		
High Order Term Relaxation Options		
Figure 2.12 Solution methods.		

After setting up all the above schemes, the solution must be initialized using two methods. hybrid or standard. The standard initialization is used for the steady state simulation for both the solvers, pressure based, or density based, and improve the convergence robustness of the solution. Therefore, the same is used in the present study.

3. Results And Discussion

After 4500 iterations of calculation, various residuals are obtained which include velocity in x, y, and z directions, continuity, turbulent kinetic energy, and energy. The residual of the present analysis is shown in the figure 3.1.



Figure 3.1 Residuals of all iterations.

Now to get the variation of properties at different points on the solar flat plate collector, contours are used. For the present CFD analysis of the solar flat plate collector, various contours are used. The various aspects of contours include of temperature, pressure, IR solar flux absorbed, velocity and the turbulence [7].

In the figure 3.2, The contours of absorbed IR solar flux is shown. It can be observed that the flux is high at some points of sbsorber plate i.e the fins which are to be heated to heat the air present under it. So the flux is higher at the fin areas and minimum at other spots.

In the figure 3.3, The contours of pressure are shown and by observing the contour lines, It is to be noted that the entire apparatus is at same pressure as it is closed and also in horizontal position.

In the figure 3.4, The contours of temperature is shown and it is observed that the temperature is high at the fins where the absorber plate transfer its heat flux and the remaining area is at minimal temperature. The temperature difference can be observed and it indicates the usage of flat plate collector can be encouraged for house hold applications in near future[8].

Figure 3.5 and 3.6 are showing the contours of turbulence energy and the velocity of the flat plate collector.



Figure 3.2 Contours of absorbed solar flux.



Fig 3.3 Contours of pressure.



Figure 3.4 Contours of temperature.



Fig 3.5 Contours of Turbulence.



Figure 3.6 Contours of Velocity.

4. Conclusion

To fulfil the rising energy demand for daily home demands, solar energy is crucial. In order to model the flat plate collectors and forecast their performance in any location, substantial research should be done for its geographical parameters. The flow rate and temperature distribution in the solar collector were investigated numerically and experimentally. Using CFD models, the impact of absorption plate effects and tube geometry on flow and heat distribution are noticed effectively. The working fluid's improved capacity to absorb heat results in a reduction in the absorber's ambient temperature and an increase in collector performance. The measured temperature difference has been found to be a reliable predictor. It also indicates that the Flat plate collectors can also be used to offset non-renewable resource energy use in the near future.

References

- [1]. Andrade Cando, Anthony Xavier, et al. "CFD Analysis of a Solar Flat Plate Collector with Different Cross Sections | Enfoque UTE." CFD Analysis of a Solar Flat Plate Collector with Different Cross Sections | Enfoque UTE, dx.doi.org, 1 Apr. 2020, <u>http://dx.doi.org/10.29019/enfoque.v11n2.601</u>.
- [2]. Thakur, A., Kumar, S., Kumar, P., Kumar, S., & Bhardwaj, A. K. (2021). A review on the simulation/CFD based studies on the thermal augmentation of flat plate solar collectors. *Materials Today: Proceedings*, 46, 8578–8585. <u>https://doi.org/10.1016/j.matpr.2021.03.550</u>
- [3]. Mohamed Selmi, Mohammed J. Al-Khawaja, Abdulhamid Marafia, 2008. Validation of CFD simulation for flat plate solar energy collector, Renewable Energy 33 (2008) 383–387.
- [4]. P. Sivakumar, W. Christraj, M. Sridharan and N. Jayamalathi, 2012.Performance improvement study of solar water heating system, ARPN Journal of Engineering and Applied Sciences, Vol.7, No 1, pp45-9.
- [5]. Abdel-Khalik S.I., 1976. Heat removal factor for a flat-plate solar collector with a serpentinetube, Journal of Solar Energy Vol 18, pp59-64.
- [6]. Wang, Dengjia & Mo, Zhelong & Liu, Yanfeng & Ren, Yuchao & Fan, Jianhua, 2022. "<u>Thermal</u> performance analysis of large-scale flat plate solar collectors and regional applicability in <u>China</u>," <u>Energy</u>, Elsevier, vol. 238(PC).
- [7]. Missirlis, D. & Martinopoulos, G. & Tsilingiridis, G. & Yakinthos, K. & Kyriakis, N., 2014. "Investigation of the heat transfer behaviour of a polymer solar collector for different manifold configurations," <u>Renewable Energy</u>, Elsevier, vol. 68(C), pages 715-723.
- [8]. Tian, Y. & Zhao, C.Y., 2013. "<u>A review of solar collectors and thermal energy storage in solar thermal applications</u>," <u>Applied Energy</u>, Elsevier, vol. 104(C), pages 538-553.

14