NUMERICAL STUDY OF FLUID FLOW CHARACTERISTIC ON V-CORRUGATED PLATE SOLAR AIR COLLECTOR USING CYLINDRICAL FIN AS A VORTEX GENERATOR

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ABSTRACT

Solar collector uses solar energy radiation drawn in by absorber plate and transferred to the fluid. Solar collector thermal efficiency can be increased by putting up heat convection coefficient and turbulence flow inside solar collector's duct. It can be achieved by giving obstacles and fins to the flow to make wider heat transfer area. The geometry of the fins is half cylindrical with 6mm,8mm, and 10 mm diameter and fin spacing between obstacles is 0,25L;0,5L;0,75L respectively. The optimum fin geometry is chosen by numerical method using Fluent 6.3.26. The experiment uses v-corrugated absorber plate and 30˚ bill shaped obstacle. Experimental sets to test the effect of fin addition to solar collector's performance and efficiency. All fin variations are tested numerically with 6,5 m/s inlet velocity and constant heat flux of 430 Watt/m^2. The numerical analysis shows that the optimum result achieved at temperature difference of 8,809 C degree, pressure drop of 357,046 Paand 0.022 ratio, using 6mm diameter fin and 0,5L spacing between obstacles.

Keywords: cylindrical fin, obstacle, solar collector, v-corrugated plate absorber, temperature deference, pressure drop, ratio.

1. INTRODUCTION

Solar energy is renewable energy that is eco-friendly and can be easily found in equator passed country, Indonesia with average solar radiation intensity of 5,6 kWh/m2 per day. This form of energy can be converted to thermal energy using solar collector. Solar collector uses solar energy radiation to be absorbed by absorber plate and transfer to the fluid. The fluid can be in the form of air or water. According to Frank and DeWitt [1], heat transfer coefficient of gas is lower than liquid so solar collector efficiency is low. The low convection coefficient between the surface of absorber plate and the fluid became a problem in solar air heater. This phenomenon made many scientist tried to make solar air heater efficiency higher. The benefits of air as a fluid is, it is lighter and non-corrosif than water. Air can be used directly to drying process, for example crops, fish, etc. Randall *et al.*[2] had studied the v-corrugated absorber plate and collerate data in Reynolds and Nusselt. Basically, solar collector consists of absorber plate to absorb solar radiation, duct as the flow channel, cover glass, and blower as the air blower.

Solar collector heat transfer coefficient can be increased by replacing flat absorber plate with v-corrugated absorber plate [3]. According to El Sebaii [3], v-corrugated absorber plate has 11-14% higher efficiency than the flat absorber plate. Karim *et al.*[4] Declared that v-corrugated solar collector is 10-15% more efficient that flat plate if used in single pass and 5-11% more efficient in double pass.

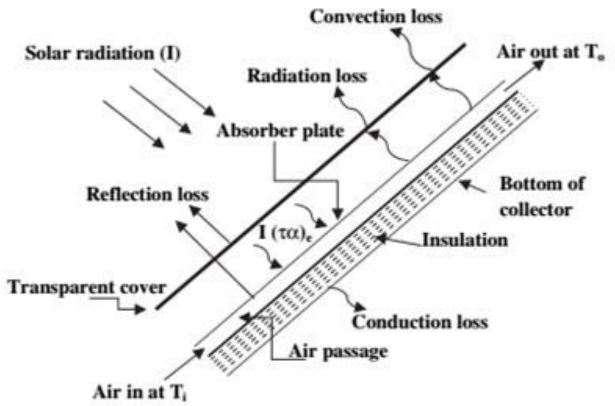

Figure-1. Schematic of conventional solar collector.

Double pass provides the highest efficiency increasing when used in flat plate collector and lowest in v-corrugated solar collector. turbulence. Kumar *et al.* [5], Layek *et al.* [6], Bhushan & Singh [7], and Gupta & Kaushik [8] made an artificial roughness on absorber plate by giving rib or groove in duct. Turbulence promoters on a surface is the most effective way to transfer heat to fluid that passing it.

Modification to make heat transfer coefficient from abosber plate to ambient higher can be done by adding fins and obstacles. Akpinar & Kocyigit [9] studied solar air heater with triangle, leaf, and rectangle obstacle that installed with 45^o angle to air flow. Peng *et al.* [10] studied pin fin obstacles by varrying the thickness and configuration. The result is the closest space configuration and the higher fin, the efficiency would be higher. Hans *et al.* [11] performed research on Solar Air Heater by adding multi ribs on absorber plate, and resulted the highest Nu number can be achieved with W/w = 6. Bekele *et al.*[12]

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studied triangle obstacle on the absorber plate with some configurations. They found that the closest space and the highest, the solar collector efficiency would be higher. Ho *et al.* [13]Studied fins on and under the absorber plate by giving the flow. Ozygen *et al.*[14] Studied the thermal performance of double pass solar air heater with aluminium as the obstacle with two different configurations. Alta *et al.*[15] Studied the effect of fin and number of cover glass in a solar collector. Esen [16] compared few pass solar air heater with three kind of obstacles, that is flat triangle, were bent on tip horizontally and combination from rectangular and triangle were bent horizontally. Romdhane [17] studied the addition of baffle with delta shaped, perpendicular and straight rectangular to the flow, and also the colors of absorber plate. Karsli [18] studied obstacle with two kind of angle and chopper pipe. Abene *et al.*[19] Studied obstacles with some kind of types that is, ogival transverse (OT), ogival inclined folded (OIF1), waisted tube (WT), waisted delta lengthways (WDL1), waisted ogival lengthways (WOL1), and transverse-longitudinal obstacles (TL). Kurtbas Turgut [20] studied solar air heater with long and small fins with the same amout of area. They found that small fins provide higher efficiency. Meanwhile, convection coefficient can be improved by increasing flow turbulence inside the v-corrugated absorber plate with 30˚ bill shaped obstacles along the flow channel, Ekadewi *et al.* [21]. The result is 30˚ bent obstacle gives the highest pressure drop per efficiency ($\Delta P/\Delta Eff$) than the others. By using of v-corrugated absorber plate and obstacle adding it is proved that solar collector heat transfer coefficient can be increased. Study about solar collector by using fins under the absorber plate along the channel has been done by Hakam *et al.*[22] by using prismatic fin type, and this type produced increasing pressure and temperature ratio ($\Delta P/\Delta T$)) 37.0672 if compared with solar collector without fin.

2. EXPERIMENTAL SET UP

The installation of solar air heater in the experiment shown on the Figure-2 below:

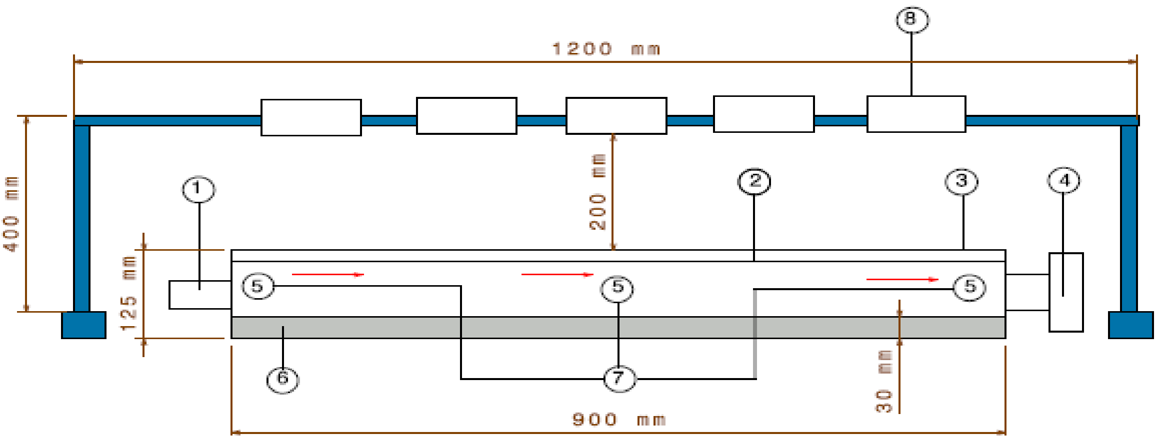

Figure-2. Schematic installation of V-corrugated solar air collector.

Description:

1 : Contraction and honey comb	4 : *Blower*	7 : *Thermocouple display*
2 : A*bsorber plate*	5 : Air flow	8 : Halogen Lamp
3 : Cover glass	6 : Isolator	

The principal work of *v-corrugated solar air collector*is the air is blown by blower with spesific velocity to the solar collector ducting channel. The fluid will pass the obstacle and fin along the channel so it will create vortex. When passing through the solar colector, the temperature will increase because of heat energy transfer in convection and radiation

3. NUMERICAL STUDY

This study is particularly concerning with v-corrugated solar collector is using 30˚ bill shaped obstacles and half cylindrical fins. Diameter of the fins are varied from 6; 8; 10 mm and fin spacing to the obstacles are varied from 0,25L; 0,50L; 0,75L. Where L is the space between two obstacles that is 50 mm. Numerical study has been done by Computational Fluid Dynamics (CFD) method with fluent 6.3.26 and Gambit 2.4.6. The first step is modeling geometry of solar collector and the varied fins using Gambit 2.4.6, and then the second step is meshing the model using Fluent 6.3.26.

Geometry that is used in this numerical study including its dimension is shown in Figure-2. The angle of the absorber plate is 20˚ with 900 mm length and triangle ducting channel with 85 mm height and 30 mm width. Obstacles are in 30˚ bill shaped with 18 mm width and 50 mm height. 17 obstacles are placed in every 50 mm along the channel. Then the domain and meshing is determined. Meshing configuration used consists of 786.180 cells, 1.654.940 faces, and 172.405 nodes.

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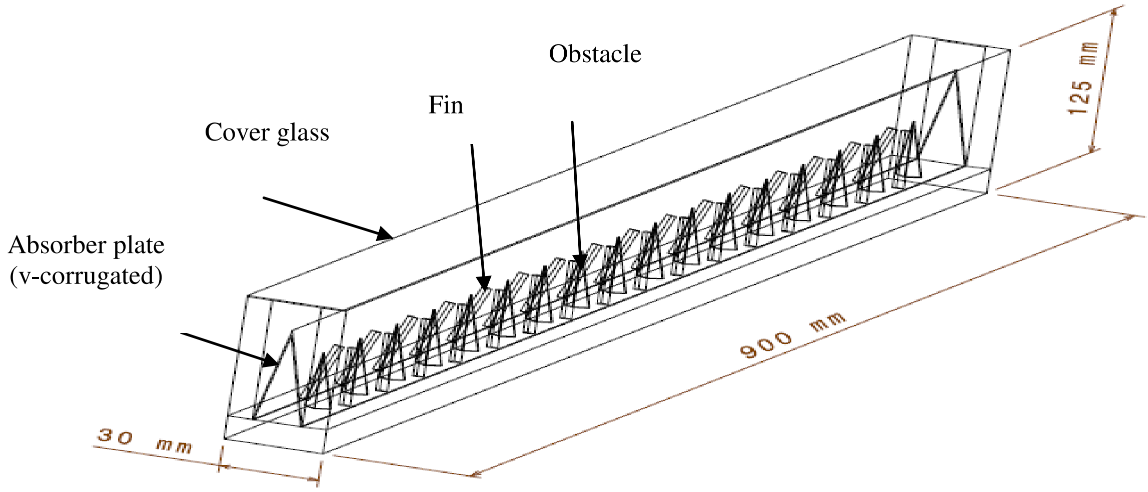

Figure-3. 20˚ v-corrugated absorber.

The setting include 3D simulation, double precision, Shear Stress Transport K-ω (SSTKω) viscous model. The material of absorber plate; obstacles; and fins are aluminum. First order scheme discretization equation, and, while the relation of velocity and pressure is using SIMPLEC. Boundary conditions of absorber plate; fins; obstacles; and channel floor are defined as wall, inlet as velocity inlet, and outlet as outflow. Absorber plate and fin receive 431 Watt/m2 Heat Flux, contrastly, channel floor and obstacles have constant temperature of 310 K. Free stream flow enters the ducting channel has velocity of 6,5 m/s and the temperature is 300 K.

Simulation result show that the outlet temperature increasing and pressure drop inside the channel which have to be analyzed. The most optimum fin is chosen by using ratio formulation, which is mathematically as follows:

$$R = \left|\frac{\Delta T_{fin} - \Delta T_{no\ fin}}{\Delta T_{no\ fin}}\right| / \left|\frac{\Delta P_{fin} - \Delta P_{no\ fin}}{\Delta P_{no\ fin}}\right| \quad (1)$$

Where $\Delta T$is the difference of inlet and outlet temperature, (Tout-Tin).$\Delta P$is pressure drop between inlet and outlet pressure, (Pin-Pout). Ratio is compared with simulation of solar collector without fins. As a result of the mathematic formulation, the largest ratio shows the most optimum fin.

In numerical study of v-corrugated solar collector in 30^{o} bill shaped along ducting channel with inline obstacles andhalf cylindrical fin on the bottom side of absorber plate. By adding fin addition, it is expected that solar collector will have higher performance than solar collector without fin. This study focuse on the optimum diameter and spacing of the fins to get the higher outlet temperatur with lower pressure drop. Fin diameter is varried from 3mm; 4mm; 5mm. Meanwhile fin spacing between obstacles (ℓ) are 0,25ℓ; 0,50ℓ; 0,75ℓ; where the ℓ is 50 mm. The optimum thickness and spacing of the fin is found out by modelling with *Computational Fluid Dynamics*methods. The geometry of solar collector is made by GAMBIT 2.4.6 and simulated by Fluent 6.3.26.

Numerical simulation steps are using GAMBIT 2.4.6 and FLUENT 6.3.26.

a) Create 3D model of v-corrugated solar collector geometry with 17 obstacles and 16 fins. Above figure (Figure-3) shows the dimension of solar collector.
b) Create meshing to the geometry before, then create volume meshing with Tgrid type. Before doing the simulation, grid independency test must be done to ensure the advantage and the efficiency of the amount of grid used (Figure-4).
c) Determined the boundary conditions of solar collector that will be simulated on Fluent (Figure-5).

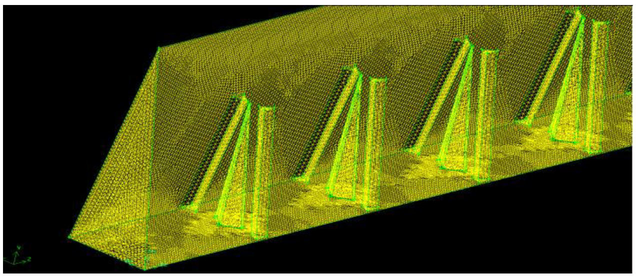

Figure-4. Tgrid meshing of solar collector using GAMBIT.

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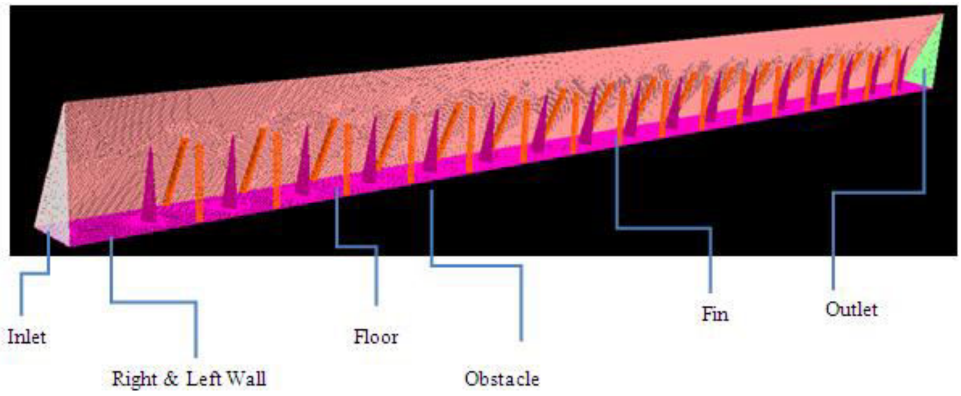

Figure-5. Boundary conditions of solar collector.

a. After reading and grid checking in Fluent, the simulation requirements are determined as belowTable-1.

Table-1. Requirement in fluent 6.3.26.

Parameter		**Input**
Model	**Solver**	**Green-Gauss cell based, 3D**
	Energy	Energy Equation
	Viscous	k-omega SST (2 equation)
Material	Air	ρ = 1,1614 kg/m^3 Cp = 1007 J/kg.K μ = 18,46 x 10^{-6} N.s/m^2 ν =15,89 x 10^{-6} m^2/s
Operating conditions	Operating Pressure	1,01325 x 10^5 Pa
Boundary conditions	Plat absorber (bottom)	Wall, with at constant Temperature of 310 K
	Inlet	Velocity inlet 6,5 m/s, Temperature 300 K
	Outlet	Outflow
	Obstacles	Wall, with at constant Temperature of 310 K
	Fins	Wall, at 430 Watt/m^2 Heat Flux
	Plat absorber	Wall, at 430 Watt/m^2 Heat Flux
Controls	Solution	Pressure-Velocity Coupling : SIMPLEC Discretization Pressure : Standard Momentum : First Order Upwind Turbulent Kinetic Energy : First Order Upwind Specific Dissipation Rate : First Order Upwind Energy : First Order Upwind
	Initialize	Inlet, velocity : 6,5 m/s
	Residuals	Absolute Criteria Continuity : 10^{-6} X velocity : 10^{-3} Y velocity : 10^{-3} Z velocity : 10^{-3} Energy : 10^{-6} k : 10^{-3} Omega : 10^{-3}

4. RESULT AND DISCUSSIONS

Numerical simulation is carry out to find out the phenomenon inside the solar collector ducting channel with fins. The first step in numerical simulation is *Grid Independency Test*.Grid Independency is done by increasing the resolution of meshing in order to gain steady simulation results.

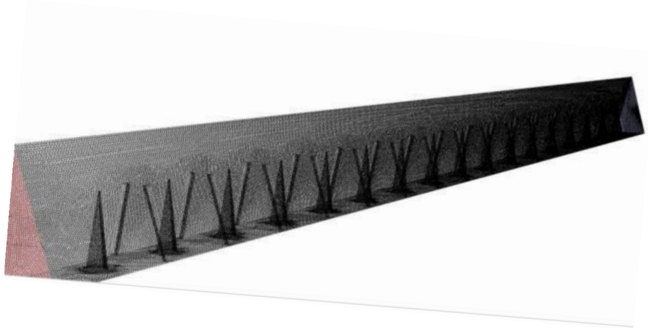

Figure-6. Meshing for grid independency test.

Dimension of meshing highly affects the result and the time of the simulation. *Grid IndependencyTest* in this simulation uses five meshing variations which affect the amount of cells, faces, and nodes.

Table-2. Cell, face, and node fromtested mesh.

Mesh	Number of iteration	Cell	Face	Node	Yplus
1	569	294,785	627,887	68,528	97.95
2	659	311,553	662,474	71,833	93.51
3	754	786,181	1,654,940	172,405	65.34
4	937	1,239,586	2,602,745	269,260	57.55
5	978	1,641,594	3,446,487	356,252	49.29

When Grid Independency Test was conducted same geometry, domain, and viscous model where used in all meshing, so we can **co**mpare number of grid and the best efficiency on numerical simulation could be found. Each meshing has the same boundary condition in fluent software. The simulation result compared is the velocity fluid on z axis where x and y coordinate are 0,0015m and 0,056 m. Velocity results are as a follows:

Table-3. The results of simulation.

Mesh	**Y** (m)	**Z Velocity** (m/s)	Error
1	0.05605	2.03018	100%
2	0.05596	2.64253	23.173%
3	0.05662	2.19935	20.150%
4	0.05699	1.81991	20.849%
5	0.05655	2.26775	19.748%

The simulation result used grid independency was plotted in below graphic:

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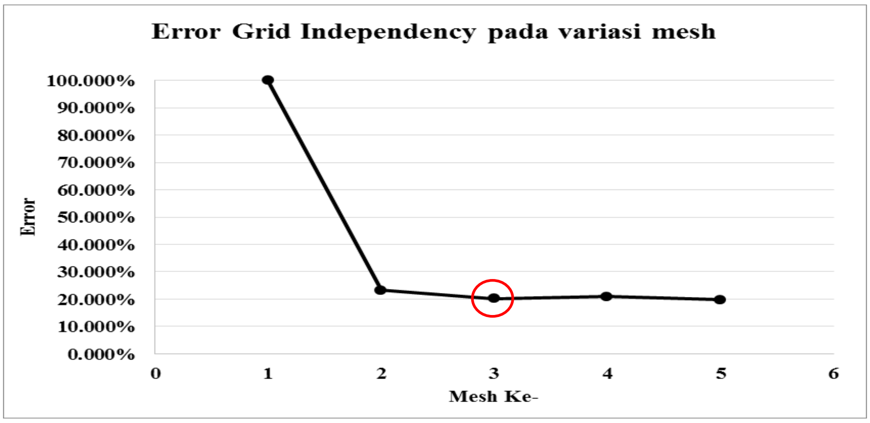

Figure-7. Graphic of velocity error.

Error value obtained from this graphic showed that 3rdmeshing has more stability if compared to others, so that meshing 3 was assumed to have grid independency.

Based on velocity error resulted from Figure-7, meshing 3 can be applied to all variation of fin dimensions. The simulation also conducted to collector without fins to find out the impact of fin installation. The simulation results as in the following table:

Table-4. The difference of temperature and pressure from result simulation all fin variation.

Fin diameter	Spacing	ΔT(K)	ΔP(Pa)	Ratio ΔP	Ratio ΔT	Total ratio
6 mm	0.25L	8.913	404.730	1.106	0.007	0.007
	0.5L	8.809	357.045	0.858	0.019	0.022
	0.75L	8.940	363.421	0.891	0.004	0.005
8 mm	0.25L	9.070	508.02	1.643	0.0103	0.006
	0.5L	8.932	432.771	1.252	0.005	0.004
	0.75L	8.991	442.675	1.303	0.0015	0.001
10 mm	0.25L	9.175	670.211	2.488	0.0219	0.009
	0.5L	8.984	544.422	1.833	0.0007	0.0004
	0.75L	8.995	562.314	1.926	0.002	0.0009
Without *Fin*		8.978	192.168			

The optimum fin is choosen by the biggest ratio of ΔP and ΔT compared to unfin solar collector, or mathematically as equation 1.

The result shows, that fin with the biggest ratio of ΔP and ΔT is 3mm fin diameter and 0,5ℓ spacing to obstacle.

Where T_{fin} is the differential temperature outlet and inlet collector with fin, and ΔP_{fin} is the differential pressure outlet and inlet collector with fin, while $\Delta P_{tanpa\ fin}$dan $\Delta T_{tanpa\ fin}$ are the differential temperature and pressure inlet and outlet without fin.

From the results, it is obtained that fin with smallest ratio of ΔP and ΔT is 3mm fin and 0,5ℓ spacing between obstacle is the most optimal fin with value of 0.022 ΔP/ΔT. This dimension is the most optimal fin can be described using velocity vector from simulation result as follow:

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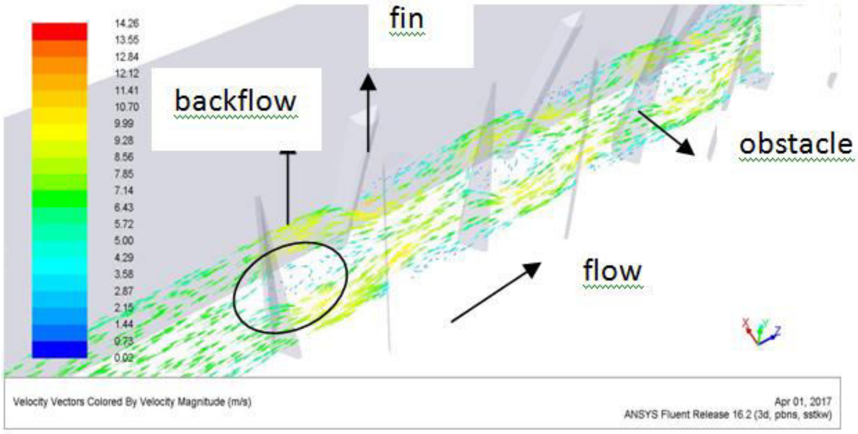
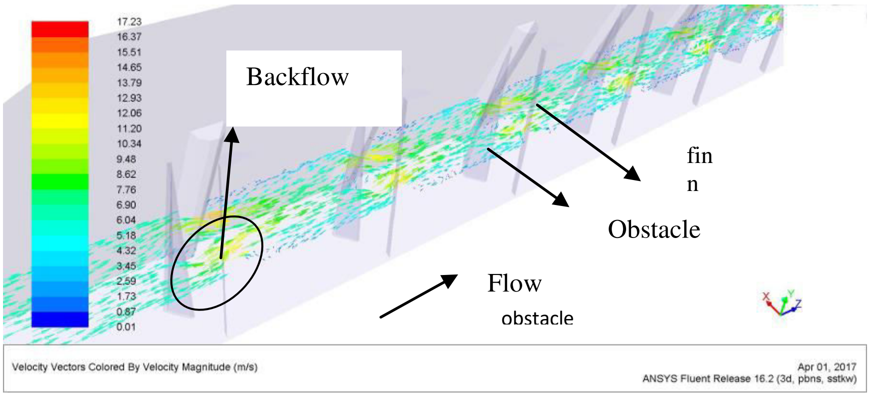


(a)



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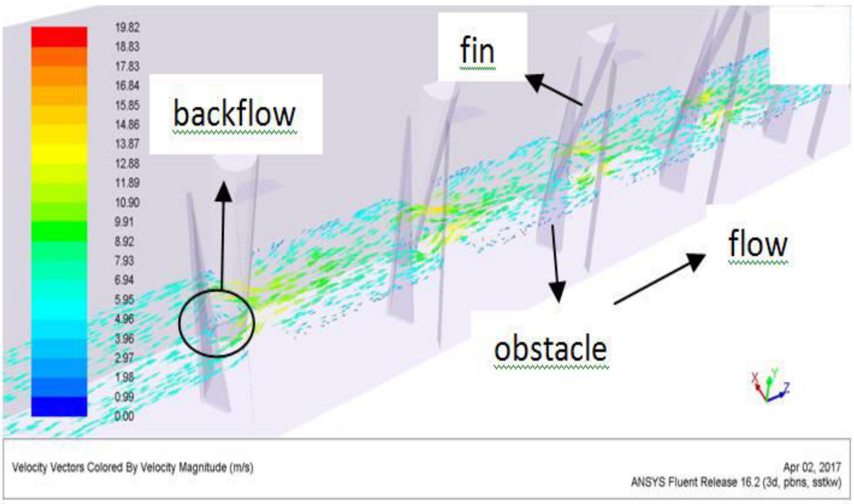

(c)

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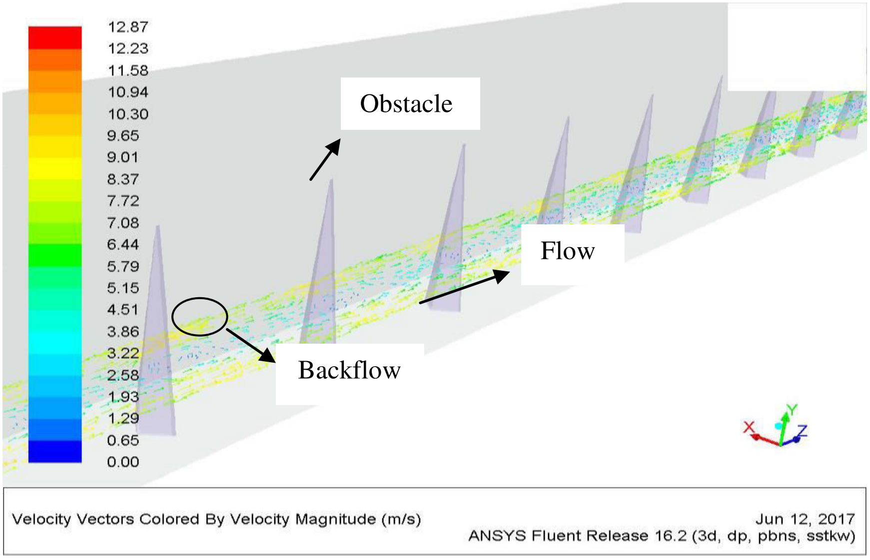

(d)

Figure-8. Velocity vector of (a) The best result from 6 mm fin diameter and 0,50 ℓ spacing to obstacle(b) The best result from 8 mm fin diameter and 0,250 ℓ spacing to obstacle; (c) The best result from 10 mm fin diameter and 0,250 ℓ spacing to obstacle (d) without fin.

The picture (Figure-8 c) shows that velocity vector on 10 mm fin diameter and spacing between obstacles0, 25ℓproduces the highest vortex behind obstacle and fin if compared with other geometry. This dimension produces highest temperature gradient. This case can be explained that this dimension fin will increase velocity rate between fins, and it will also increase secondary flow behind fins. In this research, fin with this dimension produces the highest secondary flow behind fin. When secondary flow occurs, more air flow in the gap and contact with absorber plate which is the heat source. It is the reason why fin with this dimension makes higher air outlet temperature.Fin c resulting maximum temperature differential of 9,175 K if compared with others, but produces highest pressure drop than other fin (Figure8a, 9b, and 9d). This is the reason why in this study, fin selection not only based temperature increment but also based on pressure drop and temperature increment in which minimum result will be selected as a standard, so fin 9.a (6mm diameter and 0.5l) will be selected as a standard.

5. CONCLUSIONS

From this study of solar collector with v-corrugated absorber plate added by obstacles and half cylindrical fins, it can be concluded that the optimum result is achieved at temperature difference of 8,809, pressure drop of 357,046 and 0,022 ratio using 6mm diameter fin and 0,5L spacing between obstacles.

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