Jr. of Industrial Pollution Control 33(2)(2017) pp 1693-1698
www.icontrolpollution.com
Research Article

EFFECT OF FIN SPACING ON FORCED CONVECTION HEAT TRANSFER THROUGH THE PARABOLIC DISH SOLAR RECEIVER

RAMALINGAM SENTHIL* MUKUND GUPTA AND CHINMAYA RATH

Department of Mechanical Engineering, SRM University, Kattankulathur, Chennai-603203, India

(Received 25 May, 2017; accepted 22 December, 2017)

Key words: : Concentrated solar receiver, Parabolic dish collector, Fin spacing, Fin heat transfer

ABSTRACT

In surface absorption concentrated solar receiver, fins are used to transfer heat from the absorber plate inner surface to heat transfer medium. Thin, rectangular fins are the most commonly used profile due to its high efficiency. The addition of more fins not only increases the heat transfer rate, but also increases the flow resistance. Further, there will be a reduction of convective heat transfer coefficient due to more number of fins. The heat transfer coefficient is higher with forced circulation of fluid when compared to natural laminar convection with optimum fins. The design parameters considered here for the solar receiver are fin dimensions, fin spacing and fluid mass flow rate with fin optimization study carried out for different mass flow rates applicable for concentrated solar collectors. The fin spacing decreases with the increase in mass flow rate of the working fluid. For the practical range of mass flow rates (0.1 – 0.5 kg/s) employed in parabolic dish concentrated community cooking solar receiver are to be between 12.5 and 22.5 mm.

INTRODUCTION

Fins are well known in engineering applications for their enhancing role in heat transfer; absorbing heat from the heat source and dissipating into ambient for the safe material temperatures. The fins are used in solar absorption systems to convert radiant heat into useful higher temperature thermal energy. In a concentrated solar receiver, the absorber plate is made of black coated mild steel due to its high absorptivity. Water is allowed to enter into the receiver through the inlet. Aluminum fins are attached to the inner surface of the solar absorber/receiver. The schematic layout of the surface absorption solar receiver in 16 m^2 Scheffler type parabolic dish concentrator and fin arrangement are shown in (Fig. 1 and 2) respectively.

Mass flow rate or flow velocity are important parameters while deciding the optimum number of fins when compared to fin materials. While designing a finned absorber plate, design parameters to be considered are fin dimensions, fin spacing and mass flow rate. The pressure drop inside the receiver will be higher due to high turbulence and the resulted in increase in the pumping power for closely packed fins.

The Nusselt correlations developed for natural convection from vertical finned surfaces directly exposed to air. Fin spacing was considered as the characteristic length for vertical parallel plates with fin height as another variable. Different boundary conditions were applied subjecting the fins to constant surface temperature and constant heat flux. The identified optimum fin efficiency was a function of fin spacing, fin height, fin surface temperature and

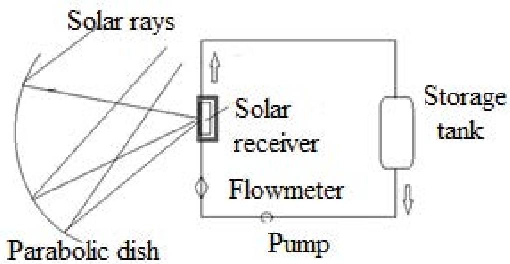

Fig. 1 Parabolic dish concentrated surface absorption solar receiver.

***Corresponding authors email:** rsenthilsrm@gmail.com

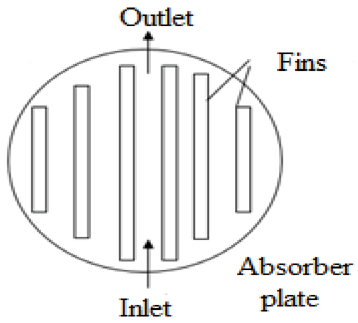

Fig. 2 Fins on the internal surface of the solar receiver.

viscosity of fluid (Bar-Cohen and Rohsenow, 1984).

The forced convective heat transfer was compared for different fin shapes and obtained the optimum spacing for longitudinal fins. The maximum total heat flux was largest for the concave parabolic fin array and smallest for the rectangular fin array. The overall surface efficiency was largest for the rectangular fin array (Rong, *et al.,* 1997).

The natural convection was studied with various fin configurations and the vertical fins attached to a vertical base plate that gave maximum heat transfer due to higher convection (Goshayeshi and Ampofo, 2009).

Most of the researchers extensively investigated the fin heat transfer performance in natural and forced circulation for heat removal using air (Mon and Gross, 2004; Ganji, *et al*., 2011; Sevilgen, 2015).

The concentrated solar receiver is investigated with forced convection of water to capture maximum heat from a hot incident surface through fins (Arunasalam, *et al*., 2012; Senthil and Cheralathan, 2015; Senthil and Cheralathan, 2016; Senthil and Cheralathan, 2016).

Determining the optimized fin spacing of fins added to the vertical absorber plate is the objective of this study. In a solar receiver, multiple fins are attached to the absorber plate; the plate and fins get heated as it absorbs sunlight, as the heat is transferred to the fins through conduction process. As water is pumped into the heater unit, forced convective heat transfer takes place from fin to water and the heat transfer depends on flow velocity, orientation of fins and fin spacing. Orientation of fin means, either the mean water flow direction is normal to fin surface or along the fin surface. For vertical fins, mean water flow is along the fin surface.

Vertical fin configuration is selected for the solar water heater since flow resistance offered by vertical fins is lesser compared to the horizontal fin configuration. As water flows over the hot fins, velocity and thermal boundary layers develop from leading edge of adjacent fins. The boundary layers will merge at the mid-plane if fins are sufficiently long and fin spacing is not too high. If the fin spacing is too high or fins are not sufficiently long, then boundary layers of adjacent fins will not merge. In this case, heat transfer study can be analyzed as convection from independent surfaces. Since total heat transferreddepends on both heat transfer coefficient and total surface area exposed to heat transfer, there must be optimal fin spacing for effective heat transfer.

The Reynolds number and Nusselt number may be calculated using the equations 1 and 2. Total heat transfer to the fluid may be calculated using equation 3.

$$Re = \rho v L / \mu \quad (1)$$

$$Nu = h L / k \quad (2)$$

$$Q_{total} = h^* A_{total}{}^* (T_{fin} - T_{water}) \quad (3)$$

The solar collector plate gets heated as it absorbs normal incident or concentrated solar energy and the thermal resistance offered by fin to conduction process is very less and temperature drop on the fin surface is less. Hence, it is assumed that an almost uniform temperature distribution develops on the fin surface. Walls of the solar water heater tank (or enclosure) should be insulated so that heat loss through the walls can be reduced. Water flow is turbulent for all the flow conditions considered.

Two-dimensional steady state heat transfers are studied in simulation. CAD geometry used for simulation consists of an enclosure with two fins for simplicity. The region in between two fins is called channel. Since the same temperature profile develops in all the channels, simulation needs to be done only for a single channel. The results obtained can be used for calculating heat transfer in an enclosure with any number of similar channels or fins. Modeling and meshing activities are done in ANSYS software. The model is meshed with quadrilateral elements and the maximum aspect ratio of quadrilateral elements is 5.

A two-dimensional steady state forced convection turbulent flow, using standard K-epsilon model, enhanced wall treatment is considered for the fin space optimization study. Gravity effects are neglected in this analysis.

Simulations are carried out for widely-employed mass flow rates of 0.01 kg/s, 0.05 kg/s, 0.1 kg/s, 0.25 kg/s and 0.5 kg/s through the concentrated solar receivers. Fin spacing is varied for each mass flow rate. All simulations are done in ANSYS FLUENT software. The three governing equations, namely the continuity equation, Reynolds averaged Navier Stokes equation and energy equation are solved. Turbulence models are used to express Reynolds stress components in terms of mean velocity gradients.

Standard k-ε model is the turbulence model used in this simulation. It uses Boussinesq approximation which expresses Reynolds stress as the product of eddy viscosity and mean velocity gradient. Eddy viscosity, being a flow property varies with flow conditions and geometry.

Using wall functions, eddy viscosity is expressed in terms of distance from the wall. In the standard k-ε model, the effects of molecular viscosity are negligible [14]. The boundary conditions for the simulation are constant wall temperature of 80^0 C with no slip conditions. The inlet, outlet and channel wall conditions are assumed adiabatic due to perfect insulation. The outlet section pipe is subjected to storage tank pressure.

RESULTS AND DISCUSSION

In the parabolic dish concentrated solar receiver, the dimensions of the circular receiver are 406 mm, depth 110 mm and plate thickness 5 mm. The aluminum fins of 3 mm thickness are fitted inside the absorption surface. The mass flow rate is lower and the water will remain in contact with the fins for a longer time and water will be heated through a higher temperature under pressure.

At the downstream portion of the channel, liquid temperature will reach nearer to fin metal temperature. From the temperature profiles, it can be inferred that temperature profile varies with fin spacing. As fin spacing increases, thermal boundary layers from the opposite facing channel surfaces merge at further downstream portion of the channel. There is a decrease in convective heat transfer coefficient of outer fin surface with increase in fin spacing. This is because as fin spacing is increased, gap between outer fin surface and enclosure wall is reduced, which increases flow resistance. Since overlapping point of boundary layers will shift downstream with increase in fin spacing, effect of one fin on its adjacent fin will be reduced and convective heat transfer coefficient of channel will increase. The specifications of the fins are given in Table 1. The properties of water are given in Table 2.

With increase in fin spacing, number of fins that can be attached to the collector plate will decrease and the total surface area exposed to convective heat transfer will decrease. Total heat transferred will depend upon the combined effect of heat transfer coefficient and total surface area exposed to heat transfer. The total heat transferred to liquid increases initially with fin spacing. In this portion, effect of increase in HTC-channel predominates over decrease in total surface area exposed to heat transfer. The different mass flow rates from 0.1 to 0.5 kg/s are simulated for optimum fin spacing and these cases are given in Tables 3-5 and (Fig. 3-5).The fin spacing corresponding to maximum heat transfer is called optimal fin spacing. With further increase in fin spacing, total heat transferred will decrease as decrease in total surface area exposed to heat transfer predominates over increase in HTC-channel.

The total heat transferred to water initially increases, reaches a maximum value and then decreases. Optimal fin spacing corresponding to mass flow rate of 0.1 kg/s is 22.5 mm. Compared to previous cases, optimum fin spacing is reduced. This is because with increased flow velocity, increment in heat transfer coefficient is fully countered by increment in flow resistance, only when number of fins is higher.

From (Fig. 4), it is understood that optimum fin spacing corresponding to mass flow rate of 0.25

Table 1. Specifications of fins

Fin material	Aluminum
Fin height	400 mm
Number of fins	2
Fin thickness	3 mm
Diameter of inlet/outlet pipe	12.5 mm
Thermal conductivity	156 W/m K

Table 2. Properties of water.

Density, ρ	1000 kg/m^3
Dynamic viscosity, μ	0.001 Ns/m^2
Specific heat capacity, C_p	4187 J/kg-K
Thermal conductivity, K	0.61 W/m-K

Table 3. Case 1: Mass flow rate=0.1 kg/s (Re number=100000)

Fin spacing (mm)	17.5	20	22.5	25	27.5
No. of fins possible	6	5	5	4	4
Mean water temperature (K)	308	308	308	309	308
HTC- outer fin surface (W/m^{2}K)	72.5	72.7	72.4	82.3	71.4
HTC- channel (W/m^{2}K)	47.9	63.4	74.4	82.3	85.1
Heat transferred from outer fin surfaces (W)	2.6	2.6	2.6	2.88	2.55
Heat transferred to a single channel (W)	1.7	2.27	2.66	2.88	3
Heat transferred to all channels (W)	8.5	9.08	10.64	8.64	9
Total heat transferred (W)	11.1	11.68	13.24	11.52	11.55

Table 4. Case 2: Mass flow rate=0.25 kg/s (Re number=250000)

Fin spacing (mm)	10	12.5	15	17.5	20
No. of fins that can be attached	10	8	7	6	5
Temperature (K)	305	305	305.5	305.5	305.5
HTC- outer fin surface (W/m^2K)	103	103	104	103	102
HTC- channel (W/m^2K)	36.5	67.9	94.9	109.7	117.3
Heat transferred from outer fin surfaces (W)	3.97	3.95	3.95	3.9	3.87
Heat transferred to a single channel (W)	1.4	2.6	3.6	4.17	4.46
Heat transferred to all channels (W)	12.6	18.2	21.6	20.85	17.84
Total heat transferred (W)	16.57	22.15	25.55	24.75	21.71

Table 5. Case 3: Mass flow rate=0.5 kg/s (Re number=500000)

Fin spacing (mm)	7.5	10	12.5	15	17.5
No. of fins that can be attached	14	10	8	7	6
Mean temperature (K)	304	304	304	304	304
HTC- outer fin surface (W/m^2K)	146.2	147	146	146	143
HTC- channel (W/m^2K)	49.2	103	139	155	162
Heat transferred from outer fin surfaces (W)	5.75	5.75	5.74	5.7	5.6
Heat transferred to a single channel (W)	1.94	4	5.4	6	6.35
Heat transferred to all channels (W)	25.22	36	37.8	36	31.7
Total heat transferred (W)	30.97	41.75	43.5	41.7	37.3

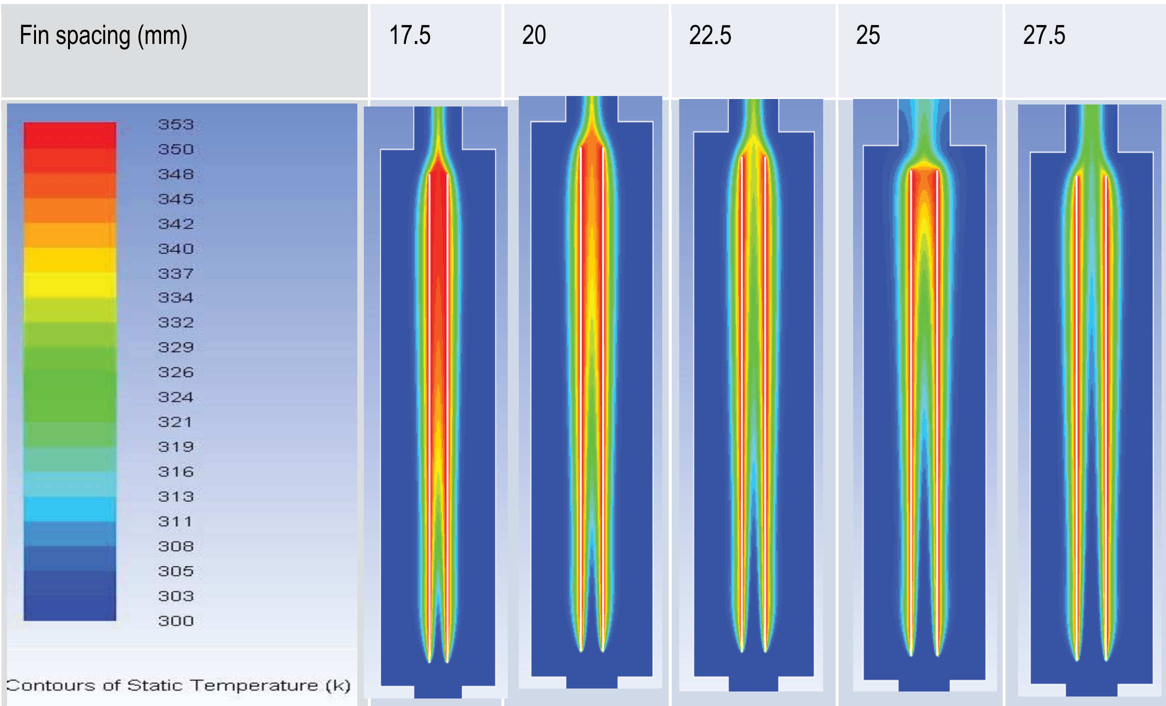

Fig. 3 Simulation results for mass flow rate = 0.1 kg/s.

kg/s is 15 mm in accordance with the finding that optimum fin distance reduces with increase in mass flow rate.From (Fig. 5), the optimum fin spacing is 12.5 mm for the water flow rate of 0.5 kg/s.

It is understood that mass flow rate is one of the important parameter to be considered while designing a water heater with fins. As expected, HTC increases with increase in fin spacing. But number of fins that can be reduced.

The experimental validation of the fins is also observed the similar results with around 5-7% variations.

CONCLUSION

The finned type solar concentrated receiver is simulated and the heat transferred to water initially increases with fin spacing, reaches a maximum value and then decreases. Optimal fin spacing for

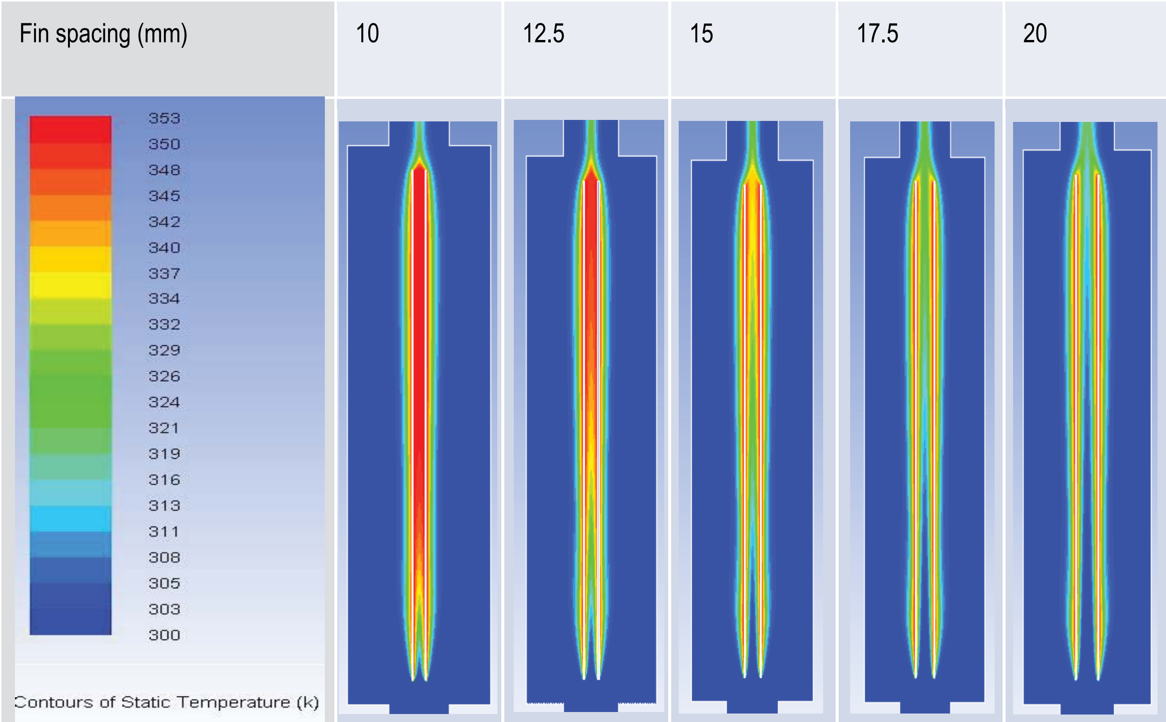

Fig. 4 Simulation results for mass flow rate = 0.25 kg/s.

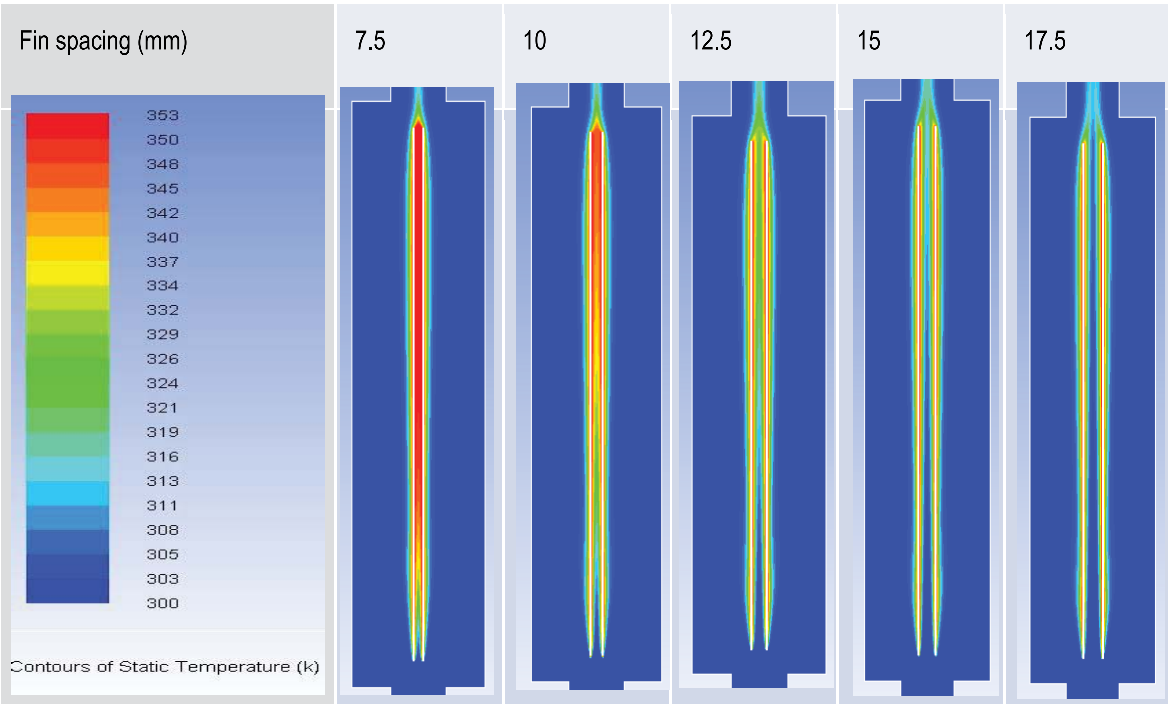

Fig. 5 Simulation results for mass flow rate = 0.5 kg/s.

an absorber plate of given area depends upon mass flow rate of fluid.

Optimal fin spacing decreases with increase in mass flow rate of water. So, the design parameters involved in the design of a fin type solar water heater are fin dimensions, fin spacing and mass flow rate of water. The optimal fin spacing was doubled when mass flow rate reduced from 0.5 kg/s to 0.01 kg/s. For the practical range of mass flow rates (0.1 – 0.5 kg/s) employed in parabolic dish concentrated community cooking solar receiver are to be between 12.5 mm and 22.5 mm.

REFERENCES

Arunasalam, A., Ravi, A., Srivatsa, B. and Senthil, R. (2012). Thermal performance analysis on solar integrated collector storage. *Undergraduate Academic Research Journal (UARJ)*. 1 : 2278-1129.

Bar-Cohen. and Rohsenow. (1984). Thermal optimum spacing of vertical natural convection cooled parallel plates. *Journal of Heat Transfer*. 106 : 116-123.

Ganji, D.D., Ganji, Z.Z. and Ganji, H.D. (2011). Determination of temperature distribution for annular fins with temperature dependent thermal conductivity by HPM. *Thermal Science*. 15 : 111-115.

Goshayeshi, H.R. and Ampofo, F. (2009). Heat transfer by natural convection from vertical and horizontal surfaces using vertical fins. *Energy and Power Engineering*. 1 : 85-89.

Mon, M.S. and Gross, U. (2004). Numerical study of fin-spacing effects in annular-finned tube heat exchangers. *International Journal of Heat and Mass Transfer*. 47 : 1953-1964.

Rong, H.Y., Shih, P.L. and Ming, C. (1997). Optimum spacing for longitudinal convective fin arrays. *Journal of Marine Science and Technology*. 5 : 47-53.

Senthil, R. and Cheralathan, M. (2015). Effect of non-uniform temperature distribution on surface absorption receiver in parabolic dish solar concentrator. *Thermal Science*.

Senthil, R. and Cheralathan, M. (2016). Effect of once-through and recirculated fluid flow on thermal performance of parabolic dish solar receiver. *Indian J. of Sci. and Technol*. 9(33).

Senthil, R. and Cheralathan, M. (2016). Effect of the PCM in a solar receiver on thermal performance of parabolic dish collector. *Thermal Science*.

Sevilgen, G. (2015). A numerical analysis of a convective straight fin with temperature-dependent thermal conductivity. *Thermal Science*.