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Study of the effect of using Folded Plates arrangement on Heat Transfer

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ABSTRACT

A folded plate is as a corrugated plate in its two directions. The effect of folded plates on the heat transfer is studied experimentally. The temperature distribution of folded plate was compared with flat plate The Arrangement of plates was changed as the following (Flat-Flat), (Flat-Folded), (Folded-Folded). Results are carried out by changing the gap between the two folded plates (1, 4 and 6 cm) with different air flow rates from 5.4 to 11.2 liter/s, Reynolds number changes from (3969 – 11384) and different heat flux in ranges of 3.8 to10 kW/m^2 based on projective area. The results show that, the folded plate produces faster uniform temperatures distributions on plate surface. By increasing heat flux, the average temperature increases. Also, it is found that as the gap between plates increase, the average plate surface temperature also increases. The obvious effect of the folded plate on temperatures is due to the more turbulence effect on the air flow generated by the geometric of the folded plate. The folded plates are a suitable shape to improve the thermal performance of heat transfer as compared to Flat plate.

Keywords: Heat transfer, folded plate, Gap between two folded plates, Heat flux, Flat plate.

1. INTRODUCTION

P., Naphon [1] studied effects of corrugated tile angles experimentally and numerically on heat transfer and flow developments in the corrugated channel under constant heat flux conditions. P., Naphon and k., Kornkumjayrit [2] studied numerically the heat transfer and flow developments in the channel with one-side corrugated studied plate under constant heat flux conditions. Pehlivan et al [3] and H., Pehlivan [4] studied effects the corrugation angle and channel height experimentally on heat transfer and for corrugated channel under constant heat flux conditions.

Heidary et al. [5] investigated the enhanced heat transfer with corrugated flow channel in anode side of direct methanol fuel cells (DMFCs) numerically by using four different shapes of corrugated boundary (rectangular shape, trapezoidal shape, triangular shape and wavy (sinusoidal) shape). Ahmed et al [6, 7] and Khairul et al [8] studied numerically the effect of copper–water Nano fluid in corrugated channel on the heat transfer and flow characteristics. Mohammed et al [9] investigated numerically the forced turbulent convective flow and heat transfer in a corrugated channel of plate heat exchanger. The corrugated channel with different corrugated tilt angles, different channel heights and different wavy heights. M., Faizal and M.R., Ahmed [10] studied experimentally effect of the spacing between plates in exchanger to give the optimum heat transfer. P., Naphon [11] studied numerically effect of various geometry configuration wavy plates under constant heat flux conditions on heat transfer and flow distributions in the channel. Y., Islamoglu and C., Parmaksizoglu [12] investigated the effect of channel height to enhance heat transfer characteristics in a corrugated heat exchanger channel experimentally. W.M., Abed and M. A. Ahmed [13] Investigated numerically Laminar forced convection in a corrugated channel with different wavy angle. The results have indicated that heat transfer increase with increasing wavy angle at same Reynolds numbers. H.M., Metwally and R.M., Manglik [14] investigated the enhanced heat transfer and flow characteristics due to curvature-induced lateral vortices in laminar flows in sinusoidal corrugated-plate channels numerically. Kabeel et al [15] investigated the effect of using Nano-particles on corrugated plate heat exchanger performance experimentally.

Sheet folding [16] is a new method for production the three dimensional long sheets from chevron plates. The used folded plate is formed from a flat metal sheet to take the final shape of folded plate. It as air flowing

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through the folded surface the air re-circulation and the vortex flows are generated, the thermal performance of the heat transfer tends to increase. Therefore, the folded plates are a suitable shape to improve the thermal performance of heat transfer and flow characteristics. The objective of study is to experimental study heat transfer using folded plates which all configuration peaks lie in an in phase arrangement. Effects of various relevant parameters on the heat transfer and flow characteristics are considered.

2. EXPERIMENTALTEST RIG & METHOD

2.1. The Test Rig Components

A schematic diagram of the experimental test rig is shown in Fig. 1. The test rig is designed so that its parts can be easily changed or repaired. The test rig consists of blower, control valve, pipe line, orifice plate, u-tube water manometer, entrance connection duct, test section, exit connection duct and finally exit pipe air. Air is blown using blower, the quantity of air which passes through pipe line is controlled using control valve then air enters to test section and finally air is discharged to the atmosphere. Air flow rate are measured by using the arrangement of Pitot tube, orifice meter and u- tube water manometer. Measuring and Calibration for volume flow rate of air are carried out before all runs.

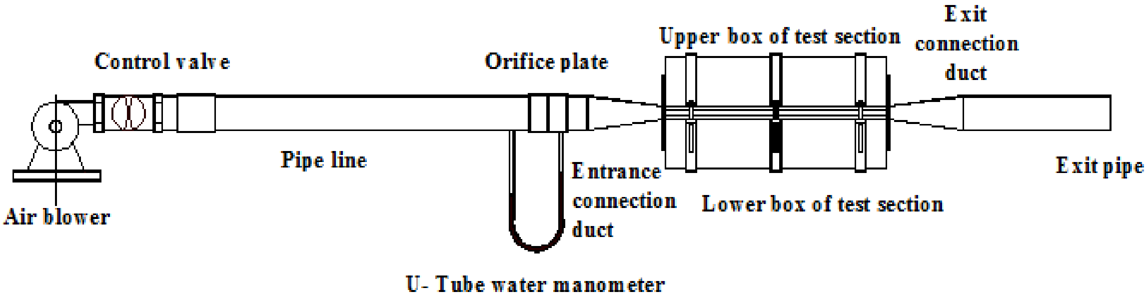

Fig.1: Schematic diagram of experimental test rig

2.2. Test Section Structure

The test section drawing is shown in Fig. 2 which Consists of two wooden boxes the external dimensions of each box, length = 53 cm, width = 18 cm, height = 11 cm and thickness = 1 cm, Each internal upper and lower surfaces of the two boxes was insulated with three consecutive layers; rock wool, glass wool and mica, 2 cm, 1 cm and 0.05 cm. Four electrical heaters were used and each two electrical heaters were fixed on the last layer of mica in each box. All sides of each box were insulated also with glass wool and mica, 1 cm and 0.05 cm. Red copper sheet of 0.5 mm thickness was used to cover each wooden box. The lower box is fixed on table while the upper box could be put on lower box and moved easily to change the distance between two tested plates. The length and width of the folded plate are 47 cm and 12 cm, as shown in Fig. 3 and Fig. 4. Five thermocouples J type fixed on back surface of lower plate and they were distributed along the plate and used to measure Temperature distribution along lower folded plate. Electrical Control Panel is used to organize and select the desired value of heat energy for all cases of experiment running under different operating conditions.

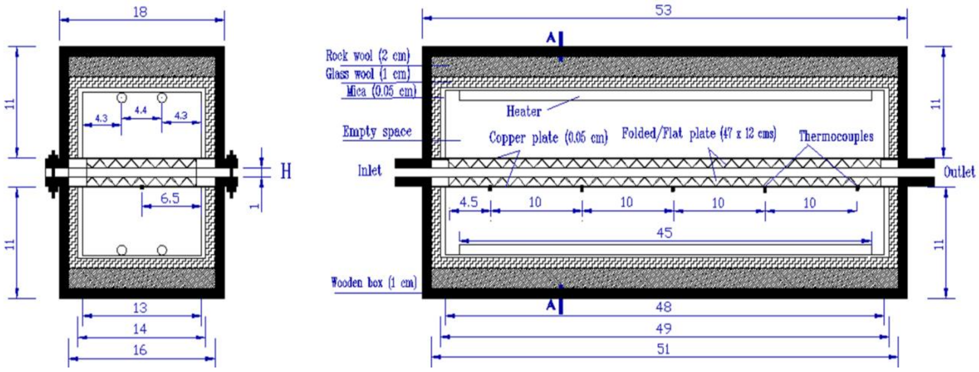

Fig. 2: Test section drawing, dimensions in (cm)

Fig. 3: Folded Plate

The study has been done under different heat fluxes, different air flow rates and different gaps between the lower and upper plate. Heat source used in this study was the electrical heaters. Electrical Control Panel was used to organize and select the desired value of heat energy. The Xplorer GLX was used to record the temperatures .

Table 1: Experimental Running Conditions

Experimental Running Conditions	Ranges
Heat fluxes	3.8 to 10 kW/m^2
Volumetric Flow rate	5.4 to 11.2 liter/s
Gap between plates	1 ,4 & 6 cm
Arrangement of plates	(F-F),(F- O),(O-O)

3. RESULTS and DISCUSSION

The average temperatures for all cases are average five measured temperature readings along lower plate length for each heat flux at the same air flow rate and the same gap between plates.

The results show that, the average temperature increases with increase of heat flux in spite of the used plate type. Also the average temperature is higher when using larger gap between plates. All these results can be shown in (Fig.5 –8). From (Fig.9 –11) it is clear that, the minimum average temperature for gap between plates = 1 cm equals 47.06 ^{o}C for case of maximum air flow rate 11.2 liter/s where heat flux is 3.8 kW/m^2 while the maximum average temperature equals 64.16 ^{o} C for case of minimum air flow rate 5.4 liter/ s where heat flux is 9.2 kW/m^2.The minimum average temperature for gap between plates = 4 cm equals 48.16 ^{o} C for case of maximum air flow rate 11.2 liter/s where heat flux is 3.8 kW/m^2 while the maximum average temperature equals 95.84 ^{o} C for case of minimum air flow rate 5.4 liter/ s where heat flux is 9.2 kW/m^2. the minimum average temperature for gap between plates = 6 cm equals 56.7 ^{o} C for case of maximum air flow rate 11.2 liter/s where heat flux is 3.8 kW/m^2 while the maximum average temperature equals 88.02 ^{o} C for case of minimum air flow rate 5.4 liter/ s where heat flux is 9.2 kW/m^2. The required period to achieve steady temperature increases by increasing heat flux and decreases by increasing air flow as shown in (Fig.12 – 14). It was found that, Maximum time required to attain the stability in temperature for gap between plates = 1 cm is 35 minute for air flow rate 8.1 liter/ s where heat flux is 10 kW/m^2. For gap between plates = 4 cm is 36 minute at air flow rate

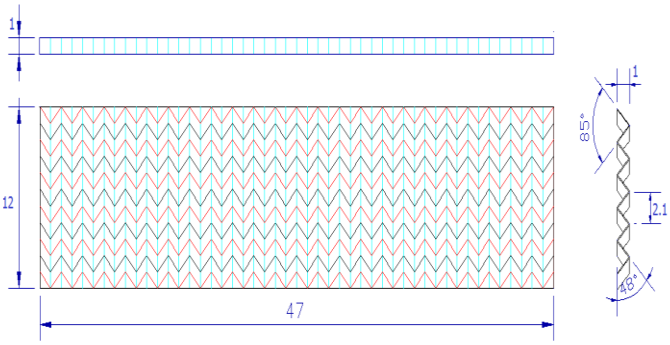

Fig. 4: Drawing of the Folded Plate, Dimensions (cm)

through five of thermocouples J type which fixed on back surface of lower plate for all cases of experimental running under different operating conditions. All cases of experimental running at same initial condition for plate (the plate is cool). Experimental running conditions that used in the current work are given at Table1 5.4 liter/ s for all heat fluxes .For gap between plates = 6 cm is 33 minute for air flow rate 8.1 liter/ s where heat fluxes are (7.5, 10 kW/m^2) and for air flow rate 9.6 liter/ s where heat fluxes are (9.2, 10 kW/m^2). While minimum time for gap between plates = 1 cm is 9 minute for air flow rate 11.2 liter/ s where heat flux is 3.8 kW/m^2. For gap between plates = 4 cm is 15 minute for air flow rate 11.2 liter/ s where heat flux is 3.8kW/m^2. For gap between plates = 6 cm is 18 minute for air flow rates (9.6, 11.2 liter/ s) where heat flux is 3.8 kW/m^2 .

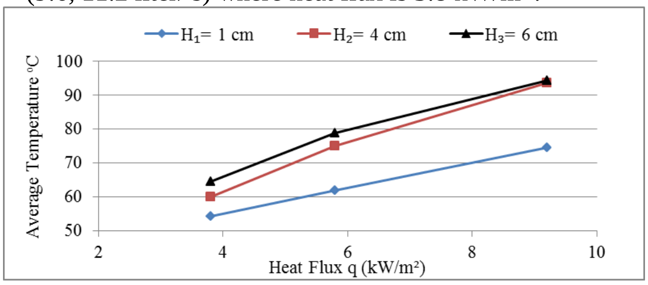

Fig.5: Effect of Heat Fluxes for different gaps on Average Temperatures for (Flat- Flat), $\dot{V}_3$ = 9.6 liter/s

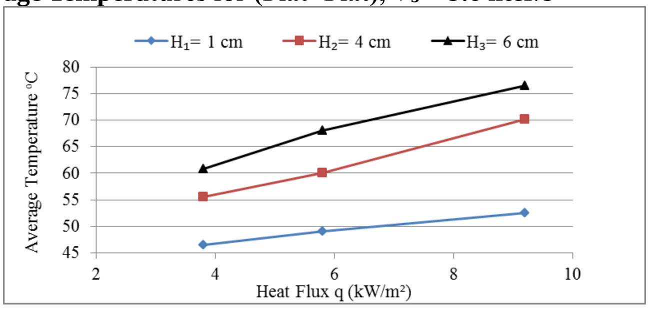

Fig. 6: Effect of Heat Fluxes for different gaps on Average Temperatures for (Flat- Folded), $\dot{V}_3$ = 9.6 liter/s

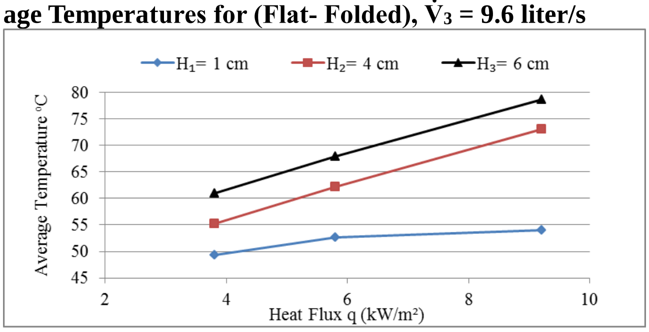

Fig.7: Effect of Heat Fluxes for different gaps on Average Temperatures for (Folded- Folded), $\dot{V}_3$ = 9.6 liter/s

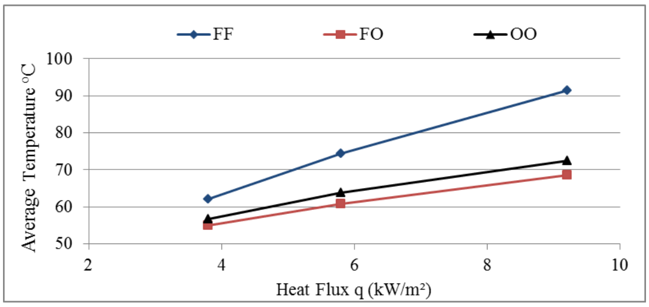

Fig .8: Effect of Heat Fluxes on Average Temperatures for (Flat- Flat), (Flat-Folded), (Folded-Folded) Plate Arrangement at H_3 = 6 cm, $\dot{V}_5$ = 11.2 liter/s and in phase

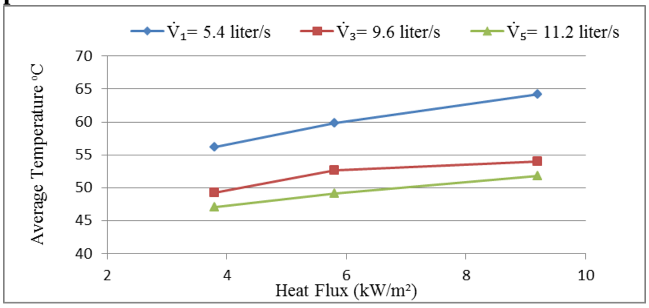

Fig.9: Effect of Heat Fluxes on Average Temperature Distribution along lower Plate in case (Folded – Folded) Plate, for H_1=1 cm and in phase

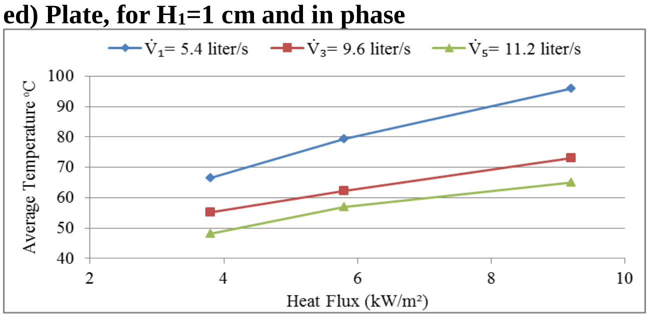

Fig.10: Effect of Heat Fluxes on Average Temperature Distribution along lower Plate in case (Folded – Folded) Plate, for H_2=4 cm and in phase

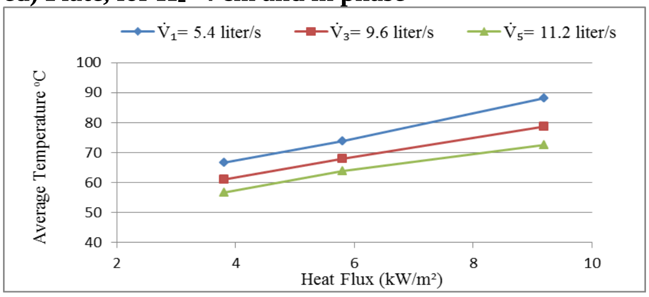

Fig.11: Effect of Heat Fluxes on Average Temperature Distribution along lower Plate in case (Folded – Folded) Plate, for H_3= 6 cm and in phase

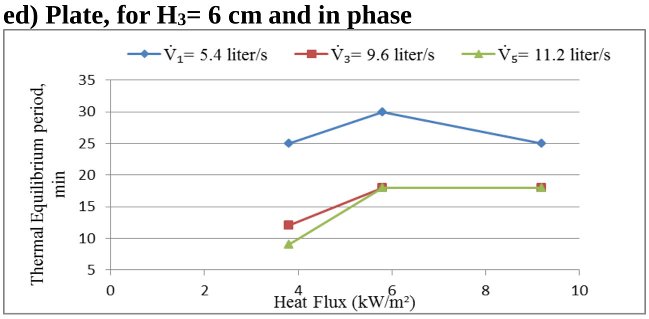

Fig.12: Effect of Heat Flux on the Required Thermal Equilibrium Period for case (Folded- Folded) Plate, in phase with H_1=1 cm

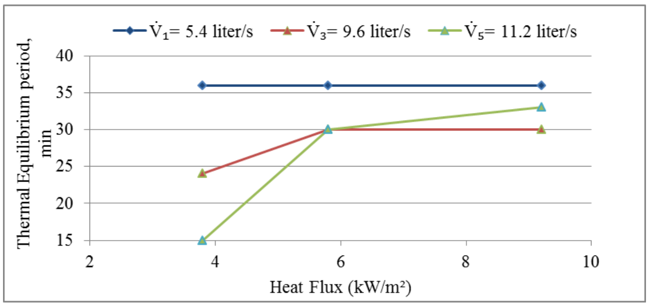

Fig.13: Effect of Heat Flux on the Required Thermal Equilibrium Period for case (Folded- Folded) Plate, in phase with H_2=4 cm

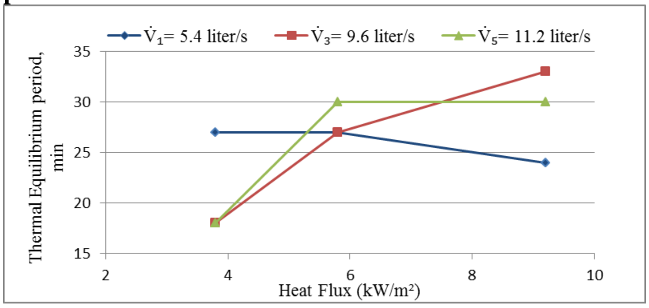

Fig.14: Effect of Heat Flux on the Required Thermal Equilibrium Period for case (Folded- Folded) Plate, in phase with H_3= 6 cm

3.1. Effect of (Folded- Folded) Plate on the Air Flow Characteristics with Different Gap between Plates

The average Nusselt number increases with the increase in the Reynolds number for different gaps between plates, as shown in (Fig. 15-17). Empirical formula for relation between Nusselt number and Reynolds number in case (Folded-Folded) as follow, for Reynold number varied from (5496 to 11384) at gap between plates = H_1 cm is Nu = 1E-05Re^2- 0.0068Re+ 2629, for Reynold number varied from (4465 to 9250) at gap between plates = H_2 cm is Nu = 3E-05Re^2- 0.1863Re+ 1766.6 and for Reynold number varied from (3969 to 8222) at gap between plates = H_3 cm is Nu = 1E-05Re^2- 0.1344Re+ 1980.2.

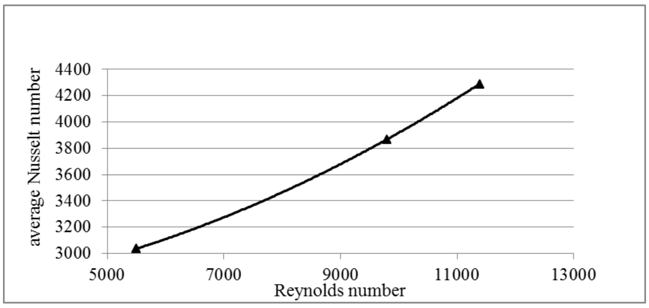

Fig. 15: Variation of Nusselt with Reynolds number for (Folded –Folded) plate in phase at H_1 = 1 cm and q = 6.3 kW/m²

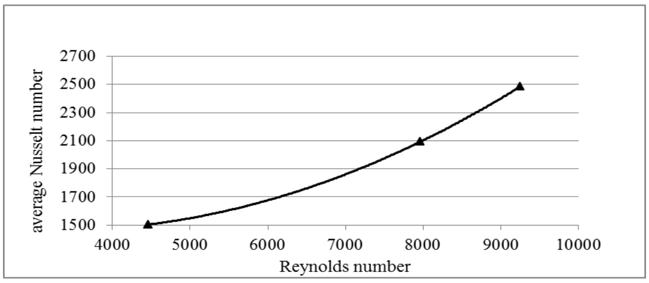

Fig. 16: Variation of Nusselt with Reynolds number for (Folded –Folded) plate in phase at H_2 = 4 cm and q = 6.3 kW/m^2.

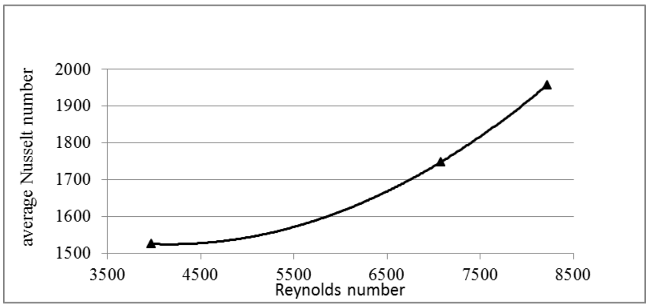

Fig. 17: Variation of Nusselt with Reynolds number for (Folded –Folded) plate in phase at H_3 = 6 cm and q = 6.3 kW/m^2.

4. Conclusion

The thermal performance for folded plate reach to 35% than flat plat in regularity Temperatures distribution and it provides 50 % of the time required to reach thermal equilibrium.

Nusselt number increases with the increase in the Reynolds number at the same gap between plates. It as air flowing through the folded surface the air re-circulation and the vortex flows are generated, thereby enhancing the convective heat transfer.

The folded plate gives a uniform temperature distribution than the flat plate. The folded plate is better selected shape if it compares with flat plate in case of heat transfer. The effect of folded plate on temperatures is due to the more turbulence effect on the air flow generated by the geometric of the folded plate.

Nomenclature

A	Projected area of Folded Plate ,m^2	t	Time, period, minute
a	Inlet cross section area, cm^2 (a = w* H)	T	Temperature , ºC
a_1	cross section area of pipe,cm^2 ($a_1 = \frac{\pi}{4}D^2$)	ΔT	Difference in temperatures between the folded surface and surrounding air area, K
D	Pipe diameter ,cm	ν	Kinematic viscosity, m^2/s ($\nu = \frac{\mu}{\rho}$)
D_h	Hydraulic diameter, cm ($D_h = \frac{4HW}{2(H+W)}$)	V_{in}	Air inlet velocity ,cm/s
h	Heat transfer coefficient , W/m^2.K ($h = \frac{q}{\Delta T}$)	VP	Velocity pressure ,cm
Δh	Water head difference ,cm	$\dot{V}$	Air flow rate, liter/s ($\dot{V} = aV_{in}$)
H	Gap between two plates, cm	w	Width of folded plate , cm
k	Thermal conductivity of the air, W/m. K	μ	Dynamic viscosity of air, kg/m .s
l	Characteristics length, cm ($l = \frac{LW}{H+W}$)	ρ	Air density ,kg/m^3
L	Length of folded plate , cm		
Nu	Average Nusselt number, ($Nu = \frac{hl}{k}$)		
q	Heat fluxes, kW/m^2 ($q = \frac{Q}{A}$)		
Q	Heat transfer rate, kW		
r	Radius ,cm		
Re	Reynolds number,($Re = \frac{\dot{V}D_h}{\nu a}$)		

Abbreviations

F- F	Flat- Flat
F-O	Flat- Folded
O-O	Folded-Folded
PFRFP	Performance of Folded Plate Related to Flat Plate

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