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EFFECTS OF WIRE COIL INSERTS ON THERMAL EFFICIENCY OF SOLAR FLAT PLATE LIQUID COLLECTORS

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KEYWORDS: solar flat plate liquid collectors; heat transfer enhancement; coiled wire inserts, thermal efficiency of solar collectors etc**.**

ABSTRACT

The efficiency of a solar liquid collector can be improved by augmenting heat transfer from the tube to the working fluid. Various types of heat transfer techniques has been used in heat exchangers which are mainly classified in active and passive types of techniques. Solar liquid collectors can also be enhanced by these active and passive devices. The passive devices do not require any external source of power and they do not harm structure of the tube or weaken the strength of tube material. For the same reasons passive devices are most widely used heat transfer augmentation techniques. Initially twisted tape inserts and conical inserts were popular devices used in enhanced solar liquid collectors mainly because of availability of established correlations of design parameters. Wire coil inserts are relatively less used and less experimented passive technique. Presence of well established correlation of design parameters does not mean that twisted tapes are the best heat transfer augmentation device. These passive devices enhance the heat transfer, but due to increased friction, pumping power requirement of the heat exchanger is also increased. The present study is therefore focused on coiled wire inserts as heat transfer enhancement device in solar liquid collectors. The effect of dimensionless parameters such as pitch of coil to tube diameter and coil wire diameter to tube diameter on thermal efficiency of the solar collector was studied under changing flow rates in the study.

INTRODUCTION

The application of techniques which augment the heat transfer are common in Design of heat exchangers. These techniques result in higher heat transfer coefficient than the normal heat transfer coefficient and thereby result in reduction of size of heat exchanger or increase in existing capacity of the heat exchanger or reduction in pumping power.

Augmentation techniques can be classified either as passive methods, which require no direct application of external power or as active methods, which require external power. The effectiveness of both types of techniques is strongly dependent on the mode of heat transfer, which may range from single-phase free convection to dispersed-flow film boiling. Few of these techniques are;

Rough surfaces, which are produced in many configurations ranging from random sand-grain type roughness to discrete protuberances. The configuration is generally chosen to disturb the viscous sub layer rather than to increase the heat transfer surface area. Application of rough surfaces is directed primarily toward single-phase flow.

Extended surfaces, which are routinely employed in many heat exchangers,. Which directly improve the heat transfer coefficients on extended surfaces by shaping or perforating the surfaces.

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Displaced enhancement devices, which are inserted into the flow channel so as indirectly to improve energy transport, at the heated surface. They are used with forced flow.

Swirl-flow devices, which include a number of geometric arrangements or tube inserts for forced flow that create rotating and/or secondary flow: coiled tubes, inlet vortex generators, twisted-tape inserts, and axial core inserts with a screw-type winding.

Mechanical aids, which involve stirring the fluid by mechanical means or by rotating the surface. Surface “scraping,” widely used for batch processing of viscous liquids in the chemical process industry, is applied to the flow of such diverse fluids as high-viscosity plastics and air.

Surface vibration at either low or high frequency has been used primarily to improve single-phase heat transfer.

Fluid vibration is the practical type of vibration augmentation because of the mass of most heat exchangers. The vibrations range from pulsations of about 1 Hz to ultrasound. [1]

Initially active techniques such as fluid stirring or surface rotation were popular but they were limited by requirement of external power. Eventually application of passive techniques such as twisted tape inserts, conical inserts and coiled wire inserts became popular, since they do not require any source of external power. These passive insert devices do not weaken mechanical strength of the tube material also, which is an additional advantage. Moreover, passive devices are easily manufactured, easily installed and they incur low cost. The swirl flow passive devices such as twisted tape inserts, conical inserts and coiled wire inserts are most widely used techniques to enhance heat transfer in solar liquid collectors.

Enhancement techniques of heat transfer mainly produce favourable conditions such as breaking the boundary layer development, increasing turbulence near the wall, increasing the heat transfer surface area and diverting core fluid which is at farthest distance from the wall and in coolest region, toward the hot surface or wall. Twisted tapes divert the core of the flowing fluid towards surface of the tube and act as swirl generator, whereas wire coils which are inserted along the wall firstly disrupt the boundary layer and secondly it increase the heat transfer area. Flow resulting over the coil is analogous to flow past immersed cylinder (which may be elliptical due to helix angle). Wakes are formed past the surface of coil which create turbulence and subsequently result in higher heat transfer rate.

LITERATURE REVIEW

HEAT TRANSFER ENHANCEMENT TECHNIQUES IN SOLAR LIQUID COLLECTORS

Solar liquid collectors are serious candidate of heat transfer enhancement techniques in order to reduce its size. Passive techniques due to their inherent advantages are preferred way of heat transfer augmentation in solar collectors. The passive devices involve methods of surface area extension (fins), Surface roughness improvers, coated surface and turbulators (which are also called swirl flow devices). Amongst all, swirl flow devices are most commonly used device to enhance heat transfer in the industries. The purpose of swirl flow devices can be listed as

1.Disturbing hydrodynamic(velocity) boundary layer and decreasing Thermal boundary layer thickness.

2.Divert core fluid in lower temperature region towards hot surface and hence mix with peripheral hot fluid.

Twisted tapes have attracted more number of the investigators as heat transfer augmentation device in solar collectors. Comparatively few studies have been done on coiled wire inserts [2].

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TWISTED TAPES

Kumar and Prasad[3] studied effect of twisted tape geometry , different mass flow rate and intensity of solar radiation on the thermal performance of serpentine solar collector with twisted tape insert. It was concluded that heat losses were reduced and an increase in thermal efficiency was observed with twisted tape enhancement.

S Jaisankar, T.K. RadhaKrishnan and K.N. Sheeba.[4] did investigation on heat transfer , friction factor and thermal performance on a tube on sheet solar panel with twisted tape insert. It was observed that when twist ratio is increased the swirl generation is decreased and both heat transfer and friction factor are minimised.

Jaisankar and Radha et al.[5] carried investigation on thermo-syphon solar water heater system focussing on heat transfer , friction factor and thermal performance and established the fact that heat transfer in twisted collector was higher than in standard collector without twisted tape.

R.L.Webb and N.H.Kim[6] suggests that merely existence of well defined design parameters correlations does not mean that twisted tape inserts are the best inserting devices.

WIRE COILS

Garcia et al.[7] carried a study on influence of artificial roughness shape on heat transfer enhancement with corrugated tubes, dimpled tubes and wire coils. They found that at Reynolds numbers below 200 roughness tubes will not improve heat transfer over smooth tubes. They also recommend that wire coil inserts should be used in Reynolds number range of between 200 to 2000, mainly because they produce best heat transfer augmentation also because of reliability of correlation between Nusselt number and friction factor. It was also pointed out that between Reynolds numbers 200 to 700 flow remains laminar but separation occurs downstream wire which promote heat transfer enhancement.

Herraro Martin et al.[8] in their work on Experimental heat transfer research in enhanced flat plate solar collectors projected viewpoint that besides thermal liquid solar collectors are good candidates for heat transfer enhancement techniques but not many studies has been carried with focus on this fact but majority of work done deal with solar air collectors. In the regard of solar liquid collectors studies done, mostly focus on enhancement techniques with twisted tape inserts. They mention that despite many of the previous researchers within liquid collectors used twisted tape as insert device , basically because of existence of well known design correlations, other effective passive tube side enhancement techniques such as wire coils are still unexplored. They carried experimentation on heat transfer effects in flat plate solar collector enhanced with spiral wire coil inserts. Collectors were enhanced with spiral wire coils of dimensionless pitch P/D (Pitch to Diameter ratio)=1 and dimensionless wire diameter W/D (Wire diameter to Tube diameter ratio)=0.0717 in riser tubes. The thermal efficiency was found to be dependent upon flow rates and for a flow rate of 144 litre per hour (0.04 kg/s) an increase in efficiency was found to be 15%. However increase in pumping power is experienced due to increase in friction losses.

REXPERIMENTATION

The solar liquid collectors operate in laminar, transition and low turbulent regions. The mass flow rate also is comparatively very low. The temperature of tube surface remains below 80^0 centigrade and temperature of hot fluid remains below 70^0 centigrade. The experiments were carried for mass flow rate in range of 0.20 kg/min to 1.3 kg/min with a tube of internal diameter of 10 mm. The Reynolds number of the flow was in range of 600 to 3800. The average flow velocity lies in the range of 0.04 m/s to 0.29 m/s.

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Experiments were conducted on a tube on plate type solar flat plate liquid collector with absorber plate size of 40 cm. × 90 cm. in the month of April 2015 at Yamunanagar, Haryana, India, which is located at Latitude 30.1^0 North and on Longitude 77.3^0 East
The dimensionless parameters, pitch of coil to tube diameter ratio (P/D) was taken 1 and 0.5 and wire diameter to tube diameter ratio was taken in range of 0.08 and 0.12. The results were compared with a smooth tube without a coiled wire insert.

DATA REDUCTION

NOMENCLATURE

n_{th}	Thermal Efficiency	Re	Reynolds Number
$m^{\cdot}$	Mass flow rate Kg/s	P	Pitch m
c_p	Specific Heat Joule/Kg K	W	Coil Wire diameter m
Δt	Temperature Change K , ^{0}C	P/W	Pitch to Wire diameter ratio
G	Global Solar Irradiance Watt/m^2	ΔP	Pressure drop n/m^2
A	Area m^2	p	Density kg/m^3
f	Darcy friction factor	u_m	Average Velocity m/s
f_f	Fanning Friction Factor	γ	p . 9.81 Kg /m^{2}s^2
L	Length m	θ	Angle from horizontal in degree
D	Diameter m	$V^{\cdot}$	Volumetric flow m^3/s

THERMAL EFFICIENCY OF SOLAR COLLECTOR

$$n_{th} = m^{\cdot} c_p \Delta t \; / \; GA$$

FRICTION FACTOR

Darcy Friction factor f for smooth tube -

Laminar flow $f = 64 / Re$

Turbulent flow $f = 0.316\, Re^{-0.25}$

Fanning Friction factor f_f for wire coiled tube [9,10] -

Laminar flow: $f_f = 16.8/(Re)^{0.96}$ *Hence,* $f = 67.2/(Re)^{0.96}$

Turbulent flow: $f_f = 9.35\,(p/w)^{-1.16}\,(Re)^{-0.217}$ & $f = 37.2\,(p/w)^{-1.16}\,(Re)^{-0.217}$

PRESSURE DROP

$$\Delta P = f\, p\, u^2 L \; / \; 2\, D \quad n/m^2$$

$$(\Delta P - \gamma\, L\, Sin\vartheta) = = f\, p\, u^2 L \; / \; 2\, D \quad n/m^2$$ *(for flow through inclined pipe)*

INCREASE IN PUMPING POWER

$$Power = \Delta P\, V^{\cdot} \; watts$$

RESULTS AND DISCUSSIONS

THERMAL EFFICIENCY AND INCREASE IN PUMPING POWER

Experiments were conducted for flow rates of 200 ml/min, 500 ml/min, 900 ml/min and 1300 ml/min for a plain copper tube, coiled wire tubes with Pitch to tube diameter ratio (P/D ratio) of 1 and 0.5. Three wire diameter to tube diameter ratio (W/D Ratio) of 0.08 , 0.1 and 0.12 for each P/D ratio were chosen for study and were compared. The increase in pumping power requirement was found to

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be fraction of a watt, despite a low pitch value of 5 mm and a high wire thickness of 1.2 mm. This is because of solar collectors operate at a very low volumetric flow rate, unlike other heat exchangers. The observations are tabulated as below.

Table 1: Flow rate 200 ml/min

Sl no	Enhancement Type	W/D = 0.08		W/D = 0.1		W/D = 0.12	
		ΔT	n_{th}	ΔT	n_{th}	ΔT	n_{th}
1.	Plain Tube	ΔT = 4.3 n_{th} = 19.34					
2.	Coiled tube P/D=1	7.5	33.49	8.3	36.64	8.8	39.75
3.	Coiled Tube P/D=0/5	9.0	40.18	9.5	41.92	9.6	43.36

Table 2: Flow rate 500 ml/min

Sl no	Enhancement Type	W/D = 0.08		W/D = 0.1		W/D = 0.12	
		ΔT	n_{th}	ΔT	n_{th}	ΔT	n_{th}
1.	Plain Tube	ΔT = 1.8 n_{th} = 20.00					
2.	Coiled tube P/D=1	3.1	35.76	3.5	38.66	3.6	41.8
3.	Coiled Tube P/D=0/5	3.7	41.34	3.9	43.07	3.9	44.09

Table 3: Flow rate 900 ml/min

Sl no	Enhancement Type	W/D = 0.08		W/D = 0.1		W/D = 0.12	
		ΔT	n_{th}	ΔT	n_{th}	ΔT	n_{th}
1.	Plain Tube	ΔT = 1.1 n_{th} = 22.39					
2.	Coiled tube P/D=1	1.8	36.21	2.0	39.72	2.1	41.76
3.	Coiled Tube P/D=0/5	2.1	42.24	2.2	43.75	2.2	44.78

Table 4: Flow rate 1300 ml/min

Sl no	Enhancement Type	W/D = 0.08		W/D = 0.1		W/D = 0.12	
		ΔT	n_{th}	ΔT	n_{th}	ΔT	n_{th}
1.	Plain Tube	ΔT = 0.8 n_{th} = 22.46					
2.	Coiled tube P/D=1	1.3	37.78	1.4	40.22	1.4	41.16
3.	Coiled Tube P/D=0/5	1.5	43.08	1.5	43.52	1.5	44.62

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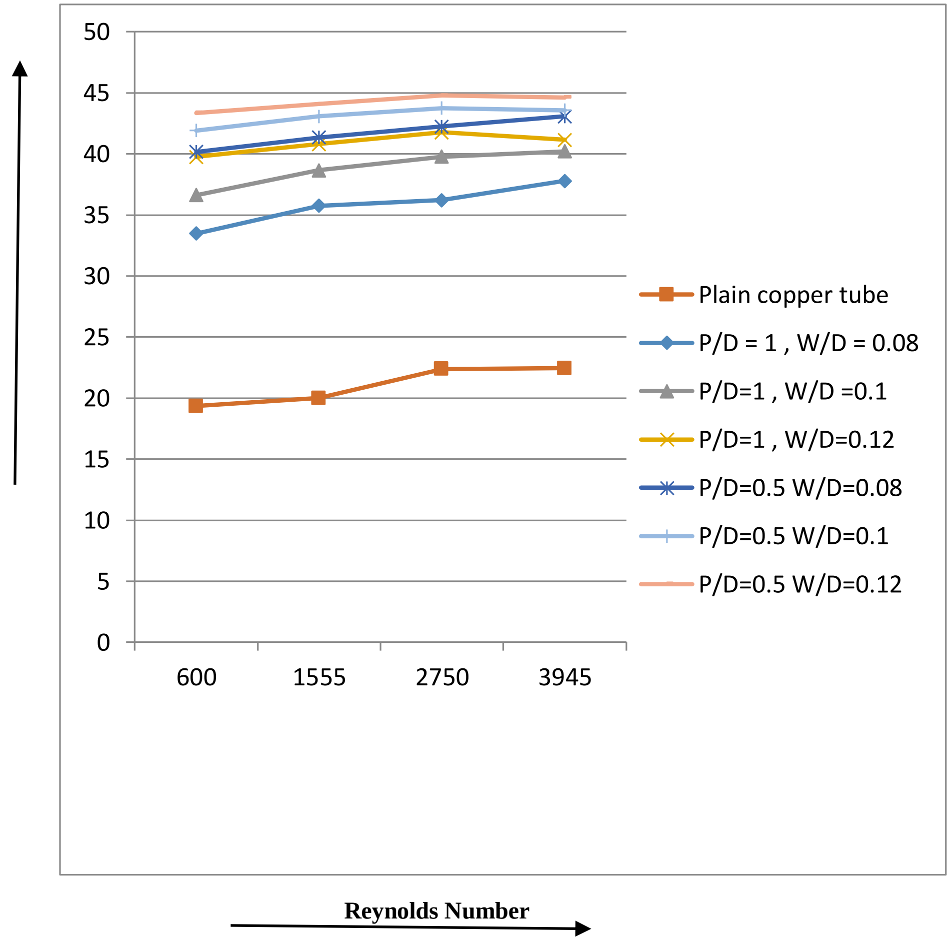
1.1.1. VARIATION OF THERMAL EFFICIENCY WITH REYNOLDS NUMBER

The thermal efficiency of solar flat plate liquid collector with coiled wire inserts are about 14% to 24% more than the thermal efficiency of collector without coiled wire inserts. The thermal efficiency of solar flat plate Liquid collector increases with Reynolds number up to 2750 consistently. There after the thermal efficiency either decreases or increases mildly. Thermal efficiency is plotted against Reynolds number as below for various P/D and W/D Ratios.

Thermal Efficiency



Reynolds Number

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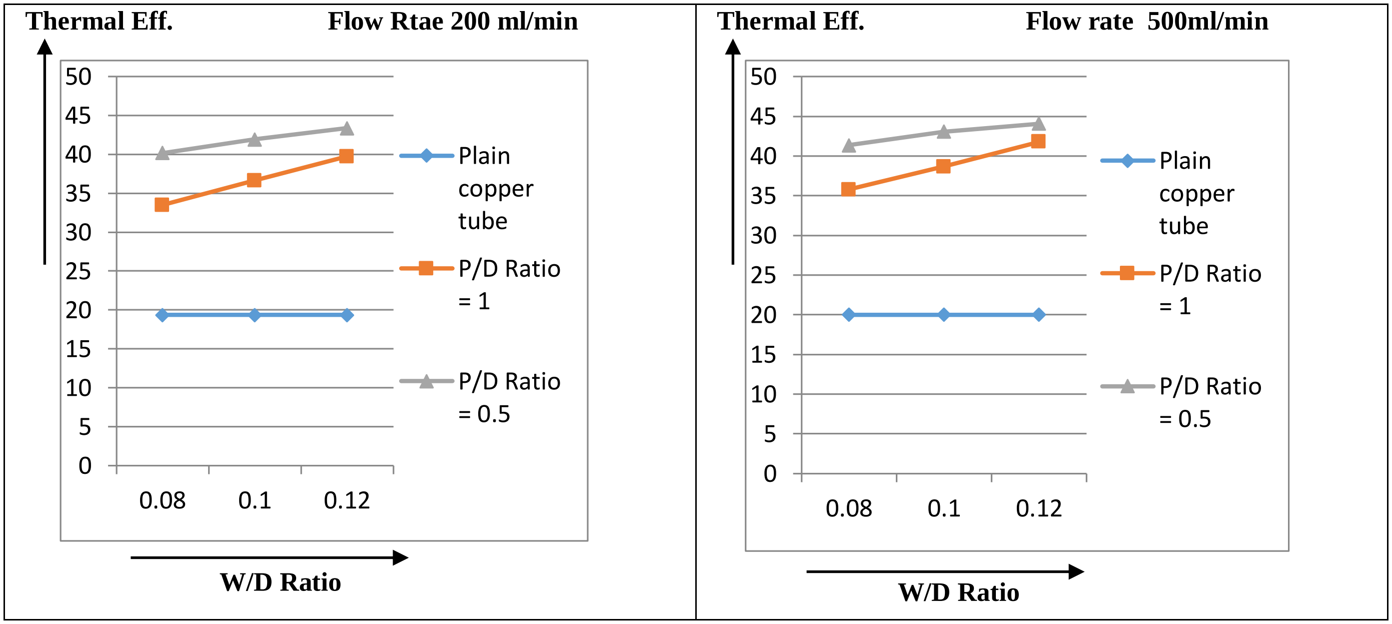
VARIATION OF THERMAL EFFICIENCY WITH P/D RATIO

1.The thermal efficiency of a coiled wire solar collector with Dimensionless parameter pitch to Diameter ratio equal to 1 (P/D=1) is found to be 14% to 20% higher than the solar collector with smooth copper tube.

2.The thermal efficiency of coiled wire solar collector further increases with decrease in P/D ratio and for a pitch to diameter ratio equal to 0.5 (P/D =0.5) , the thermal efficiency of solar collector is found to be 3% to 7% higher than that of a coiled wire collector with pitch to diameter ratio equal to 1.

VARIATION OF THERMAL EFFICIENCY WITH W/D RATIO

The thermal efficiency of a solar liquid collector enhanced with coiled wire inserts in general increases with increase in insert wire thickness or W/D Ratio, pitch kept constant. But the increase in thermal efficiency decreases with increase in W/D ratio. For each flow rate thermal efficiency is plotted against W/D ratio as below, pitch being kept constant.



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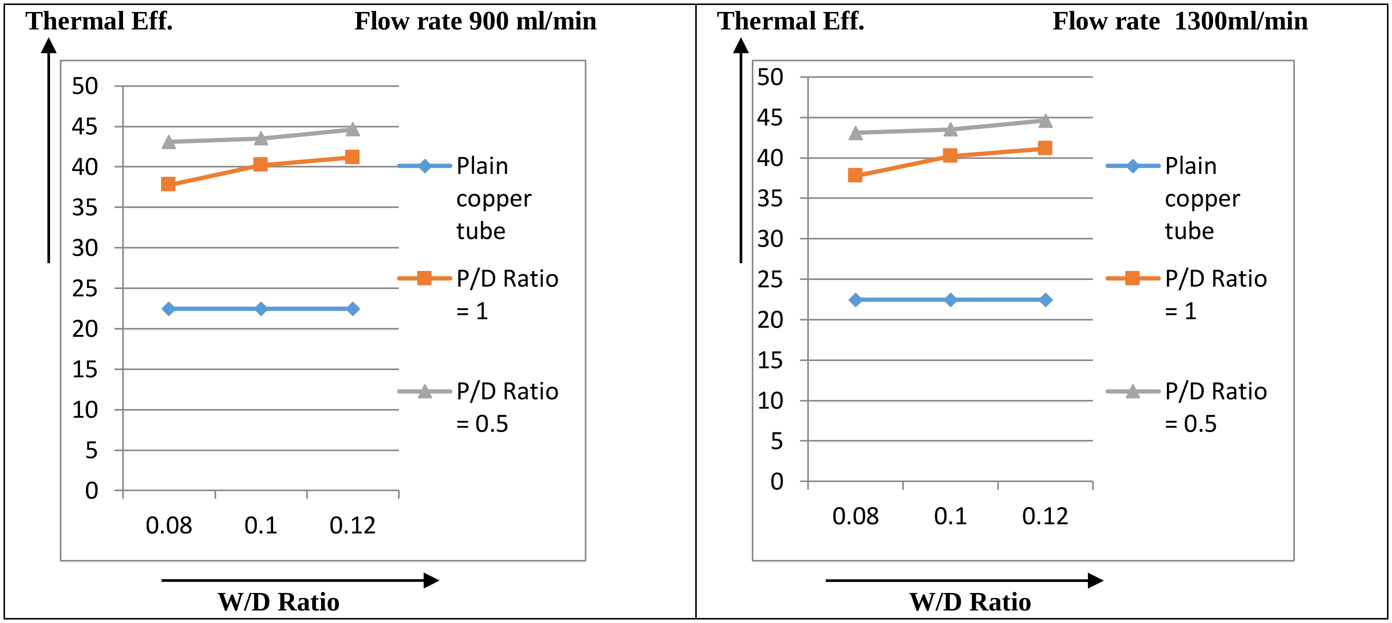

CONCLUSIONS

The thermal efficiency of solar liquid collectors enhanced with wire coil inserts increases with decrease in pitch to tube diameter ratio (P/D ratio). Thermal efficiency also increases with increase in coil wire thickness to tube diameter ratio (W/D ratio). The increment in thermal efficiency flattens as P/D ratio is decreased and W/D ratio is increased, which implies that it will not be worthy to decrease the P/D ratio and increase the W/D ratio after a limit.

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