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# Study of Effects of Dimensionless Parameters on Thermal Efficiency of Enhanced Solar Liquid Collector with Coiled Wire Inserts

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## ABSTRACT

*Solar liquid collectors are good candidate of heat transfer enhancement. The efficiency of a solar liquid collector can be improved by augmenting tube side heat transfer using enhanced techniques used in heat exchangers. Various types of heat transfer enhancement techniques has been used in heat exchangers which are mainly classified in two types, active and passive techniques. Solar liquid collectors can also be enhanced by these active and passive devices. Passive techniques, mainly swirl flow devices are more popular enhancement techniques in solar liquid collectors as they do not require any external source of power and also they do not affect the mechanical strength of tube material. Initially twisted tape inserts and conical inserts were popular passive devices used in enhanced solar liquid collectors mainly because of availability of established correlations. Wire coil inserts are relatively less experimented passive technique. This study is focused on tube side heat transfer augmentation of a solar flat plate liquid collector by wire coil inserts and effect of various dimensionless parameters on thermal efficiency of solar collector.*

***Keywords:*** *Solar collectors; solar flat plate liquid collectors; Heat transfer enhancement; Twisted tape; Coiled wire.*

## 1.0 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. 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

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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]. The swirl flow passive techniques such as twisted tape inserts, conical inserts and coiled wire inserts are most widely used techniques to enhance heat transfer in solar collectors. These enhancement techniques mainly produce favourable conditions such as perturbing the peripheral boundary layer, increasing turbulence near the hot surface of tube, increasing the surface area and guiding core fluid around centreline which is in the coolest region, towards the hot inner surface of the tube and thereby higher mixing with the hot fluid. 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 inner diameter firstly, disrupt the boundary layer and secondly, they increase the heat transfer area.

## 2.0 Literature Review

### 2.1 Twisted tapes

Kumar and Prasad [2] studied effect of twisted tape geometry , different mass flow rate and intensity of solar radiationon the thermal performance of serpentine solar collector with twisted tape insert. It was found out that heat losses were reduced and thermal efficiency was increased by enhancement of a tube with twisted tapes. Jaisankar et al.[3] carried investigation on heat transfer , friction factor and thermal performance on a tube on sheet solar panel with twisted tape insert with different twist ratio. It was seen that when twist ratio is increased, the swirl generation is decreased and both heat transfer and friction factor are reduced. Jaisankar et al. [4] worked on thermo-syphon solar water heater system with focus on heat transfer , friction factor and thermal performance data and established the fact that heat transfer in twisted collector was higher than in standard collector without twisted tape and thus twisted tapes are a useful insert device.

### 2.2 Wire coils

Garcia et al.[5] carried out a study on effects of artificial roughness shape on heat transfer increase 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 concluded that wire coil inserts should be used in Reynolds number range of between 200 to 2000, mainly because they produce best heat transfer augmentation and 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 past wire which promote heat transfer enhancement. Wire coil inserts however advance the transition Reynolds number and at Reynolds number 700 the flow turns turbulent.

Herraro Martin et al.[6] in their work on Experimental heat transfer research in enhanced flat plate solar collectors, pointed out that besides thermal liquid solar collectors are good candidates for heat transfer enhancement techniques but few studies has been performed with focus on this fact and majority of work done deal with solar air collectors. In the regard of solar liquid collectors studies done in past, 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 worked on heat transfer effects in flat plate solar collector enhanced with spiral wire coil inserts. Solar liquid 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 pressure loss due to friction losses.

## 3.0 Experimentation

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.

Experiments were conducted on a tube on plate type solar flat plate liquid collector with absorber plate size of 40 cm. × 90 cm. and a copper tube length of 2.6 m welded at the rear side of absorber plate, in the month of April 2015 at Yamunanagar, Haryana, India, which is located at Latitude 30.10 North and Longitude 77.30 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.

### 3.1 Selection of dimensionless parameters

#### 3.1.1 P/D

The dimensionless parameter, pitch of coil to tube diameter ratio (P/D) was taken 1 and 0.5. Most of the previous studies have been done with a ratio of 1 or more.

#### 3.1.2 W/D

The dimensionless parameter, wire diameter to tube diameter ratio (W/D) was taken in range of 0.08 and 0.12. Most of the previous studies have been carried out around a ratio of 0.07.

#### 3.1.3 S/D

The dimensionless parameter distance of wire coil from tube wall to tube diameter ratio (S/D) was not considered in the study , since it does not increase the heat transfer surface area if a non zero value of the parameter is chosen.

## 4.0 Data Reduction

### 4.1 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 $\Delta t$ Temperature Change K , $^0$C *G* Global Solar Irradiance Watt/m$^2$ $\Delta P$ Pressure drop n/m$^2$ *P/W* Pitch to Wire diameter ratio *A* Area m$^2$ *p* Density kg/m$^3$
*f* Darcy friction factor $u_m$ Average Velocity m/s $f_f$ Fanning Friction Factor $\gamma$ *p . 9.81* Kg /m$^2$s$^2$ *L* Length m $\theta$ Angle from horizontal in degree D Diameter m $V^{\cdot}$ Volumetric flow m$^3$/s

### 4.2 Thermal efficiency of solar collector

$n_{th} = m^{\cdot} c_p \Delta t / GA$ …(1)

**C. Friction Factor**

Darcy Friction factor f for smooth tube -

Laminar flow $f = 64 / Re$ …(2)

Turbulent flow $f = 0.316\ Re^{-0.25}$ …(3)

Fanning Friction factor $f_f$ for wire coiled tube [7,8] -

Laminar flow: $f_f = 16.8/(Re)^{0.96}$ …(4)

Turbulent flow: $f_f = 9.35\ (p/w)^{-1.16}\ (Re)^{-0.217}$ …(5)

### 4.3 Pressure drop

$\Delta P = f\ p\ u^2\ L / 2\ D$ n/m$^2$ …(6)

$(\Delta P - \gamma\ L\ Sin\theta) = = f\ p\ u^2\ L / 2\ D$ n/m$^2$ …(7)

(flow through inclined pipe

### 4.4 Pumping power increase

Power = $\Delta P\ V^{\cdot}$ watts …(8)

## 5.0 Result and Discussions

### 5.1 Thermal efficiency and increase in pumping power of solar collector

Experiments were conducted for several flow rates in plain copper tube and then in enhanced tube with wire coils of combination of various P/D ratio and W/D ratio. The results of coiled wire inserts were then compared with plain tube. Few observations are tabulated in table 1 and 2 [9].

**Table 1: Flow Rate = 500 ml/min**

| S No. | Enhancement Type | W/D = 0.08 | | W/D = 0.1 | | W/D = 0.12 | |
|---|---|---|---|---|---|---|---|
| | | ΔT | *nth* | ΔT | *nth* | ΔT | *nth* |
| 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 2: Flow Rate = 1300 ml/min**

| SNo. | Enhancement Type | W/D= 0.08 | | W/D = 0.1 | | W/D = 0.12 | |
|---|---|---|---|---|---|---|---|
| | | ΔT | *nth* | ΔT | *nth* | ΔT | *nth* |
| 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 |

The increase in pumping power requirement was found to 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.

### 5.2 Variation of thermal efficiency with P/D Ratio

**Figure 1: Variation of Thermal Efficiency with Pitch**

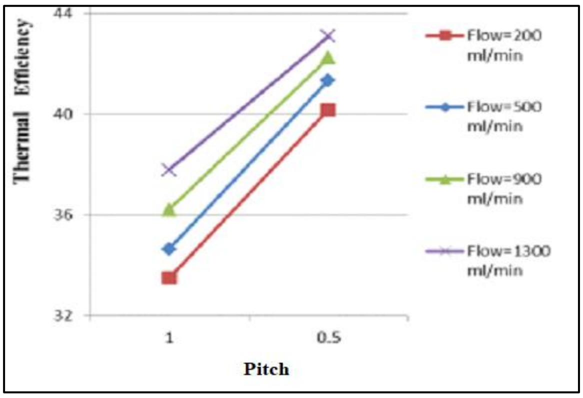
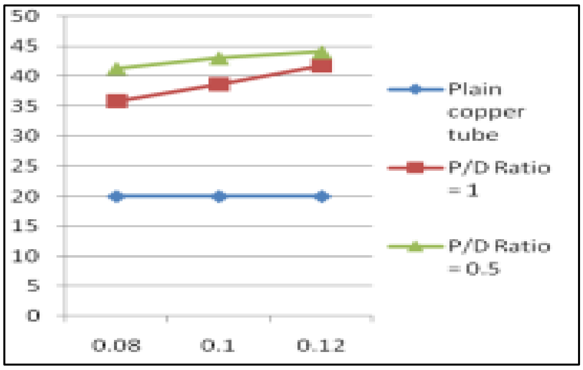
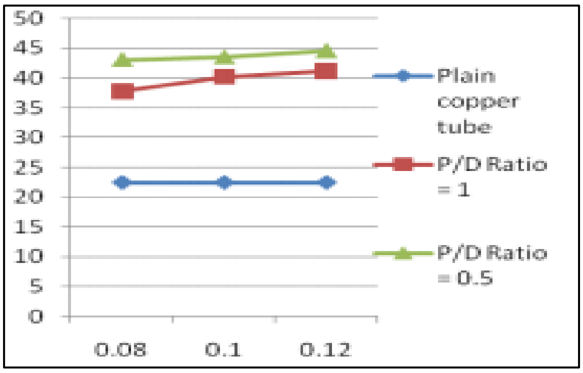



**Figure 2: Thermal Efficiency with Flow Rate @ 500ml/min**




W/D Ratio

**Figure 3: Thermal Efficiency with Flow Rate @ 1300ml/min**




W/D Ratio

For all the wire thickness, thermal efficiency of solar collector increases with decreasing pitch. The slope of lines flattens as the flow rate increases and also with wire thickness. The lines are most steep in case of wire thickness 0.8 mm and least steep in case of wire thickness 1.2 mm. This means that increase in thermal efficiency is decreasing with increasing the wire thickness and after a thickness probably further improvement in efficiency will not be possible. The thermal efficiency VS pitch graphs for flow rates 200 ml/min , 500 ml/min , 900 ml/min and 1300 ml/min are plotted, wire thickness being kept constant. The graph corresponding to wire thickness 0.8 mm is shown by figure 1.

In general, it is observed that

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.

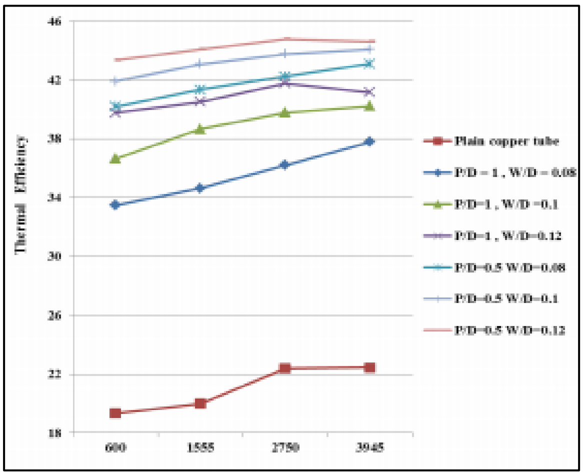
### 5.3 Variation of thermal efficiency with W/D ratio

The thermal efficiency of a solar collector enhanced with coiled wire inserts in general increases with increase in insert wire thickness or W/D Ratio, pitch kept constant. But 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.

### 5.4 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 for various P/D and W/D Ratios as-

**Reynolds Number**




## 6.0 Conclusions

The thermal efficiency of solar liquid collectors enhanced with wire coil inserts can be increased either by decreasing pitch or by increasing coil wire. 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 pitch or increase the wire diameter after a certain limiting value. The thermal efficiency of solar liquid collector increases consistently up to Reynolds number 2750. Beyond this regime, thermal efficiency either drops or increases insignificantly. For flow rates above 900 ml/min, wire thickness beyond 1.2 mm will not be beneficial.

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