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Enhancement of Heat Transfer Rate in a Solar Flat Plate Collector Using Twisted Tapes and Wire Coiled Turbulators

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***Abstract*—**Effects of insertion of coiled wire in juxtaposition with twisted tapes on heat transfer rate and solar radiation without disturbing the flow inside the riser tubes in a solar flat plate collector is experimentally reconnoitered in this present work. The wire coil used as a turbulator is placed inside the riser tube while the twisted tape is inserted into the wire coil to create a continuous swirling flow along the tube wall. The results of the heat transfer have been compared well with the available results. The heat transfer rate in the collector has been found to be increased by 18% to 70%. Solar water heaters having inserts in the flow tubes perform better than the conventional plain ones. It has been observed that heat losses are reduced consequently increasing the thermal performance about 30% over the plain water heaters under the same operating conditions. The effect of twisted tape with wire coils, flow Reynolds number, and the intensity of solar radiation on the thermal performance of the solar water heater has been presented. Effects of insertion of coiled wire in juxtaposition with twisted tapes on heat transfer rate and solar radiation without disturbing the flow inside the riser tubes in a solar flat plate collector is experimentally reconnoitered in this present work. The wire coil used as a turbulator is placed inside the riser tube while the twisted tape is inserted into the wire coil to create a continuous swirling flow along the tube wall. The results of the heat transfer have been compared well with the available results. The heat transfer rate in the collector has been found to be increased by 18% to 70%. Solar water heaters having inserts in the flow tubes perform better than the conventional plain ones. It has been observed that heat losses are reduced consequently increasing the thermal performance about 30% over the plain water heaters under the same operating conditions. The effect of twisted tape with wire coils, flow Reynolds number, and the intensity of solar radiation on the thermal performance of the solar water heater has been presented.

***Keywords*—**Solar Flat Plate Collector, Heat Transfer, Twisted tape, Wire coiled turbulators

I. Introduction

In many engineering applications, high performance thermal systems are needed and thus, various methods to increase the heat transfer are developed extensively. The conventional water heaters are generally improved by various augmentation techniques with emphasis on several types of surface enhancement. Enhanced surfaces can create one or more combinations of the following conditions that are favorable for the increase in heat transfer rate with an undesirable increase in friction. (1) Interruption of the boundary layer development and rising degree of turbulence, (2) increase of heat transfer area and (3) generating of swirling or secondary flows. Till date several studies have been focused on passive heat transfer enhancement methods. Reverse/Swirl flow devices (rib, groove, wire coil, conical ring, snail entry, twisted tape, winglet etc.,) form an important group of passive augmentation technique. The reverse flow of turbulator is widely employed in heat transfer engineering applications. The turbulators are inserted into the flow to provide an interruption of the boundary layer development, to increase the heat transfer surface area and to cause an enhancement of heat transfer by inducing the turbulence in the flow. Therefore an efficient water heater with low operational cost can be obtained without increasing any external surface area.

For decades, lots of wire coils and twisted tape devices employed for augmentation of laminar and turbulent flow heat transfers have been reported and discussed [1]. However, few researches for wire coil inserts have been come across in comparison with those for twisted tape inserts as pointed out in [2], [3]. Wire coils or twisted tapes are of practical interest and therefore their data are required to extend the use of this technique. Several investigations were carried out to determine the effect of coiled wire or the twisted tape elements on heat transfer and friction factor for a long time [4]-[15]. This is because the wire coil or twisted tape insert in a tube create swirling flows that modify the near wall velocity profile due to the various vorticity distributions in the vortex core. The fluid mixing between the tube core and the near wall region is enhanced because of the swirl induced tangential flow velocity component. However, accompanying with the swirl induced heat transfer enhancement, the shear stress and pressure drag in a tube with the coiled wire or twisted tape insert are accordingly increased. For this type of enhanced tube, the through flow Reynolds number (Re), the coil pitch ratio (CR) and the twist ratio (Y) of the twisted tube are the governing parameters to signify the pressure drop and the heat transfer characteristics. A comparison of the thermal and hydraulic performances of twisted tape or wire coiled inserts was introduced by Wang and Sunden [16] for both laminar and turbulent flow regions. They found that the coiled wire performs effectively in enhancing heat transfer in a higher turbulent flow region whereas the twisted tape yields a poorer overall efficiency. This can be probably explained for laminar or turbulent flow regime, the wire coiled flow along the tube surface is trapped in the coil

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groove especially for lower CR values resulting in low heat transfer rate in the tube. The use of combined wire coil and twisted tape inserts maybe fruitful since the continuous swirl flow generated by the twisted tape can help to wash up the trapped flow in the coil groove leading to high heat transfer in the tube.

For using compound turbulators, Promvonge and Eiamsa ard [17]-[19] investigated the effects of the conical nozzle, conical ring or V nozzle together with a swirl generator on heat transfer and friction characteristics in a uniform heat flux tube and found that for both enhancement devices the increase in heat transfer rate is about 20-50% of using a single enhancement device but also due to a substantial rise in pressure loss. In the literature review above most studies are mainly focused on the effect of a specific range of coil pitch and coiled wire thickness for wire coil or twist ratio and tape thickness for twisted tape inserts on heat transfer and friction characteristics of air or water flow in the tubes. The investigation on combined coiled wire and twisted tapes are already been reported. Therefore the main aim of the present work is to extend the data available on the wire coiled turbulator with a twisted tape swirl generator. In the literature review above most studies are mainly focused on the effect of a specific range of coil pitch and coiled wire thickness for wire coil or twist ratio and tape thickness for twisted tape inserts on heat transfer and friction characteristics of air or water flow in the tubes. The investigation on combined coiled wire and twisted tapes are already been reported. Therefore the main aim of the present work is to extend the data available on the wire coiled turbulator with a twisted tape swirl generator.

II. Experimental Setup

The experiment consists of a flat plate collector of 2m2 aperture area connected with well insulated storage tank of 125 liters capacity named as plain tube collector. The cold water from the lower header is evenly distributed in the riser tube. The riser tubes are brazed to a bottom of a black absorber plate and absorbed energy is conducted in to the riser tube. The heat is transferred by convection of tube from wall to the fluid. Finally hot water is collected from the upper header and stored in an insulated storage tank. The temperature difference in storage tank accelerates the driving force and the cycle is repeated until the temperature between inlet and outlet of the water is zero. A single transparent glass covers if 4mm thickness transmits the solar energy to the absorber plate. The collector and pipe are well insulated to minimize the heat losses. Absorber plate, riser tubes and headers are made of copper. Taps are provided to measure inlet and outlet temperature of water, absorber plate temperature, riser tube temperature and pressure drop in each riser tube. The twisted tape inserted collector has the same design and dimensions that of the plain tube collector and is fitted with twisted tape and wire coils. The length of the riser tube is 1500mm with 47mm inner diameter and 50mm outer diameter and thickness of 1.5mm. The wire coil is made of circular steel wire with 5mm wire thickness or diameter (Fig. 1). The wire coils of different spring pitch ratios (CR = H/d= 4,6 and 8) were inserted into the tube by wall attached position while the twisted tapes of 2mm thick steel strip with 35mm width for two pitch ratios (4 and 6) were fitted tightly into the coil placed in the riser tube. The collector with twisted tape and wire coil are kept in outdoor condition facing south direction with a tilt angle of 320. The experiment is carried out for the entire day. The storage tank is completely drained in the evening after the experiment and is refilled with clean tap water in early morning. Thermometers are used to measure inlet, outlet, plate and ambient tube temperature and stored in the temperature recorder. Solar radiation is measured is measured by light meter and pressure drop inside the tubes by differential pressure transducer. To quantify the uncertainties of measurements the reduced data obtained experimentally were determined. The uncertainty in the data calculation was based on ASME Measurement Uncertainty. The maximum uncertainties of non-dimensional parameters were ±5% for Reynolds number, ±7.6% for nusselt number and ±9.5% for friction factor.

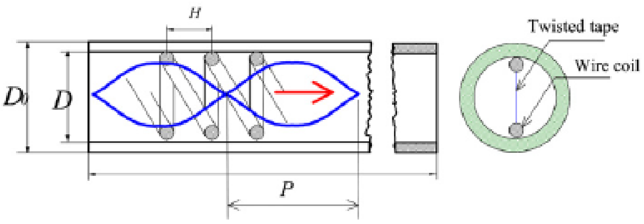

Fig. 1 Design view of the wire coil and twisted tape

Fig. 2 Riser tube with wire coil and twisted tape

III. Math

The slope of the collector is calculated from

$$\beta = Q\text{-}d \quad (1)$$

Angle of Inclination *(d)* is calculated by

$$d = 23.45 \sin [0.9683(284+n)] \quad (2)$$

where, Q is the latitude at the test site & n is the day's number in that year.

$$Q = 12^0 \text{ North}$$

For Example, for January 20th

$$d = 23.45 \sin [0.9683(284+20)] = -20.34$$
$$\text{Slope of the collector } (\beta) = 12\text{-}(-20.34)$$
$$\beta = 32$$

The Slope of the collector varies between $28^0$to 35^0

For best performance, the slope of the collector is chosen as 32^0. The collector is made to face the south direction since the Indian Sub-continent lies in the northern hemisphere.

IV. Results and Discussions

The experiment was carried out in the month of August for an entire day simultaneously for both the collector setups. The results from the experiment are tabulated below. The experiment was carried out in the month of August for an entire day simultaneously for both the collector setups. The results from the experiment are tabulated below.

TABLE I
AVERAGE TEMPERATURE VALUES OF PLAIN COLLECTOR SETUP

Time (Hrs)	Inlet (^{0}C)	Outlet (^{0}C)	Solar Radiation (w/m^2)
9.00	34	41	540
10.00	36	45	630
11.00	39	52	713
12.00	44	64	771
13.00	47	76	785
14.00	53	61	641
15.00	48	58	602
16.00	45	51	589

TABLE II
AVERAGE TEMPERATURE VALUES OF WIRE COIL AND TWISTED TAPE SETUP

Time (Hrs)	Inlet (^{0}C)	Outlet (^{0}C)	Solar Radiation (w/m^2)
9.00	33	41	540
10.00	39	53	630
11.00	41	62	713
12.00	44	76	771
13.00	47	91	785
14.00	56	87	641
15.00	45	69	602
16.00	42	61	589

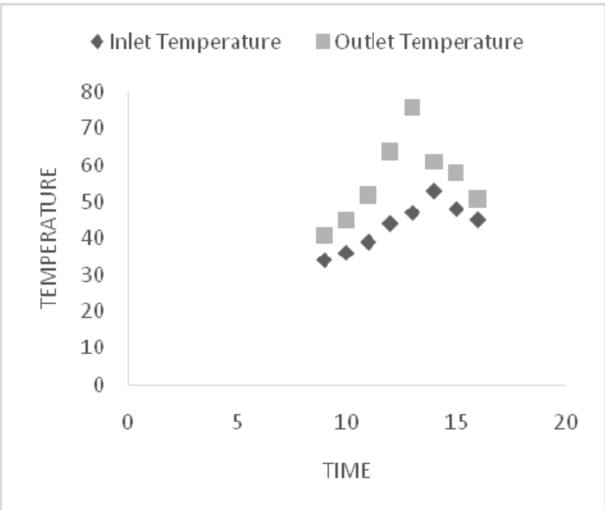

Fig. 3 Inlet and Outlet temperature data from plain collector setup

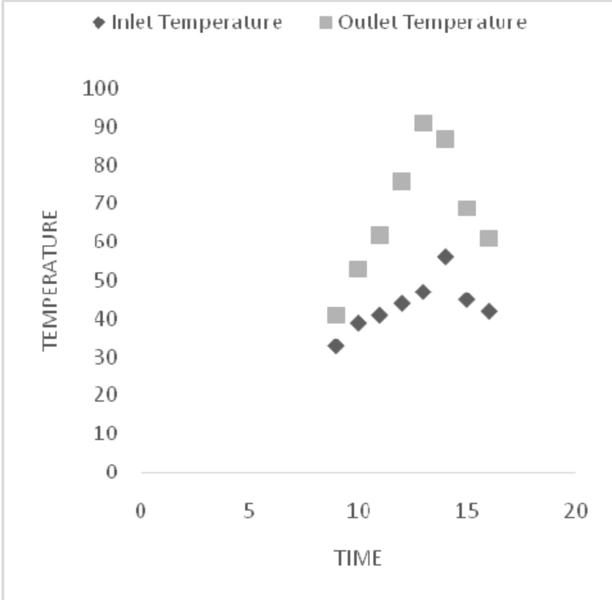

Fig. 4 Inlet and Outlet temperature data from wire coil and twisted tape setup

The observation from Figs. 3 and 4 shows that the nusselt number twisted tape with wire coiled collector setup is higher than that of a plain collector setup for a given Reynolds number. The tangential flow modifies the intensity of swirl generation in radial direction for every pitch distance and increases the hydraulic length of fluid flow. The friction factor for tapes inserted collector is higher than that of a plain collector because of the flow mixing effects caused by tangential direction of fluids which increases the wetted surface area. Hence enhanced heat transfer effect increases the fluid velocity which affects the pressure loss near the tube wall. These effects are more in tapes inserted collector than that of the plain ones. Hence fluid particle mixing is more in minimum fin ratio which cause increase in the nusselt number.

V. Conclusion

An experimental study has been carried out to investigate the friction factor and heat transfer characteristics in a solar water heater and the results has been compared with the conventional one. The use of twisted tape along with wire coils causes a high pressure drop thereby providing considerable heat transfer augmentations. Twisted tape generate turbulency superimposed with swirlness inside the flow tube and consequently result in enhanced heat transfer. Therefore this combined twisted tape with wire coil should be applied in solar flat plate collectors instead of the plain ones to obtain the highest performance at low operational cost.

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