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Effect of Nano-Nickel Oxide Coating on Solar Flat Plate Collector

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Abstract*: *Solar flat plate collectors nowadays find more applications considering the cost involved with conventional water heating systems using fossil fuels. The performance of these systems can usually be enhanced by varying select important parameters of the system for improved heat transfer ability of the collector. Therefore, this work is aimed at evaluating the effects of nano-Nickel Oxide (NiO) coatings on liquid flat plate collector for better heat transfer effect. Two flat plate collectors are designed and fabricated with same operating parameters such as collector area, system size and spacing, pipe diameter and size of collecting tank, etc. The heat transfer effect is simultaneously studied in these two units to observe the effect of nano coating in comparison with black chrome coating.

Keywords*: *nano-NiO coating, flat plate collector, solar water heating, heat transfer performance

I. INTRODUCTION

Solar water heater is a kind of renewable energy system widely used for domestic and small commercial applications. It is a passive thermal system consisting of flat plat collector, heat transfer fluid and storage tank as main components [1]. Many different kinds have been developed and in use with varying constructional and functional features. Typical variations aimed at capturing increased solar radiation include concentrating collectors [2], cylindrical trough collectors, parabolic reflectors [3], and etc.

The flat plate collector (FPC) employed in solar water heaters consists essentially of an absorber plate, a transparent cover plate (like a glass or polycarbonate cover) and a heat transport fluid (like water or air), all enclosed in an air-tight thermal insulation to avoid heat leakage [2].

The principle of energy conversion in all these systems is that the solar radiation incident on the adsorber plate is converted into heat and then the heat is utilized for raising the temperature of the water being in circulation [1]. The water can be circulated either by natural convection or with an assistance of a pump.

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II. REVIEW OF LITERATURE

Flat plate collectors normally yield an efficiency of about 60 to 70 % under optimum design [1]. The output performance depends on various parameters, one being the absorbtivity of the FPC [3], others include collector design, properties of heat transfer fluid, collector orientation, etc. [1]. Many research outcomes are reported in the literature for the improvement of heat transfer efficiency of flat plate collector. The selective coating of the adsorber plates with materials of high absorptance is reported in [4] ; use of nano copper oxide and nano titanium dioxide as selective coating material is discussed in [5] and the effect of water based Al_2O_3 nanofluid is presented in [6]. The black paint embedded with a nickel-aluminium metallic particle results an improvement of about 5 °C comparing with non-embedded paint [7].

Nanomaterials exhibit distinct and enhanced properties owing to size effects and large surface-to-volume ratio [8]. Nano Nickel oxide find wider applications in recent years, having good chemical and thermal stability [9]. Nano Nickel oxide (of 99 % of purity, <50 nm size) purchased from M/s Sigma Aldrich is used in this research.

III. EXPERIMENTAL METHODS

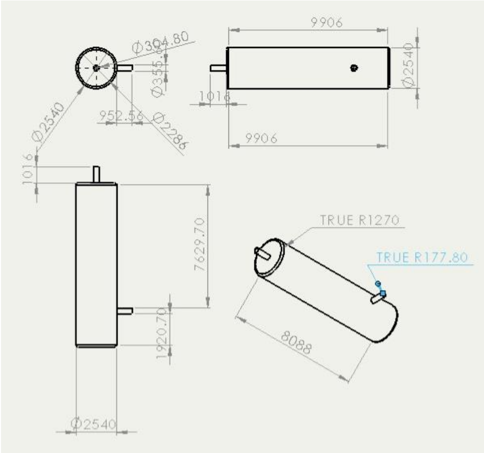
A. Objectives of the work

The prime objective of this work was to identify the suitability of nano NiO as a selective coating material for solar liquid flat plate collector. Thin sheets of copper, aluminium, steel or stable polymers are usually used for adsorber plates. The aluminium sheet is chosen as the collector material in this work. The effect of nano NiO as a better coating material was studied by comparing its overall heat transfer performance with that of black chrome coated unit by testing two similar units at same time. The black chrome has an absorbtivity of 0.93 [3], hence, an improved performance with nano NiO is the main objective of this work.

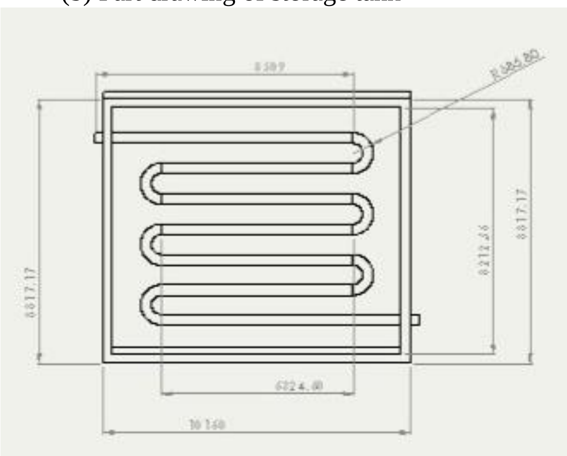
B. Design and materials

The flat plate collector system is designed for a storage tank capacity of 3 litres. The part and assembly drawings done with SOLIDWORKS software are shown in Fig. 1.

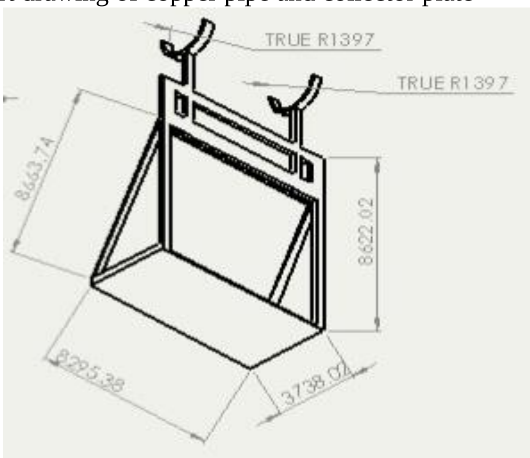
(a) Assembled 3D model of the complete unit



(b) Part drawing of storage tank



(c) Part drawing of copper pipe and collector plate



(c) stand

Fig. 1. CAD modeling and part drawings (select parts)

All required materials – nano NiO, aluminium sheets, copper pipes, glass cover plate, digital thermometers, black chrome paint and wood materials are arranged from reliable suppliers. The specifications of various materials used in the construction are given below and few items shown in Fig. 2.

Insulating Wood box
Inside width: 400 mm
Inside height: 300 mm
Plywood thickness: 17.74 mm
Copper tube
Diameter: 5 mm
Total length: 10 feet
Aluminium plate (Collector)
Width: 400 mm
Height: 300 mm
Thickness: 0.97 mm
Glass cover plate
Thickness 4 mm
Width: 400 mm
Height: 300 mm
Coating material
Black chrome paint
Nano NiO mixed with black chrome

Copper tube

Glass cover plate

Aluminium sheet

Black nano NiO powder

Fig. 2. Various materials used in construction

C. Construction, Coating and Assembly

The wooden box is made by usual carpentry work. The stand unit is fabricated by arc welding after cutting the steel rods to the required size. The stand is made such that the inclination for collector is maintained at 43 ° as per the longitude / latitude requirement for Vallam location, where the experiment is conducted. The copper tube is bent in such a way that the circulating water flows smoothly without any disturbance due to sharp bends. The various components under different fabrication stages are shown in Fig. 3.

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Collector box – before coating


Steel stand Aluminium Collecting tank

Fig. 3. Components under different fabrication stages

The glass cover plate is carefully placed on the wooden box to cover it air-tight. To provide leak proof joints, silicon paste is used wherever necessary. The digital thermometers are placed at appropriate places to measure the inlet and outlet temperature. The insulation is provided on hot water outlet pipe coming out from the collector area to the storage tank.


Collector coated with black chrome Collector coated with black chrome mixed with nano NiO

Fig. 4. Collectors after coating

The collector units are then coated as shown in Fig. 4 above. One unit is coated with black chrome paint of 2 mm thickness and the collector of other unit is coated for same 2 mm thickness with black chrome paint mixed with nano NiO powders. The mixing quantity is: 50 ml paint added with 3 g of nano NiO. The mixed paint is stirred well for getting uniform and homogeneous paint. Both the units after being coated were dried for 2 to 3 days before being put to use.

The fabricated units are assembled properly as per the model shown in Fig. 1(a). The units are then taken to open space to expose them with solar radiation as shown in Fig. 5. The water is filled in the tanks through inlet and then closed so that the test is conducted for fixed volume of water. The water gets circulated by natural convection and the units are then ready for testing their performance.

Fig. 5. Testing of the units (under same conditions)

IV. RESULTS AND DISCUSSION

A. Test methodology

The efficiency of flat plate collectors can be given as [1]

$$\eta = \frac{\text{Useful energy gain}}{\text{Incident solar energy}} = \frac{F_R A[I\tau\alpha - U_L(T_i - T_a)]}{AI}$$

Where,

F_R – collector heat removal factor

A – collector area in m^2

I – intensity of solar radiation in W/m^2

τ– transmission coefficient of glazing

α – absorption coefficient of plate

U_L – overall heat loss coefficient of collector, W/m^2

T_i – inlet fluid temperature, °C

T_a – ambient temperature, °C

As seen from the above 'Hottel-Whillier-Bliss equation' for the useful energy gain, when all other factors remain same, a system with 'more energy transferring ability' from the incident solar radiation will perform better than others.

Hence, the test is designed such that, the design, the working fluid, the inlet and ambient temperatures and all other operating conditions are kept same for both systems, with only difference being the coating material. Then, the outlet temperature of the water measured with digital thermometers placed integral with the units will indicate the efficiency of the collectors.

B. Test results and inference

Therefore, the outlet temperature measurements were taken simultaneously on both black chrome system as well as nano coated system to study the effect of nano-coating. The tests were conducted for 6 days, 3 days each during 2nd and 3rd week of May, daily from 9 am to 3 pm, at an interval of one hour. The average temperature readings measured with both the units is presented in Table - I below and the results obtained are shown in Fig. 6 and Fig. 7 for graphical comparison.

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Table - I: Output Temperature readings of FPC

To Time (From Time 9 am)	Duration in hour	T_{out} (°C)			
		Week 1 (T_{in} 30 °C)		Week 2 (T_{in} 32 °C)	
		black chrome coated unit	nano NiO coated unit	black chrome coated unit	nano NiO coated unit
9 am	-	30	30	32	32
10 am	1	35	39	36	38
11 am	2	39	44	39	43
12 pm	3	44	48.3	44	49
1 pm	4	52	55	48	54
2 pm	5	57	60.3	53	59
3 pm	6	63	66.2	54.3	59.7

We noted that the results obtained from black chrome unit are comparable with standard data available with literature. The readings for both the units are considerably consistent during two different weeks.

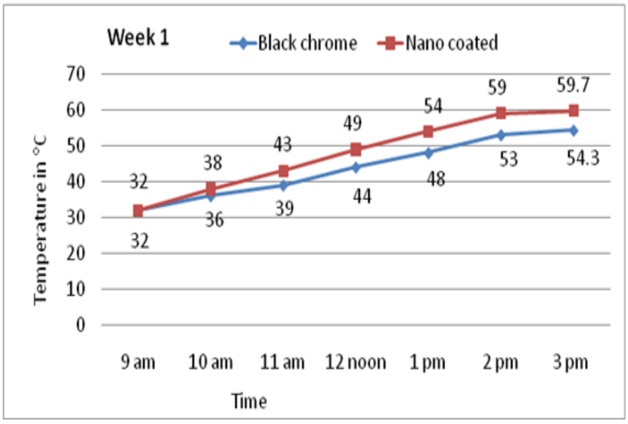

Fig. 6. Performance comparison for Week 1

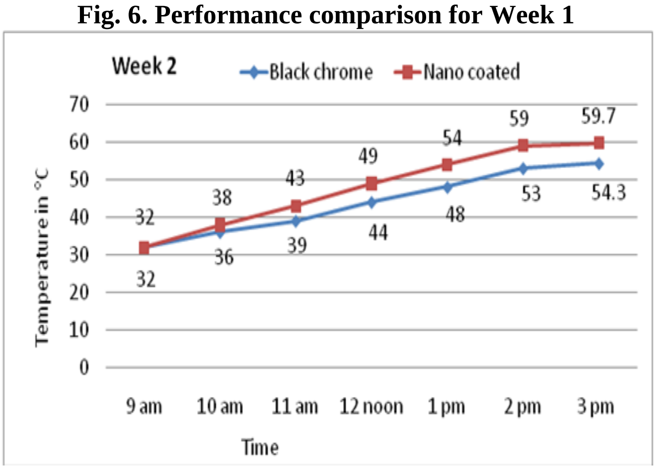

Fig. 7. Performance comparison for Week 2

As recorded in the experiments, the results obtained from nano NiO show consistent performance over two weeks. In both weeks, the outlet temperature of nano coated system was measured to be high, which is the objective of this work. The difference is typically of the range from 3 to 5 °C as evidenced from the results.

V. CONCLUSION

In this work, two similar FPC units were developed to study the effect of coating material on Aluminium collector. The performance tests were conducted on both the units simultaneously at same solar irradiance. On a typical week, the temperature readings measured with digital thermometers show an outlet temperature difference of around 5.4 °C higher for nano-NiO coated unit. On another week too, the temperature difference was measured to be higher with nano-NiO coated unit by 3.2 °C. Thus, the results indicate that the flat plate collector system with nano-NiO coating gives better results in comparison with black chrome coated unit.

Hence, it can be concluded that the nano-NiO coating significantly improves the conversion of solar radiation into heat energy at the collector surface and enhances the overall heat transfer efficiency of the collector system. This work can be extended for optimizing the coating parameters like particle size, coating thickness, etc. and then can be employed with commercial systems.

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