Thermal Performance of a Wall Heat Collection Prototype with Al_2O_3+BN/H_2O Nanofluid

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Abstract— In this experimental study, we have attempted to combine the curtain wall structures, building construction practices, heat transfer mechanisms, and a natural circulation loop designed to develop an innovative, wall-integrated solar heater using Al_2O_3 + Boron nitride/water (BN/H_2O) nanofluid on the concept of an "energy-harvesting" façade. A nanofluid is a dilute suspension of nanometer-size particles and fibers dispersed in a liquid. As a result, when compared to the base fluid, changes in physical properties of such mixtures occur, e.g., viscosity, density, and thermal conductivity of all the physical properties of nanofluids, the thermal conductivity is the most complex and for many applications the most important one. Interestingly, experimental findings have been controversial and theories do not fully explain the mechanisms of elevated thermal conductivity. In this paper, experimental and theoretical studies are reviewed for collector efficiency using nanofluid thermal conductivity and convection heat transfer enhancement. This work accomplished by performing an experimental investigation using two different types working fluid, water and Al_2O_3 + BN/ water nanofluid with 2%, 4%, 6% of volume fraction of nanopowder by varying the flow rates of the fluid. For this combination of working fluid the efficiency of system is found, 41.64%, 48.79%, and 55.82% respectively. The flow rates are 25LPH, 50LPH, 75LPH and 100 LPH. The highest values of efficiency are found at 100 LPH.

Key words: BN/H_2O, 100 LPH

I. INTRODUCTION

Air-conditioner (AC) has become almost indispensable for every family, but the traditional air-conditioner has some disadvantages as following: (1) Traditional AC systems consume too much energy. To meet their demands, natural resources are burned to generate electricity, which causes greenhouse effect and to exacerbate a lot of pollution on the earth. (2) The refrigerant of traditional air conditioner, Freon, once leaked, will cause irreversible damage to the ozone sphere and make life suffer from ultraviolet radiation. This system avoids the internal air in the building to get heated up by the solar radiation. The radiations are absorbed by the collector, hence reduces the extra load on the air conditioner and thus the efficiency of the air conditioner increases. This is one of the advantages of this system.

Solar thermal designates all technologies that collect solar rays and convert the solar energy to usable heat for use in water, Solar water heating (SWH) is one of the most popular solar thermal systems and accounts for 80% of the solar thermal market worldwide. Over the past four decades, SWHs have gained wide applications in the building sector globally. This setup is simply positioned on the walls or balconies and effectively buffers the solar heat gain and even capture this heat energy and transfer it in such a way that it can be used. which prevent the occupation of roof space and shorten the distance of piping runs, and there by improve the building's aesthetic view. Thus attempt is made to develop an innovative wall heat collection prototype based on the façade energy-harvesting concept.

The present study aims to provide insights into an innovative, wall-integrated solar water heater with nanofluid for which little or no information is available. The thermal performance of the proposed prototype is experimentally investigated for the physical configuration under consideration of particular emphasis in this study, the operational performance assessment of the solar heater under practical conditions.

II. LITERATURE SURVEY

A wall-integrated solar heating system refers to an architectural design approach that combines hot water generation with the building's construction system. This combination allows this system to feature a hot water generation function and become part of the building façade. Environmental control devices and/or designs in buildings that are capable of harvesting solar thermal energy can effectively capture and store this solar energy and provide energy through the use of, for instance, a hot water system [1–3] or a low-power thermoelectric material [4].Thermal energy storage (TES) is the key component for such solar energy use, and it is one of the most promising and sustainable methods for energy storage in buildings.

The TES systems used in buildings can be easily divided into three types: sensible, latent, and thermo chemical energy storage (TCES).Because of its numerous advantages, such as its wide range of storage temperatures, high thermal capacity, no toxicity, low cost, and easy obtain ability, water is often used as the storage medium in a solar water heating (SWH) system for domestic solar utilization [5–10]. However, more effective integration of solar collection in SWH systems within the building envelope is always desirable [11, 12].SWH technology is also suitable for renewable energy exploitation to be applied in residential building refurbishment. Goli´ca et al.[13] defined a general model of SWH integration into residential building refurbishment techniques. Rodriguez-Hidalgo et al investigated the instantaneous performance of solar collectors for domestic hot water use using an experimental solar facility [14]. A cool-down test was conducted in [15] using a single storage tank to determine heat loss characteristics. Dominguez-Munoz et al. [16]proposed the application of reliability analysis methods to design solar thermal systems to consider the true stochastic nature of the problem. Corbin and Zhai [17] proposed a BIPV/T collector and demonstrated its potential for providing increased electrical efficiency of up to 5.3% over a naturally ventilated BIPV roof, reducing the negative effects of integration into the building facade.

In this study, we can attempt to combine the curtain wall structures, building construction practices, heat transfer mechanisms, and a natural circulation loop design to develop an innovative, wall-integrated solar heater based on the concept of an "energy-harvesting" facade. The main heat transfer mechanism of this prototype is based on the concept of natural circulation loops (thermosyphon). Natural circulation loops with various configurations and operating conditions have been the subject of numerous studies because of their wide range of technological applications. In a natural circulation loop, the fluid flow, which is driven by thermally induced density gradients, removes heat from the heated section of the loop, and that heat can be transferred to a cooler section at a higher elevation. Such a loop can serve as a low-cost and highly reliable passive heat-transfer device. Comprehensive studies on single-phase natural convection loop performance and the effects of various parameters, such as heated and cooled section orientations, tilt angles, wall thermal conductivity, loop heights, and pipe. diameters, can be found in the literature [18]

III. DESIGN AND DEVELOPMENT OF EXPERIMENTAL SETUP

1) The literature review in connection with the applications of nanofluid in solar energy could be carried out. The particular attention could be given towards as nanofluid in single phase closed thermosyphon.
2) Concluding remarks obtained from the literature review could be utilized to find innovative idea to harness solar energy incident on curtain wall
3) The primary considerations during the design stage include how this device would integrate with the building construction and whether this integration would result in an excessive increase in installation costs.
4) After analyzing the construction of conventional exterior walls, we are hopeful that our prototype will be integrated with the "vertical framing and detaching" construction, which is one of the simplest approaches for modularization and has the lowest entry barrier among metal curtain wall systems
5) The vertical framing and detaching system primarily consists of vertical frames, lintels, windows, and upper and lower wall boards, as shown in Fig. 1(a). Both the location and function of the glazing were maintained. The lower and upper wall boards of the lower curtain wall were integrated and subsequently replaced with the developed prototype
6) Mathematical model can be developed in order to investigate thermal performance of proposed curtain wall integrated solar heater using nanofluid as an absorbing medium.
7) Experimentation will be carried out for testing thermal performance of Curtain wall integrated solar heater prototype using nanofluid as absorbing medium
8) The results obtained (from experiment) can be analyzed to identify the feasibility of developed SWH to harness the solar energy incident on curtain wall.

A. *Experimental Setup:*

The experimental test cell can be consisted of an exterior wall plate[which acts as a radiation collector] (1), a vertical flow duct, having square cross section (2), a circulation piping loop (3), and a cooling sleeve (4). The exterior wall (1) width can be 40 cm and the height could be 80 cm, which is a commonly used curtain wall height.

On one side of the wall, solar radiation will be used to heat the wall surface, simulating the solar radiation received by the exterior wall plate on the other side (inside the curtain wall), the vertical flow duct measured 30 mm wide by 20 mm high and can be welded specifically to form a heat exchanger. The circulation tubes (3) could also use as structural support for the curtain wall; therefore, the tube material used in this study can be copper. The joints between the circulation tube and square duct could be constructed with filet material, and the tubes can be shaped to maintain a constant cross-sectional area throughout the circulation loop. The outer radius of the tube can be 12.7 mm, the inner radius could be 11 mm, and the wall thickness can be 1.7 mm. To align the loop with the exterior wall, we have to fix the horizontal distance S to be approximately 200 mm to match the typical wall thickness. Therefore, the overall exterior size of the test cell was 40 cm wide, 20 cm deep, and 80 cm high, which matches the dimensions of typical metal curtain walls. In addition, valves were installed at the top and bottom of the loop to allow for the removal and addition of fluid.

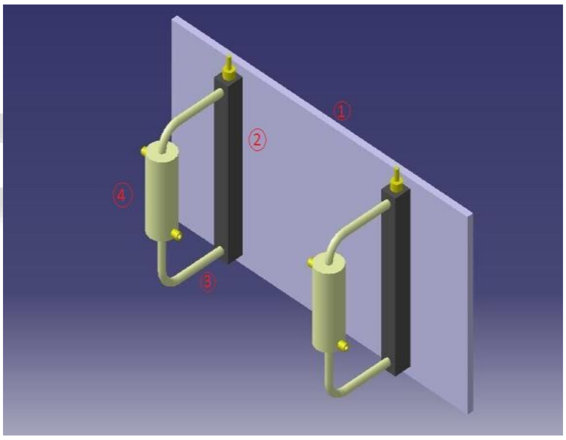

Fig. 1: Proposed Developed Prototype in This Experiment

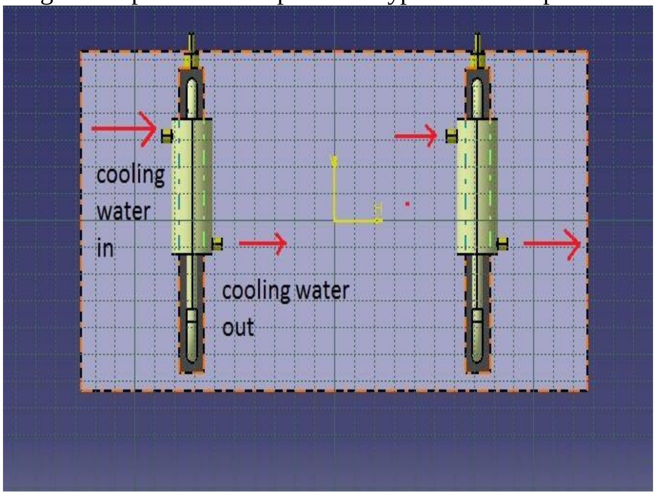

Fig. 2: A: Experimental Test Cell CAD View

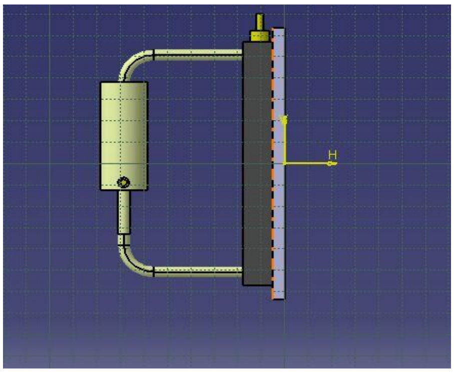

Fig. 2: (b) Experimental test cell CAD View

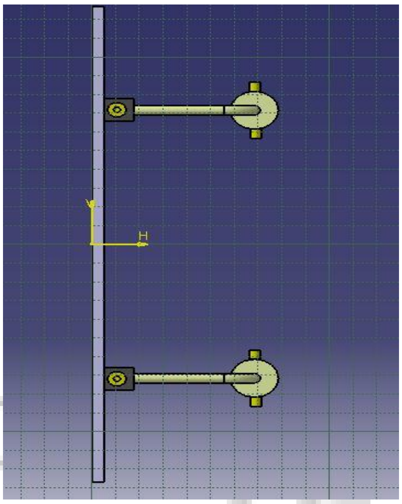

Fig. 2: (c) Experimental test cell CAD View

Fig. 2: (d) Experimental test cell actual View

Test cell, Circulation tubes, Cooling sleeve, Insulating over cooling sleeve, Temperature sensors and indicator, Pyranometer, Calibrated measuring flasks/Rotameter, Flow Control valve

The cooling section (4) can be opposite the heated section. This section includes a cylindrical cooling sleeve made of aluminum. In addition, the cooled section uses water from a thermally regulated bath to extract heat from the loop. The cooling sleeve measured 61 mm × 300 mm and had internal dimensions of 40 mm × 280 mm. Cotton can be wrapped around the cooled section and the exterior of the circulation tube as insulation to reduce heat losses from the system. Desired radiation intensity measurements can be taken using a pyranometer. We installed K-type thermocouples at various points around the loop to measure the water and wall temperatures. In addition, we have to install the resistance temperature detectors (RTDs) at the cooling water entrance and exit in the cooling sleeve.

B. Nanofluid Preparation:

The selected nanopowder for the proposed study is AL_2O_3 + BN (5 ml)/H20 nanofluid 50nm size with water as base fluid. This selection of nanoparticle material is done on the basis of enhancement of thermal conductivity obtained with addition of nanoparticle material. As the thermal conductivity of AL_2O_3 is high hence it is expected that addition of nanoparticle material with higher thermal conductivity leads to enhancement in thermal conductivity and higher heat transfer coefficient.

Purposely the addition of BN is to be added in the nanofluid in small quantity because BN is having very high thermal conductivity and it can give high rise in thermal conductivity compared to addition of AL_2O_3 nanoparticle.The nano powder is to be purchased from the Nanoshel USA. The amount of nano powder required for the same can be calculated as below.

The total volume of nanofluid to be prepared

V nf = Volume of circulating pipes x No. of loops

The amount of nanopowder required is calculated by,

Vol. fraction of nanofluid (%) = Vol. of Nanoparticle/Vol. of Nanofluid But,

Vol. of nanoparticle = Mass of nano particle /Density of nano particle

Hence

$$\text{Volume fraction of nanofluid is} = \frac{(\text{Mass of nanoparticle/Density of nanoparticle})}{\text{Volume of nanofluid}}$$

Thus for given volume fraction of nanofluid and decided amount of nanofluid to be prepared the mass of nanoparticle to be added in the base fluid can be calculated. As the quantity of nanopowder required for the same for volume fraction basis is large and considering the cost of same it will be later decided the weather to conduct the experiment with preparation of nanofluid on volume basis or weight basis.

C. Test Methodology:

In order to Thermal performance of curtain wall-integrated solar water heater with nanofluid, it has been decided to vary the mass flow rate from 25LPH, 50LPH, 75LPH in the step of 100 LPH. Heat exchanger is placed at backside of collector. Cold water is get supplied to heat exchanger, it absorb heat from hot fluid. Whole teat set up is mounted vertically.

D. Test Parameters and Calculations:

Experimentation was carried on the designed setup as shown in fig 1.

Parameter	Description
Mass Flow Rate	25LPH, 50LPH, 75LPH, 100LPH
Time	11.00am to 4.00pm

Table 1: Test Parameters

All the necessary components were assembled and experimental set was developed. The necessary instruments were attached at correct configuration and the set up is ready for the experimentation.

E. Formulae Used:

Heat Supplied by Solar Energy (Qs) = It x A

Heat Gain by hot Water (Qg) = m x Cp xΔT

Efficiency = Qg/Qs

IV. RESULTS AND DISCUSSION

Experiments were carried out by using two working fluids for heat pipes such as: pure water, AL_2O_3 + BN/water. The results are depicted in Figs. 4.2-4.5. By varying the mass flow rate, inlet water temperature and outlet water temperature for four different working fluid are measured.

Fig 4.1 shows the variations in solar intensity. From fig 4.1 it can be say that variations in solar intensity is very less for all days of testing.

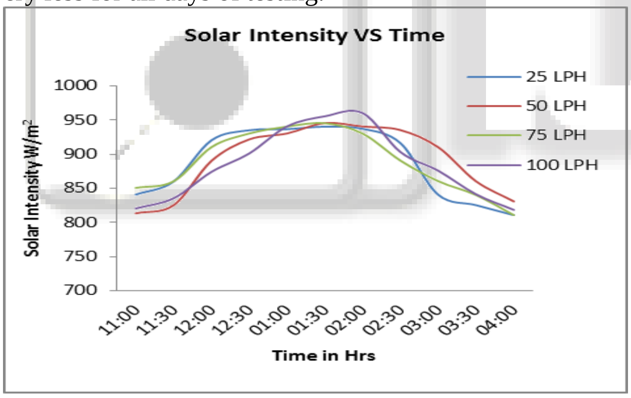

Fig. 3: Variation in Solar Intensity w.r.to Time

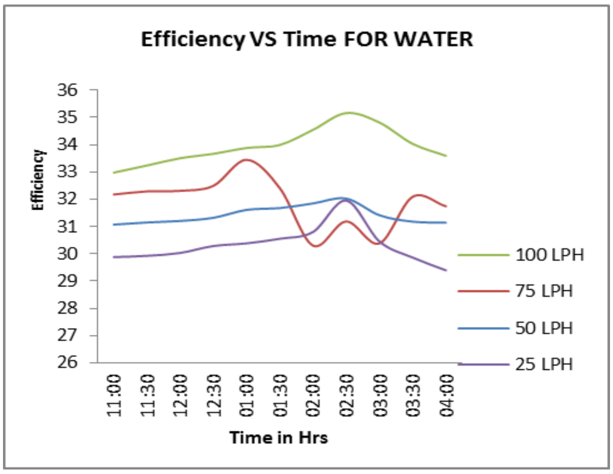

Fig. 4: Variation in Efficiency w.r.to Time for Water

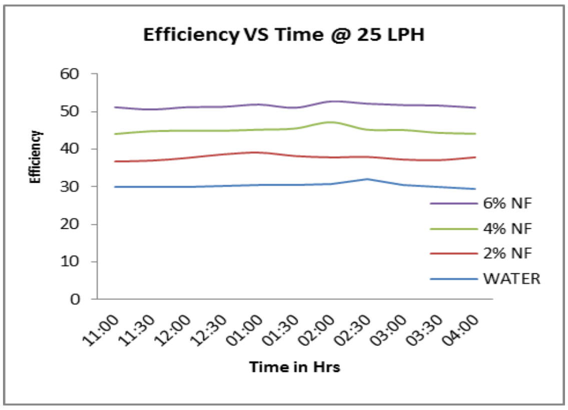

Fig. 5: Variation in Efficiency w.r.to Time at 25LPH

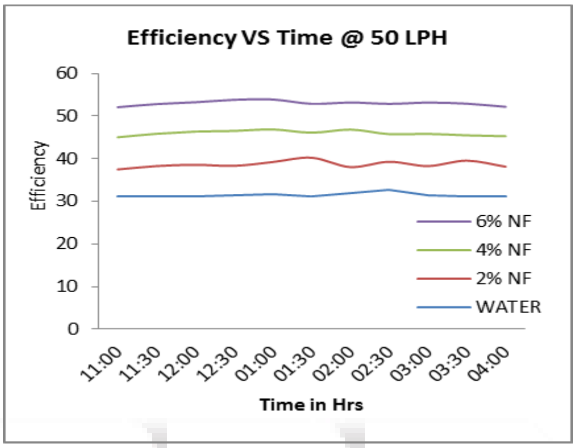

Fig. 6: Variation in Efficiency w.r.to Time at 50LPH

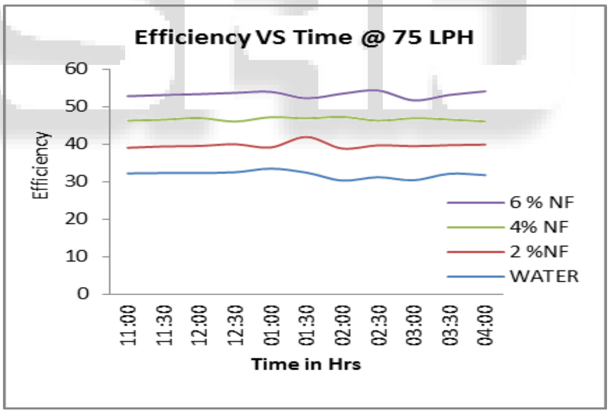

Fig. 7: Variation in Efficiency w.r.to Time at 75LPH

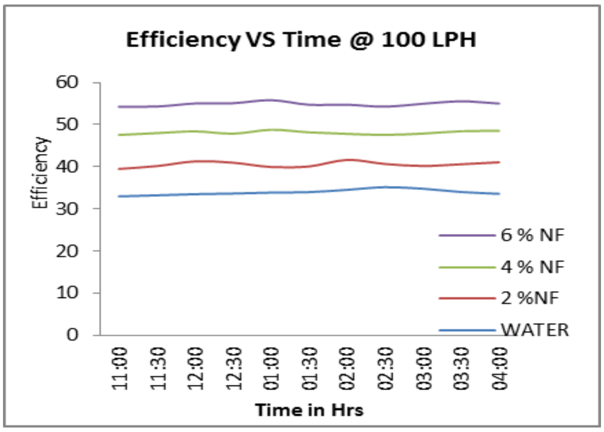

Fig. 8: Variation in Efficiency w.r.to Time at 100LPH

From Fig 4.2 to Fig 4.6 it is conclude that because of using nanofluid, efficiency of curtain wall-integrated solar water heater is improved.

Fig 4.7 and Fig 4.10 shows the variations in Δt temperature.

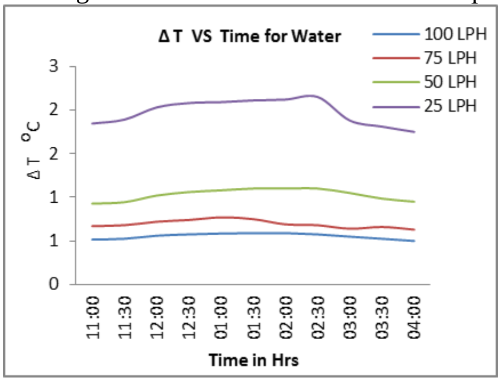

Fig. 9: Hourly variation at Δt Temperature for Water

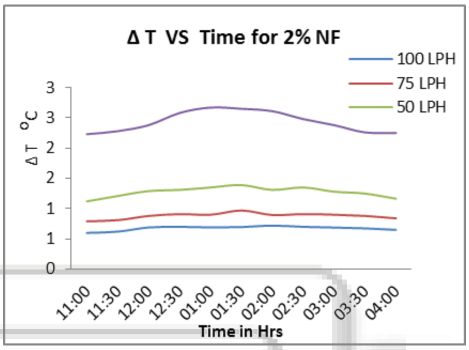

Fig. 10: Hourly variation at Δt Temperature for 2% nanofluid

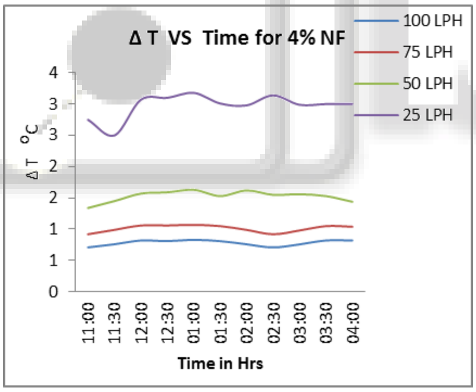

Fig. 11: Hourly variation at Δt Temperature for 4% nanofluid

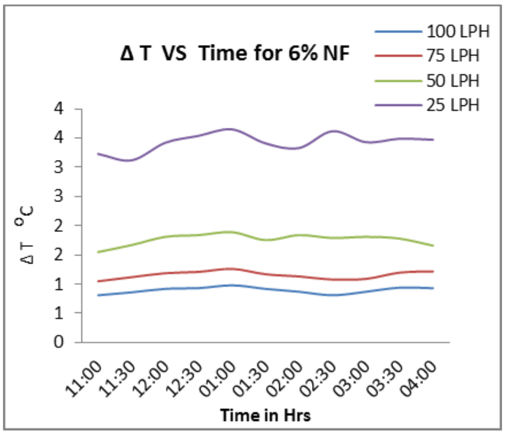

Fig. 12: Hourly variation at Δt Temperature for 6% nanofluid

From Fig 4.7 to Fig 4.10 it is conclude that because of using nanofluid, output temperature of hot water is improved.

V. Conclusion

An experimental study has been carried out to investigate the thermal performance of curtain wall-integrated solar water heater by using different working fluids such as: pure water, AL_2O_3 + BN /water nanofluid. Following conclusions are made from the experimental study and is detailed below:

1) The efficiency thermal performance of solar collector is higher by using 6% nanofluid followed by pure water.
2) The Δt temperature is found to increase low mass flow rate for both fluid as pure water and nanofluid.
3) For same working fluid efficiency slightly increases as mass flow rate increases.

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