Effect of Nanofluids on Solar Plate Collector
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Abstract:
Solar Plate collector being a green renewable device draws its energy from sun and incorporates a blackened surface for radiation absorption, thus providing a possibility to help overcome these energy concerns. Huge investment costings of plate collectors and comparatively less efficiency have provide rays to make effort in enhancing their performance. Use of nanofluids which have some predominant characteristics because of miniature sized nanoparticles and vast intertactical contact area can be fruitful. The thermal properties especially thermal conductivities of nanofluids have an effective influence on efficiency of collectors. A mathematical model based on numerical analysis of heat transfer using different nanofluids and energy conservation equations for nanofluids flow is formulated to figure out behavioral thermal characteristics of plate collectors using nanofluids.

Keywords: Efficiency, Solar Plat Collector, Nanofluid, Heat Transfer Improvement.

I. INTRODUCTION

Energy Usage sharply rose with introduction of Industrial Revolution in 1970s and plotted some serious energy concerns forcing scientists to discover new energy sources. The cost of fossil fuels soring to new heights and a substansible reduction in conventional energy sources led to use of renewable energy sources predominantly solar energy. Abundance availability of solar energy at almost every place on earth and due to very less implementation cost it has found applications in solar water heaters, air conditioners, solar cookers, electricity generation from solar panels. Solar collectors transform the available solar radiation from sun into heat. These solar radiation being the source of abundant amount of energy conduct solar energy through photons of fluid [1]. Introduction of nanoscience has provided us a new reach to promote technology to a next level. Nanofluid which is basically a mixture of miniaturized nanoparticles has reinforced thermal as well as physical properties such as thermal diffusivity and conductivity, viscosity and conductive and convective heat transfer coefficients in comparison to conventional fluids. Performance and efficiency of plate collectors can be highly improved by use of these nanofluids instead of conventional base fluids. Recent research has shown that [2] volume fraction of nanoparticles has sound effects on collector’s efficiency due to high surface area of nanoparticles provided. Further increment in amount of aluminium nanoparticles in water as a conventional fluid enhanced the efficiency of collector. Enhancement in efficiency was observed when Taylor et al. [3] examined both theoretical and experimental results in lab dish receiver for power tower collectors by use of the nanofluids receiver. Kullar et al. [4] concentrated solar radiations on nanofluid-based parabolic collectors andinvestigated the increment of absorption capacity theoretically. On comparison with the results obtained from experimental data for a conventional parabolic solar collector, his results illustrated 5-10 % higher efficiency compared to conventional models.

II. MATHEMATICAL MODEL

Mathematical model can be used to find important characteristics and efficiency of solar panel collector.

The model is based on the following assumptions:
- Nano fluid used for heat transfer behaves as homogeneous and isotropic fluid i.e. absorbed heat can spread out through nanofluid symmetrically.
- Heat transfer nanofluid is assumed as an incompressible fluid and it also considered as a Newtonian fluid So that calculation can be simplified.
- Temperature and velocity of heat transfer fluid at inlet in heat exchanger tube are constant i.e. by assuming velocity constant uniform flow of heat transfer nanofluid create in heat exchanger tube. Therefore no turbulence will be there and so losses due to turbulence can be neglected.
- Thermophysical properties of the HTF and nanofluids are also constant.
- By assuming flow turbulence loss is neglected so there will be heat losses are only due to friction. Those losses are also assumed to be neglected or very low.
- The heat transfer process is radially symmetric over whole cylinder so uniform heat transfer takes place.

The useful gain of heat by heat transfer fluid is given by the following equation:[5]

\[ Q_t = m_t C_p \Delta T_f \]

In every heat exchanger tube, heat balance can be as follows:[6]

\[ (T_1 - T_o) m_t C_p = 2\pi R_c h_c m_t (T_1 - T_{surface}) \]

The heat transfer coefficient and Reynolds number can be calculated approximately as:[7]

\[ h_c = \left( \frac{\sigma_v}{D_c} \right) R_e \]

\[ R_e = \left( \frac{m_t D_c}{\mu_w A_t} \right) \]
Here, b and n are mathematical constant and value of each are 0.3 and 0.6 respectively.

The relation between thermal conductivity and thermal diffusivity of thenanofluids can be given as:[8]

\[ \alpha_t = (\text{heat conducted/heat stored}) = \sigma_w / (\rho_l C_p) \]

Due to heat released by solar radiation, mass flow rate of heat transfer fluid can be calculated as follows:[5]

\[ m_t = (GA_{\text{part}} \eta_n)/(1000 C_p \Delta T_i) \]

Therefore efficiency of solar plat with particular heat transfer nanofluid is calculated from equation as follows:

\[ \eta_n = Q_t / (GA_{\text{part}}) \]

Equation (2) with the finite difference formulation of the time derivative is used to calculate temperature of nanofluid in the storage tank as follows:[4]

\[ T_{m+1} = T_m + (m_t C_p \Delta T_i)/(\rho_b V_f C_p) \]

After the injection of thenano particles into the fluid base (HTF), the thermophysical properties of the HTF with nanoparticles can be calculated as follows:[9]

\[ \omega_{\text{total}} = \alpha_{\text{particles}} + \omega_{\text{base fluid}} \]

III. NOMENCLATURE FOR MATHEMATICAL MODEL

- \( \eta_n \): solar plate efficiency
- \( \omega \): thermo physical properties of heat transfer nanofluid
- \( \Phi \): concentration of heat transfer nanofluid
- \( Q_t \): heat released by HTF or useful heat
- \( T_i \): inlet temperature
- \( T_o \): outlet temperature
- \( T_{\text{surface}} \): temperature at surface of cylinder
- \( R_b \): radius of heat exchanger tube
- \( l_b \): radius of length of tube
- \( h_t \): heat transfer coefficient of nanofluid
- \( m_t \): mass flow rate of heat transfer fluid
- \( C_p \): specific heat of heat
- \( \Delta T_i \): temperature difference of heat transfer fluid
- \( \sigma_c \): thermal conductivity of water
- \( D_b \): hydraulic diameter of cylinder
- \( R_c \): reynolds number for heat transfer fluid
- \( \mu_b \): viscosity of water
- \( A_b \): area of flowing fluid
- \( \Delta t \): time period for finite difference formulation
- \( \sigma_r \): thermal diffusivity of heat transfer fluid
- \( \alpha_t \): thermal conductivity of heat transfer fluid
- \( \rho_b \): density of heat transfer fluid
- \( G \): Radiation on solar panel
- \( A_{\text{part}} \): area of solar panel
- \( T_{n_m} \): temperature of phase change material at mth element
- \( \rho_s \): Density of at phase change material solid phase
- \( C_{p_s} \): phase change material specific heat at solid phase
- \( V_f \): phase change material volume

IV. FLOW CHART FOR NUMERICAL PROCEDURE

Flow chart for mathematical model we can find solar plate heat characteristic or efficiency by assuming different parameter as variable i.e if mass flow rate is taken as variable then solar plate efficiency can be obtained for different mass flow rate. By taking mass flow rate as variable, mass flow rate can be found at optimum efficiency of solar panel. Likewise if solar radiation is taken as variable then solar panel efficiency can be obtained for different solar radiation. By taking solar radiation as variable, at optimum solar panel efficiency radiation can be obtained and so angle between solar flat plate and ground which is kept at time of installment of solar panel can be obtained.

V. PERFORMANCE OF SOLAR COLLECTOR USING NANOFLUIDS

Solar Collector’s performance for steady state condition can be obtained from energy balance. These balancing helps to find out the overall diffusion of incident radiation in productive energy grains, thermal and optical losses. ASHRAE [10] provided the basic equation for analyzing the performance of solar collectors.

\[ Q_c = A_c[ S - U_1(T_p - T_a)] \]

Where, \( S \) - Solar energy absorbed by a collector, \( G_T \) - Incident solar energy, \( U_1 \) - heat transfer coefficient, \( T_p \) - mean absorbed plate temperature, \( T_a \) - ambient temperature, \( A_c \) - Collector area.

Optical Properties: Solar energy concentrated in visible spectrum region (300–700 nm) is very large. Water as a conventional fluid absorbs only 13% of incident energy. To enhance the absorption of incident radiation nanoparticles are added to base fluids. It is found that optical properties of nanofluid efficiently rises [11]; the increment in absorption of incident radiation is about nine times when nanoparticles are used instead of pure water.

Transmittance: The most effective conditions for solar collectors are minimum transmittance and maximum absorptance. Addition of nanomaterials to the conventional fluid
increases absorption with increment indispersion of the incident radiation within the fluid [12]. Now as the sum of transmitted, absorbed and reflected radiation is unity with increase in absorptivity and allowing the reflectivity to remain constant leads to decrease in the transmittance [13].

**Extinction Coefficient**: The amount of energy possessed by incident light reduces as a result of dispersion and absorption of light. This decrease in energy is termed as extinction. Thus extinction coefficient is obtained by addition of dispersion and absorption coefficient.[14] *]

\[
Q_{\text{extinct}} = Q_{\text{absorb}} + Q_{\text{disperse}}
\]

\[
Q_{\text{disperse}} = \frac{8}{3} \beta^4 \left( \frac{n^2 - 1}{n^2 + 2} \right)^2
\]

\[
Q_{\text{absorb}} = 4 \beta \ln \left( \frac{n^2 - 1}{n^2 + 2} \left( 1 + \frac{\beta^2}{15} \left( \frac{n^2 - 1}{n^2 + 2} \right) \left( n^4 + 27n^2 + 38 \right) \right) \right)
\]

\[
\beta = \frac{\pi D}{\lambda}
\]

Where, \( \beta \) = Particle size constant , \( n \) = relative refractive index of the nanofluid. Here the value of \( Q_{\text{disperse}} \) is very less than \( Q_{\text{absorb}} \), hence it is neglected. So absorption coefficient is only taken into account for calculating extinction coefficient. As the absorption coefficient increases due to addition of nanomaterials, the value of extinction coefficient also increases. Nanomaterials are responsible for absorption at small wavelength and conventional fluid help in the case of larger wavelengths.

**Thermal Properties**: Thermal losses occur due to wastage of heat in :- apparatus and between apparatus and users. These losses occur due to convective, conductive and radiative heat transfer from absorber dish to upper and back portion of box. Losses between user and collector plate are mainly due to improper heat transmission from fluid pipe to atmosphere. Thermal efficiency can be improved by either reducing the thermal losses or by enhancing the heat rate to transmission channel [15]. Wang et al. and Trisaksri et al. utilized nanomaterials for improving thermal properties of colloidal mixture.

**Effect OfCuO/Water Nanofluid On Efficiency Of Plate Collector**

Effects of CuO-Water as working fluid were examined by Ali Jabarimoghadam et all.[16] to plot the efficiency of plate collectors as function of temperature from his experimented data in order to get the optimum mass flow rates for pure water and CuO as nanofluids.

![Figure 1](http://ijesc.org/)

**Figure 1**: The efficiency of solar plate collector calculated for different mass flow rates using water as operating fluid [16].

As shown in Fig 2 Ali Jabarimoghadam et all.[15] plotted the results for CuO used as operating fluid, efficiency enhanced with reduction in flow rates. This is due to the fact that lesser the mass flow rate, slower will be the velocity of fluid allowing to absorb solar radiation at much higher extent. Hence maximum efficiency is obtained with 1 kg/min which is its optimum value.

**Figure 2**: The efficiency of solar plate collector calculated for different mass flow rates using CuO as operating fluid [16]

**Effect OfAl₂O₃/Water Nanofluid On Efficiency Of Plate Collector**

In order to get the optimum mass flow rates for pure water and CuO as nanofluids.

![Efficiency](http://ijesc.org/)

**Figure 3**: The efficiency of solar plate collector for optimum mass flow rates using water and CuOas operating fluid [16]

**Effect OfAl₂O₃/Water Nanofluid On Efficiency Of Plate Collector**

\[
\eta = \frac{F_R (\tau a) - F_R U_I ((T_i - T_0)/G_T)}{T_i T_f / G_T}
\]

The above equation for efficiency correlates the fruitful energy obtained to total energy in form of radiations incident on collector. On performing the efficiency experiment close to normal incidence conditions, Fig 4 illustrates that intercept of line obtained on vertical axis marked as efficiency gives value of \( F_R (\tau a) \). The efficiency of collector reaches its maximum value at this point and slope obtained for line gives the value \( F_R U_I \) which indicates the path of travel for energy along the collector. Stagnation point occurs for the line intersecting with horizontal axis for zero collector efficiency.
Figure 4 and Table 1 show the plot of values for experimental results by Tooraj Yousefi et al. [16] and it can be inferred that the constant FRUL are very near to each other for water and 0.2 wt% Al2O3. From Table 1 the constant FR(τα) for Al2O3 has value as high as 28.4% when compared to water. As a result, solar efficiency for water is less than 0.2 wt% Al2O3 by 28.4%. On comparison of efficiencies for Al2O3 with two different mass fraction, it can be concluded from equation 3 that parameter FR(τα) dominates when (Ti - Ta)/GT < 0.018 and FRUL dominates for (Ti - Ta)/GT > 0.018. Table 1 shows that for (Ti - Ta)/GT > 0.018, parameter FRUL is less for 0.4 wt% Al2O3 than 0.2 wt% Al2O3 so the efficiency of 0.4 wt% is high in this range and vice versa.

Comparison of solar panel efficiency between different nanofluid.

From the above comparison it can be inferred that for same nanofluid concentration CuO has maximum solar efficiency while Fe3O4 has the least. The efficiency for Al2O2 and SiO2 is almost equal for same NF concentration.

VI. REFERENCES


[14]. Taylor RA, Phelan PE, Otanicar TP, Adrian R, Prasher R. Nanofluid optical property characterization: towards efficient

