

Enhancement of Flat-Plate Solar Collector Thermal Performance with Silver Nano-fluid

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Abstract

This research is to study performance of a flat-plate solar collector when silver nano-fluid is taken as the working fluid. With higher thermal conductivity of the working fluid the solar collector performance could be enhanced compared with that of water.

In this study, water mixed with 20 nm silver nano with concentrations at 1,000 and 10,000 ppm were undertaken as the working fluid in three identical closed-loop flat-plate solar collectors each of 0.15 x 1.0 m². The tests were performed following ASHRAE Standard 93-2003. The flow rate of working fluid was between 0.8 - 1.2 liter/min-m² and the inlet temperature was controlled in a range of 35 - 65 °C.

The results showed that as the concentration of the nano particles increased the thermal performance increased. The solar collector efficiency with the nano-fluid was still high even the inlet temperature of the working fluid was increased. For 10,000 ppm concentration, the values of $F_R(\tau\alpha)$ and $F_R U_L$ were 0.690 and 4.869 W/m²K, respectively compared with 0.684 and 7.178 W/m²K, respectively for 1,000 ppm concentration and 0.720 and 8.318 W/m²K, respectively for water.

Key words: Silver nano-fluid, Flat-plate solar collector, Thermal performance.

1. Introduction

Thailand locates near the equator which has high solar radiation by around 18 MJ/m²-day [1] therefore, solar water heating systems are now becoming popular in some industries, hotels, hospitals including household applications. Forced circulation flat-plate solar collector is suitable for generating hot water not exceeding 60-70 °C of which the efficiency of

unit with water as a working fluid is between 40-60 %. According to ASHRAE STANDARD 93-2003 [2], the standard of water mass flow rate is varied in a range of 70-75 liter/hr-m² (about 1.2 liter/m²-min) and the solar thermal characteristics such as $F_R(\tau\alpha)$ and $F_R U_L$ are tested when the solar radiation is more than 790 W/m².

Performance of solar collector could be improved by several methods, for example, use

of high-voltage electric fields [3] and sound waves [4], etc. In addition, use of high thermal conductivity working fluid is another interesting method that the fluid could get more heat rate from the solar collector then the heat loss rate could be reduced.

Nano-fluid could be derived from suspended metal particles in liquid then a higher thermal conductivity could be achieved [5]. Some researchers had taken nano-fluid as working fluids in heat pipe applications and they found that the heat transfer of their units was higher than water [6-10].

In this study, use of silver nano-fluid as working fluid in solar collector was considered. The solar collector characteristics were compared with those of water. The testing was carried out following the ASHRAE STANDARD 93-2003. Moreover, effects of working fluid flow rate on the solar collector performances were also considered.

2. Flat- Plate Solar Collector

The solar collector model following the ASHRAE STANDARD 93-2003 is undertaken when the mass flow rate of solar collector is 75 liter/m²h (1.2 liter/m²min) for water as a working fluid. The collector efficiency, the system efficiency and the useful heat gain from the collector are

$$\eta_{coll} = \frac{Q_u}{A_c I_T} = [F_R(\tau\alpha)_e - F_R U_L(T_{fi} - T_a)] / I_T \quad (1)$$

Where

$$\begin{aligned} Q_u &= A_c [F_R(\tau\alpha)_e I_T - F_R U_L(T_{fi} - T_a)] \\ &= \dot{m}_f C_p (T_{fo} - T_{fi}). \end{aligned} \quad (2)$$

For fluid with nano-metal particles, more heat rate from the solar collector could be absorbed then the term $F_R U_L$ will be less thus more heat gain and better collector efficiency are obtained.

3. Silver-nano fluids

Thermal conductivity of nano-fluids depends on of thermal conductivity of the based fluid and the nano-particle material. The thermal conductivity of solid-liquid mixtures is introduced by Wasp [11] as

$$\frac{k_{nf}}{k_f} = \frac{k_p + 2k_f - 2\alpha(k_f - k_p)_f}{k_p + 2k_f + \alpha(k_f - k_p)} \quad (4)$$

The volume fraction (α) of the particles is defined by

$$\alpha = \frac{V_p}{V_f + V_p} = m \frac{\pi}{6} d_p^{-3}. \quad (5)$$

Density (ρ_{nf}) of nano-fluid can be estimated from Pak and Cho's equation [12] as

$$\rho_{nf} = \phi \rho_p + (1 - \phi) \rho_w \quad (6)$$

Where ϕ is volume fraction, ρ_p is density of particle and ρ_w is density of based fluid.

The specific heat of nano-fluid can be estimated from Pak and Cho's equation as

$$Cp_{nf} = \phi Cp_p + (1 - \phi) Cp_w \quad (7)$$

It can be calculated from Xuan and Roetzel's equation [13] as

$$(\rho Cp)_{nf} = \phi(\rho Cp)_p + (1 - \phi)(\rho Cp)_w \quad (8)$$

Where Cp_{nf} is specific heat of nano-fluid, Cp_p is specific heat of nano particles and Cp_w is specific heat of based fluid.

4. Experimental Setup

Fig. 1 shows an experimental setup. The test units comprised of a reservoir tank, a circulating pump, a cooler and three identical small flat-plate solar collectors each having a collector area of $0.15 \times 1.0 \text{ m}^2$. Each collector has its own flowmeter to measure the mass flow rate. The based working fluid was water flowing in one solar collector and the working fluids in the other solar collectors were silver nano-fluids of 20 nm size at 1,000 and 10,000 ppm. The tests were performed following the ASHRAE Standard 93-2003 with the flow rate of $1.2 \text{ liter/min-m}^2$ and then the flow rates were varied between $0.8 - 1.6 \text{ liter/min-m}^2$. The inlet temperature was adjusted in a range of $35 - 65 \text{ }^\circ\text{C}$ by the electric heater.

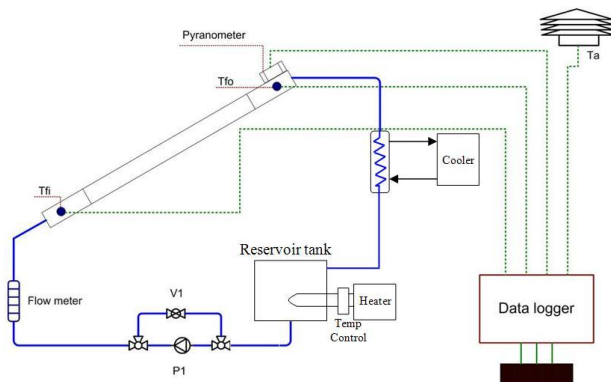


Fig.1. Diagram of the experimental setup

The tests were carried out around noon on some clear sky days. The mass flow rate of each fluid flow was read directly from a rotameter with an accuracy of $\pm 0.0035 \text{ Liter/min}$, the temperatures of the fluids at the inlet and the outlet ports of the solar collectors and the ambient temperature were measured and recorded by a set of K-type thermocouples with an accuracy of $\pm 0.1 \text{ }^\circ\text{C}$. A pyranometer

having an accuracy of $\pm 55 \text{ W/m}^2$ was used to measure the solar radiation incident on the solar collector. During the experiment a fan was used to control the wind speed over the collectors at the average value of about 3.35 m/s .

5. Results

Fig. 2 presents the temperature difference between inlet and outlet solar collector and the mass flow rate in the cases of silver nano-fluid with 1,000 ppm, 10,000 ppm and water, respectively. Since higher the concentration of nano-particles, higher thermal conductivity of the working fluid was obtained then the fluid could get more heat rate from the solar collector. It could be seen that when the nano-fluid concentration was increased, the temperature difference between inlet and outlet would be higher compared with that of water. However, at 1,000 ppm of silver nano-particles, the insignificant results were obtained. It could be noted that for 10,000 ppm of silver nano-particles, especially for low flow rate (0.8 kg/min-m^2) and high inlet temperature, the temperature difference was more deviated from that of water. This meant that the nano-fluid could get more heat rate thus the heat loss from the collector was less compared with that of water. It was undoubtful that when the mass flow rate and the inlet temperature increased the temperature difference decreased.

The useful heat gains from the solar collectors at various inlet temperature and mass flow rate are shown in Fig. 3. The changes were similar to those shown in Fig. 2. The silver nano-fluid at 10,000 ppm showed better performance compared with water while the fluid at 1,000 ppm gave similar results with water.

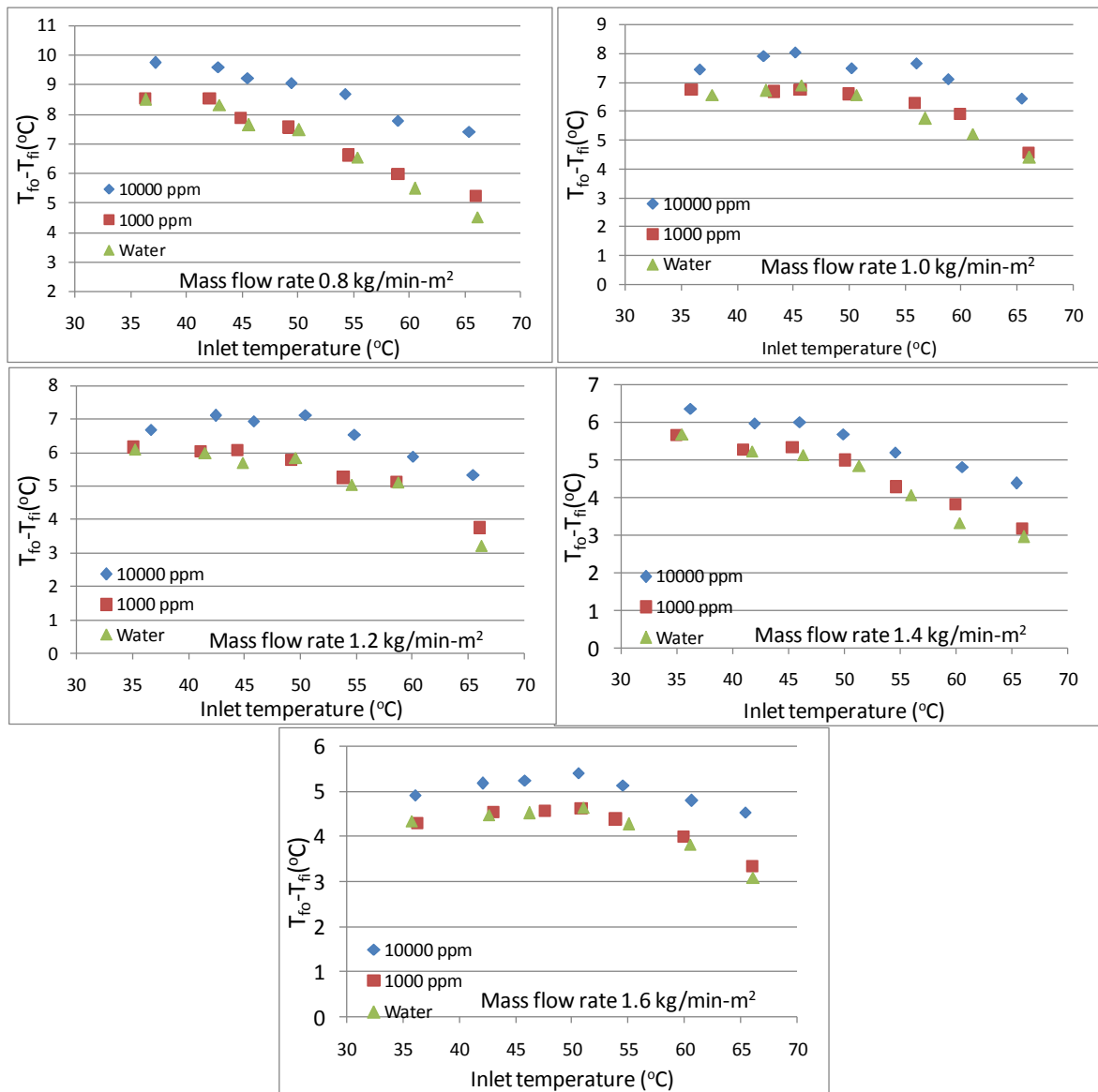


Fig. 2 The temperature difference between inlet and outlet solar collector and the mass flow rate in the cases of silver nano with 1,000 ppm, 10,000 ppm and water

Fig. 4 shows the performance curves of the solar collectors under the ASHAE Standard with silver nano-fluid at 10,000 ppm, 1,000 ppm and water. It was found that the collector efficiency of the silver nano-fluid at 10,000 ppm was higher than that for water. Again, the silver nano-fluid at 1,000 ppm still gave similar result with water. For 10,000 and 1,000 ppm concentrations, the values of $F_R(\tau\alpha)$, $F_R U_L$

were 0.690, 4.869 W/m^2-K and 0.684, 7.178 W/m^2-K , respectively. While in the case of water the values were 0.720 and 8.318 W/m^2K , respectively. This meant that using of silver nano-fluid as a working fluid was able to increase solar collector performance. Then the flat-plate collector could operate at higher temperature compared with water.

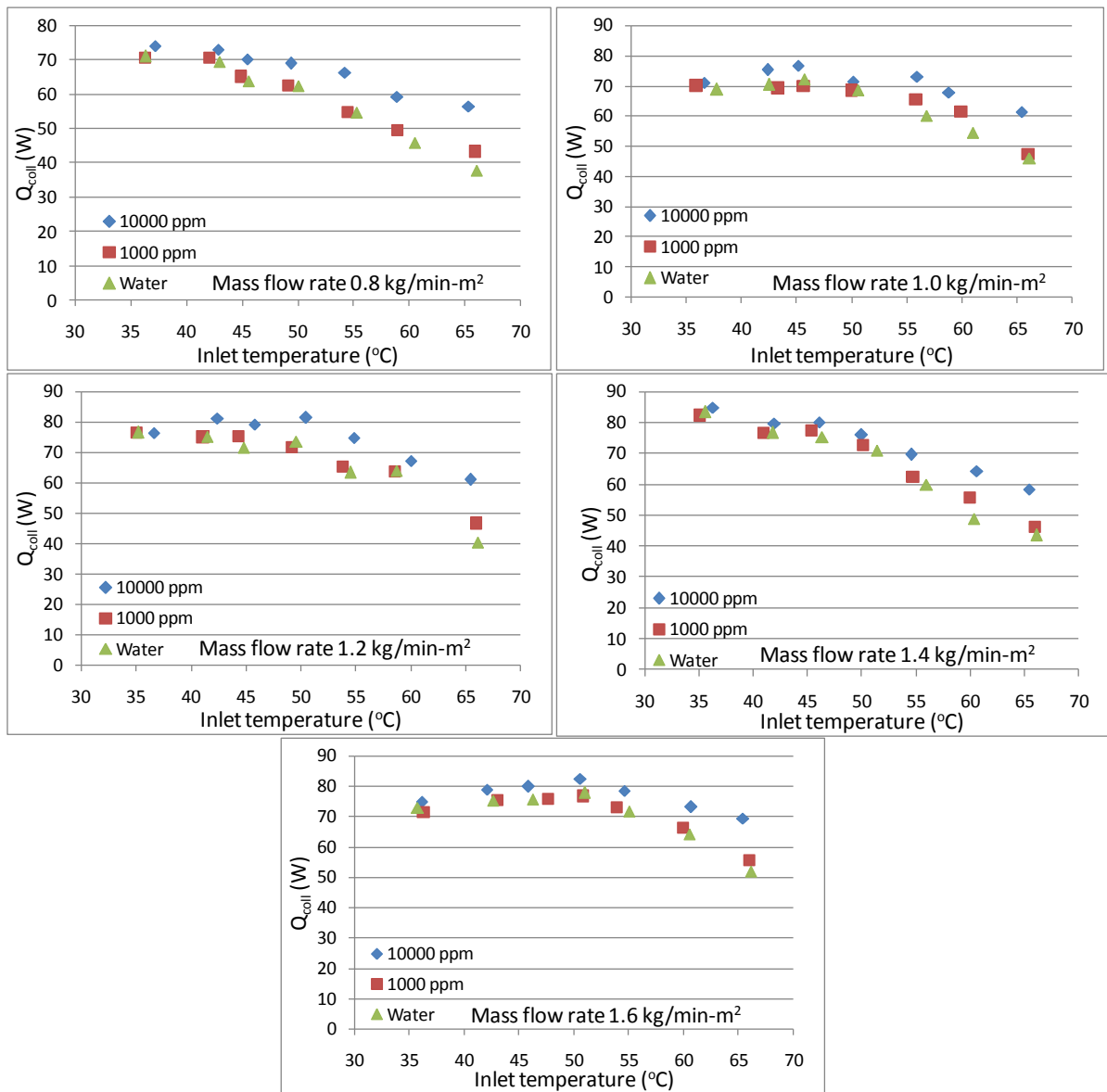


Fig. 3 The variations of useful heat gain from solar collector at various inlet temperature and mass flow rate in the cases of silver nano-fluid with 1,000 ppm, 10,000 ppm and water

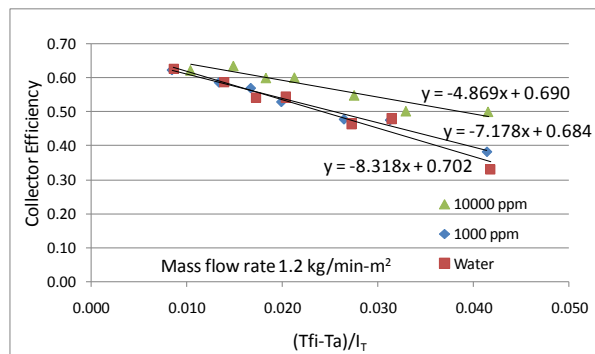


Fig. 4 The performance curves of silver nano-fluid at 10,000 ppm, 1,000 ppm and water

6. Conclusions

The thermal enhancement of solar collector performance was investigated with silver nano-fluid as working fluid. The silver nano-particle size was 20 nm with concentrations at 1,000 and 10,000 ppm and the based working fluid was water. The experiments were undertaken with three identical flat-plate solar collectors each had an area of 0.15 x 1.0 m². The summary results are as follows:

1. When the concentration of silver nano-fluid increased more heat from solar collector or less heat loss was obtained then the difference between inlet and outlet temperatures of the working fluid from the flat-plate solar collector increased. However, the concentration at 1,000 ppm showed insignificant results compared with water.

2. For silver nano-fluid concentration of 10,000 ppm, the thermal solar characteristics, $F_R(\tau\alpha)$ and $F_R U_L$ were 0.690 and 4.869 W/m²-K while for 1,000 ppm concentration, the values were 0.684 and 7.178 W/m²K and for water were 0.720 and 8.318 W/m²K, respectively.

3. Use of silver nano-fluid as a working fluid could improve thermal performance of flat-plate collector compared with water, especially at high inlet temperature.

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8. Nomenclature

A_c	Solar collector area (m ²)
C_p	Heat capacity of water (J/kg °C)
F_R	Collector heat removal factor
I_T	Solar radiation (W/m ²)
k	Thermal conductivity (W/mK)
\dot{m}_f	Water mass flow rate (kg/s)
\dot{Q}_{coll}	Heat rate from solar collector (W)
\dot{Q}_u	Useful heat gain from solar collector (W)
T_a	The ambient temperature (°C)
T_{fo}	Outlet temperature (°C)
T_{fi}	Inlet temperature (°C)
U_L	Overall heat loss (W/m ² °C)
$(\tau\alpha)_e$	The transmittance- absorptance product
η_{coll}	Collector efficiency (%)

9. References

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