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Nano Fluid in Water as Base Fluid in Flat-Plate Solar Collectors with an Emphasis on Heat Transfer

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Abstract

Objectives: The objective of this paper is to review the heat transfer of Nano fluid in water as a base fluid in Flat-Plate Solar Collectors, and provide an optimal solution to improve the heat transfer. **Methods/Statistical Analysis:** This study used a sample of the heat exchanger consists of three small solar collectors which a copper tube passes from each of them, and there is a surface area the size of 1*0.15m^2. The current cycle was analyzed using the amount of energy stored to transfer the heat. **Findings:** In constant Reynolds number, the convective heat transfer coefficient of Nano-fluids in the heat-absorbing pipes (with concentration 1000ppm) is slightly greater than that used the water as working fluid. Also in the concentration 10000ppm, this rate is doubled. **Application:** The findings concluded that the use of Nano-fluid in flat-plate solar collector reduces the total heat loss coefficient of solar collector, and obtains the amount of more heat energy.

Keywords: Heat Transfer, Nano Fluid in Water, Solar Collectors, Silver Nano Fluids

1. Introduction

Nowadays, the necessity of substantial increase in heat flux and downsizing heat transfer equipment are the issues raised in the processes of heat transfer. Many sources have reported about the methods to increase heat transfer in systems. Most of these methods are based on changes in the structure of equipment such as increase the heating surfaces (blades), shake the heating surfaces, fluid injection or suction and the application of electric current or magnetic field. These techniques are responsible for an increasing demand for heat transfer hardly in the systems with high energy transmission necessary including laser and electronic systems. In the meantime, a topic that is important and little attention has been paid to it; it is the role of the thermal properties of fluids in heat transfer. In the issue of heat transfer efficiency in equipment such as heat exchangers, the thermal conductivity of energy carrier fluid and heat transfer convection coefficient have a fundamental role. Conventional fluids in heat transfer and energy carriers in industries include fluids such as water, ethylene glycol and oils. It is well known that metals in solid form have a very high thermal conductivity than fluids[1,2]. Very small size of particle used and low volume fraction of nanoparticles eliminate issues such as sedimentation and agglomeration and it reduces the cost required to maintain and transport these fluids, and there is no abrasion problem and damage to the system on the particles due to very small size.

Moreover, the relatively large surface of the particles reduces the non-equilibrium effects between liquid and solid and it leads to suspension stability. Also, whatever the particle size is smaller, the relative surface is higher in heat transfer and thus, by reducing the particle size, the thermal efficiency of particulate matter increases as a function of heat transfer surfaces. Nano fluids are a new class of heat transfer fluids and it comes through the suspension of nanoparticles in the conventional heat transfer fluids known as a base fluid[3-7]. In this paper, after reviewing the current status of solar collectors, the transfer of Nano fluid heat in water as a base fluid is checked in flat-plate solar collectors and then with an overview of research conducted in Iran and the world, we will offer an optimum solution for the Nano fluids in water.

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2. Solar Collectors Energy Analysis

The idea of solar collector use and the capture of sun power come from pre-history, when Archimedes, a Greek scientist, invented a way to burn the Roman ships in the year 212 BC[8]. The first application of solar energy is the concentrator collector's use. During the eighteenth century, craftsmen were making iron laminated, glass lens and mirrors using solar furnaces with the fusibility of iron, cooper and other metals. The furnace were using throughout Europe and the Middle East. One of these furnaces which had the temperature capability of 1750°C, was designed by a French scientist named Lavoisier.

During the last 50 years, various designs and structures was carried out using the concentrator collectors to transfer heat to the working fluid which provide the power required to drive a mechanical means. Two basic solar technologies used routinely include central receivers and distributed receivers. Central receiver systems use a heliostat (two-axis tracking mirrors) to concentrate the solar radiation energy on a single tower-mounted receiver (solar power, 1978). Distributed receivers technologies include parabolic dishes, Fresnel dishes, parabolic troughs and special bowels. Parabolic dishes pursue the sun in two axes using their mirrors, to focus radiation energy on a point receiver (solar power, 1978). Solar energy converters are the types of special heat exchangers for the conversion of solar radiation energy to the internal energy of transmitter. Solar converter is a major component in any solar system. Also solar converter is a device for absorbing solar input radiation and converts it to heat and then transfers to a fluid which is circulating in the collector (usually air, water or oil).

Therefore, solar energy is stored in the form of warm water or heat energy in tanks to use at night or at times when the weather is cloudy. Generally there are two solar collector types: non-concentrator (fix) and concentrator. Non-concentrator solar collector has a flat area to absorb the solar radiation while concentrator solar collector has usually a concave reflective surface for focusing the solar radiation beam towards a smaller recipient surface consequently, radiation flux increases. There are many types of solar collectors in the market as shown in Table 1.

In general, solar collectors are distinguished because of the move (fixed, rotating uniaxial, biaxial rotating) and the operating temperature. At first is checked the constant type of collectors. The collectors are always in a fixed position and they do not follow the sun. Three types of such collectors are as following categories:

A) Flat Plate Collectors (FPC);

B) Stationary Compound Parabolic Collectors (CPC);

C) Evacuated Tube Collectors (ETC).

3. Flat-Plate Collectors

An example of a solar collector is shown in Figure 1.

When solar radiation passes through a transparent, it collide with a black absorber contains high absorption coefficient. Thus, a large part of the energy is absorbed by

Table 1. Solar collectors[9]

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat-plate collector (FPC)	Flat	1	30-80
	Evacuated tube collector (ETC)	Flat	1	50-200
	Compound parabolic collector (CPC)	Tubular	1-5	60-240
Single-axis tracking			5-15	60-300
	Linear Fresnel reflector (LFR)	Tubular	10-40	60-250
	Parabolic trough collector (PTC)	Tubular	15-45	60-300
	Cylindrical trough collector (CTC)	Tubular	10-50	60-300
	Parabolic dish reflector (PDR)	Point	100-1000	100-500
	Heliostat field collector (HPC)	Point	100-1500	150-2000

Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.

the screen and then it is transferred to the fluid in the pipe by a medium to store or use. The absorbent bottom page and the sides of the cabinet are well insulated to avoid their conduction losses. The liquid pipes can be welded to the absorber plate or they can be as an integral part of the page. They are connected to the header with large diameter at both ends. In order to reduce the displacement losses from the absorber plate, is used the transparent cover. This takes place through the inhibition of stagnant air layer between the absorber plate and the glass[10].

Also, the glass plate reduces the radiation losses of the collector because the glass is a transparent material thus it receives the short-wavelength radiation from the sun. But since the waves of solar short wavelength gain a long wavelength after dealing with the absorber plate, thus the glass is virtually opaque for the waves and not passes them (the greenhouse effect). Flat plate collectors are placed usually in a fixed position and they do not need to chase the sun. Collectors must be oriented directly towards the equator and to the south in the northern hemisphere and to the north in the southern hemisphere. The curvature optimal angle of the collector is equal to latitude location with the yaw angle more or less than 10° to 15° so that it depends on its application[9]. A flat-plate collector generally includes the components shown in Figure 2.

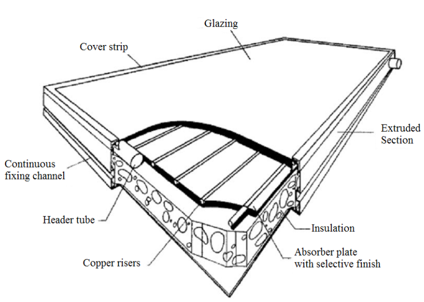

Figure 1. Picture of a Flat-plate collector[9].

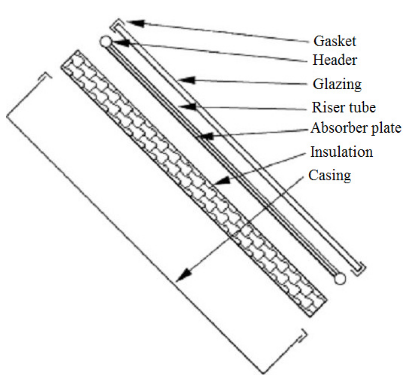

Figure 2. Components of a FPC[9].

The simultaneous use of the sensible heat of a storage material and the latent heat of phase-change material to store thermal energy is a method commonly used in solar thermal systems and it is considered by many researchers, especially in recent years[11]. These materials store the thermal energy considerably and then heat at a constant temperature as unseen before reaching the phase transition temperature[12]. Increasing the heat exchange between the fluid in the reservoir and the fluid passing through the collector leads to improve the performance of the system. One of these modern methods is the use of nanotechnology. Development of nanotechnology has led to the emergence of a class of Nano-structured materials with high-performance so that they have the ability to absorb thermal energy and release it when needed[13].

4. Nano Fluid Energy

Recently, the use of Nano-fluid which they are stability suspension of Nano-fibers and solid Nanoparticles, has been proposed as a new strategy in heat transfer operations. Recent researches on Nano fluids show the significant increase of thermal conductivity than liquids without the nanoparticles or together with larger particles (macro particles). Another difference of this type of fluid is severe thermal conductivity citizenship of the temperature and also a tremendous increase of critical heat flux in the heat transfer of their boiling. Development of the heat transfer properties of Nano fluid needs to consider the several factors of base fluid and the Nano particles dissolved in fluid base. Understanding the relationship between the different components of Nano fluids and their thermophysical properties is a key point in engineering applications to achieve Nano fluid with desirable properties. In general, based on different nanoparticles properties and also base fluid, it can be achieved to the different combinations of Nano fluids and also thermophysical different parameters depending on the type of composition. In Figure 1 is shown schematically complex interactions between Nano fluid parameters and the thermophysical properties of nanoparticles on the one hand, and base fluid on the other hand[14].

In this study, Figure 3 is the decision matrix which is one of the important approaches in systems engineering, was brought as a semi-quantitative method in order to the multi-purpose rank of engineering Nano-fluids properties[14]. The overall trends in different solutions of nanoparticles, which investigated by the previous researches and works of other researchers, was given in Table 2 as the decision matrix. In this table all engineering parameter is shown in a separate column and properties of Nano fluids in a row. Each cell in the table shows the orientation and strength of the effects of a particular parameter in the properties of Nano fluids. The marks ×, Δ, ○, ▪ are respectively indicating no dependence, weak, medium and strong dependence on Nano fluid parameters so that they are initialized in importance the values of zero, 0.25, 0.50 and 1[15].

The relative importance of each Nano fluids parameter is estimated as the sum of the scores in heat transfer. As can be seen in the table, the Nano-fluid focus parameters (volume percent of nanoparticles), type of base fluid and in the next step, nanoparticles gender are important. Therefore in this research, these three parameters are considered in the selection of Nano fluids as design parameters (decision-making parameters). For example, it is observed that these three parameters are the only parameters affecting the specific heat value of Nano fluid.

Since the density of Nano fluids is important in the calculation and analysis of the issue, can be obtained from the following equation:

$$\rho_{nf} = \phi\rho_p + (1-\phi)\rho_{bf} \tag{1}$$

Where, ρ_{nf} is Nano-fluid density $(\frac{kg}{m^3})$, ϕ is the percentage of nanoparticles, ρ_p is the density of nanoparticles $(\frac{kg}{m^3})$, ρ_{bf} is the main fluid density $(\frac{kg}{m^3})$, the specific heat capacity of Nano-fluid obtained from the following equation:

$$C_{pnf} = \phi C_p + (1-\phi)C_{bf} \tag{2}$$

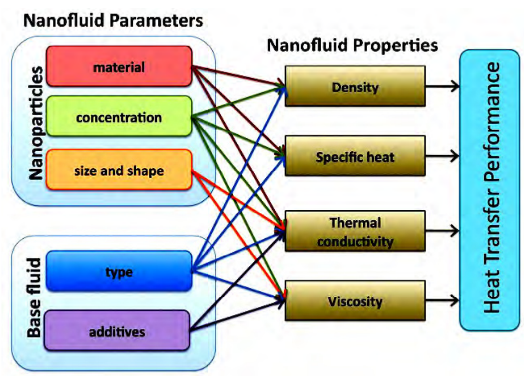

Figure 3. The different compounds of nanoparticles soluble and their effects on the various thermophysical properties of Nano fluids[14].

Table 2. Decision matrix approach in designing Nano-fluid[14]

	Nano fluid Parameters	Nanoparticle Material	Nanoparticle Concentration	Nanoparticle Shape	Nanoparticle Size	Base Fluid	Zeta Potential/ Fluid PH	Kapitza resistance	Additives	Temperature
Nano Fluid Properties										
Stability	⇑	▲	▲	▲	□↓	○	□	×	□	?
Density	⇑	□	□↑	×	×	□	×	×	×	×
Specific Heat	⇑	□	□↓	×	×	□	×	×	×	▲
Thermal Conductivity	⇑	○	□↑	○	□↑	▲	○	□↓	▲	○
Viscosity	⇓	▲	□↓	□	□↓	□↑	□	×	○	□
Heat Transfer Coefficient	⇑	□	□↑*	□	□↑	□	□	□↓	○	□
Pumping Power Penalty	⇓	×	□	□	□↑	□	□	×	○	□
Relative Importance		4.0	6.25	3.75	5.0	5.25	4.0	2.0	2.75	3.75

Where, C_{pnf} is Specific Heat of the Nano-fluid $(\frac{J}{kg.k})$, C_{bt} is specific heat of the main fluid $(\frac{J}{kg.k})$. The amount of energy stored in Nano-fluid (PCM) is calculated from the following equation:

$$Q_{PCM} = Q_L + Q_s \tag{3}$$

As the amount of sensible and latent heat of the Nano-fluids is calculated as follows:

$$Q_s = m_w c_{p,w} \Delta T + m_{pcm}\left[c_{s,pcm}(T_m T_i) + c_{l,pcm}(T_f - T_m)\right] \tag{4}$$

$$Q_l = m_{pcm} L_{sl} \tag{5}$$

As long as there are two phases, energy storage is done at a constant temperature and proportional to the mass of the latent heat of phase change material. The charging time of Nano-fluids in the tank also can be obtained from the following equation:

$$t_{pcm} = \frac{Q_{pcm}}{Q_w^*} \tag{6}$$

In this regard, Q_{pcm} is calculated in relation to the amount of energy stored in Nano-fluid and Q_w^* is the intensity of the energy stored in water so that it can be transported from the collector to the storage tank by converters and obtained the following equation:

$$Q_w^* = m_w^* Cp_w (T_{out} - T_{in}) \tag{7}$$

5. Silver Nano-Fluid and its Important Role in Heat Transfer in the Solar Collector

Most researches on the thermal conductivity of Nano-fluids has been done in the field of fluids containing metal oxide nanoparticles[16,17]. Masuda has reported a 30 percent increase in the thermal conductivity by adding 3.4% alumina to the water. Lee has reported a 15% increase for the same Nano-fluids with the same volume percent and he believes that this difference is due to the difference in size of the nanoparticles used in the research. The average diameter of alumina particles used in the first experiment is 13 nm, and it is 33 nm in the second test. Zai and colleagues have reported a 20% increase for 50% by volume the Nanoparticles. Another group concluded similar for silicon carbide nanoparticles. Lee saw a modest improvement in the thermal conductivity of Nano-fluids containing copper oxide nanoparticles compared to alumina particles; while Wong has reported a 17% increase in the thermal conductivity for only 0.4% by volume of copper oxide nanoparticles in the water. For ethylene glycol-based Nano-fluids was been reported an increase above 40% for 0.3% by volume of copper with an average diameter 10 nanometers. Patel saw an increase above 21% for 11% by volume suspension by gold and silver nanoparticles dispersed in water and toluene respectively. Also, in some cases there is no significant increase in conductivity. Reason to use silver nanoparticles is thermal properties particularly high thermal conductivity in this metal and the easy production possibility of the Nano-fluid in knowledge-based companies in the country. Figure 4 shows a comparison of multi-material temperature conductivity coefficient as it is indicative of the high thermal conductivity of silver.

Some studies investigated heat transfer of silver Nano-fluid in flat-plate solar collectors. In an experiment was used three small solar collectors which there is a copper tube in each of them and an absorbent surface the dimensions $1 \times 0.15 m^2$ [18]. The inner diameter of the copper pipe is equal to 1.6 mm. In the current cycle, the authors used the water (with a concentration of 1000ppm) and the silver Nano-fluid (with a concentration of 10000ppm). According to the results, the performance of the solar collector is shown in Figure 5.

The small amounts of $F_R U_L$ show the less thermal loss so the Nano-fluid shows a better performance in comparison with water. Also, the silver Nano-fluid does not show a good performance for lower concentrations. In the heat transfer of the flat-plate solar collector, the silver particles as Nano fluid were dispersed in the water as a base fluid (Figure 5). The silver particles were mixed with

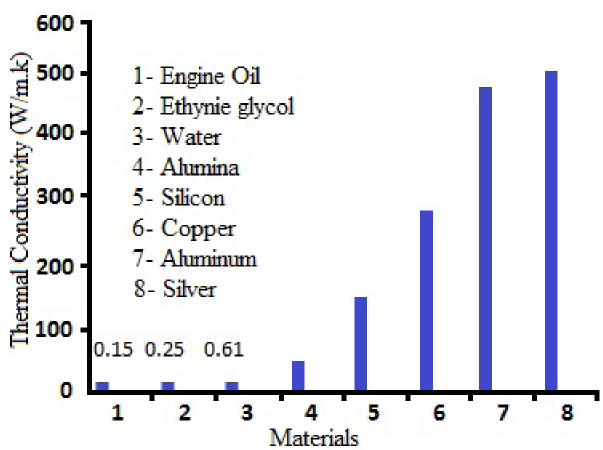

Figure 4. The thermal conductivity of the solids and liquids at 300 K[19].

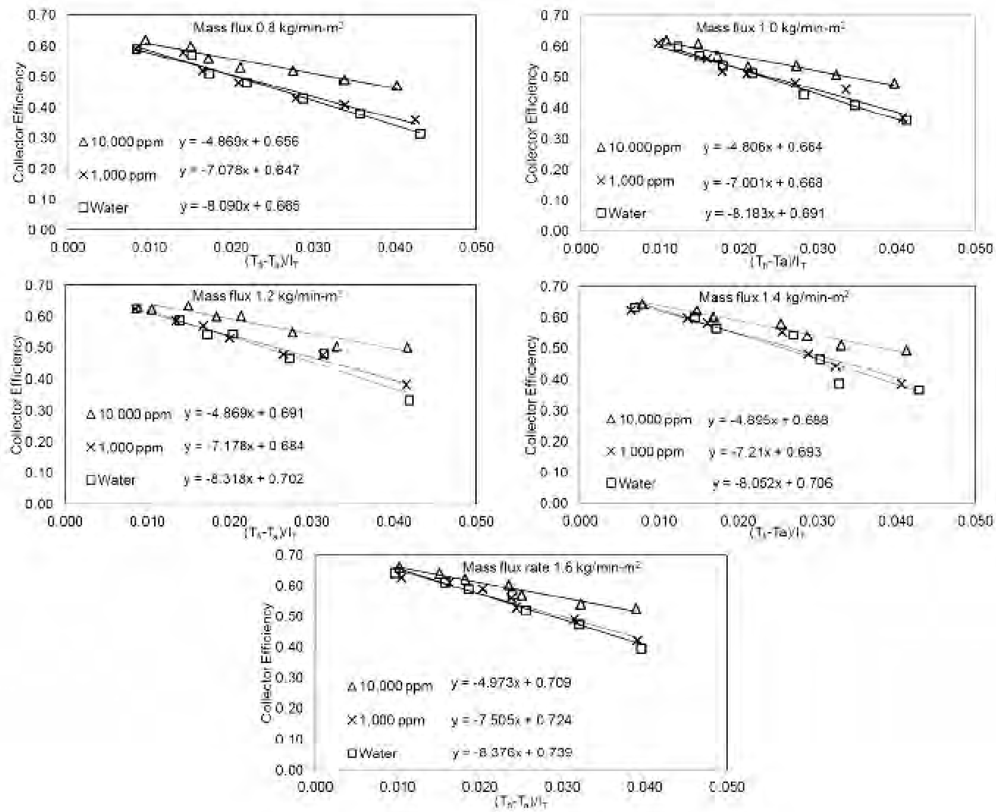

Figure 5. The performance of the solar collector at different flow rates and the comparison of the results in the case of silver Nano-fluids with a concentration of 1000 ppm and 10000 ppm, and also the water[18].

water (size 21 nm) at a concentration of 1000 and 10000 ppm and this work has been done with the area 1*0.15 sq.m for three closed-loop solar collectors. The mass flow rate passing through the pipes varies between 0.8 to 1.2 lit/min.m^2 and the inlet temperature in the range of 35 to 61°C. The experiment was carried out in the open environment and in the stable condition.

The results show that in constant Reynolds number, the convective heat transfer coefficient of Nano-fluids in the heat-absorbing pipes (with concentration 1000ppm) is slightly greater than that used the water as working fluid. Also in the concentration 10000ppm, this rate is doubled. It means that in the case of Nano fluids used, the total heat loss coefficient of the solar collector is reduced and therefore more heat energy is obtained especially when the inlet temperature of the fluid in the pipes is more. In the experiment, the heat loss characteristics of the solar collector are equal to 0.691 and 4.869 W/m^2.k for the state that the concentration of silver Nano fluid is 10000ppm (in steady state with mass flux equal to 1.2 kg/min.m^2) and the amount of solar radiation in the test environment is 18 mj/m^2 with a concentration of 1000ppm and 0.648 W/m^2.k and 7.178 W/m^2.k. Ideally, the efficiency of the flat plate solar collector is around 40 to 60 percent so that it works with a mandatory cycle[18].

6. Conclusion

The use of silver Nano-fluid in flat-plate solar collector reduces the total heat loss coefficient of solar collector, and obtains the amount of more heat energy.

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