Chapter

Nanofluid: New Fluids by Nanotechnology

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Abstract

Recently, nanotechnology has played a major part in multifields of heat transfer processes and developed a remarkable progress in the energy applications. One of the most plausible applications of nanotechnology is to produce nanoparticles of high thermal conductivity and mixing with the base fluids that transfer energy forming what is called nanofluids. Adding of nanoparticles to the base fluid shows a remarkable enhancement of the thermal properties of the base properties. Nanotechnology has greatly improved the science of heat transfer by improving the properties of the energy-transmitting fluids. A high heat transfer could be obtained through the creation of innovative fluid (nanofluids). This also reduces the size of heat transfer equipment and saves energy.

Keywords: nanofluids, nanoparticles, thermal conductivity, base fluids

1. Introduction

Nowadays, the energy demand worldwide is steadily increasing due to the fast progress in technology in all fields of life. On the other hand, the fossil fuel had been taken to decrease, and the alternatives of energy sources are still under research to raise their efficiency. Besides, the fossil fuel has led to the environment degradation and global warming [1].

Revolution of nanotechnology and its unique features compared with the large scale of its originality has been given a major focus. This dramatic growth stemmed from the multiapplications in various fields of life: medicine, agriculture, engineering, and industry. Nanotechnology, as a scientific major, studies the properties of nanoscale materials. Nanotechnology-based techniques could be produced by small particles in the size of nano of some solid materials such as alumina and titanium oxide that have relatively high thermal conductivity. The word "nano" is described as 1 billionth of meter or 10^{-9} m. **Figure 1** shows a comparative sample of different sizes of materials from large scales to nanoscales. These nanosized particles are mixed in the base fluid of heat transfer forming a colloidal solution in the stable case, while its addition to the base fluids of low thermal conductivity probably increases the heat transfer characteristics of the base fluids. This creative fluid is known as nanofluid, which has a new heat transfer characteristic as one of the recent outcomes of nanotechnology. This makes, of course, saving energy exactly similar to reducing the volume of heat transfer equipment.

Nanotechnology has been widely used in various engineering applications as a promising alternative in saving energy and reducing the cost of producing

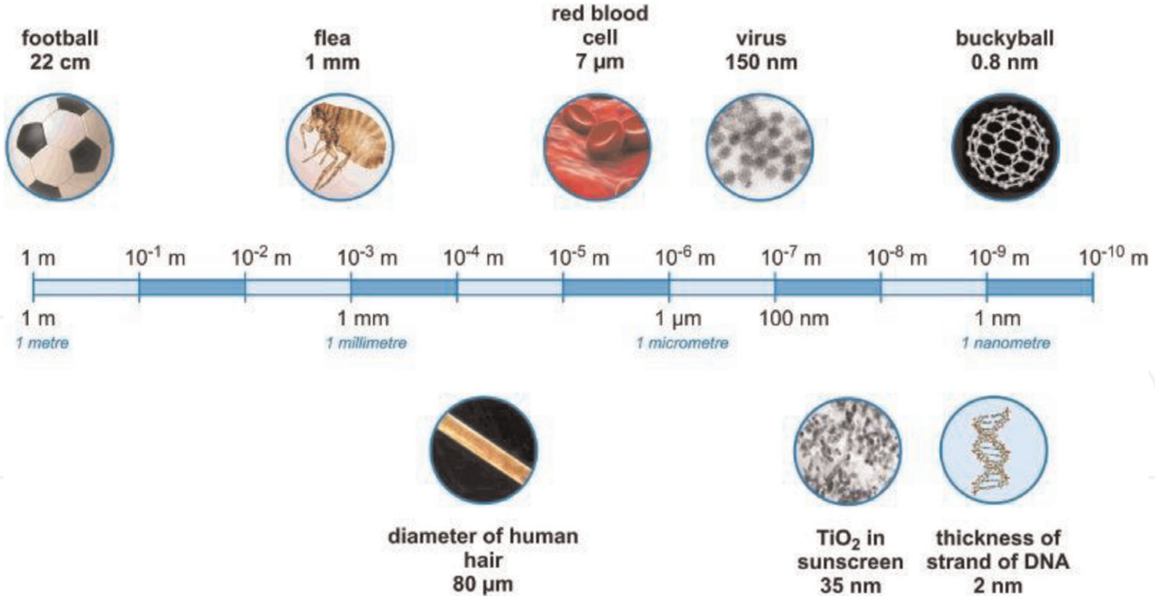

Figure 1.
A comparative of things from large scale to nanoscale.

engineering facilities. This important application is represented by the reduction of nanoparticles to the size of the nanoparticles and their mixing with fluids of low thermal properties to give a good type of fluid known as nanofluid.

2. Nanofluids

With the advancement of nanotechnology and its ability to increase the performance of solar devices by exploiting it, a new fluid known as nanofluid has been originated. This is assembled by mixing the base fluid of low thermal conductivity with solid nanoparticles of high thermal conductivity, and hence the new fluid (nanofluids) has high transfer characteristic compared with the base fluids [1, 2]. A nanofluid is a fluid in which nanometer-sized particles, suspended in the base fluid, form a colloidal solution of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes, while the base fluids include water, ethylene glycol, and oil. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powe red engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, and heat exchanger and in grinding, machining, and in boiler flue gas temperature reduction.

2.1 Methods of preparing nanofluids

Nanofluids are produced by several techniques: first step, second step, and other techniques. To avoid the sedimentation of nanoparticles during its operation, surfactant may be added to them. Nanofluid preparation is the first step ahead of any implementations. Therefore, it entails more focus from researchers to obtain a good stage of stability. Colloidal theory states that sedimentation in suspensions ceases when the particle size is below a critical radius due to counterbalancing gravity forces by the Brownian forces. Nanoparticles of a smaller size may be a better size in the different applications. However, it has a high surface which leads to the formation of agglomerates among them [3, 4]. Therefore, to obtain a stable nanofluid with optimum particle diameter and concentration, it is considered a big challenge for researchers. Two common methods are used to produce nanofluids, the two-step method and the one step method, and others have worked up some innovations.

2.1.1 The two-step method

The two-step method is the common method to produce nanofluids. Nanoparticles of different materials including nanofibers, nanotubes, or other nanomaterials are first produced as nanosized from 10 to 100 nm by chemical or physical methods. Then, the nanosized powder will be dispersed in base fluids with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. As resulting from high surface area and surface activity, nanoparticles tend to aggregate reflecting adversely on the stability of nanofluid [4–8]. To avoid that effect, the surfactant is added to the nanofluids.

The two-method preparation has been done by many researchers [9–14].

Figure 2 shows a block diagram of preparation of two-step method [15].

2.1.2 One-step method

The one-step process is simultaneously making and dispersing the particles in the base fluids which could be reduced to the agglomeration of nanoparticles. This method makes the nanofluid more stable with a limitation of the high cost of the process [16–25].

2.1.3 Other created methods

Some researchers create other methods to obtain new prepared methods for nanofluid with relatively high characteristics and more stability. Wei et al. [26] developed a method to synthesize copper nanofluids. This method can be synthesized through a novel precursor transformation with the help of ultrasonic and microwave irradiation [27]. Chen et al. [28] obtain monodisperse noble-metal colloids through using a phase-transfer method. Feng et al. [29] have used the aqueous-organic phase-transfer method for preparing gold, silver, and platinum nanoparticles with the solubility in water. Phase-transfer method is also used to prepare stable kerosene-based F_3O_4 nanofluids [30]. As stated above, the research proved that nanofluids synthesized by chemical solution method could be enhanced in conductivity with more stability [31].

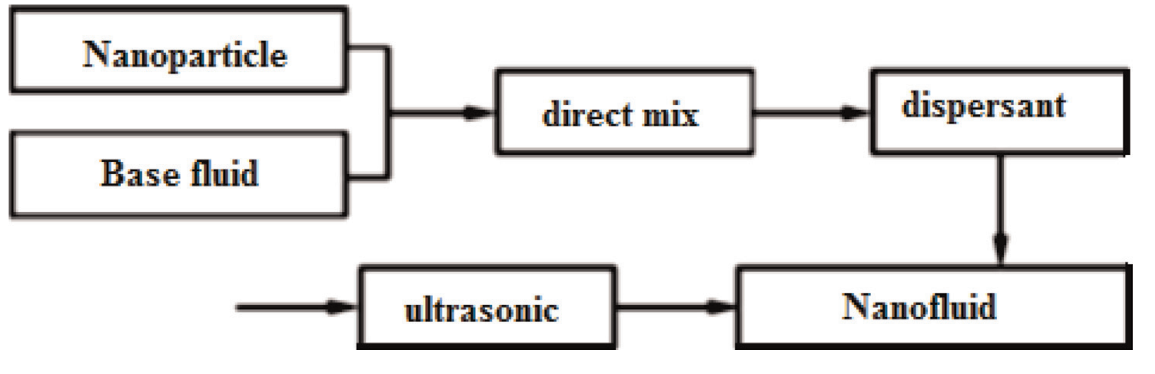

Figure 2.
Two-step method of preparation of nanofluids [15].

2.2 Thermophysical properties of nanofluids

Nanofluids have novel properties different from base fluids that included thermophysical properties such as specific heat, density, viscosity, and thermal conductivity.

Mixing the nanoparticles into the base fluid changes the thermophysical properties of the base fluid. The most important thermophysical properties of nanofluids are nanofluid viscosity, nanofluid convective heat transfer, nanofluid thermal conductivity, and nanofluid specific heat.

The value of specific heat and density of the nanofluids can be determined by correlations, whereas the viscosity and thermal conductivity have different correlations.

2.2.1 Nanofluid thermal conductivity

Conventional heat transfer fluids, such as oil, water, and ethylene glycol (EG) mixture, are poor heat transfer fluids. Hence, many trials by researchers to enhance the heat transfer convection of these fluids through increasing their thermal conductivity. High thermal conductivity is obtained for the nanofluids by adding nanoparticle of solid materials of high thermal conductivity.

Nanofluids are basically advanced heat transfer fluids as an alternative to the pure base fluids to improve the heat transfer process through the addition of nanoparticle materials that have the properties of higher thermal conductivity. This attracted the attention of researchers to test many nanoparticles that have different thermal conductivity to obtain a high rate of heat transfer and use them in different applications.

The literature reported multiequations describing the thermal conductivity of nanofluids. The prominent results reported that there are improvements of 5–10% of the thermal conductivity of nanofluids using the base fluid (water, PAO). As is reported, there is no critical improvement in the thermal conductivity in comparison to the conventional base fluid dependent on particle size and base fluid thermal conductivity [32–37].

Conventional models of effective thermal conductivity of suspensions are reported for some researchers [32].

$$\frac{\mathrm{k_{eff}}}{\mathrm{k_m}} = 1 + \frac{3\ (\alpha - 1)\ \mathrm{v}}{(\alpha + 2) - (\alpha - 1)\mathrm{v}} \quad (1)$$

$$\frac{k_{eff}}{k_m} = \frac{\alpha + (n-1) - (n-1)(1-\alpha)\ v}{(\alpha + 2) - (\alpha - 1)v} \quad (2)$$

$$\frac{k_{eff}}{k_m} = 1 + 3\beta v + \left(3\beta^2 + \frac{3\beta^2}{4} + \frac{9\beta^2(\alpha + 2)}{16(2\alpha + 3)} + \dots\right)v^2 \quad (3)$$

$$\frac{k_{eff}}{k_m} = 1 + \frac{3(\alpha - 1)}{(\alpha + 2) - (\alpha - 1)v}\left[v + f(\alpha)v^2 + 0\left(\alpha^3\right)\right] \quad (4)$$

where k_{eff} is the effective thermal conductivity of the suspension, n is a shape factor of nanoparticle, ν is nanoparticle volume fraction, and k_m and k_c are the thermal conductivity of the suspending medium and solid particle, respectively. Also α and β are empirical fitting parameters which are defined as (k_c/k_m) and (α −1)/(α +1).

2.2.2 Nanofluid convective heat transfer

Nanofluids have been proven a great potential for heat transfer enhancement [44–47]. Nanofluids have been presented as a promising tool and a good alternative to base fluids to save energy, compact devices of low cost and design of multiequipment used in a different applications with nanofluids as working fluids.

Experimental investigation [38] on Cu- or water-based nanofluids has demonstrated great enhancement of heat transfer and also reported that friction factor has a very meager part in the application process. Other scholars [39] have concluded that a systematic and definite deterioration of the natural convective heat transfer occurs for the forced convection reliant on the solution concentration, the particle density, and the aspect ratio of the cylinder. Experimental investigation on Al_2O_3 nanofluids using water as base fluid has been studied by various research groups, and they concluded that the heat transfer coefficient in laminar flow [40–42] increases up to 12–15% and in the case of turbulent flow, it ranges up to 8% [43, 44]. CNT, CuO, SiO, and TiO_2 nanofluids using water have been investigated [45–47]. Among these, CNT nanofluid produced similar results to that of Al_2O_3 nanofluid. Ding et al. [48] have concluded that the enhancement of heat transfer could be obtained by varying the flow condition and the fluid concentration. Alternatively, CuO has been investigated for several wall boundary conditions, and it has reached good results [3]. The increase in the concentration of the nanofluid on contrary gives very weak results on the heat transfer coefficient for volume fraction greater than 0.3% [49]. It is noted from the experiments that the heat transfer coefficient enhancement can be achieved in the range of 2–5%.

2.2.3 Nanofluid viscosity

Viscosity is one of the parameters that influences the behavior of nanofluids. Researchers have conducted experiments to test the viscosity through adding the nanoparticles to the different base fluids, and hence they found out that the viscosity is significantly affected by both variations of temperature and volume fraction of nanoparticles [50–56]. They have reported correlated equations to quantify the viscosity based on their experiments using different nanofluids. The following correlated equations are examples that have been reported by some researchers.

$$\mu_{eff} = \left(1 + 2.5\varnothing_p + 7.349\varnothing_p^2 + \dots\right)\mu_b \tag{5}$$

Model for spherical nanoparticles [57]:

$$\mu_{nf} = \mu_f \frac{1}{(1-\varnothing)^{2.5}} \tag{6}$$

Model for simple hard sphere systems, the relative viscosity increases with particle volume fraction ø [57]:

$$\mu_{eff} = \frac{9}{8} \frac{\left(\varnothing_p/\varnothing_{pmax}\right)^{\frac{1}{3}}}{1-\left(\varnothing_p/\varnothing_{pmax}\right)^{\frac{1}{3}}} \mu_b \tag{7}$$

The model is valid for spherical nanoparticles and for $0.5236 \le \Phi \le 0.7405$ [55]. Meaning of Φ = volume fraction and μ = dynamic viscosity.

The SiO_2 nanofluid has been investigated [48] and concluded that nanofluid viscosity is dependent on the volume fraction. Other researchers [58] have analyzed commercial engine coolants dispersed with alumina particles. They found out that the nanofluid produced with calculated amount of oleic acid (surfactant) has been tested for stability. While the pure base fluid demonstrates Newtonian behavior over the measured temperature, it turns to a non-Newtonian fluid with addition of a few alumina nanoparticles.

2.2.4 Nanofluid specific heat

The specific heat of material is quite an important property to define the thermal performance of any material [36]. Specific heats of nanofluids may differ according to the type of base fluids, nanomaterials, and concentration of nanoparticles found in base fluids. Pak and Cho [59] have investigated the impact of volume fraction of Al_2O_3 on specific heat. The investigation showed that 1.10–2.27% decrease in specific heat occurred for 1.34–2.78% volume fraction of nanoparticle size of 13 nm. Zhao et al. [68] also noticed a fall in the specific heat capacity of CuO nanofluid by 1.16–5% compared to base fluid EG for volume fraction of 0.1–0.6% and particle size which ranges from 25 to 500 nm. Some nanofluids show inconsistent behavior with volume convergence. Shahrul et al. [60] have conducted a comparative revision on the specific heat of nanofluids used in energy applications. They have concluded that for most nanomaterials in base fluids, specific heat decreases with the increase in volume fraction. Sonawane et al. [61] have investigated specific heat of Al_2O_3/ATF and reported the anomalous conduct of specific heat with volume convergence. Increase in specific heat capacity has also been reported in experimental observations [36, 62–68]. Fakoor Pakdaman et al. [69] have found out that there is 21–42% decrease in specific heat capacity of MWCNT/water nanofluid for 0.1–0.4% vol. a fraction in the range of 5–20 nm size. However, Kumaresan et al. [64] have observed 2.31–9.35% gain. In specific heat capacity of MWCNT/(EG/DW, 30/70) nanofluid for 0.15–0.45% concentration, particle size was kept at 30–50 nm. Nowadays, the result of experimental data does not signal a discreet and clear-cut indication that there is the only reduction in the heat capacity with an increment of volume concentration, as has been reported by several academic figures. Experimental observations on various nanofluids show increase of specific heat capacity [62–70], whereas experimental observations exhibit decrease in specific heat capacity performed by many researchers [59, 61, 71–81].

The specific heat of nanofluid can be determined as function of the particle volume concentration using the following equation [80]:

$$\left(\rho C_p\right)_{eff} = (1-\varphi)\left(\rho C_p\right)_{bf} + \varphi\left(\rho C_p\right)_p \tag{8}$$

And

$$\rho_{eff} = (1-\varphi)\rho_{bf} + \varphi\rho_p \tag{9}$$

3. Applications of nanofluids for heat transfer process

Nowadays, nanofluids play a vital role in heat transfer equipment as a good alternative in developing the efficiency of the heat transfer equipment and in turn of reducing the size of the equipment and saving energy.

Since water is a good medium for heat transfer and it is also a good medium for receiving and storing solar energy during sunrise time, therefore, water is a good medium for the heating processes and one important source for the application of solar energy [2, 82, 83]. It is granted that the thermal efficiency of the FPSWH is relatively low, and therefore researchers have exerted many efforts to increase its performance. The thermal efficiency of the FPSWH has improved by using specific techniques [84]. Researchers to enhance the performance of FPSWH and the thermal efficiency using different methods [85–89] have conducted many studies.

The recent researches have revealed that nanofluids have a large effect on increasing heat transfer. This is done through mixing the nanoparticles materials that have high thermal conductivity into the working fluid (or called the base fluid).

Now, nanofluids are promising mediums as alternatives to the base fluids, and hence the researches are still under investigation to improve and develop the heat transfer equipment systems.

Many works have been conducted to improve the performance of flat plate solar water heater using different nanoparticles to the base fluid [63–73].

To improve the performance of flat plate solar collector, scholars had conducted experimental and theoretical studies on flat plate solar collector using nanofluids with different binary materials (nanoparticles + base fluids) as a working fluid.

Salem Ahmed et al. [90] have conducted an experimental work on the performance of chilled water air conditioning unit with and without alumina nanofluids.

They have used the first method to prepare Al_2O_3 water nanofluids with different concentrations by weight, which vary from 0.1, 0.2, 0.3, and 1% wt. Under operation conditions, experiments have been investigated including a variation of flow rate of chilled water/alumina nanofluids and the air through the cooling coil. The results have shown that less time is scored to get the desired chilled fluid temperature for all the different concentrations of nanofluids (Al_2O_3-water) compared with pure water.

Again, the findings have shown a reduction of the power consumption and increase in the cooling capacity, which is in turn an increase in the COP by about 5 and 17% for alumina nanoparticles, concentration of 0.1 and 1% by weight, respectively. A schematic diagram of the experimental work shown in **Figures 3** and **4** shows the TEM image of the alumina nanoparticles (Al_2O_3) used in the experiments.

Xu et al. [91] have conducted experimental and theoretical studies comparing a novel of parabolic trough concentrator with traditional solar water heater using nanofluid, CuO/oil. **Figure 5** shows a configuration of the novel parabolic trough concentrator and the traditional solar heater.

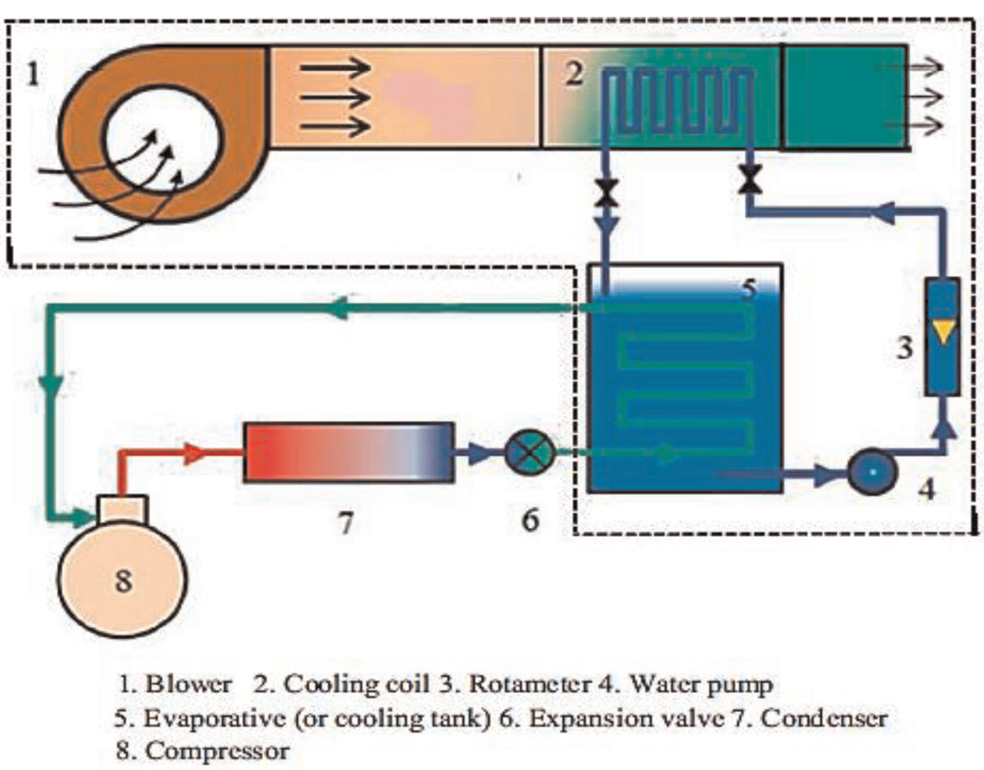

Figure 3.
A schematic diagram of the chilled-water air conditioning unit [90].

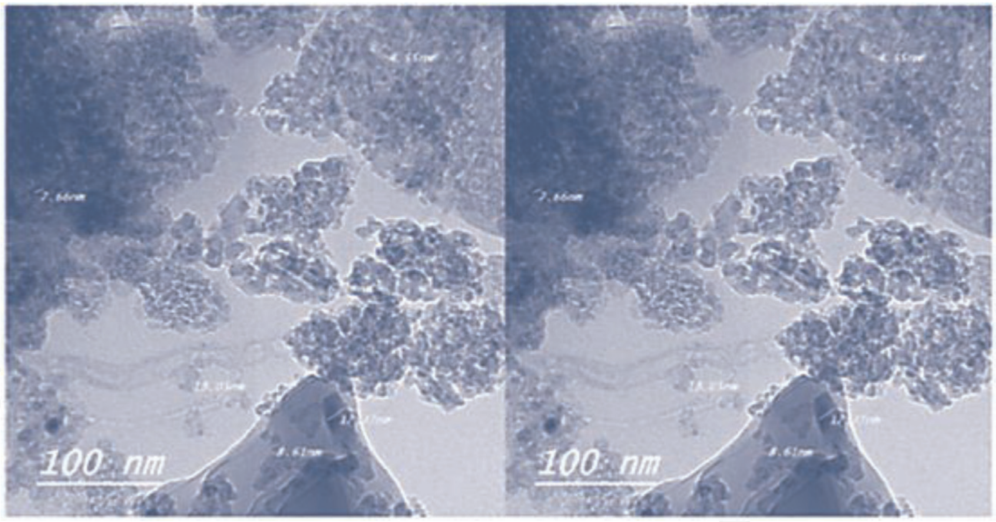

Figure 4.
TEM image of Al_2O_3 nanoparticles used in the experiments [90].

As is shown in **Figure 5b**, a kind of oil added with certain nanoparticles (CuO) acts as a working fluid. The nanoparticles dispersed in the oil inside the inner tube directly capture the solar radiation instead of the tube wall coating. The solar collection efficiency curves for the two collectors suggested that the NDASC was superior to a conventional IASC within a preferred working temperature range, but inferior when the tf exceeded a specific critical temperature ($t$cr) as shown in **Figure 6**.

Said et al. [92] have used TiO_2-water nanofluid as a working fluid for enhancing the performance of a flat plate solar collector for the volume fraction of the nanoparticles 0.1 and 0.3%, respectively, and mass flow rates of the nanofluid vary from 0.5 to 1.5 kg/min, respectively. Thermophysical properties and reduced sedimentation for TiO_2 nanofluid have been obtained using PEG 400 dispersant. Energy efficiency has increased by 76.6% for 0.1% volume fraction and 0.5 kg/min

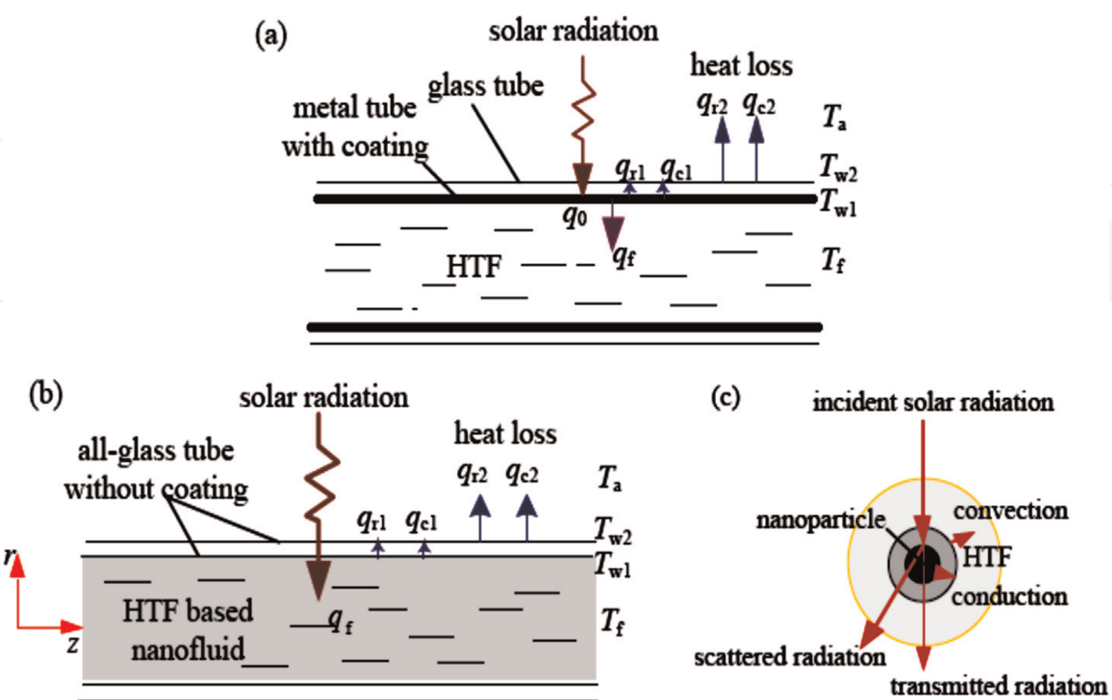

Figure 5.
Schematics of solar collection principles. (a) A conventional indirect absorption solar collector (IASC); (b) the proposed novel nanofluid-based direct absorption solar collector (NDASC); and (c) the heat transfer around nanoparticles inside the tube of NDASC [91].

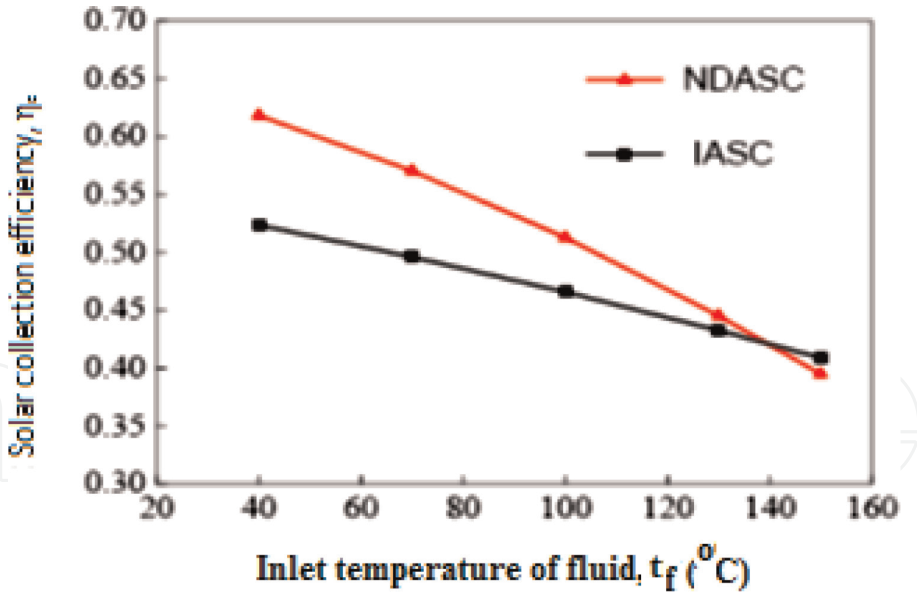

Figure 6.
Variations of solar collection efficiencies with tf,i for both the NDASC and the IASC [91].

flow rate, whereas the highest energy efficiency obtained has been 16.9% for 0.1% volume fraction and 0.5 kg/min flow rate.

The thermal efficiency of the FPSC (μ) and the energy efficiency are given, respectively, as [92].

The schematic of the solar collector and the experiment is presented in **Figure 7**. They also showed that the pressure drop and pumping power of TiO_2 nanofluid were very close to the base fluid for the studied volume fractions [92].

Polvongsri et al. [93] have performed an experimental work to study the performance of a flat plate solar collector (**Figure 8**) using a silver nanofluid as the

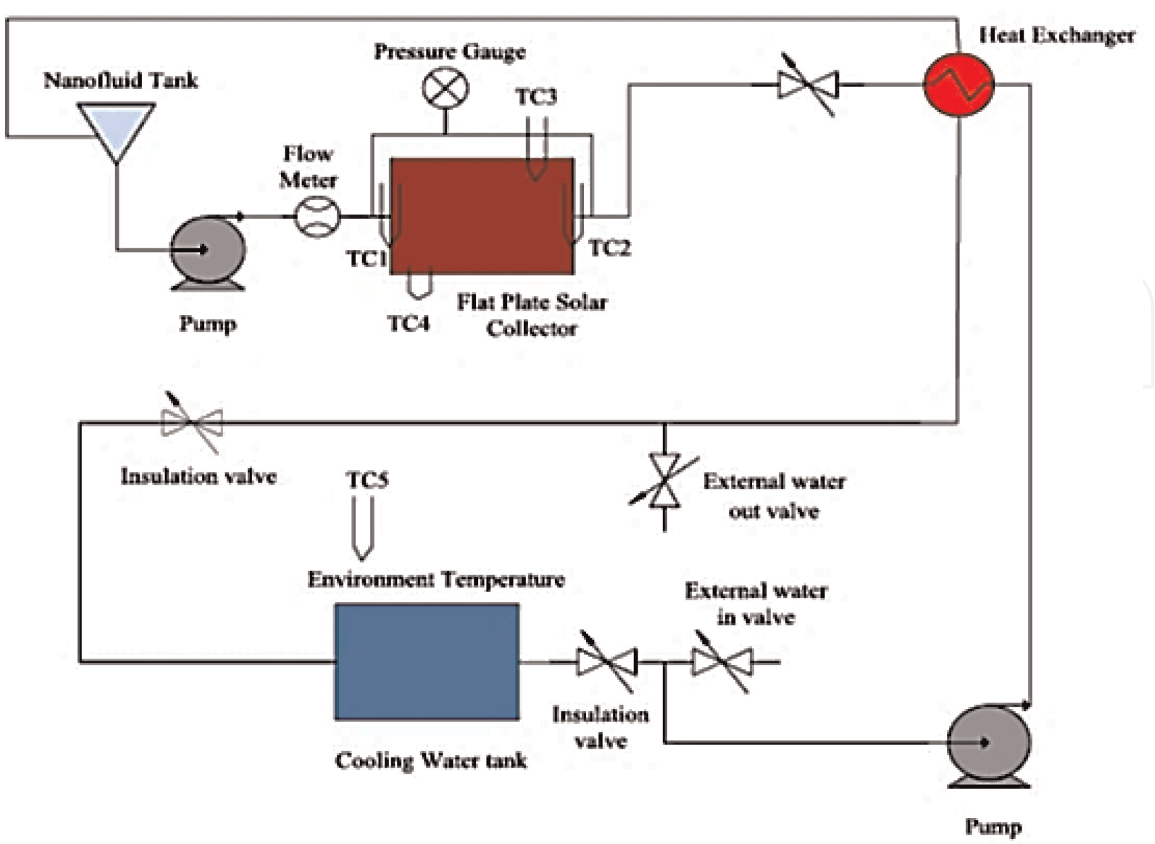

Figure 7.
The presentation of the experimental setup in schematic diagram [92].

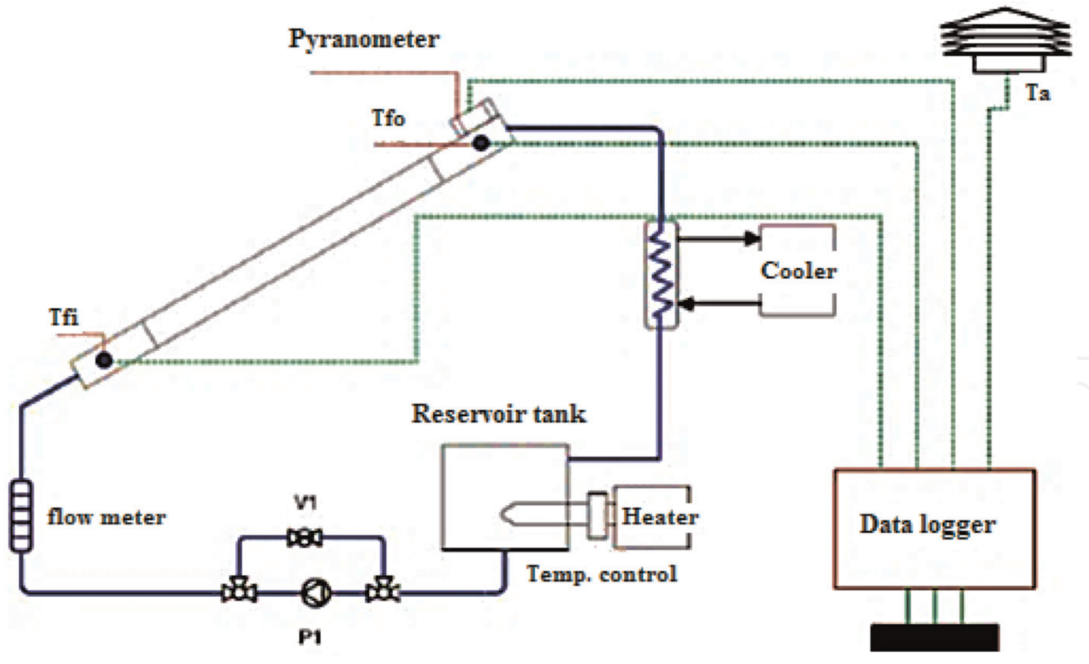

Figure 8.
Diagram of the experimental setup [93].

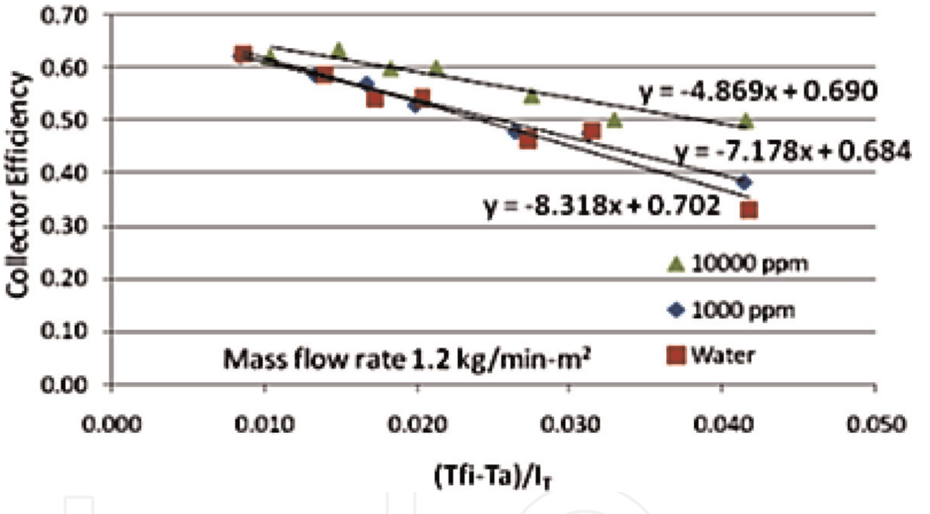

Figure 9.
The performance curves of silver nanofluid at 10,000 and 1000 ppm and water [93].

working fluid, while water was mixed with 20 nm silver nano with concentrations of 1000 and 10,000 ppm. The operating conditions of experiments to be done at a flow rate of working fluid between 0.8 and 1.2 l/min-m^2 and the inlet temperature were controlled in a range of 35–65°C.

It is remarkable that using silver nanofluid as a working fluid could improve the thermal performance of flat plate collector compared with water, especially at high inlet temperature as shown in **Figure 9**.

4. Conclusions

This chapter reviews the recent applications of nanotechnology for nanofluids. These applications revealed that nanofluids have a promising alternative to enhance the performance of heat transfer equipment considering the cost, safety, potential of size reduction, and environmental protection. The present chapter provides a comprehensive overview of nanofluid as one of the important applications of nanotechnology and how to obtain it and its thermal properties. There are challenges hindering the preparation of nanomaterials, including the stability of nanofluids to take into consideration and worthy of attention on the part of researchers.

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