

# Fluid Flows for Heat Transfer Enhancement by Using ZnO/Water Nanofluids with Different Concentrations

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**Abstract.** An empirical study on forced convective heat transfer and flow thermal properties of a nanofluid consisting of three various concentrations of ZnO nanofluids (0.09, 0.2 and 0.44%) and water which flows in a cooling coil made of copper pipe (heat exchanger) under laminar flow conditions are investigated. The ZnO nanoparticles of 40 nm diameter are used in this study. Working fluid flow rate of 0.5 lpm to have the fully laminar regime ( $Re < 1325$ ). The results prove that the heat transfer coefficient of ZnO/water nanofluid when concentration 0.44 % is higher than that of other concentrations and also the water at same conditions (temperature and velocity).

## 1. Introduction

A nanofluid is a fluid with a colloidal dispersion of man-sized particles of another substance in water or other base fluids. In a colloid two substances are distinguishable but can interact through weak surface molecular forces. The nanoparticles used in nanofluids commonly have an average size below 100 nm. Relatively, large surface area of nanoparticles increases the stability of nanofluid and reduces the problem of sedimentation of nanoparticles. Heat transfer increased with increase in surface area of nanoparticles compared to micro particles because of increased stability of nanofluids.

Nanofluids are gaining popularity among academic researchers and receiving more attention from industry as they continue to demonstrate improvements in heat transfer properties of liquid cooling processes.

Rana et al. (2013) performed experiments in subcooled flow boiling of ZnO/water nanofluids with different low particle concentrations ( $\leq 0.01$  volume %) in horizontal annulus at heat fluxes from 100 to 450 kW/m<sup>2</sup> and flow rates from 0.1 to 0.175 lps at 1 bar inlet pressure and constant sub cooling of 20°C to determine bubble behavior and heat transfer with flow rates of ZnO. They observed that increase in heat flux leads to increase in bubble diameter; the heat transfer coefficient increases with increase in heat flux and particle volume fraction of ZnO.

Based on the following key properties, ZnO nanomaterial is selected for experimentation:

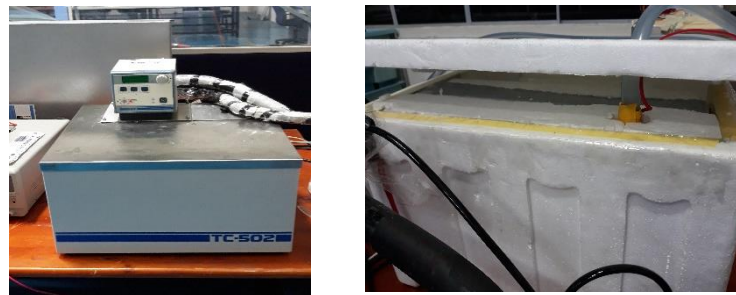
- (1) Corrosive resistant,
- (2) Good thermal conductivity,
- (3) Easy availability in purity ranges from 94% to 99.9%,
- (4) Excellent size and shape capability,
- (5) Low cost.



## 2. Experimental Setup

Preparation of nanofluid is the first key step towards using nanophase particles to enhance the heat transfer performance of conventional fluids. The nanofluid does not simply refer to a liquid-solid mixture of base fluid and nanoparticles. A nanofluid has some special requirements such as uniformity, stability, low agglomeration of particles, and no change in physical properties of the conventional fluid. In general, the following are the effective methods used for preparation of suspensions: (1) using surface activators and/or dispersants, and (2) using stirrer and ultrasonic vibrations. These methods can change the surface properties of the suspended particles and can be used to suppress the formation of particle clusters in order to obtain stable suspensions.

The experimental devices used includes fluid flow lines, a centrifugal pump, a flowmeter, a tank of working fluids, two-water bath (one to control the working fluid temperature and another one is for controlling the heat sources temperature, i.e., the water tank that simulate the battery), two cooling coils (heat exchanger), data logger and twelve-thermocouples (K-type) were used for temperature measurement. The working fluid was pumped to the heat exchanger in the test compartment from a tank that the temperature was controlled by the first temperature bath. A water that the temperature was being controlled from the second temperature bath was pumped to a tank (simulated battery) in the test compartment as the heat load of the battery. A heat exchange occurs in the test compartment and the temperature differences between inlet and outlet of the working fluid flows were measured. The details of tested conditions were shown in table 1. ZnO/water nanofluids had been prepared by two-step method so that dispersing ZnO nano-powder in water and stirring the mixture for approximately 2 hrs, then the mixture was placed in an ultrasonic bath for about 8 hrs to complete the mixing processes.



**Figure 1.** Cooling System

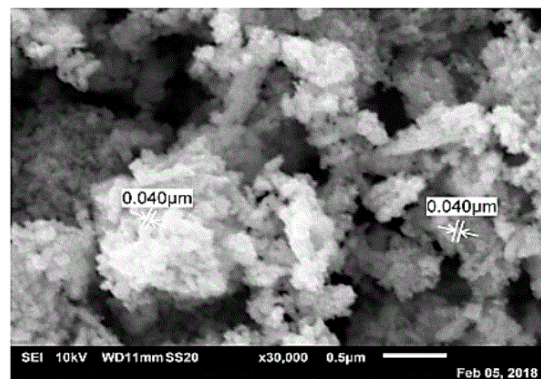
The purpose of the conducted experiment is to understand the heat exchange process and know heat removal rate from simulated battery model. Using water and ZnO/water as the working fluid in this study.

**Table 1.** Specifications and test conditions.

Elements	Specifications
Volume flow rate of the pump	0.5 lpm
The surface area of copper tube (one coil) ( $A_{Si}$ )	0.0346 m <sup>2</sup>
Cross-sectional area of copper tube (one coil) ( $A_{ci}$ )	$1.9635 \times 10^{-5}$ m <sup>2</sup>
length of one coil	2.2 m
Number of coils	2
The ambient temperature in the compartment	40 °C
Working fluid temperature in tank	29 °C
Test compartment size	( 43.5×27×7 ) cm <sup>3</sup>

## 2.1 Shape and Size Nanoparticles

Should be investigate from the nanoparticles size and shape, as spherical shape particles give higher thermal conductivity improvement from cylindrical particles (Xie et al., 2003). Wu et al. (2010) proposed the Scanning Electron Microscope (SEM) to be used to study the shape and size of nanoparticles. Water was used as the base fluid. The nanoparticles (ZnO, 99.9% metals oxide) was purchased from US-Research Nanomaterial.



**Figure 2.** SEM image of dry ZnO nanopowders

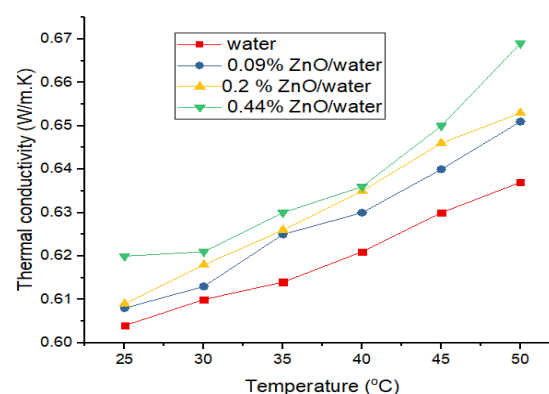
Figure 2, the SEM image of dry ZnO nanopowders which shows the nanometre-sized (40nm), and most of the nanopowders are spherical in shape.

## 2.2 Thermophysical Properties of Working Fluids

The values for thermophysical properties of the nano-fluid (ZnO/water) at different concentrations are taken at the average temperature of working fluid in cooling coils.

The density of ZnO/water is the calculated values by using analytical models suggested by Pak and Cho (1998), while thermal conductivity, viscosity, and specific heat have been measured by using a KD2 Pro, viscometer (model LVDV- Pro, Brookfield Instruments) and differential scanning calorimetry (DSC) respectively.

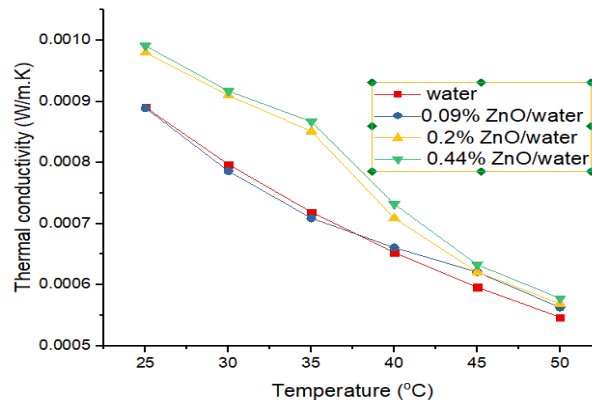
## 2.3 Influence of particle concentrations and temperature on thermal conductivity



**Figure 3.** Effect of volume concentration and temperature on ZnO/water nanofluid thermal conductivity

In Figure 3, it is noted that the thermal conductivity increased with increasing volume concentration and temperature. The measured thermal conductivity of 0.09%, 0.2% and 0.44% nanofluid at 50°C is 6.1%, 6.2% and 6.22% respectively higher than the nanofluid at 25°C.

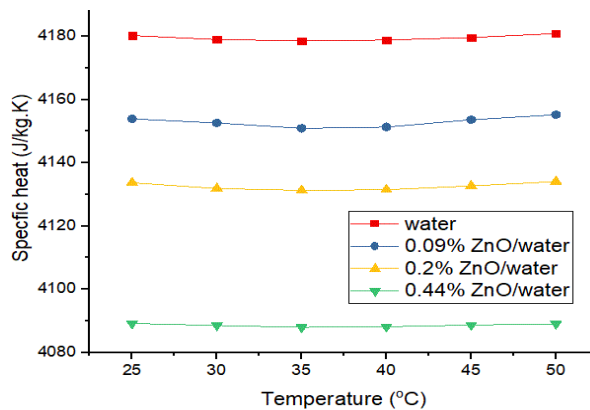
## 2.4 Influence of particle concentrations and temperature on dynamic viscosity



**Figure 4.** Effect of fraction concentration and temperature on ZnO/water nanofluid viscosity

Figure 4 shows that the nanofluid (ZnO/water) viscosity decreases with increasing temperature. The 0.09% nanofluid at 50°C is 36% lower than those at 25°C. The 0.2% and 0.44% nanofluid also show similar observation with 41.9% and 42% decrement respectively. And it is observed that the dynamic viscosity of nanofluid (ZnO/water) increases with increasing nanoparticle volume concentration in water.

## 2.5 Influence of particle concentrations and temperature on specific heat



**Figure 5.** Effect of fraction concentration and temperature on ZnO/water nanofluid specific heat

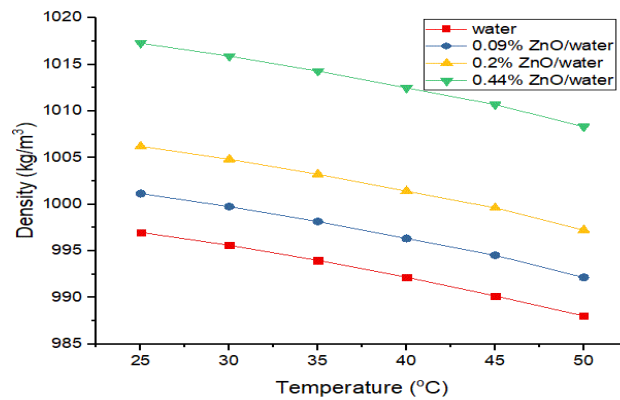
In Figure 5, it is showed that the specific heat capacity of ZnO/water decreases moderately with increasing temperature and decreases highly with the particle volume concentration changes.

The density of nanofluid and base fluid are calculated at the average bulk temperature, which is proposed by Pak and Cho (1998) and Abbasian and Amani (2012) respectively.

$$\rho_{nf} = \phi \rho_{np} + (1 - \phi) \rho_{bf} \quad (1)$$

$$\rho_{bf} = -9.339158 \times 10^{-8} T_b^4 + 1.364893 \times 10^{-4} T_b^3 - 0.07714568 T_b^2 + 19.251515 T_b - 764.475639 \quad (2)$$

In Equations (1,2),  $\rho$  is density of working fluids, ' $T_b$ ' indicates temperature which is the average values of inlet and outlet temperature of the water moving through the heat exchanger, ' $\phi$ ' indicates volume concentration, 'np' indicates (ZnO) nanoparticle, 'nf' indicates (ZnO/water) nanofluid and 'bf' indicates water (base fluid).



**Figure 6.** Effect of fraction concentration and temperature on ZnO/water nanofluid density

In Figure 6, it is noted that the density of ZnO/water increases substantially with increasing particle volume concentration and decreases with increasing temperature.

## 2.6 Determination of Heat Transfer Processes

To get coefficient of heat transfer ( $h$ ) and Nusselt number ( $Nu$ ), the following method has been performed. According to Newton's cooling law:

$$q = h (\Delta T_b - \Delta T_w) \quad (3)$$

Heat transfer rate can be defined as:

$$Q = \dot{m} C_p (T_{in} - T_{out}) \quad (4)$$

Regarding the equation of  $Q$  in the above equations:

$$h = \frac{Nu_{av} k}{d_i} \quad (5)$$

Nusselt number was determined from Kay's correlation which is referred than Hausen.

$$Nu_{av} = \frac{h d_i}{k} = 3.66 + \frac{0.0668 Re Pr (d_i/L)}{1 + 0.04 [(d_i/L) Re Pr]^{2/3}} \quad (6)$$

$$Pr = \frac{\mu \times C_p}{k} \quad (7)$$

Where,

$Q$ ... heat transfer rate,  $A$ ... area of coil,  $\Delta T$ ... temperature difference of the cooling working fluids,  
 $\dot{m}$  ... mass flow rate,  $T_{in}$  and  $T_{out}$  ... inlet and outlet temperatures,  $T_w$  ...tube wall temperature,  
 $T_b$  ...bulk temperature,  $d_i$ ... inside diameter of the tube,  $C_p$ ...specific heat of working fluids,  
 $\mu$ ...dynamic viscosity of working fluid,  $k$ ...thermal conductivity of working fluids,  $Nu_{av}$ ...average Nusselt number for the heat exchanger.

## 3. Results and Discussions

Firstly, before conducting methodical experiments on the application of nanofluids as working fluid in the heat exchanger, some experiments were carried out on water for the verification of the heat exchanger and accuracy of the experimental setup. Noting that the Nusselt number increases with increasing Reynolds number.

Table 2 shows the calculation results of three important non-dimensional quantities for (ZnO/water) nanofluid and (water) base fluid. As expected, the Nusselt number is seen to rise with increasing in Reynolds number, while the Prandtl number is increasing with increase in volume fraction.

**Table 2.** Results of non-dimensional quantities for (ZnO/water) at bulk mean temperature with different concentrations.

Types	0 %	0.09%	0.2%	0.44%
Reynolds number	1324	1322	1318	1307
Prandtl number	5.401	5.399	5.400	6.16
Nusselt number	4.5243	4.5223	4.5199	4.5147

Table 3 shows the results of heat transfer coefficient and heat transfer rate for base fluid and nano-fluid.

**Table 3.** Summary of heat transfer coefficient, mass flow rate and heat transfer rate for nano-fluid (ZnO/ water) at bulk mean temperature with different concentrations.

Volume Concentrations (%)	The coefficient of heat transfer (h) W/m <sup>2</sup> . °C	Heat transfer rate (Q) W
0	558.32	30.9
0.09	559.4	34.8
0.2	560.7	46.5
0.44	563.6	66.3

#### 4. Conclusions

In this paper, experimental facility was used to study heat transfer characteristics of ZnO/water nanofluid. The working fluid was cooled in tank. Flow heat transfer experiments in sub-heated region were carried out to study heat transfer characteristics of ZnO/water nanofluid. The results of the present investigation are summarized as follows.

- After preparation of the nanofluid without any surfactants, and then based on the photo capturing method to check stability, it was noted that ZnO/water nanofluid can be made partial stability (6 hrs) by using stirrer and ultra-sonication.
- Dispersion of the ZnO nanoparticles into the water increases the viscosity and thermal conductivity of the ZnO/water nanofluid, this augmentation increases with the increase in nanoparticle volume concentrations.
- Experimentally, dispersion of the ZnO nanoparticles in water significantly improves the heat transfer rate of the heat exchanger. The degree of the heat transfer improvement depends on the amount of ZnO nanoparticle added to water. When the volume concentration of 0.44 %, the heat transfer rate enhancement of 53.4 % compared to water was recorded.

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### **Acknowledgments**

Thanks to all the authors and those who contributed and helped in completing this paper.