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Research Article

Analyzing How the ZrO_2 Far Infrared Material Affects the Performance of Smooth Tube Heat Exchangers

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The aim of this study was to investigate the effect of the 100 nm ZrO_2 far infrared material on the heat exchange efficiency of smooth tube heat exchangers. In the experiments designed for this purpose, the ZrO_2 powder and water based acrylic paint were mixed separately using a two-step mixing method and the mixture samples were sprayed, respectively, onto heat exchangers for testing their heat exchange efficiency under stable ambient conditions. Results from the experiments showed 31.8% and 21.5% increases in heat transfer in the heat exchanger sprayed with 7.5 wt.% ZrO_2 powder and with inlet water temperatures at 45°C and 55°C relative to the heat exchanger sprayed with 0 wt.% acrylic paint and 26.4% and 18.9% increases in heat transfer relative to the heat exchanger not sprayed with acrylic paint. The experiments also verified that heat could be transferred through radiation. The additive ZrO_2 nanopowder in these experiments is proven to be able to improve the efficiency of heat exchangers through radiation, thereby increasing the feasibility of its application in practice.

1. Introduction

To deal with the issues of global warming and energy shortage in recent years, all industries have been putting a lot of effort into improving the performance of their equipment. Nevertheless, improving heat exchangers remains the fastest and most effective way that requires less investment for performance improvement in most equipment. Many researchers have also offered in succession their solutions for efficiency improvement in heat exchangers, such as by broadening the surface areas for heat exchange [1], modifying surface contact properties [2–8], improving the flow field effect [9], and enhancing the heat transfer property of fluids [10–13] for the same purpose of improving the efficiency of heat exchangers.

Far infrared materials have been commonly used in the healthcare industry in recent years and widely acclaimed for their role in improving blood circulation [14, 15], inflammation treatment, and wound healing. Among them, the waveband with wavelengths between 4 and 14 um can be absorbed effectively by organisms and is known as a growth ray [16].

In 2009, Guan et al. [17] proposed the addition of a far infrared material in powder form (tourmaline powder) into latex paints, which can prevent the generation of volatile organic compounds (VOCs) after the paints have been applied and improve human health because tourmaline itself can generate anions and release them into the air.

In 2007, Li et al. [18] discovered that using the tourmaline/resin composite as a material for fuel boiler benches could save 2.87% of diesel consumption and reduced the mass concentrations of CO and NO in fumes by 15.9% and 14.5%, respectively.

In 2013, Qin et al. [19] achieved the advantage of reduced diesel consumption and improved torque and power in diesel engine oil nozzles by placing rubber sheets that contained far infrared powder in the nozzles.

In this study, the effect of the ZrO_2 material on the performance of heat exchangers and the feasibility of its application in practice were investigated through a series of experiments, in which a material that was harmless to humans was sprayed onto heat exchanger exteriors in a nondestructive way.

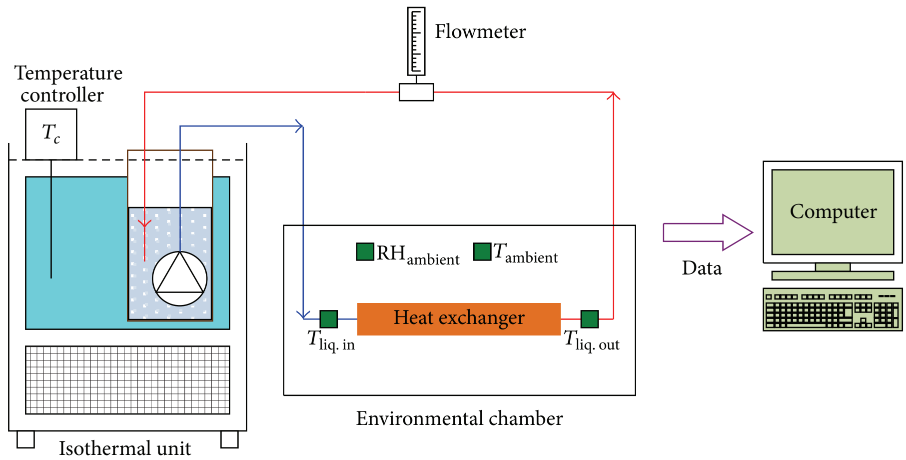

Figure 1: Layout of device in heat exchange experiment.

2. Interrelated Theories

2.1. Far Infrared Ray. Light is electromagnetic radiation that has a wavelength in the range of 300 nm (ultraviolet) to 14,000 nm (far infrared). In the optical spectrum, the infrared has longer wavelengths than visible light and the wavelength range is about 0.75~1000 nm, between red light and microwave. The far infrared is the long wave portion of the infrared. Since the infrared has an overboard spectral range, it is divided into near, mid, and far infrared in science for convenience in research.

2.2. Methods of Heat Transfer. Heat is related to temperature. Matter usually contains more energy at higher temperatures. Heat transfer has three patterns: conduction, convection, and radiation. Any form of heat exchange follows one of the patterns or their combinations. Conduction and convection mean, respectively, heat transfer through solids or static liquids or that through the movement of liquids while radiation does not rely on any media for heat transfer, but on the emission of electromagnetic radiation instead for heat exchange.

2.3. Overall Heat Transfer Capacity Ratio. In this experiment, water based acrylic paint served as the baseline and was compared with samples that contained 100 nm ZrO_2 nanoparticles to see how they affect the improvement in heat exchanger efficiency. The experiment setup was of the same type of heat exchangers to be tested under the same conditions in order to calculate the differences in heat transfer efficiency between the heat exchangers sprayed with the acrylic paint and nanoparticles, that sprayed with the acrylic paint alone, and that equipped with bare copper tubes. Accordingly, the overall heat transfer capacity ratios (r_{OHTC}) in these heat exchangers can be represented by the following equation:

$$r_{OHTC} = \frac{Q_{Improve}}{Q_{base}} = \frac{\left(T_{liq.out} - T_{liq.in}\right)_{Improve}}{\left(T_{liq.out} - T_{liq.in}\right)_{base}}. \quad (1)$$

3. Experiments

3.1. Experimental Apparatus and Procedures. In this study, the 100 nm ZrO_2 far infrared material was added to water based acrylic paint to form different mixtures, which were then sprayed onto the surface of smooth tube heat exchangers to investigate whether this can improve the efficiency of the heat exchanger. The material was added in powder form and different concentrations, that is, 0.0 wt.%, 1.0 wt.%, 2.5 wt.%, 5.0 wt.%, 7.5 wt.%, 10.0 wt.%, 12.5 wt.%, and 15.0 wt.%. The mixing of all fluid samples was done using a two-step mixing method that included an ultrasonic oscillator and an electromagnetic agitator. Both machines were run three times and each run lasted for one hour to obtain the samples for the experiment. All the samples were sprayed in the same amount of 4 g, respectively, onto smooth tube heat exchangers in the same configuration. The water and air piping systems shown in Figure 1 were used to assess how the ZrO_2 far infrared material affects the performance of these heat exchangers by comparing those sprayed with the material with those either sprayed with the acrylic paint alone or equipped with bar copper tubes. The main steps included ensuring stable inlet water temperatures in the heat exchangers with water supply from a thermostatic sink (B403L, FIRSTEK, Taiwan); maintaining the water flow in a stable state with the combination of a direct current water pump (MCP-655, SWIFTECH, United States) and flowmeter (ND05-P, AICHI, Japan); and capturing data with a data capture device for analysis. The experiment parameters are listed in Table 1.

3.2. Uncertainty Analysis. The uncertainty of experiment results is dependent on deviations in measurement parameters in experiments. In the experiment for overall heat transfer capacity efficiency, the devices used included flowmeters for measuring flow rates, PT-100 platinum thermocouples for measuring inlet and outlet fluid temperatures in the heat exchangers, and temperature and humidity sensors for measuring temperatures and humidity levels. The uncertainty of

Table 1: Parameters in heat exchange experiment.

Items	Parameters
Mass of sprayed sample	4 g
Inlet water temperature of heat exchanger	45°C, 55°C
Sprayed sample	0.0 wt.%, 1.0 wt.%, 2.5 wt.%, 5.0 wt.%, 7.5 wt.%, 10.0 wt.%, 12.5 wt.%, and 15.0 wt.%
Flow ratio	0.5 L/min
Ambient temperature/humidity	25 ± 1°C/50% RH ± 3% RH

total heat exchange ratios can be represented by the following formula:

$$u_{r_{\mathrm{OHTC}}} = \left(\left[\left(\frac{\Delta\dot{m}}{\dot{m}}\right)^2 + \left(\frac{\Delta T_{\mathrm{ambient}}}{T_{\mathrm{ambient}}}\right)^2 + \left(\frac{\Delta T_{\mathrm{liq.in}}}{T_{\mathrm{liq.in}}}\right)^2 + \left(\frac{\Delta T_{\mathrm{liq.out}}}{T_{\mathrm{liq.out}}}\right)^2 + \left(\frac{\Delta \mathrm{RH}}{\mathrm{RH}_{\mathrm{ambient}}}\right)^2\right]_{\mathrm{improve}} + \left[\left(\frac{\Delta\dot{m}}{\dot{m}}\right)^2 + \left(\frac{\Delta T_{\mathrm{ambient}}}{T_{\mathrm{ambient}}}\right)^2 + \left(\frac{\Delta T_{\mathrm{liq.in}}}{T_{\mathrm{liq.in}}}\right)^2 + \left(\frac{\Delta T_{\mathrm{liq.out}}}{T_{\mathrm{liq.out}}}\right)^2 + \left(\frac{\Delta \mathrm{RH}}{\mathrm{RH}_{\mathrm{ambient}}}\right)^2\right]_{\mathrm{base}}\right)^{1/2}. \quad (2)$$

The accuracy was ±0.01 L/min for the flowmeters, ±0.01°C for the PT-100 platinum thermocouples, and ±0.5°C and ±3% RH for the temperature and humidity sensors. As calculated using formula (2), the uncertainty of the experimental conditions for total heat exchange ratios was ±9.3% in maximum and was maintained below ±9.3% in all the experimental conditions.

4. Results and Discussion

Figures 2 and 3 represent, respectively, the heat exchanger sprayed with 0 wt.% acrylic paint that served as the baseline for comparison and improvement trends in total heat exchange efficiency with different inlet water temperatures and powder concentrations. They reveal that higher powder concentrations with inlet water temperatures of 45°C and 55°C contributed to the trend of increase followed by a decline in total heat exchange efficiency and the powder concentration of 7.5 wt.% in particular was responsible for the greatest improvement in total heat exchange efficiency, that is, by 31.8% and 21.5%. When the powder concentration was higher than 7.5 wt.%, improvement in total heat exchange efficiency tended to decline gradually whether the inlet water temperature was 45°C or 55°C. The reason for this limitation is that the heat transfer coefficient of the mixture of the ZrO_2 material and the acrylic paint was far lower than those of the copper contact surfaces in the heat exchangers. Therefore, spraying excessive amounts of the powder onto the heat

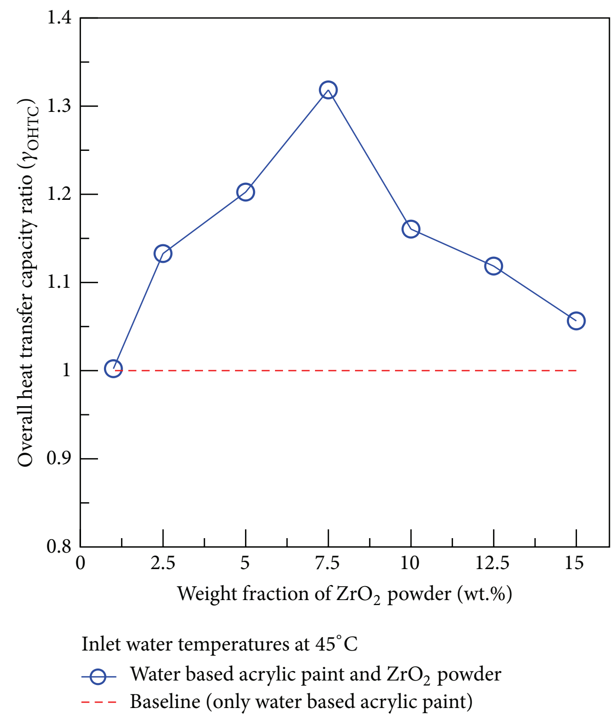

Figure 2: Relationship between weight fraction and heat exchange efficiency with the inlet water temperature at 45°C (spraying with acrylic paint as the baseline).

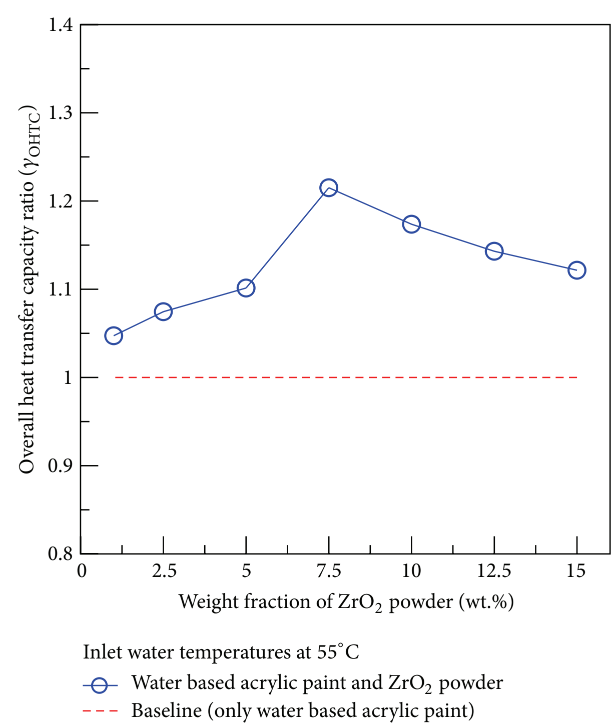

Figure 3: Relationship between weight fraction and heat exchange efficiency with the inlet water temperature at 55°C (spraying with acrylic paint as the baseline).

exchangers may be regarded as contributing to the formation of thermal resistance, thereby blocking the path of heat dissipation.

Figures 4 and 5 represent, respectively, the same heat exchanger sprayed with 0 wt.% acrylic paint and with an additional insulation coating that again served as the baseline for comparison and improvement trends in total heat exchange efficiency with different inlet water temperatures and powder concentrations. They also reveal that the powder concentration of 7.5 wt.% in particular with inlet water temperatures at 45°C and 55°C contributed to the greatest improvement in total heat exchange efficiency and brought about improvement by 17.9% and 11.9%. Compared with Figures 2 and 3, the two figures show similar trends, which covered the results from experiments with and without insulation. According to the results, the condition of additional insulation coating did improve heat exchange efficiency although to a lesser extent relative to the condition of no insulation.

The results from the condition of no insulation in Figures 2 and 3 reveal that spraying the ZrO_2 material could actually improve total heat exchange efficiency when conduction, convection, and radiation mechanisms were available, whereas the results from the condition of additional insulation coating in Figures 4 and 5 confirm that spraying the ZrO_2 material could still improve total heat exchange efficiency even though the conduction and convection mechanisms were rendered negligible due to the isolation by the insulation and only the radiation mechanism remained. This result further shows that the sprayed ZrO_2 material could still improve total heat exchange efficiency although it had a lower heat transfer coefficient than the copper surfaces of the heat exchangers. This means that the material can release heat by emitting far infrared rays, that is, transferring heat through radiation. The results in **Figure 4** show that the powder concentration, when exceeding 12.5 wt.%, tended to bring about less improvement in total heat exchange efficiency than the baseline. The reason is that higher concentrations created greater thermal resistance, which enhances the effectiveness of the insulation, but eventually also caused the heat released through radiation to be less than that blocked by the material.

The experiment results above were obtained using the heat exchanger sprayed with acrylic paint that contained 0 wt.% of the powder as the baseline for comparison. This comparison model may serve as a reference for application in antirust and anticorrosion engineering for heat exchangers and may become the mechanism for blocking heat on the unprotected painted surfaces of heat exchangers in practice. Accordingly, Figures 6 and 7 represent, respectively, a heat exchanger not sprayed with acrylic paint that served as the baseline for comparison and improvement trends in total heat exchange efficiency with different inlet water temperatures and powder concentrations. They reveal that higher powder concentrations with inlet water temperatures at 45°C and 55°C contributed to the trend of increase followed by a decline in total heat exchange efficiency and the powder concentration of 7.5 wt.% in particular was responsible for the greatest improvement in total heat exchange efficiency, that is, by 26.4% and 18.9%. Improvement in total heat exchange efficiency in these conditions tended to be less compared with the baseline in Figures 2 and 3, that is, spraying with acrylic paint.

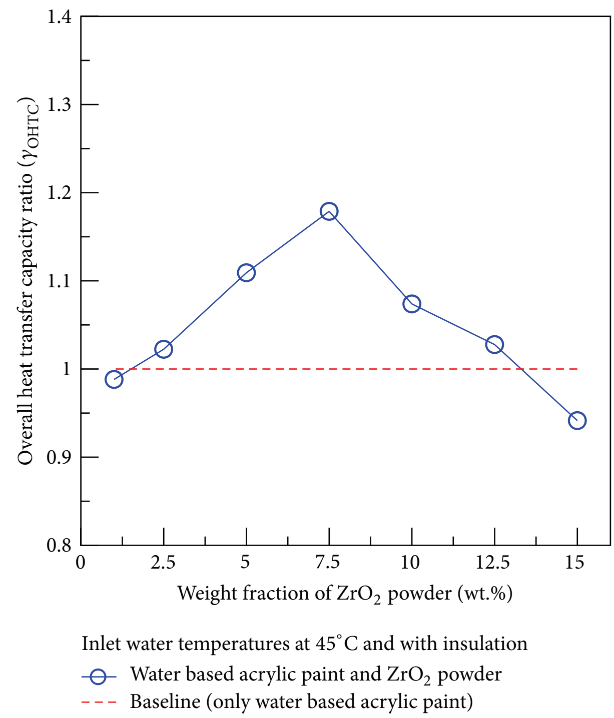

Figure 4: Relationship between weight fraction and heat exchange efficiency with the inlet water temperature at 45°C and with insulation (spraying with acrylic paint as the baseline).

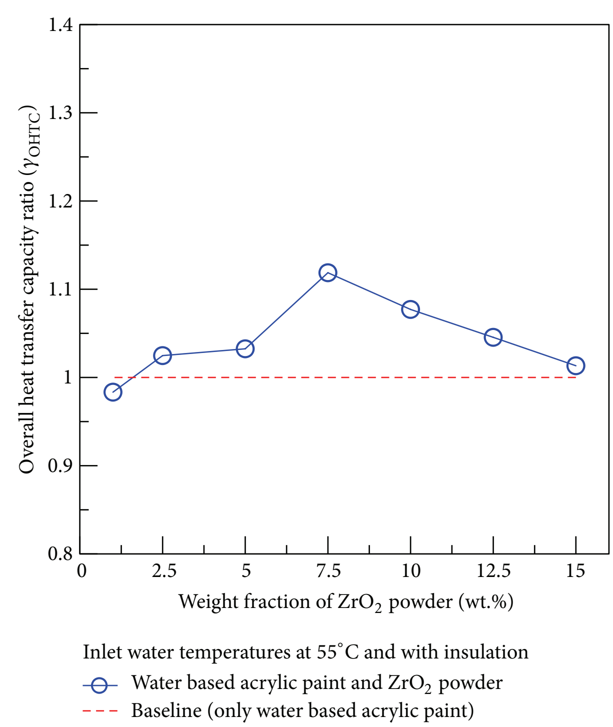

Figure 5: Relationship between weight fraction and heat exchange efficiency with the inlet water temperature at 55°C and with insulation (spraying with acrylic paint as the baseline).

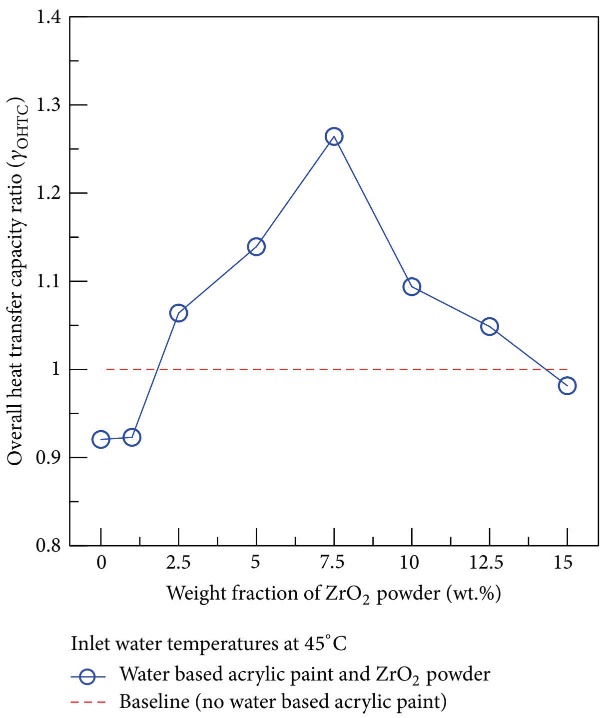

FIGURE 6: Relationship between weight fraction and heat exchange efficiency with the inlet water temperature at 45°C (no acrylic paint as the baseline).

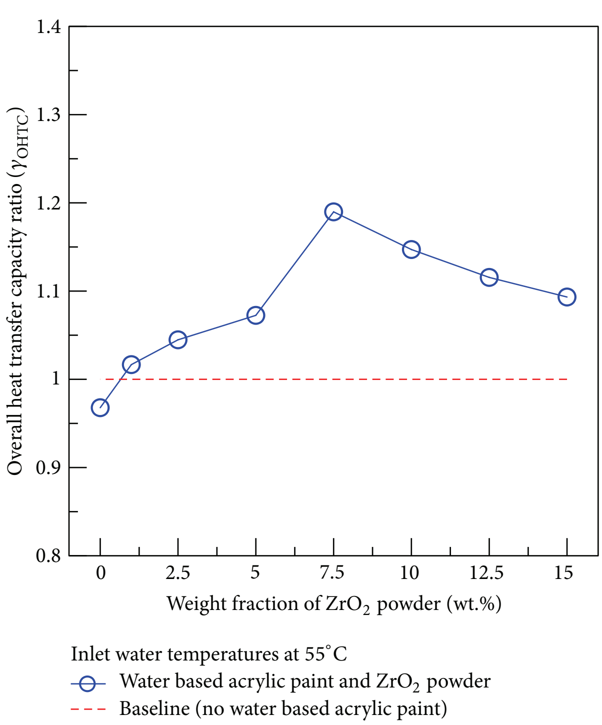

FIGURE 7: Relationship between weight fraction and heat exchange efficiency with the inlet water temperature at 55°C (no acrylic paint as the baseline).

5. Conclusions

The following experiment results were obtained by adding appropriate amounts of the ZrO_2 material to acrylic paint and spraying the mixture onto heat exchanger.

(1) This approach was actually able to improve the total heat exchange efficiency of these heat exchangers.

(2) The consequent heat transfer through radiation could enhance the practical feasibility of this approach.

(3) The ZrO_2 powder in the concentration of 7.5 wt.% with inlet water temperatures at 45°C and 55°C contributed to improvement in heat transfer efficiency by 31.8% and 21.5% relative to the heat exchanger sprayed with 0 wt.% acrylic paint, by 26.4% and 18.9% relative to the heat exchanger not sprayed with acrylic paint, and by 17.9% and 11.9% relative to the heat exchanger sprayed with 0 wt.% and with an additional insulation coating.

Conflict of Interests

The authors declare that they have no competing interest and no commercial interest in this paper.

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