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The performance of a heat pump using nanofluid ($R22+TiO_2$) as the working fluid – an experimental study

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Abstract

It has been well known that the nano-particles, including metals, oxides, carbides, or carbon nanotubes, can increase the conduction and convection coefficients and consequently, enhance the heat transfer. Using nanofluids as working fluids in the refrigeration, air-conditioning and heat pump systems has attracted much attention. This work set-up a test rig to experimentally study the system performance of a heat pump with nanofluid as refrigerant, which was prepared by mixing 5wt% TiO2 with R22. Results show that adding the nano particle TiO2 didn't changed the heat absorbed in the evaporator clearly but increase the heat released in the condenser. As a results, compared to using pure R22, when using R22 + TiO2, the COP of the cooling cycle was decreased slightly, however, the COP of the heating cycle was increased significantly increased power consumption of compression.

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Keywords: Heat pump, nanofluid, system performance, experiment

1 Introduction

A nanofluid is a fluid containing nanometer-sized particles (1–100 nm). It has been well known that the nano-particles, including metals, oxides, carbides, carbon nanotubes etc., can increase the conduction and convection coefficients and consequently, enhance the heat transfer [1]. Therefore, there are many potential applications of nanofluids, one of which is to use it as the working fluid in the cycles of refrigeration, air-conditioning and heat pumps. Many works have been conducted in the past few decades, which, in general, can be classified into four categories: (I) the fundamental properties, such as density, thermal conductivity, viscosity and surface tension; (II) the effect of nanofluids on heat transfer, including thermal conductivity, boiling etc.; (III) lubricity and material compatibility; and (IV) system performance,

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for example the coefficient of performance (COP) and energy saving. Saidur et al. have reviewed the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems [1], which reveals that the categories of (I) and (II) have attracted the most of the attention. There is no doubt that the knowledge about the property, heat transfer and material compatibility provides the basis for the development of heat pumps using nano-fluid as working fluids; however, before such heat pumps can be applied in a large scale, the system performance has to be thoroughly investigated. Table 1 gives a short summary on studies performed on the system performance with nanofluid as the working fluid.

Table 1 Studies on the system performance with nanofluid as the working fluid

Author	**Cycle type**	**Nano-fluid**	**Performance**	**Method**
Bi et al. [2]	refrigeration	R600a + TiO2	energy saving of 9.6%.	experiment
Subramani and Prakash [3]	refrigeration	R134a + Al2O3	25% reduction of power consumption	experiment
Sabareesh [4]	refrigeration	R12 + TiO2	COP increased by 17%.	experiment
Kumar and Elansezhian [5]	refrigeration	R134a + Al2O3	10.3% reduction of energy consumption	experiment
Xing et al. [6]	refrigeration	R600a + C60	5-6% COP improvement	experiment
Reji kumar and Sridhar [7]	refrigeration	TiO2 – R600a	energy consumption reduced by 11% and COP increases by 19.6%.	experiment
Abbas et al. [8]	Air-Condition	R134a + Carbon Nanotubes	COP increased by 4.2%	experiment
Fedele et al. [9]	HP	R134a+R22	No obvious improvement	experiment

It is clear that many works have been done regarding the refrigeration system, but not the heat pump. However, the heat pump represents an energy-efficient alternative to produce thermal energy. Based on the fact that the building sector consumes approximately one third of the world's energy consumption, it is of significance to carry out more works to investigate the system performance of the heat pump using nanofluids as working fluids. In addition, the work conducted by Fedele et al. shows quite different results from the works about the refrigeration systems that no obvious improvement about the COP was observed when introducing the nanofluid. Hence, further investigation is needed. This work systematically studied the system performance of the heat pump using R22 and the nano particle TiO2. Experiments were conducted at different cooling and heating loads.

2 The experiment setup and procedure

Figure 1 displays the sketch of the heat pump system, which mainly consists of a scroll compressor, a condenser, an evaporator and a thermal expansion valve. The key parameters are listed in Table 2.

Table 2 summary of the key parameters

Parameter	Value
Compressor displacement	8.02m^3/h
Compressor power capacity	2.1kW
Area of evaporator	1.1 m^2
Area of condenser	1.2 m^2

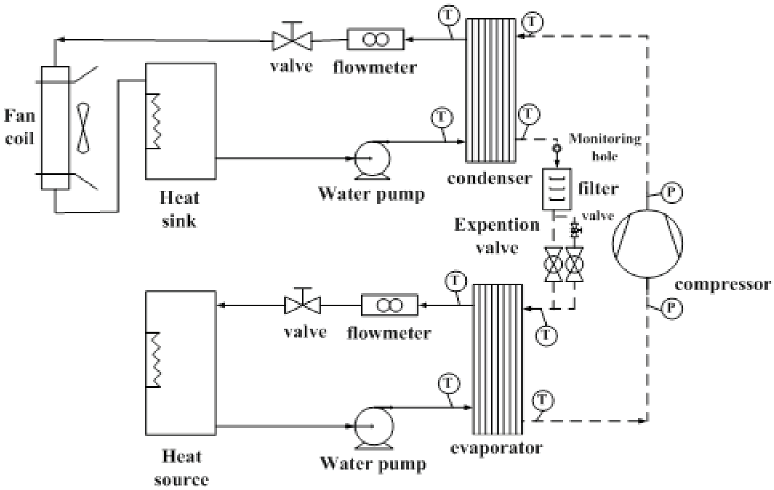


Figure 1 the sketch of the heat pump system

Using the system shown in Figure 1, experiments were conducted for the cooling and heating cycles respectively. In order to understand the effect of nanofluids, the same experiment was carried out for both pure R22 and R22+TiO2. The content of TiOs is 5wt%.

To test the performance at different cooling loads, the flow rate of cooling water passing through the condenser was fixed and the water flow rate passing through the evaporator varies between 0.148L/s and 0.400L/s. To test the performance at different heating loads, the control of water flow rates in the evaporator and condenser was vice versa.

The consumed power (W), the water flow rates ($\dot{v}$) in the evaporator and condenser and the water temperatures at the inlet and outlet of the evaporator and condenser were measured. Then cooling/heating capacity (q_c/q_h) can be calculated as:

$$q_{c/h} = \dot{v} \cdot \rho \cdot C_p \cdot \Delta T$$

where ρ is the density of water, C_p is the heat capacity of water and ΔT is the temperature difference between the inlet and outlet of evaporator/condenser. Consequently, the COP is calculated as:

$$COP_{c/h} = \frac{q_{c/h}}{W}$$

3 Results

3.1 cooling cycle

Figure 2 shows the results about the inlet and outlet temperatures of water in the evaporator and condenser, at different water flow rates in the evaporator. In general, no matter with or without the nanofluid, the temperature difference between the inlet and outlet at different water flow rates varies in a similar manner. It becomes smaller at higher flow rates in the evaporator, but a little larger in the condenser. Comparatively, the difference about the heat that the working fluid absorbed in the evaporator is quite small; however, on the contrary, when using R22+TiO2, much more heat was released in the condenser. The increase of heat releasing is due to the more work consumed by the compressor, which can be seen from Figure 3(a). As a result, the COP of cooling for R22+TiO2 was decreased, as shown in Figure 3(b).

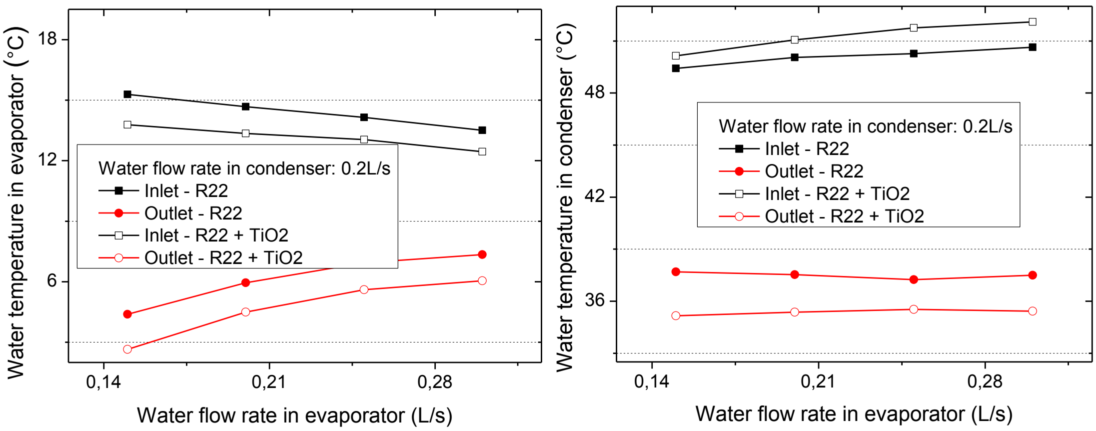
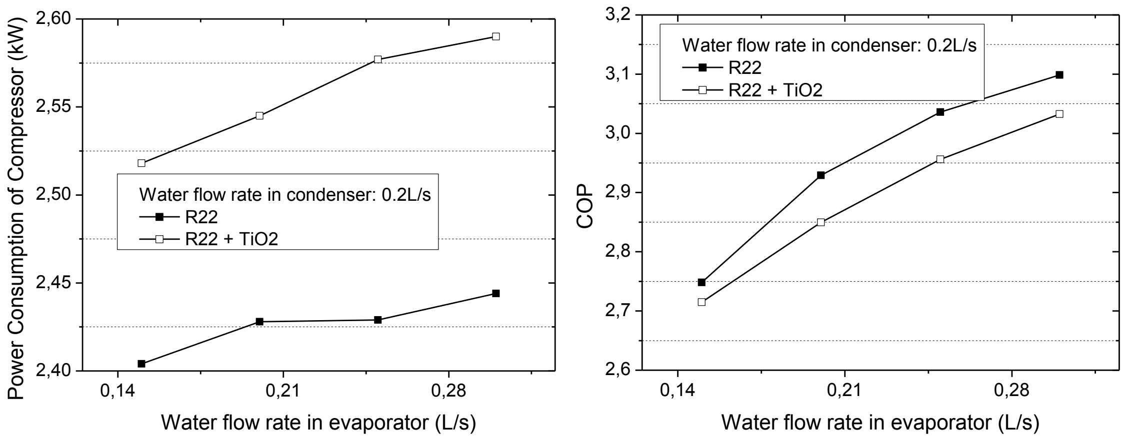


Figure 2 the inlet/outlet temperatures of water in the evaporator and condenser at different cooling load



(a) power consumption (b) COP

Figure 3 Power consumption and COP of the cooling cycle

3.2 heating cycle

Figure 4 shows the results about the inlet and outlet temperatures of water in the evaporator and condenser, at different water flow rates in the condenser. It is similar to the cooling cycle that the nanofluid didn't affect the temperature difference between the inlet and outlet at different water flow rates clearly. But contrary to the cooling cycle, the temperature difference becomes smaller at higher flow rates in the condenser and doesn't change clearly in the evaporator. It is also same that the difference about the heat that the working fluid absorbed in the evaporator is quite small; but R22+TiO2 releases much more heat in the condenser. The big drop of the power consumption shown in Figure 5(a) is mainly due to the drop of water temperature in the evaporator, which decreases the inlet temperature of the compressor. But, in general, the COP of heating was also increased largely, as shown in Figure 5(b).

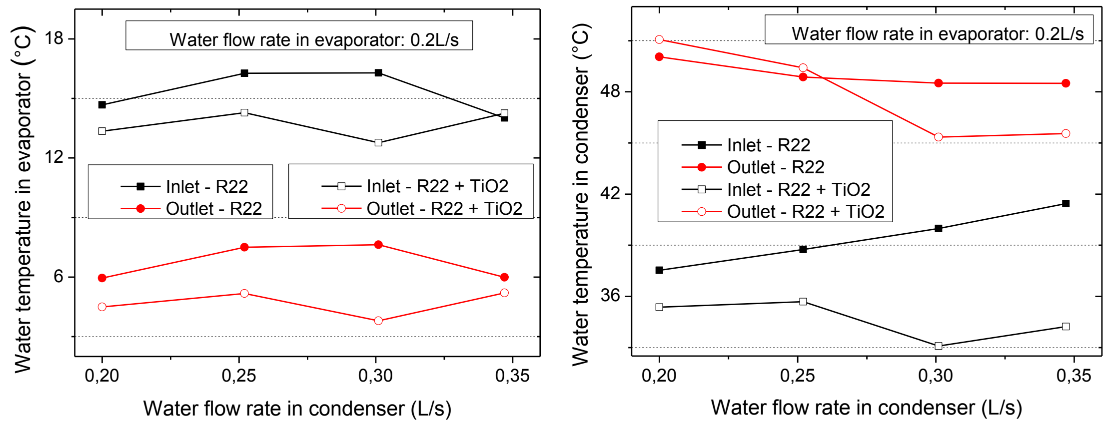
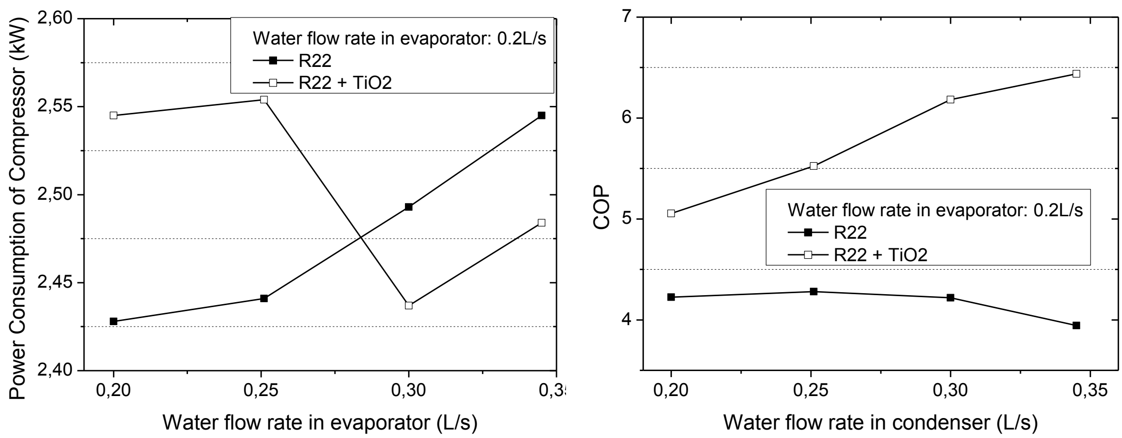


Figure 4 the inlet/outlet temperatures of water in the evaporator and condenser at different cooling load



(a) power consumption (b) COP

Figure 5 Power consumption and COP of the heating cycle

4 Discussions

It has been mentioned that Fedele et al. concluded that adding nano particles into the working fluid doesn't clearly affect the performances of both the cooling and heating cycles of heat pumps. For the cooling cycle, similar findings were obtained from our experiments; however, for the heating cycle, this work has demonstrated a big increase of the COP, up to 80%. The big discrepancy should be further investigated to understand the effects of the nanofluids.

Moreover, it has been found that adding nano particles into the working fluid increases the power consumption of the compressor. In order to further improve the system using nanofluid, the mechanism of the compression of nanofluids should be investigated.

5 Conclusions

Due to the ability to increase the conduction and convection coefficients and consequently, enhance the heat transfer, using nanofluids as working fluids has the potential to improve the system performance of heat pumps. This work experimentally studied the system performance of a heat pump with R22 and TiO_2 (5wt%) as refrigerant. Results show that even though adding the nano particle TiO_2 decreases the COP of the cooling cycle slightly, the nanofluid can increase the COP of the heating cycle significantly, which is mainly due to the increased power consumption of compression.

Acknowledgement

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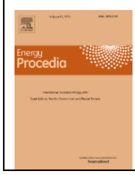

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Dr. Li Zhao is a professor at Tianjin University, China. His research interest lies in the development of high temperature heat pumps and advanced Organic Rankine Cycle, with special focuses on the development of novel working fluids.