Performance of a domestic refrigerator using TiO$_2$-R600a nano-refrigerant as working fluid

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**A R T I C L E   I N F O**

Article history:
Received 13 May 2009
Received in revised form 17 December 2009
Accepted 30 July 2010
Available online 24 August 2010

Keywords:
Nano-refrigerant
Performance
Refrigerator

**A B S T R A C T**

In this work, an experimental work was investigated on the nano-refrigerant. TiO$_2$-R600a nano-refrigerants were used in a domestic refrigerator without any system reconstruction. The refrigerator performance was then investigated using energy consumption test and freeze capacity test. The results indicate that TiO$_2$-R600a nano-refrigerants work normally and safely in the refrigerator. The refrigerator performance was better than the pure R600a system, with 9.6% less energy used with 0.5 g/L TiO$_2$-R600a nano-refrigerant. Thus, using TiO$_2$-R600a nano-refrigerant in domestic refrigerators is feasible.

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**1. Introduction**

Nano-refrigerant was proposed on the basis of the concept of the nanofluids, which was prepared by mixing the nanoparticles and traditional refrigerant. There were three main advantages followed for the nanoparticle used in the refrigerator.

Firstly, nanoparticles can enhance the solubility between the lubricant and the refrigerant. For example, Wang and Xie [1] found that TiO$_2$ nanoparticles could be used as additives to enhance the solubility between mineral oil and hydrofluorocarbon (HFC) refrigerant. The refrigeration systems using the mixture of R134a and mineral oil appended with nanoparticles TiO$_2$ appeared to give better performance by returning more lubricant oil back to the compressor, and had the similar performance compared to the systems using polyol-ester (POE) and R134a.

Secondly, the thermal conductivity and heat transfer characteristics of the refrigerants should be increased, which have been approved by a lot of investigations. For instance, Jiang et al. [2] measured the thermal conductivities of CNT-R113 nano-refrigerants and found that the measured thermal conductivities of four kinds of 1.0 vol.% CNT-R113 nano-refrigerants increase 82%, 104%, 43% and 50%, respectively. Wang et al. [3] carried out an experimental study of boiling heat transfer characteristics of Al$_2$O$_3$ nanoparticles dispersed in R22 refrigerant, and found that nanoparticles can enhance the heat transfer characteristic of the refrigerator, and the bubble size diminish and move quickly near the heat transfer surface. Wu et al. [4] investigated the pool boiling heat transfer of the R11 refrigerant mixed with nanoparticles TiO$_2$, and the results indicated that the heat transfer enhancement reached 20% at a particle loading of 0.01 g/L. Park and Jung [5] investigated the effect of carbon nanotubes (CNTs) on nucleate boiling heat transfer of halocarbon refrigerants of R123 and R134A. Test results showed that CNTs increase nucleate boiling heat transfer coefficients for these refrigerants. Especially, large enhancement up to 36.6% was observed at low heat fluxes of less than 30 kW/m$^2$. Peng et al. [6] found that the heat transfer coefficient of CuO-R113 was larger than that of pure refrigerant R113, and the maximum enhancement of heat transfer coefficient was 29.7%. Ding et al. [7] investigated the migrated mass of nanoparticles in the pool boiling process of both nano-refrigerant and nano-refrigerant–oil mixture, and found that the migrated mass of nanoparticles and migration ratio in the nano-refrigerant were larger than those in the nano-refrigerant–oil mixture.

Finally, nanoparticles dispersed in lubricant should decrease the friction coefficient and wear rate. Lee et al. [8] investigated the friction coefficient of the mineral oil mixed with 0.1 vol.% fullerene nanoparticles, and the results indicated that the friction coefficient decreased by 90% in comparison with raw lubricant, which lead us to the conclusion that nanoparticles can improve the efficiency and reliability of the compressor. Jwo et al. [9] carried out the performance experiment of a domestic refrigerator using hydrocarbon refrigerant and 0.1 wt.% Al$_2$O$_3$-mineral oil as working fluid, the results indicated that the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%.

In the previous work, the author has investigated the basic characteristics of the TiO$_2$-R134a nano-refrigerants, including the dispersion behavior [10], thermal conductivity and flow boiling
The performance of a domestic refrigerator with nanoparticles added was also investigated. In the former experiment, the nanoparticles were added into the refrigeration system in two different ways. In one way the nanoparticles were added to the refrigeration system by first adding them into the lubricant to make a nanoparticle–lubricant mixture. Then, the mixtures were put into the compressor as the lubricant [13]. In the other way nanoparticles and traditional refrigerant were mixed directly to make nano-refrigerant [14]. The results of both of the ways had showed the better performance of the refrigerator with nanoparticles added.

Isobutane (R600a) is more widely adopted in domestic refrigerator because of its better environmental and energy performances. In this paper, a new refrigerator test system was built up according to the National Standard of China. A domestic R600a refrigerator was selected. TiO₂-R600a nano-refrigerant was prepared and used as working fluid. The energy consumption test and freeze capacity test were conducted to compare the performance of the refrigerator with nano-refrigerant and pure refrigerant so as to provide the basic data for the application of the nanoparticles in the refrigeration system.

2. Experiments

2.1. Experimental system

The experimental apparatus was built according to the National Standard of China (GB/T 8059.1–3–1995) [15] with a testing environment, domestic refrigerator and data collection and processing system as showed in Fig. 1. The refrigerator was placed on a platform in a constant temperature room. The room temperature was controlled by three adjusting heaters and an air conditioner. The fluctuation of the ambient temperature was ±0.5°C, which was illustrated by Fig. 2. The airflow velocity in the room was less than 0.25 m/s.

The experimental domestic refrigerator was a BCD-228GS/MS type manufactured by Xinfei Electric Co. Ltd., which was a double-door, multi-controlled refrigerator. The specifications of the refrigerator were shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Refrigerator specifications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross capacity</td>
<td>228 L</td>
</tr>
<tr>
<td>Refrigerant</td>
<td>R600a</td>
</tr>
<tr>
<td>Charged mass</td>
<td>60 g</td>
</tr>
<tr>
<td>Compressor type</td>
<td>Reciprocating</td>
</tr>
</tbody>
</table>

19 resistance thermometers and three pressure transducers were placed on the chill compartment, fresh food storage compartment and refrigeration system pipeline, and the detail arrangement was illustrated in Fig. 3. The power consumption of the domestic refrigerator was measured by a digital Watt-h meter with a precision of 1.0%. Table 2 summarizes all the characteristics of the plant instrumentation.

2.2. Performance test

In this study, the performance tests of the domestic refrigerator comprise of energy consumption test and freezing capacity test. According to the National Standard of China, the energy consumption of the domestic refrigerator should be measured when the refrigerator operates continuously 24 h under a steady operating
condition that the average temperature of the fresh food storage compartment is less than 5°C, and the temperature of chill compartment is less than 0°C. The freezing capacity is evaluated by the time that measurement package temperature drops from 25 ± 1°C to 0°C within 24 h under the specified test conditions. During the performance tests, the operating parameter was recorded including compressor suction and discharge pressure, evaporating temperature, and so on.

2.3. Experimental procedure

The experimental procedure is arranged as followed.

(1) A performance test is made for the pure R600a system firstly. The experimental results are established to be a foundation for comparison.
(2) TiO$_2$-R600a nano-refrigerants with different concentrations were put into the refrigeration system, and the tests were conducted again under the same condition.

2.4. Preparation of the TiO$_2$-R600a nano-refrigerant

Nano-refrigerant was prepared in a recommended method for nanofluids, the nanoparticles were mixed into the refrigerant and then the mixture was kept vibrated with an ultrasonic oscillator to fully separate nanoparticles. The purity of the R600a used in the tests, which was supplied by the Dupont Company, was higher than 99.8%. The TiO$_2$ nanoparticles were provided by Zhejiang Hongsheng Nanotech Co. Ltd. The average particle diameters were about 50 nm and the mass purity was about 99.5%. The nanoparticles masses were measured on an AB204-N balance manufactured by Mettler (Switzerland) with a precision of 0.1 mg.

The stability of the nano-refrigerant was an important and basic problem. On the basis of the former study on the dispersion of nanoparticles in the refrigerant [10], 0.1 and 0.5 g/L concentration were selected for the further investigations. The refrigerant masses added to the refrigerator had to be strictly controlled to be less than ±1 g in accuracy.

3. Results and discussion

Figs. 4 and 5 compared the compressor discharge and suction pressures of the refrigeration system over one on-off cycle, showing that both pressures were reduced for the nano-refrigerant rel-
ative to the R600a system, in which the largest reduction one was 0.5 g/L. The results above were similar with the former investigation about TiO₂-R134a nano-refrigerant as working fluids [14].

Figs. 6–8 showed the evaporation temperature, fresh food storage compartment temperature and frozen food storage compartment temperature. The results showed that the evaporation temperature was reduced with the nano-refrigerant, which lead to the lower fresh food and frozen food storage compartment temperatures.

Table 3 summarized the system parameter from the energy consumption tests. The energy consumption results were listed in Table 4. Every test was run at least 4–5 times under the same condition to ensure the repeatability. All the results presented here had less than 1% difference in the energy consumption for parallel tests. From Table 4, energy consumption of TiO₂-R600a nano-refrigerant system was lower than that of pure R600a. The energy consumption of 0.865 kW h/day was least at a nanoparticle concentration of 0.5 g/L, which is 9.6% less than the pure R600a system. From Table 3, the on-time ratio was 43.39% for the 0.5 g/L TiO₂-R600a nano-refrigerant system, which is less than for the pure R600a system, which also reduces the energy consumption as shown by the energy consumption results listed in Table 4.

Fig. 9 described the freezing velocity of the refrigerator with different working fluids. It was obviously that the freezing velocity of nano-refrigerant system was more quickly than the pure R600a system.

These results confirm that the refrigerator performance with TiO₂-R600a nano-refrigerant is better than with the pure R600a. The reason may be that the nanoparticles enhance the heat transfer characteristics of the refrigerant and also improve the friction characteristics of the lubricant.

4. Conclusions

In this paper, TiO₂-R600a nano-refrigerants were used as a working fluid of domestic refrigerators. The results indicated that TiO₂-R600a can work normally and efficiently in refrigerator. Compared with refrigerator using pure R600a as working fluids, 0.1 and 0.5 g/L concentrations of TiO₂-R600a can save 5.94% and 9.60% energy consumption respectively and the freezing velocity of nano-refrigerant system was more quickly than the pure R600a system.

In addition, the results were similar to the author’s early research of using TiO₂-R134a as working fluids. So the above works have demonstrated that nanoparticles can improve the performance of the domestic refrigerator.
Table 3
Energy consumption test results.

<table>
<thead>
<tr>
<th>Proportion (g/L)</th>
<th>$T_{on}$ (°C)</th>
<th>$T_{off}$ (°C)</th>
<th>On-time ratio (%)</th>
<th>$P_{on}$ (bar)</th>
<th>$P_{off}$ (bar)</th>
<th>$T_{Evp}$ (°C)</th>
<th>$T_{Cond}$ (°C)</th>
<th>$T_{Room}$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.33</td>
<td>-18.13</td>
<td>46.67</td>
<td>0.595</td>
<td>5.611</td>
<td>42.14</td>
<td>-24.30</td>
<td>33.87</td>
</tr>
<tr>
<td>0.1</td>
<td>5.40</td>
<td>-18.80</td>
<td>44.12</td>
<td>0.583</td>
<td>5.700</td>
<td>45.09</td>
<td>-24.96</td>
<td>34.91</td>
</tr>
<tr>
<td>0.5</td>
<td>5.36</td>
<td>-19.06</td>
<td>43.39</td>
<td>0.574</td>
<td>5.463</td>
<td>47.18</td>
<td>-25.14</td>
<td>34.18</td>
</tr>
</tbody>
</table>

Table 4
Energy consumption results.

<table>
<thead>
<tr>
<th>Concentration (g/L)</th>
<th>Energy consumption (kW h)</th>
<th>Energy saving (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.9567</td>
<td>5.94</td>
</tr>
<tr>
<td>0.1</td>
<td>0.8999</td>
<td>9.60</td>
</tr>
<tr>
<td>0.5</td>
<td>0.8649</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 9. Freezing capacity.

Acknowledgements

This study was supported by the National Natural Science Foundation of China (Grant Nos. 50806060 and 50836004) and the Specialized Research Fund for the Doctoral Program of Higher Education (200806981012).

References