A New Type of Enhanced Heat Transfer Technology for Mobile Heat Storage Medium

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Abstract. Mobile heat storage technology is to alleviate the energy supply and demand both sides on the time, intensity and location does not match the effective way, is the rational utilization of energy and the effective ways to reduce environmental pollution, but the current mobile heat storage technology is not used widely in domestic, the main factor of restricting its development is exothermic filling time is too long, cause heat loss and power consumption is too large. After analyzing the heat transfer module of the mobile heat storage system and searching a lot of literature, it is found that Hydrogen fluoride ether (HFE) has excellent heat transfer characteristics. Through the principle exploration and experimental verification, the following conclusions are finally drawn: Adding HFE7000 with a concentration of 1.2% into the heat exchange module can improve the heat exchange effect by about 58%, which has good energy-saving and emission reduction.

Key words: waste heat recovery, mobile heat storage, energy conservation and emission reduction, efficient and flexible.

1. Introduction

With the rapid development of urbanization, urban heating sources are increasingly tight, but the large amount of low-temperature waste heat generated by enterprises around the city has not been properly recovered and utilized, which not only wastes energy but also causes environmental pollution. Based on this situation, mobile heat storage technology was born.

On the one hand, with the improvement of residents' living standards, the demand for heating in winter increases sharply in areas where central heating is not traditionally used. Demand for emergency heating has increased dramatically in areas where central heating is already in place, with increasing requirements for heating quality. At the same time, there are a large number of emergency situations in the heating demand and outdoor temporary venue heating demand. On the other hand, nearly 60 ~ 65% of China's industrial energy is converted into waste heat resources, but the comprehensive recovery rate is only 35.2%, of which the recovery rate of low-temperature waste heat is less than 25%, and the potential of waste heat reuse is huge.

Therefore, the combination of mobile heat storage vehicle and industrial waste heat recovery and reuse provides a low energy consumption and low-cost solution for emergency heating.
At present, there are mature on the market, mobile regenerative car, but its regenerative process for 40 minutes to an hour, thermal efficiency is low, the storage charge exothermic time is long, so the heat exchange efficiency, this caused in the process of regenerative heat loss is large, extra power consumption increase, of a single mobile heating devices in the overall efficiency and heating capacity. Therefore, it is very necessary to improve the heat exchange effect of heat storage process, shorten the time of charging and releasing heat, and further improve the flexibility and efficiency of mobile heating.

However, relevant companies in the market did not improve the heat transfer module. The heat transfer working medium is common water/water vapor. Although this working medium is cheap and easy to obtain, the heat transfer effect is not good, which affects the availability of the project. Therefore, by reading a large number of literatures and combining with the characteristics required by the heat transfer module of the mobile regenerator, this paper designs a new medium enhanced heat transfer technology based on the original mobile regenerator to optimize the heat transfer module. The purpose of adding a certain concentration of Hydrogen fluoride ether (HFE) into the working medium for heat transfer is to enhance fluid disturbance, destroy boundary layer and improve heat flux, thus improving heat transfer effect and heat transfer efficiency, so as to optimize the heat storage performance of the working medium and verify its feasibility through experiments.

2. Experimental Apparatus and Principles

2.1. HFE Enhanced Heat Transfer Principle

When Hydrogen fluoride ether is added to the heat transfer medium, the drop of HFE can strengthen the flow disturbance, destroy the laminar flow area of the wall, expand the turbulent flow area, and thus enhance the heat transfer. When the HFE is near the hot side of the tube wall, small droplets of HFE boil quickly, forming two-phase bubbles of steam and liquid that quickly fill the tube. In a cold wall, bubbles lose heat and drop as liquid. These bubbles affect the overall heat flow in two ways. On the one hand, the bubble itself can take away a lot of heat from the hot surface, on the other hand they also increase the water around the feather the speed of rising and falling, is simply to strengthen water disturbance, the plume is faster, to strengthen heat transfer, to overcome the traditional mobile regenerative car charger thermal process heat flux density is low, heat transfer power is low, heat transfer time is long, cause loss of heat.

2.2. Experimental Equipment and Process

The experimental system is designed to restore the heat transfer workflow of the mobile regenerator to the greatest extent by simplifying the heat transfer module of the mobile regenerator.

In order to simulate the working process of the mobile heat storage vehicle to the greatest extent, the experimental device is divided into three parts: heating tank, circulation system and heat exchange tank. Among them, the purpose of heating the water tank is to simulate the waste heat energy in the experiment. The temperature of hot water in the water tank is controlled at 75℃ (due to the influence of equipment, the temperature of industrial waste heat cannot be simulated). Due to the excellent heat exchange effect of copper pipe and obvious experimental effect, the industrial heat transfer pipe is simulated with copper pipe with a diameter of 10mm.

The purpose of the circulating system is to simulate the circulating process of heat exchange quality in industry. Therefore, in order to circulate water in the pipeline, a pressurized pump with the power of 86.4W was used in this experiment. The flowmeter is installed in the heat exchange tube to monitor the flow change, which ranges from 5-20l/min.

In the process of the hot water tank to simulate heat transfer working medium and the process of phase change materials for heat transfer, due to the phase change materials is difficult to handle, the water temperature is adopted instead of phase change materials and thermal properties of heat exchange, the initial temperature of 30 ℃, heat transfer working medium by studying the heat water tank, water temperature changes within 5 min of heat-exchange effect of equivalent substitution.

The heat transfer process of mobile heat storage can be simplified as Figure 1:
3. Experimental Results and Analysis

3.1. Pre-experiment: Simulation

3.1.1. Method 1: Numerical Fitting + Computer Simulation. The relationships of upsilon to the qualitative temperature $T$ were fitted by means of interpolation on the upsilon's Pr, dynamic viscosity, and thermal conductivity, and the upsilon was concluded as follows:

$$\lambda = -6.06 \times 10^{-6} t^2 + 0.0017 t + 0.5687$$

$$\Pr = \frac{239.3}{(17.04 + t)}$$

$$\nu = 1.428 \times 10^{-6} e^{-0.027t} + 2.495 \times 10^{-7} e^{-0.0027t}$$

and the upsilon was well fitted.

In this preliminary experiment, experiments and physical properties related to HFE were extracted from the literature, and according to the principle, the addition of HFE could influence the disturbance of the system, namely, it was related to Reynolds number. According to the above fitting formula, a
three-dimensional relation diagram of velocity, temperature and Reynolds number could be drawn (Figure 3).

![Figure 3. Three-dimensional diagram of the relationship between velocity, temperature and Reynolds number](image3.png)

As can be seen from FIG. 3, when the flow rate $U$ and temperature $T$ both rise, the surface color gradually changes from blue to yellow, and the Reynolds number also gradually increases, which represents the enhancement of heat transfer working medium disturbance. Therefore, the relationship between velocity $u$ and temperature $T$ is used to characterize the degree of disturbance. Based on the upsilon's relationships, the upsilon's heat transfer coefficient $H$ is established as follows:

$$h=0.0489(u/\upsilon)^{0.8}Pr^{0.3}$$

$\lambda$, heat flow density $q=h(200-2t)$ (assume the upsilon temperature is fixed at 100 °C), and the following two diagrams are plotted (here the upsilon is set at 1.5% HFE7000).

![Figure 4. Simulation result diagram](image4.png)

(a) When the fluid is water                (b) When HFE is added

In FIG. 4, the points on the surface corresponding to the flow velocity $u$ and the qualitative temperature $T$ are the heat flux values. Compared with FIG. 4 (a) and (b), under the same condition of $U$ and $T$, HFE can increase the heat flux $Q$ as a whole by about 2 times, so this experiment is feasible.

3.1.2. Method 2: CFD Simulation. Used in this study ANSYS19.0 workbench module of fluid in pipe domain for grid division and numerical calculation, when we join the HFE, $K$ - epsilon turbulence model in a certain mass flow rate of hydrogen fluoride ether gas-liquid two phase particles and particle state using the rebound DPM model, simulate the velocity distribution after China's entry into wto and the particle trajectory (as shown in figure 5).

All parameters: initial velocity 1.5m/s, total length 3m, diameter 10mm, wall thickness 2mm.
Through simulation it can be seen that the deeper the color orange color, represents the faster the speed, (a) (b) two image contrast, particles into the relative velocity of fluid in pipe, enhance the disturbed state of the entire tube, to enhance the turbulence level, improves the convective heat transfer coefficient, so once again proved that the project is feasible.

3.2. Experiment 1: The Effect of Different Kinds of HFE on Heat Transfer

This experiment will compare the different heat transfer effects of three HFE(HFE7000, HFE7100 and HFE7200). We used the equivalent substitution method and the control variable method. In the experiment, we controlled the temperature of the water in the heating zone to remain unchanged, added water into the heat exchange zone, and measured the heat exchange heat and final temperature of the water in the heating zone within 5 minutes to characterize the heat exchange intensity in the tube, and compared the varieties with the best effect.

Experimental parameters: the fluid flow velocity was controlled with variable speed, and the volume flow was controlled within 5L/ min-20L /min. After calculation, this section was all the sufficiently turbulent area in the tube, and the temperature of the heating area was controlled within 75℃, and the initial temperature in the heat exchange box was all 30℃.

In this experiment, heat exchange experiments were conducted under 10 flow rates respectively, and the influence of three HFE on the final temperature was plotted (FIG. 6).
It can be seen from Figure 9 that the three broken lines after adding HFE are all above the broken lines before adding HFE, which can improve the final temperature of water in the box body, indicating that the addition of the three HFE can improve the heat transfer effect. Among them, the HFE7000 broken line is at the top, and the final temperature is the highest. When the flow rate is 20L/min, the final temperature can reach 57℃, making the heating rate of the water in the tank up to 6℃/min. HFE7000 was 63.6% higher than that without HFE7100 and HFE7200. HFE7100 and HFE7200 could also increase heat exchange by 42.3% and 31.25%.

3.3. Experiment 2: The Effect of Mixing a Variety of Fluids on Heat Transfer
A single fluid has an obvious effect on the heat transfer effect. This optimization experiment verifies the effect of mixing multiple fluids on the heat transfer effect. The three materials were combined (all with a concentration of 1.5%): "HFE7000+HFE7100", "HFE7000+HFE7200", "HFE7200+HFE7100", "HFE7000+HFE7100+HFE7200".

![Figure 7. Change of final temperature with flow at different concentrations](image)

It can be seen from Figure 7 that the four broken lines with HFE7000 added almost coincide with the broken lines with HFE7000 added only, which indicates that compared with the combined addition alone, the final temperature does not change significantly and the heat transfer effect does not improve significantly. Economic issues should also be considered comprehensively. So we eliminated the method of adding the working medium combination.

3.4. Experiment 3: The Effect of HFE Concentration on Heat Transfer

![Figure 8. Change of final temperature with flow at different concentrations](image)
It can be seen from Figure 8 that the HFE7000 broken line with a concentration of 1.2% is at the top, and the heat transfer effect is the best, and the final temperature can be raised to 62°C at the highest. However, when the concentration increases to 1.5%, the final temperature decreases instead. It can be known that the heat transfer effect is best when the concentration is about 1.2%. When the flow rate is 20L/min, HFE7000 can increase the heating rate to 6.4°C/min and heat exchange by 69.6%.

4. Conclusion

This paper combined HFE enhanced heat transfer technology with mobile heat storage system, verified the effect of HFE on shortening heat transfer time by simplifying the industrial heat transfer process, and drew the following conclusions:

1) It is found in this experiment that all the three HFE can greatly improve the heat transfer effect and shorten the heat transfer time, among which HFE7000 has the most significant improvement in the heat transfer effect.

2) When the volume concentration of HFE7000 reaches 1.2%, the heat transfer effect can be increased by 69.6% at the highest and by more than 58% on average, showing a very significant optimization effect.

3) Mixed addition of various HFE has no obvious effect on the improvement of heat transfer effect.

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