Experimental performance of a phase change material-based road/rail container for cold chain transportation

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Introduction

The fast-rising demand for fresh food and increasing awareness of worldwide environmental urgently require the upgrade of current cold chain transportation technology. This paper presents the operational achievements of a phase change material-based cold energy storage container which was used for both rail and road cold chain transportation. The innovative container consists of 10 cold energy storage plates which contain the phase change materials. A separate charging facility was set up to charge the thermal energy storage plates. The charged container was then shipped by both rail and road carrying four kinds of typical fresh vegetables and fruits. The charging time and efficiency, the internal temperature and relative humidity of the container during the delivery, the system COP was revealed. The energy, cost and environmental comparisons with these of the diesel-powered reefer container were carried out. The quality of the carrying items before and after the shipping was compared as well.

2. Experimental Set-up

2.1 Charging facility

A separate charging facility was set up which was used to charge the container. As illustrated in Fig. 1, the charging facility mainly consists of the electricity-powered refrigeration unit, a heat transfer fluid (HTF) storage tank and a cycling pump. The cycling pump was used to cycle the HTF between the tank and the container through the charging loop.

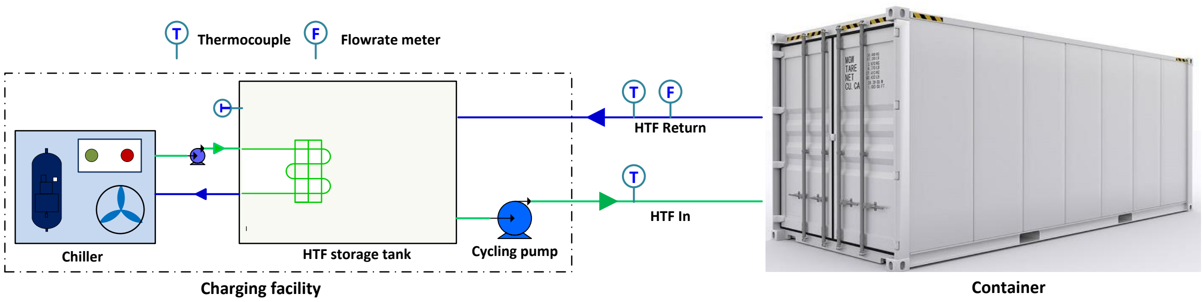

Fig. 1 Schematic of the charging process

2.2 Materials

2.2.1 PCM

The PCM RT5 was purchased from Rubitherm Company (Germany). The latent heat, melting and solidification temperature and the specific heat capacity of the PCM are summarised in Tab. 1.

Tab.1 Thermo-physical properties of the PCM

Density kg/m³	Latent heat kJ/kg	Melting/freezing point °C	Specific heat capacity kJ/kg·K	Thermal conductivity W/(m·K)
880(l)/770(s)	180	4.96/4.84	2.0 ±0.2	0.2

2.2.1 HTF

The 25 wt. % Ethylene glycol (EG) aqueous solution was used as the HTF. The thermos-physical properties of the HTF (at -5 °C) are shown in Tab.2.

Tab. 2 Thermo-physical properties of the HTF

Density kg/m³	Freezing point °C	Specific heat capacity kJ/kg·K	Thermal conductivity W/(m·K)
1025	-10.7	3.89	0.49

2.3 Thermal energy storage plate

The cold TES plate mainly consists of a shell and the embedded tubes which are used as the charging loop. The outer size of the cold TES plate is 1.8(Length) *1.0(Width) *0.1(Height) m, which is shown in Fig.3.

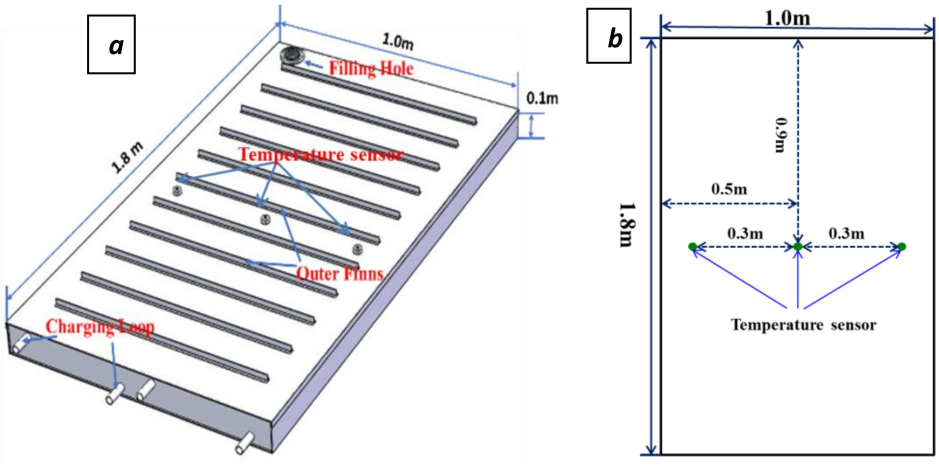

Fig.3 The detailed three-dimensional view of a TES plate (***a***) and the locations of temperature sensors (***b***).

Before the installation, the liquid phase PCM was filled into the plates through the filling hole (See Fig.3 as well). For each plate, 126 kgs of PCMs were filled. For each plate, three temperature sensors (RTD (PT100) probes) with the uncertainly at ±1% were installed with the insertion depth at 0.05m. The locations of the thermocouples were shown in Fig.3b.

2.4 Container

The outside dimensions of the TES container are 12.192(Length)*2.43(Width)* 2.896(Height) m. Ten TES plates were installed inside the container. The distributions of the plates and the temperature & relative humidity sensors are shown in Fig.4(a). One sensor was fixed on the external surface of the container which was used to obtain the ambient temperature and RH.

The transient temperature and RH were recorded through a wireless data logger system. The temperature sensors (RTD (PT100) probes)and the RH sensors were calibrated by the suppliers showing the uncertainly at ±1% and ±3%, respectively. This indicates good reliability of the experiment data. The photo of the plates and the charging loop inside the container are shown in Fig. 5(b).

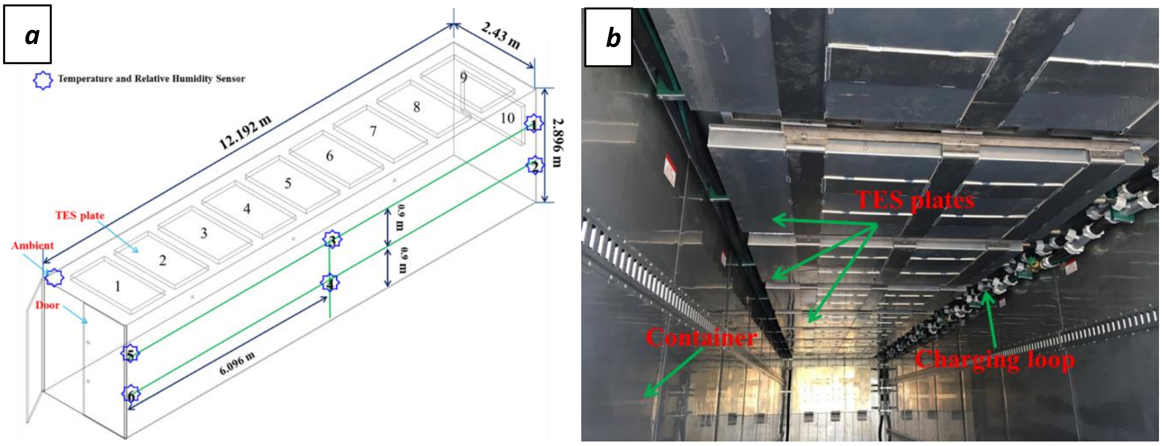

Fig.4 The locations of the plates and the sensors (a), the photo of plates and the charging loop inside the container (b).

2.5 Road & rail transport

After fully charged, the container was loaded with four kinds of typical items including the Strawberry, Mango, Lettuce and Leaf lettuce. The container was transported by the truck first and was then transferred to rail transportation. The total distance was ~2500 km which took up to 96.4 hours. During the whole process, the internal temperature and RH at various locations were recorded by the data logger system. The quality of shipped items inside the container before and after the transportation was compared.

Conclusion

This paper studied a PCM-based cold energy storage container that was used for cold chain transportation. The charging rate and efficiency, the internal temperature and relative humidity of the container under the dynamic operation, and the system COP was presented. The energy, cost and environmental benefits, compared with the diesel-powered reefer container, was revealed. The quality of the carrying items before and after the shipping was shown as well.

The proposed container performs stabilized and uniformly internal temperature with discharging time up to 94.6 hours. The charging time was found to be 6 hours with charging efficiency at 38.6%. The internal RH located between 80-90% which is suitable to maintain the good quality of the shipping items. The system COP can achieve up to 1.84 which is higher than that of the diesel-powered reefer container. The energy consumption decrease, operation cost-saving, and emission reduction are found to be 86.7%, 91.6%, and 78.5%, respectively. Both the visual check and the qualified evaluation prove the high reliability of the TES-based container for fresh food transportation. What's more, the container can be transferred between the road and rail without extra energy supply. The improved flexibility and performance enhancement allow the container to be more feasible for real applications with reduced risks during the transfer.

Acknowledge

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