Journal of Energy Research and Reviews

Volume 16, Issue 1, Page 12-20, 2024; Article no.JENRR.111813
ISSN: 2581-8368

Performance Assessment of Solar Ice Slurry Cold Storage System for Solar Refrigerated Vehicle

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2024/v16i1327

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/111813

Short Research Article

Received: 08/11/2023
Accepted: 11/01/2024
Published: 16/01/2024

ABSTRACT

This article mainly analyzes the ice slurry cold storage system in solar refrigerated vehicles, calculates and studies the thermal properties of the ice slurry, the cold load of the refrigerated vehicle, and the solar photovoltaic panels, and calculates the fuel savings of using solar power generation. Study the demand for ice slurry in ice slurry storage systems under different energy utilization efficiencies, analyze the economy of solar ice slurry generation systems, and calculate the recovery period of the system in this paper. The daily power generation of solar photovoltaic panels can run the electric motor for 2.93 hours. The solar refrigerated truck can save 7.91 liters of oil per day and reduce carbon dioxide emissions by 1.25×107 liters per day. The average annual electricity cost savings are 4026.67 CNY. Based on the total cost of the photovoltaic energy storage hybrid quality system, it will take 3.89 years to recover the cost. Calculate the density and enthalpy of the ice slurry based on the thermophysical model of the ice slurry, and provide different utilization amounts for the ice slurry mass generated by the ice slurry generation system at different efficiencies. Calculate the total weight of the ice slurry system.

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Keywords: Ice slurry; solar energy; cold storage system; refrigerated truck.

1. INTRODUCTION

Ice slurry is a pumpable solid-liquid phase change material (PCM) containing a large number of small ice crystal particles. The diameter of ice crystals is generally within the range of 0.1~1mm, and it has the advantages of large latent heat of phase change and high heat transfer efficiency [1,2]. Ice slurry is also commonly referred to as a secondary refrigerant or heat transfer fluid. Ice slurry can serve as both a heat exchange medium for cold energy carriers and a cold storage medium for cold energy storage. It has been widely used in many fields of cold and hot energy storage, such as renewable energy storage, power peak shaving and valley filling, building energy conservation, and new energy vehicles [3]; Due to the solid-liquid phase transition accompanying the flow and heat transfer of ice slurry, ice particles release a large amount of cold energy during the phase transition process, and can maintain the fluid at a relatively low temperature level. Therefore, it has significant advantages in the field of phase change cold storage [4]. In the construction industry, the electricity consumption of building refrigeration and air conditioning accounts for a large proportion of the total energy consumption of buildings, especially during the summer daytime in commercial and office centers in cities. The use of an ice slurry cold storage system can utilize relatively inexpensive electricity at night for ice storage, releasing cold energy during peak electricity usage during the day, thereby achieving the goal of peak shaving and valley filling, and reducing operating costs. Many scholars [5,6] believe that ice slurry not only has the potential to become a cold and heat source for air conditioning, but also has the potential to become a cooling medium in various fields. At present, the use of ice slurry as a medium in cold storage systems has been applied in various cooling scenarios, mainly in areas such as energy conservation and environmental protection, factory and building cooling, and large-scale shopping mall refrigeration [7], to meet the growing cooling needs.

Due to its refrigeration unit, refrigerated trucks have higher energy consumption and emissions than ordinary trucks, and traditional refrigerated trucks still rely on fossil fuels for power supply. Solar energy is abundant in summer resources, and the demand for refrigerated trucks in summer is correspondingly increasing. Therefore, the combination development of solar energy and refrigerated trucks [8] is increasingly attracting market attention. Some domestic companies have also conducted research and development on solar powered refrigerated vehicles. Henan Song Chuan Refrigeration Technology has developed and manufactured a solar powered refrigerated vehicle, which relies entirely on solar panels installed on the roof to power the refrigeration system. The remaining electricity is stored in the battery and can be used for cooling at night without consuming diesel, reducing exhaust emissions, However, the refrigerated truck did not take into account the low power generation rate of the solar panels during continuous cloudy and rainy days, and the refrigerated truck will not be able to work for cooling. At present, there is relatively little academic research on the application of solar energy in refrigerated vehicles.

Considering that dynamic ice slurry, as a new type of refrigeration material, has superior heat transfer and energy storage characteristics compared to chilled water, Bellas [9] compared the heat transfer performance of ice slurry and chilled water through experiments. The results showed that under the same conditions, the cooling capacity of ice slurry with an ice content of 5% to 30% was 5-6 times that of chilled water, and its fluidity was good. Gao et al. [10]. prepared water-based graphene oxide (GO), Al2O3, and GO Al2O3 composite nanofluids using a two-step method, and studied the effect of thermal cycling on the stability and thermal conductivity of nanofluid ice slurry. The results showed that as the phase transition cycle increased, the stability gradually decreased, and the minimum temperature of thermal cycling decreased. Finally, it was found that the mixed nanofluid ice slurry can ensure the dispersion stability and thermal conductivity of the fluid. Gao et al. [11]. simulated the flow state of ice slurry in a horizontal circular pipe based on the Euler-Euler dual fluid model particle dynamics method. The study found that during the flow process, ice crystals tend to aggregate at the top of the pipe, and the uniformity of ice crystals increases with the increase of flow rate and IPF. At an IPF of 10%, compared with pure water ice slurry and water, the heat transfer coefficient increased by about 9% and 15%, respectively. Gao et al. [12]. established an experimental device for producing ice slurry using an opposed nozzle impingement jet, and the results showed that the IPF decreased with increasing initial water temperature. Within the initial water temperature range of 2.5~10.5 ℃, the maximum IPF of the impingement jet was about 4 times that of the traditional non impingement jet, and its average cooling coefficient was about 1.6 times. Xu et al. [13]. developed an experimental system for measuring transient temperature data during the solidification process of phase change materials. Their simulation results are consistent, using experimental data to accurately predict nucleation temperature and time. The ice crystals in the ice slurry have a higher latent heat of melting, so the ice slurry can have a higher energy storage density, which is of great help in energy storage and emission reduction. Compared with other cold and heat storage systems, the ice slurry system can directly supply the ice slurry storage tank to the cooling coil without the need for other devices, reducing the cost of building the system. In the preliminary experimental research, our research group found that the new refrigeration material ice slurry obtained by the spray method has good cold storage performance and its energy utilization rate is also good. This article analyzes the advantages and disadvantages of the economic performance of the solar ice slurry storage system, and conducts research and analysis on the relevant mechanisms.

2. ICE SLURRY PROPERTY MODELS

The thermal properties of ice slurry depend on the thermal properties of ice crystals and the thermal properties of the carrier fluid solution. Ice crystal particles have a significant impact on the physical properties of ice slurry at different volume fractions, particle concentrations, categories, and sizes. This article selects the ice content IPF=50% in the ice slurry system for calculation, and selects ethylene glycol at -20 ℃ as the refrigerant. The physical properties of ethylene glycol are: volume percentage concentration of 40%, density of 1071.98 kg/m3, and specific heat capacity of 3.334 kJ/(kg·K).

Ice slurry is divided into solid-liquid phases, so it is necessary to analyze the physical properties of its solid-liquid phases: the physical properties of ice crystals and the physical properties of ice slurry.

2.1 Properties of ice crystals [14]

1) The density expression of ice crystals:

$$\rho_{ice} = 916.67 - 0.15T + 3.0 \times 10^{-4}T^2 \quad (1)$$

In the formula: ρ_{ice} is the density of ice, kg/m3; T is the temperature of ice, ℃.

2) The expression for the thermal conductivity of ice crystals:

$$\lambda_{ice} = 2.23 - 9.7 \times 10^{-3}T + 4.7 \times 10^{-5}T^{-2} \quad (2)$$

In the formula: λ_{ice} is the thermal conductivity of ice, W/(m·K); T is the temperature of ice, ℃.

3) The expression for the specific heat of ice crystals:

$$c_{p,ice} = 2106.9 + 7.5982T + 3.2628 \times 10^{-3}T^2 \quad (3)$$

In the formula: $c_{p,ice}$ is the specific heat of ice crystals, kJ/kg; T is the temperature of ice, ℃.

2.2 Properties of ice slurry [15]

1) Density. Due to the small difference in density between the solid and liquid phases in the ice slurry, the density of the ice slurry can be calculated by linear weighting of two different state properties:

$$\rho = \frac{1}{\frac{IPF}{\rho_{ice}} + \frac{(1-IPF)}{\rho_1}} \quad (4)$$

In the formula: IPF is the ice content; ρ1 is the density of the carrier fluid solution, kg/m³

2) Enthalpy. For the two-phase flow of ice slurry, its enthalpy value not only includes sensible heat, but also latent heat generated by the melting of ice crystals in the slurry. Therefore, its enthalpy value also includes latent heat.

The enthalpy value of ice slurry can be obtained by weighting the enthalpy values of ice crystals and carrier fluids, expressed as:

$$H_{il} = H_i \emptyset_i + H_{cf}(1 - \emptyset_i) \quad (5)$$

In the formula, H_{il} is the enthalpy value of the ice slurry, kJ/kg; H_i is the enthalpy value of ice particles, kJ/kg; H_{cf} is the enthalpy value of the carrier fluid, in kJ/kg. Among them, the enthalpy value of ice particles in the ice slurry includes two parts: latent heat and sensible heat, which are expressed as:

$$H_i = -r + c_{p,i}T \quad (6)$$

$$c_{p,i} = 2.12 + 0.008T \tag{7}$$

In the formula, r is the latent heat of ice particles, which is 332.4kJ/kg; $c_{p,i}$ is the specific heat capacity of ice particles, kJ/(kg·K). So the specific enthalpy value expression of ice particles is:

$$H_i = -332.4 + 2.12T + 0.008T^2 \tag{8}$$

The formula for calculating the enthalpy value of the carrier fluid is:

$$H_{cf} = H_w + \Delta H_M + \int_{T_0}^{T} c_{p,cf}\, dt \tag{9}$$

In the formula, H_w is the enthalpy value of water, kJ/kg, which is 4.7841 kJ/kg; ΔH_M is the mixing enthalpy value at the corresponding mass fraction, kJ/kg; $c_{p,cf}$ is the specific heat capacity of the carrier fluid solution, kJ/(kg·K).

By integrating the above formulas, the enthalpy value calculation formula for ice slurry can be obtained:

$$H_{il} = (-r + c_{p,i}T)\emptyset_i + \left(H_w + \Delta H_M + \int_{T_0}^{T} c_{p,cf}\, dt\right)(1 - \emptyset_i)$$

$$= (-332.4 + 2.12T + 0.008T^2)\emptyset_i + (H_w + \Delta H_M + \int_{T_0}^{T} c_{p,cf}\, dt)(1 - \emptyset_i) \tag{10}$$

3. COOLING LOAD ASSESSMENT

3.1 Heat Transfer Coefficient

The length of the refrigerated truck is 9.6m, the length of the cargo box is 7010mm, and the width of the cargo box is 2300mm. The usable top floor area is 16.123m2. The cold insulation material of the compartment is 100 mm thick polyurethane foam, and the two sides are 5 mm thick glass sheet skins.

The calculation formula for the heat transfer coefficient K of the carriage is:

$$K = \frac{1}{\frac{1}{h_0}+\frac{\delta_1}{\lambda_1}+\frac{\delta_2}{\lambda_2}+\frac{\delta_3}{\lambda_3}+\frac{1}{h_{in}}} \tag{11}$$

$$h_0 = 5.67 + 17.5\sqrt{u} \tag{12}$$

In the formula, K - heat transfer coefficient of the carriage, W/(㎡·K);h0 - Surface heat transfer coefficient of the outer wall of the carriage, W/(㎡·K);δ1, δ3 - Thickness of glass sheet on both sides of polyurethane foam, m;λ1, λ3 - Thermal conductivity of fiberglass sheet, W/(m·K) ;δ2 - Thickness of polyurethane foam, m;λ2 - Thermal conductivity of polyurethane foam, W/(m·K) ;h_{in} - Surface heat transfer coefficient of the inner wall of the carriage, W/(㎡·K) ;u - Speed of refrigerated truck, m/s

By substituting the known data into the above equation, the heat transfer coefficient of the carriage can be calculated to be 0.231 W/(㎡·K).

3.2 Cooling Load of Carriage

The cooling load of the carriage [16] includes: the cooling load caused by heat transfer in the carriage, the cooling load generated by the infiltration of hot air into the carriage gaps, the cooling load generated by solar radiation, and the cooling load generated by opening the door when loading and unloading goods.

(1) Cooling load caused by heat transfer in the carriage body

According to the structure of the carriage, the carriage can be regarded as a multi-layer uniform flat wall with good contact between the multi-layer flat walls and no thermal resistance. Cooling load caused by heat transfer in the carriage body the calculation formula for is:

$$\phi_1 = KA(\theta_w - \theta_n) \tag{13}$$

In the formula ϕ1- Cooling load caused by heat transfer in the carriage body, W; A - Calculated heat transfer area of the carriage, ㎡ ; θ_w - calculated temperature outside the carriage, ℃ ; θ_n - Calculated temperature inside the carriage, ℃

By substituting known parameters, the cooling load required for heat transfer in the carriage can be calculated to be 1248.05W.

(2) The cooling load generated by the infiltration of hot air into the gaps of the carriage

It is difficult to accurately calculate the cooling load generated by the infiltration of hot air into the gaps of the carriage. Generally, 10% to 20% of the cooling load caused by the heat transfer of the carriage body is taken, while in this article, 15% is taken. From this, it can be calculated that the cooling load generated by the infiltration of hot air into the gap of the carriage is 187.21W.

(3) The cooling load generated by solar radiation

The cooling load generated by solar radiation the calculation formula for is:

$$\phi_3 = \frac{KA_y t\Delta\theta}{24} \tag{14}$$

In the formula ϕ3- Cooling load generated by solar radiation, W; Ay - The area of solar radiation on the carriage, ㎡, taken as 50% of the calculated heat transfer area of the carriage; t - Daily exposure time of the sun, h; $\Delta\theta$ - The difference between the average surface temperature of the carriage and the calculated temperature outside the carriage, ℃

By substituting known parameters, the cooling load generated by solar radiation can be calculated to be 180.00W.

(4) Cold load generated by opening doors during loading and unloading of goods

Cold load generated by opening doors during loading and unloading of goods the calculation formula for is:

$$\phi_4 = f(\phi_1 + \phi_3) \tag{15}$$

In the formula ϕ4- Cold load generated by opening the door during loading and unloading of goods, W;f - Door opening frequency coefficient

By substituting known parameters, it can be calculated that the cooling load generated by opening the door during loading and unloading of goods is 714.03W.

(5) Total cooling load

From the above data, it can be calculated that the required total cooling load ϕ is 2329.29W. The parameters used for calculation are shown in Table1.

4. ELECTRIC POWER PRODUCED BY PHOTOVOLTAIC PANELS

Select NP12-250AH type battery with a capacity of 250 A·h and a working voltage of 48 V. Select JKM335M-60 photovoltaic panel [17] with a single peak power of 335W, a peak output voltage of 34.0 V, a peak output current of 9.87A, and a short-circuit current of 10.36 A. Select a KV-300 electric compressor, a three-phase asynchronous motor with an input power of 1464W and a rated working voltage of 380V.

4.1 Photovoltaic Panel Components

1) Number of photovoltaic panels in series n_s

$$n_s = \frac{U_p}{U_m} \tag{16}$$

In the formula, n_s is the number of photovoltaic panels connected in series; U_p is the actual voltage of the photovoltaic panel module, V; U_m is the peak output voltage of a single photovoltaic panel, V

The actual voltage of photovoltaic panel components is taken as 1.4-1.5 times the working voltage of the battery, and this calculation is taken as 1.4 times. The working voltage of the battery is 48V, so the actual voltage of the photovoltaic panel module is 67.2V.

It can be calculated that the number of photovoltaic panels connected in series is 1.98, taking 2.

2) Number of photovoltaic panels in series n_p

$$n_p = \frac{\varphi t_d P}{U t_a I_m \eta_B f_e S_p} \tag{17}$$

Table 1. Coefficients and parameter values

Coefficient	Symbol	Value	Unit
Thermal conductivity of fiberglass sheet	λ1, λ3	0.4	W/(m K)
Thermal conductivity of polyurethane foam	λ2	0.024	W/(m K)
Surface heat transfer coefficient	h_{in}	8	W/(m K)
Speed of refrigerated truck	u	24	m/s
Heat transfer area of the carriage	A	104	m^2
Outside temperature	θ_w	32	℃
Inside temperature	θ_n	-20	℃
Sunshine duration	t	12	h
Temperature difference	Δθ	30	℃
Door opening frequency coefficient	f	0.5	

In the formula, n_p is the number of parallel photovoltaic panels; φ is the tilt angle correction coefficient for solar photovoltaic modules; t_d is the maximum continuous working time of the battery, h; P is the rated input power of the motor, W;U is the motor voltage, V; t_a is the annual average daily sunshine time h/d under standard testing conditions; I_m is the short-circuit current of the photovoltaic panel, A; η_B is the charging efficiency of the battery; f_e is the compensation coefficient for the loss of solar photovoltaic modules; S_p is the dust compensation coefficient

It can be calculated that the number of parallel photovoltaic panels is 3.93, taking 4.

3) Number of photovoltaic panels

$$n = n_s n_p \tag{18}$$

In the formula, n represents the number of photovoltaic panels

By substituting known parameters, the number of photovoltaic panels can be obtained as 8.

4) Maximum current, maximum electrical power

The maximum current generated by photovoltaic panels The calculation formula for I_{max} is:

$$I_{max} = n_P I_m \tag{19}$$

In the formula, I_{max} is the maximum current generated by the photovoltaic panel module, A

The maximum electrical power generated by photovoltaic panel components The calculation formula for P_{max} is:

$$P_{max} = nP_m \tag{20}$$

In the formula, P_{max} is the maximum electrical power of the photovoltaic panel, W

P_m is the peak electrical power of a single photovoltaic panel, W

The maximum electrical power generated by the photovoltaic panel components is calculated to be 2680 W.

5. ANALYSIS OF FUEL SAVINGS

Under idle conditions, the rated input power of the electric motor is 3200W, and the calculation formula for the engine's fuel consumption m is:

$$m = \frac{nM_{tq}b}{9550\rho} \tag{21}$$

In the formula, m represents the engine fuel consumption under idle conditions, L/h; n is the engine idle speed, min-1; M_{tq} is the engine torque, N·m; b is the fuel consumption rate; ρ is the density of zero grade light diesel fuel

Substituting known parameters into the equation yields a fuel consumption of 2.7L/h.

The calculation formula for the daily power generation Ed of photovoltaic panel module design is:

$$E_d = P_{max} t_a \eta \tag{22}$$

$$\eta = \eta_k \eta_n \eta_b \tag{23}$$

In the equation, E_d is the designed daily power generation of photovoltaic panel modules, W·h/d; η is the system conversion efficiency; η_k is the efficiency of the photovoltaic controller; η_n is the conversion efficiency of the inverter; η_b is the conversion efficiency of the frequency converter

By substituting the above parameters, the designed daily power generation of the photovoltaic panel module is 9360.49 W·h/d, and it can be obtained that the designed daily power generation of the photovoltaic panel module can operate the motor for 2.93 hours. From this, it can be concluded that the solar ice slurry system can save 7.91 liters of fuel per day. The density of zero grade light diesel is 840g/L, and the carbon dioxide emissions per liter of diesel are 1.58×10^6 liters, can save 7.91 liters of fuel per day, can reduce carbon dioxide emissions by 1.25×10^7 liters per day. The parameters used for calculation are shown in Table 2.

6. ANALYSIS OF ICE SLURRY QUANTITY IN SOLAR ICE SLURRY SYSTEM

6.1 Quality Analysis of Ice Slurry System

The refrigeration unit of the ice slurry refrigeration system uses ice slurry as the cold storage medium. Ice slurry is introduced into the heat exchange tube, and the air temperature is reduced through the low-temperature latent heat of the ice slurry and the heat exchange with the hot air. Then, the cold air is blown into the chamber through a blower. Copper is used as the main material for the pipeline, and due to its good insulation, the inner and outer walls of the pipeline can be regarded as having the same temperature. The pipeline is embedded in the carriage with 34mm copper pipes, with a length of 460mm and a thickness of 2mm. 25 copper pipes are selected as the heat exchange pipes. The total weight of the heat exchange copper tubes used is 20.3kg.

The refrigeration unit uses ice slurry as the storage medium, and the ice slurry needs to be stored in an ice storage cylinder. Therefore, we have chosen an ice storage bucket with a height of 900mm, a bottom diameter of 575mm, a thickness of 10mm, and a volume of 0.234 m2. If 60% of the volume of ice slurry is filled during operation, the mass of the ice slurry is 134.88kg. The total cooling load calculated earlier ϕ is 2329.29W, this article conducts different calculations and analyses on different energy utilization rates. The energy utilization rate in the system is 60%, so we need a cooling capacity of 3882.15W generated by the ice slurry. Assuming the refrigeration system operates for 10 hours, the required energy for the refrigeration system is 38.82 kW·h, which is 139757 kJ. The physical properties of the ice slurry above indicate that the mass of ice slurry required to generate so much energy is 186.46kg. It can be concluded that the total weight of the slurry refrigeration system is 341.64kg. The energy utilization rate in the system is 70%, so the cooling capacity generated by the ice slurry we need is 3327.56W. Assuming the refrigeration system operates for 10 hours, the required energy for the refrigeration system is 33.28 kW·h, which is 119792 kJ. The physical properties of the ice slurry above indicate that the mass of ice slurry required to generate so much energy is 159.82kg. It can be concluded that the total weight of the slurry refrigeration system is 315kg. The energy utilization rate in the system is 80%, so we need 2911.61W of cold energy generated by the ice slurry. Assuming the refrigeration system operates for 10 hours, the required energy for the refrigeration system is 29.12 kW·h, which is 104818 kJ. The physical properties of the ice slurry above indicate that the mass of ice slurry required to generate so much energy is 139.85kg. It can be concluded that the total weight of the slurry refrigeration system is 295.03kg.

6.2 Economic Benefit Analysis of Solar Power Units

If the above-mentioned solar refrigerated vehicle ice slurry system is adopted, the required equipment is shown in Table 3.

According to calculations, the daily charging capacity of the solar panel for the battery is 9360.49 W·h/d, all of which is used to drive the refrigeration system. Therefore, the annual charging capacity is 3369.6 kW h. On average, calculated at 1.195 yuan per kilowatt hour, it can save 4026.67 yuan per year. As the total cost of a photovoltaic energy storage hybrid refrigeration system is about 15700 CNY, it will take 3.89 years to recover the cost.

Table 2. Coefficients and parameter values

Coefficient	Symbol	Value	Unit
Angle correction coefficient	φ	0.95	
Maximum continuous working time of battery	t_d	14	h
Rated input power of electric motor	P	1464	W
Motor voltage	U	380	V
Annual average daily sunshine duration	t_a	4	h/d
Charging efficiency of batteries	η_B	0.85	
Loss compensation coefficient	f_e	0.9	
Dust compensation coefficient	S_p	0.9	
Engine idle speed	n	800	min-1
Engine torque	M_{tq}	140	N m
Fuel consumption rate	b	200	g/(kW h)
Zero light diesel density	ρ	840	g/L
Efficiency of photovoltaic controllers	η_k	0.99	
Conversion efficiency of inverters	η_n	0.9	
Conversion efficiency of frequency converters	η_b	0.98	

Table 3. Equipment status of solar refrigerated vehicle ice slurry system

Component	Type	Number	Unit	Unit price (CNY)	Total price (CNY)
Solar panels	JKM335M-60	2	set	570	1140
Photovoltaic controller and inverter	PC18-6015F JYP-5K-2	1 1	set set	1800 2780	4580
Storage battery	NP12-250AH	4	piece	1200	4800
Refrigerator	KV300	1	set	5000	5000
Other auxiliary materials	Components: power supply connection lines	1	set	180	180
Total					15700

7. CONCLUSION

This paper calculates and analyzes the ice slurry storage system of a solar powered refrigerated vehicle, mainly focusing on the thermal properties of the ice slurry, the cold load of the refrigerated vehicle, and the solar photovoltaic panels. It estimates the reduction of carbon dioxide emissions by using solar power generation and draws the following conclusions:

(1) The daily power generation of solar photovoltaic panels can run the electric motor for 2.93 hours and save 7.91 liters of fuel per day for solar refrigerated trucks. The daily carbon dioxide emissions can be reduced to 1.25×10^7 liters The average annual electricity cost savings are 4026.67 CNY. Based on the total cost of the photovoltaic energy storage hybrid quality system, it will take 3.89 years to recover the cost.

(2) The refrigeration unit of the ice slurry refrigeration system uses ice slurry as the storage medium, and ice slurry is introduced into the heat exchange tube. The heat exchange tube and ice slurry cylinder are designed, and the ice slurry density and enthalpy value are calculated through the ice slurry thermal property model. Different utilization amounts of the ice slurry generated by the ice slurry generation system are given at different efficiencies, and the total weight of the ice slurry system is calculated.

ACKNOWLEDGEMENTS

This study is supported by Key Research and Development and Promotion Project in Henan province- Science and Technology (International Cooperation) (182102410087, 222102520016); The funding from Henan Province of China under Henan International Joint Laboratory of Thermo-fluid Electro-chemical System for New Energy Vehicle.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ziad Youssef et al. State of the art on phase change material slurries[J]. Energy Conversion and Management. 2013;65: 120-132.
2. Song Wenji, Feng Ziping, Xiao Rui. Progress in ice slurry technology and its applications [J]. New Energy Progress. 2019:7(02):129-141.
3. Liu Shengchun, Rao Zhiming, Sun Zhili The application of dynamic ice slurry in multiple fields [J] Low Temperature and Superconductivity. 2011;39(009):71-76
4. Liu Shengchun, Hao Ling, Ning Ning Hong. Review and simulation analysis of heat transfer characteristics of ice slurry flow [J]. Low Temperature and Superconductivity. 2015;43(11):59-65+77.
5. Kauffeld M, Wang M J, Goldstein V, et al. Ice slurry applications[J]. International Journal of Refrigeration. 2010;33(8):1491-1505.
6. Zhang P, Ma Z W. An overview of fundamental studies and applications of phase change material slurries to secondary loop refrigeration and air conditioning systems[J]. Renewable and Sustainable Energy Reviews. 2012;16(7): 5021-5058.
7. Saito A. Recent advances in research on cold thermal energy storage[J]. International Journal of Refrigeration. 2002;25(2):177-189.
8. Li Yong. Research on energy management strategies for solar refrigerated transport vehicles [D]. Jiangsu University; 2018.

9. Bellas J, Chaer I, Tassou S A. Heat transfer and pressure drop of ice slurries in plate heat exchangers[J]. Applied Thermal Engineering. 2002;22(7):721-732
10. Gao Y. et al. Influence of thermal cycling on stability and thermal conductivity of nanofluid ice slurry, International Journal of Thermal Sciences. 2023;185: 108113.
11. Gao Y. Ning Y, Xu M, Wu C, Mujumdar AS, Sasmito AP, Numerical investigation of aqueous graphene nanofluid ice slurry passing through a horizontal circular pipe: heat transfer and fluid flow characteristics, International Communications in Heat and Mass Transfer. 2022;134:106022.
12. Gao Y, et al. Experimental investigation of producing ice slurry with water using opposed-nozzle impinging jet method, Applied Thermal Engineering. 2023;219: 119568.
13. Xu M, Gao Y, Fang F, Akhtar S, Chaedir BA, Sasmito AP. Experimental and unified mathematical frameworks of water-ice phase change for cold thermal energy storage, International Journal of Heat and Mass Transfer. 2022;187:122536.
14. Jiang Jinjun. Production process and thermal properties analysis of ice slurry [J]. Coal Mine Safety. 2013;44(12):169-171.
15. Xie Xiaokai. Flow characteristics and thermodynamic analysis of ice slurry [D]. Hunan University of Science and Technology; 2017.
16. Chen Peng. Development and performance research of a new type of solar powered secondary semiconductor refrigeration refrigerated vehicle [D]. Harbin University of Commerce; 2022.
17. Liu Zhiqiang. Design of Solar Light Refrigerated Vehicle System [D]. Southwest Jiaotong University; 2017.

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