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Ultrasonic wave promoting ice melt in ice storage tank based on polynomial fitting calculation model

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Abstract

The existence of floating ice in ice storage tanks in an ice storage system affects the normal operation of the ice storage automatic control system. For the ice storage tank in an ice storage system, the ice "problem", puts forward the way of melting ice in an ultrasonic assisted manner. This paper establishes a polynomial mathematical model of observation data changes over time, by setting a variable's value used to model the polynomial fitting method. It could be used in the design and operation index model or higher polynomial model fitting process of melting ice. Ultrasonic wave is used to solve the floating ice problem of ice storage tank in the operation of ice storage, and the effects of ultrasonic power density, ice-water ratio, ice size, initial ice amount and other parameters on the characteristics of ice melting are tested and analysed through experiments, which provides an important reference for the practical application of this technology. It is found that the ultrasonic wave can obviously promote and strengthen the melting of ice, and the influence of power, ice–water ratio and ice size conforms to the normal theory and practice law. The greater the power, the smaller the ice–water ratio and the smaller the ice size, the faster the melting speed will be. Due to the multiple effects of technology and economy, the power density has an optimal value, which needs to be optimised according to the actual situation in the application. For large size ice, the promotion effect of high-power ultrasonic on melting ice is more obvious.

Keywords: ice storage, ultrasonic wave, melting ice, power density.
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1 Introduction

With the development and progress of society, the application of new technologies in the construction industry has achieved rapid development, and the popularity rate of ice storage central air conditioning in large public buildings is increasing day by day. Ice storage central air conditioning is one of the most effective energy storage methods on the demand side because of its good peak-shifting and valley filling function on the power grid. For users, the outstanding advantages of cold storage air conditioning include low outlet temperature of air conditioning, good refrigeration effect, low temperature air supply system to save investment and fan energy consumption. The dehumidification effect is remarkable, the air conditioning environment relative humidity is low and the air quality is improved. The peak-valley price difference is used to balance the power grid load and reduce the investment in power construction; reduce the annual operating cost of air conditioning; reduce the capacity of chillers and reduce one-time investment. The system has high reliability. In the case of failure or power failure of the main engine, the cold storage system can be used as an emergency cold source. To cope with the changeable cooling load changes, the system adjustment is more convenient and flexible, and the cooling capacity expansion elastic space is large.

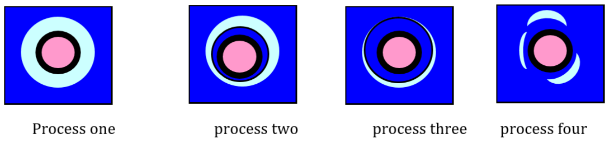
The cold storage system mainly includes ice storage and water storage, each of which has its own advantages and disadvantages and has a wide range of applications. Although ice storage has the advantages of small space volume and large storage capacity, it also has some problems, such as slow melting speed, complicated control and floating ice in ice storage tank, which has become the focus of research and technical improvement in this field. At present, ice storage technology has experienced three generations of development. The first generation is ice storage, the second generation is ice coil storage and the third generation is dynamic ice storage. The research focus includes the development of technology and equipment for ice making and storage, melting and cooling, transportation, development of cold media, optimisation algorithm and control of the system. In China, the second-generation cold storage technology has been widely used due to its comprehensive advantages such as reliability and economy, but the problems exposed by it cannot be ignored. For example, the problem of "floating ice in ice storage tank" in the ice storage tank seriously affects the release of cold quantity in the ice storage system and reduces the effect of cold storage.

"Ice storage tank ice" problem is static ice storage system's ills, the coil in the process of melting ice, part of the ice tube icicles formed pieces. These pieces that form ice floats not only limit the release of cold quantity, but making the ice storage cold ice sensor is difficult to accurately control the system work, affecting the automation control of the system. At present, the common method used by the ice storage industry and research institutions at home and abroad to solve the problem of "floating ice in the ice storage tank" is to melt the ice through air stirring and compressed air heating. However, the problem for this solution is that the energy consumption of the fan increases the energy consumption of the system, and the heating of the air also consumes a large amount of cold capacity in the ice storage tank, which is not conducive to the energy saving operation of the system.

In view of the problem of the "floating ice in ice storage tank", this study proposes the technology of ultrasonic melting ice, which makes full use of the cavitation and mechanical effect of ultrasonic to promote the melting of ice. Compared with air stirring, the energy point is more concentrated and the energy consumption is lower. The technology is simple in form and convenient for control, and can be used in the construction of static cold storage system and the transformation of old system. Compared with the current air aeration mode adopted in the industry, it can reduce the energy consumption of the system, and also reduce the loss of cold storage quantity, which is helpful for energy saving. In this paper, the characteristics of ice melting under different ultrasonic power and action time were tested by experiments which provide an important reference for the popularisation and application of this technology.

The formation process of floating ice in ice storage tank

During ice storage and ice melting, the glycol circulating pump is opened to melt the ice on the ice storage coil through the plate heat exchanger and release the cold quantity stored in the ice storage coil. The melting process is divided into four processes, as shown in the figure below:



In process 1, the ice has just started to melt, and there is no water ring between the ice storage coil and the ice. After Process 2 melts for a while, small rings of water begin to appear between the ice storage coils and between the ice sheets. In Process 3, with the extension of melting time, the water ring between the ice storage coil and the ice becomes larger and larger, but the ice is not broken. As the water ring between the ice storage coil and the ice becomes larger and larger, the ice becomes thinner and thinner. Finally, the ice breaks and forms broken ice floating on the surface of the ice storage tank. It cannot be melted for a long time and accumulates more and more until the ice storage tank floating ice is finally formed.

2 Experimental apparatus and methods

2.1 Main experimental devices and parameters

Model of Ultrasonic Cleaner KMD-2812, power 0∼ 600 W, frequency 28 KHz, capacity 300 × 400 × 300 (mm), manufacturer: Shenzhen Komeida Ultrasonic Equipment Co., Ltd.

Electronic balance model JJ1000, precision 0.01 g, manufacturer: Changshu Shuangjie Test Instrument Factory.

Ice mould: bottom 17 × 23 mm, top 28 × 31 mm, high 26 mm (large); Bottom 7 × 12 mm, top 12 × 17 mm, height 14 mm (small)

Ice freezing: −18 °C, time >24 h

2.2 Experimental method

First, clean the ultrasonic cleaning machine, measure a certain quality of tap water and pour it into the ultrasonic cleaning machine tank. The water temperature of the tap water constant at 18 °C during the experiment cycle. Turn on the power supply of the ultrasonic generator, and rotate the power button to adjust to the set value until it is stable. Take it out of the refrigerator and quickly weigh a certain mass of ice cubes and put them into the water tank. At the same time, observe the initial value of water temperature (the initial value in the experiment period is 19 °C), and start the timing. At certain intervals, the ice cubes were quickly removed with a sieve and weighed, and then quickly put back into the tank after weighing, while recording the water temperature, until the ice is basically melted and the whole experiment is over. The laboratory is located in Jinnan area of Tianjin, and the room temperature for the experiment is within the range of 22–24 °C.

The analysis variables were calculated according to the experimental data, in which the power density was the ratio of the power value to the water mass, W/kg water. The ice–water ratio is the mass ratio of ice to water. The residual ice rate is the ratio of the remaining ice mass to the initial ice mass,%.

3 Results and analysis

Ultrasonic is the elastic mechanical vibration wave. When the ultrasonic intensity reaches a certain value in the liquid medium, there will occur a cavitation phenomenon, namely the ultrasonic propagation in the liquid, caused by a kind of peculiar physical phenomena. There is also the production of hollow liquid cavity which grows up, compresses, is closed and bounces in a fast repetitive movement by a peculiar physical process. Local high pressure and high temperature are generated when the cavity collapses and closes. Combined with the mechanical wave characteristics of ultrasonic wave, it can play a good role in promoting the melting of ice. Moreover, due to the good directivity of ultrasonic wave, it can be controlled within the ice in application to improve the efficiency of energy utilisation. In this paper, the effects of ultrasonic power density, ice–water ratio, ice size and initial ice volume on the melting speed and water temperature are tested and analysed by experiments.

3.1 Influence of power density

Power is the most direct factor affecting the effect of ultrasonic wave. The experiment first tested the influence of different power density on the change of ice melting speed and water temperature under the conditions of ice-water ratio 0.2 and initial ice volume 2.3 kg. The results are shown in Figures 1 and 2.

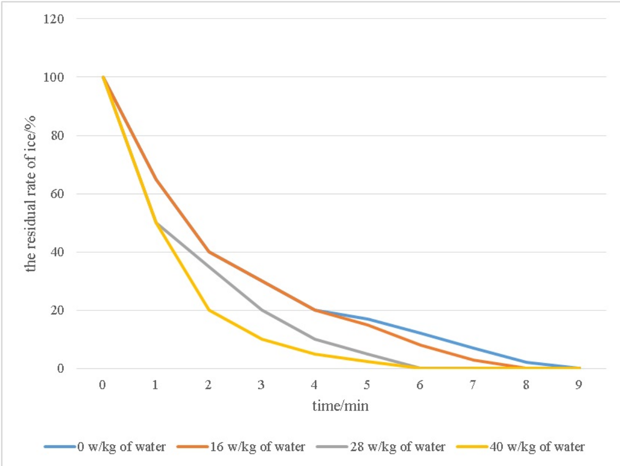


Fig. 1 Influence of power density on melting ice

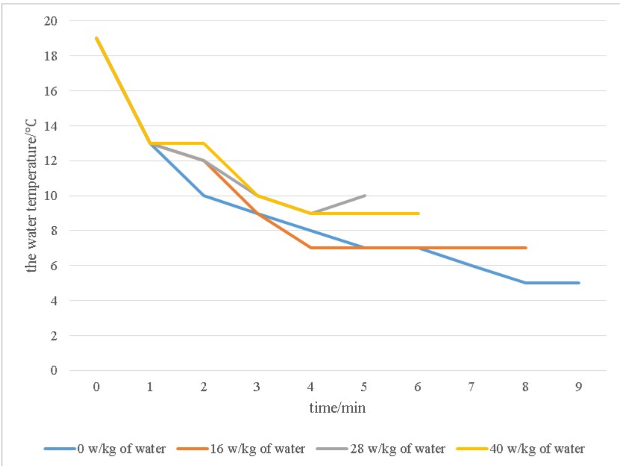


Fig. 2 Influence of power density on water temperature

It can be seen from Figure 1 that, in the absence of ultrasonic wave and under the action of ultrasonic wave with different power, the ice melting speed is not linear, but slows down the ice melting with the increase of time. The main reason is that with the melting of ice, the released cold quantity makes the water temperature decrease gradually (as shown in Figure 2), which reduces the heat transfer and temperature difference of ice water. It can also be seen from the figure that there is no significant difference between the ice melting speed and the water temperature change at the lower power density (e.g., 16 W/kg water) and no supergeneration, while the ice melting speed and the water temperature change at 28 W/kg water and 40 W/kg water are similar under the higher power condition. It shows that the lower power density does not have a significant impact, and the higher power density is not better, which will lead to an increase in energy consumption. Therefore, a comprehensive comparison of the technical performance and economy shows a certain optimal value.

3.2 Influence of ice–water ratio

Two power densities, 16 W/kg water and 40 W/kg water, were selected for the experiment, and the initial water volume was 11.5 kg. The effects of different ice–water ratios on the melting speed and the change of water temperature were tested. The experimental results are shown in Figures 3–6.

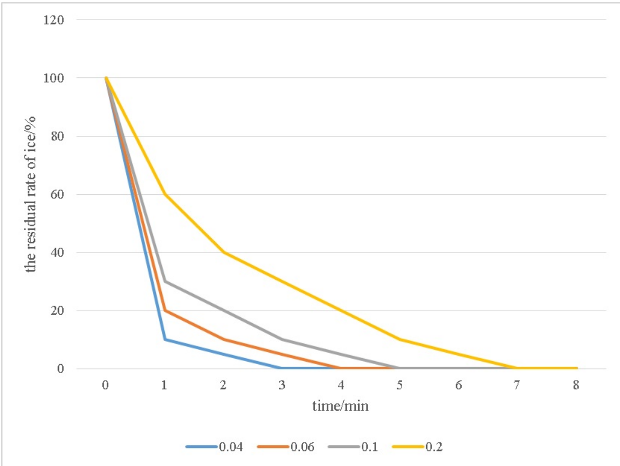


Fig. 3 Influence of ice-water ratio on melting ice (16 W/kg water)

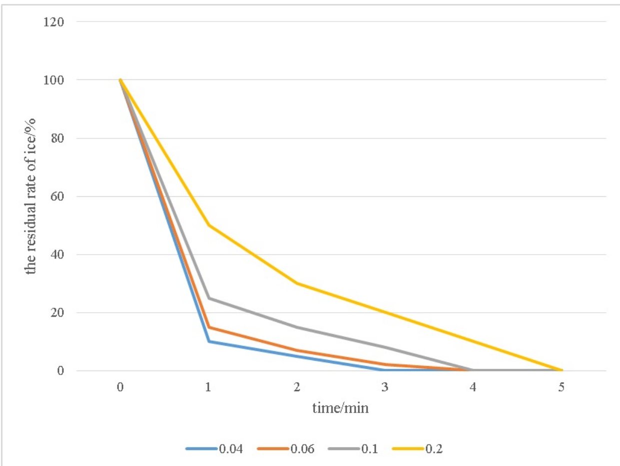


Fig. 4 Influence of ice–water ratio on melting ice (40 W/kg water)

As can be seen from the figure, under two power density conditions, different ice–water ratios have the same law of influence on the change of ice melting speed and water temperature. The larger the ice–water ratio is, the slower the ice melts, the longer the time required for total melting and the lower the temperature of the water temperature at the end. These conclusions are combined with the normal cognition in theory and practice, because under a certain initial water volume, the larger the ice–water ratio, the larger the ice storage capacity, the longer the cooling release time, the slower the ice melting speed and the lower the termination water temperature. Although the larger the ice–water ratio, the more the cold is released to the environment and

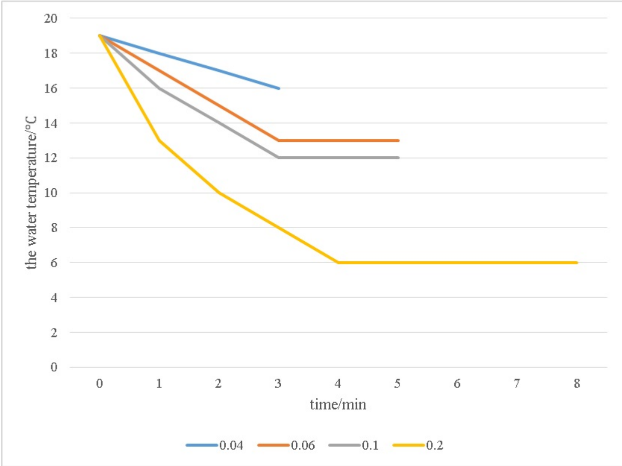


Fig. 5 Influence of ice–water ratio on water temperature (16 W/kg water)

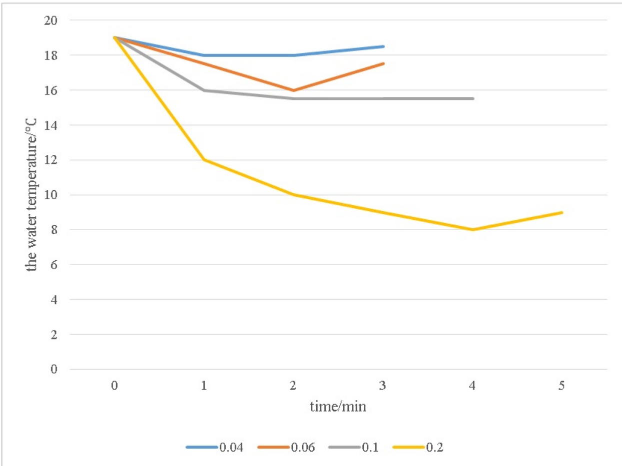


Fig. 6 Influence of ice–water ratio on water temperature (40 W/kg water)

the faster the rate of cold loss, but not enough to offset the difference caused by the increase of cold.

3.3 Influence of ice size

The size of ice block determines the surface area of ice block and then affects the heat transfer area of ice water. In this experiment, the melting velocity of ice under different power density and different ice size combinations was measured. In the experiment, the ice–water ratio was 0.2 and the initial ice mass was 2.3 kg. The results are shown in Figure 7.

As can be seen from the figure, under the same power condition, the melting rate of small ice cubes is significantly faster than that of large ice cubes, especially under the condition of low power (16 W/kg water), the difference is more obvious. Similarly, for large ice cubes, the difference effect of power on ice melting is more obvious when ice melting is difficult.

3.4 Influence of initial ice volume

The effects of different initial ice amount on melting speed and water temperature were tested under the conditions of ice–water ratio 0.2 and power density 40 W/kg water. The results are shown in Figures 8 and 9.

As can be seen from the figure, since the ice–water ratio and power density are the same, the influence of

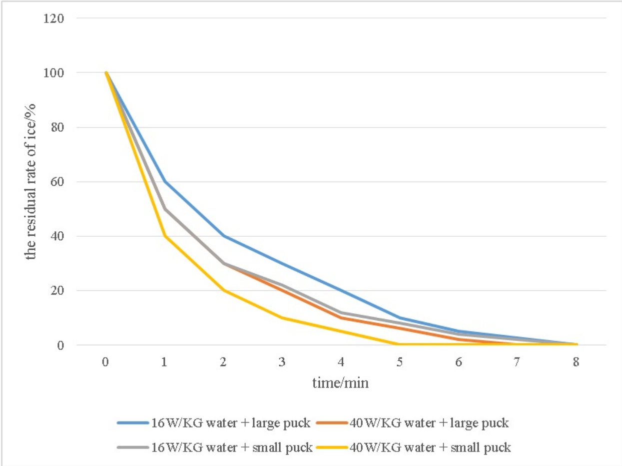


Fig. 7 Influence of ice size on melting ice

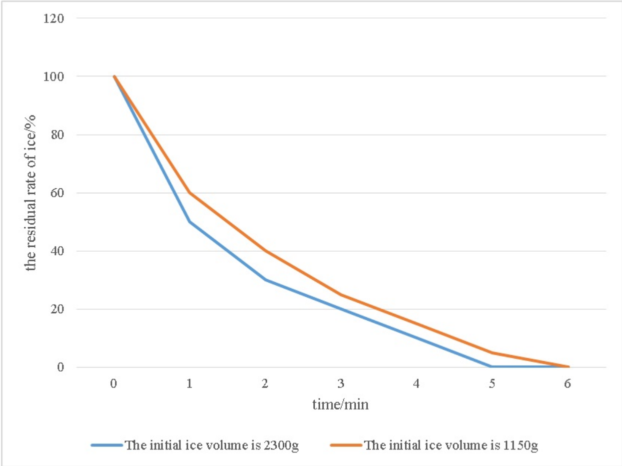


Fig. 8 Influence of initial ice amount on melting ice

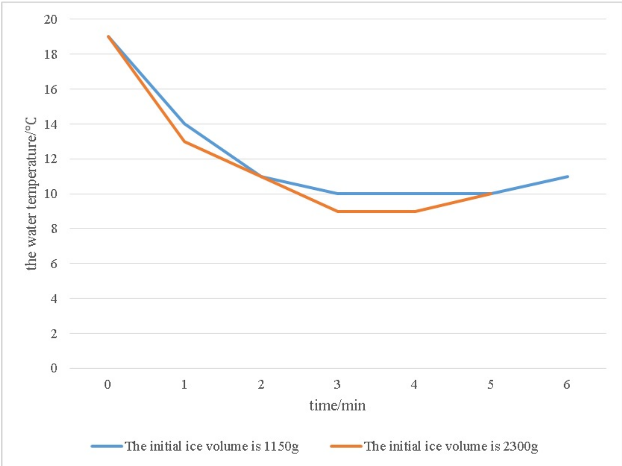


Fig. 9 Influence of initial ice quantity on water temperature

Table 1 Ice-melting curve fitting R^2 value table

Condition variables		Exponential fitting	Logarithmic fitting	Polynomial fitting		
Fixed amount	**Change the amount**			**2 times**	**3 times**	**4 times**
The ice-water ratio is 0.2, the initial ice amount is 2.3 kg, and the size is large	Water power 0 w/kg	0.9825	0.9707	0.9732	0.998	0.9998
	Water power 16 w/kg	0.9724	0.9804	0.9829	0.9982	0.9998
	Water power 28 w/kg	0.9695	0.976	0.9855	0.9981	0.9998
	Water power 40 w/kg	0.9752	0.982	0.9915	0.9998	1
Power 16 W/kg water, initial ice volume 2.3 kg, large size	Ice water ratio of 0.04	0.9698	0.8382	0.9507	1	1
	Ice water ratio of 0.06	0.9772	0.7987	0.8776	0.9742	0.9971
	Ice water ratio of 0.1	0.9845	0.8755	0.9198	0.9848	0.9991
	Ice water ratio of 0.2	0.9724	0.9804	0.9829	0.9982	0.9998
The ice-water ratio was 0.2, and the initial ice volume was 2.3 kg	Power 16 W/kg water + large size	0.9734	0.9804	0.9829	0.9982	0.9998
	Power 16 W/kg water + small size	0.9792	0.9646	0.9776	0.9985	0.9999
	Power 40 W/kg water + large size	0.9752	0.982	0.9915	0.9998	1
	Power 40 W/kg water + small size	0.9735	0.9504	0.9782	0.9981	1

the initial ice quantity on the change of ice melting speed and water temperature is not very obvious, and the insignificant difference is mainly caused by the difference in heat released by the system into the environment. The results indicate that the cooling capacity of ice is mainly released into water, and the ice–water ratio and power density have a greater influence on the heat transfer of melting ice, and the environmental heat dissipation does not play a major role during the experimental time.

3.5 Melting ice curve fitting

For the convenience of engineering design and practical operation, the melting ice curve (residual ice rate changes with time) in the above analysis can be fitted, and the R^2 value of the fitting formula can be obtained, which is listed in Table 1, so as to select the appropriate fitting model formula. As can be seen from the data in the table, the R^2 values of each melting curve fitted by the exponential model are within the range of 0.9695–0.9845, and the R^2 values fitted by the logarithmic model are within the range of 0.7987–0.982. The R^2 values of 2–4° polynomial model fitting were 0.8776–0.9915, 0.9742-1 and 0.9971-1, respectively. It can be seen that the exponential model used for curve fitting and process description has good applicability for the melting process under various conditions, while the logarithmic model has poor applicability and large deviations in some cases. Polynomial fitting requires a higher degree expression, such as 3 or 4°.

4 Conclusion

The experimental test and analysis show that the ultrasonic wave can obviously promote and strengthen the melting of floating ice in the ice storage tank, and the influence of power, ice–water ratio and ice size conforms to the normal theory and practice law. The greater the power, the smaller the ice–water ratio and the smaller the size of ice, the faster the melting speed will be. In addition, it is found that due to the multiple effects of technology and economy, the power density has an optimal value, which needs to be optimized according to the actual situation in the application. For large-sized ice, the promotion effect of high-power ultrasonic on melting ice is more obvious. In order to guide better the engineering practice, exponential model or higher degree polynomial model can be used to describe the melting process in the design and operation. Using ultrasonic wave to solve the floating ice problem of ice storage tank in the operation of ice storage can reduce the energy consumption of the system, and reduce the loss of ice storage quantity during the operation of the system, so that the whole system can operate with more energy saving.

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