Application Analysis of Dynamic Ice Slurry System in Precooling of Fruit and Vegetable

Guangpeng Li[1,*], Qi Wang [1] and Qinhua Xu [1]

[1]Shandong Institute of Commerce & Technology, Jinan, Shandong 250103, China

Abstract: Ice slurry precooling technology is a preservation technology that has unique advantages in the preservation of fruits and vegetables. It can make fruits and vegetables quickly drop to a suitable storage temperature. This paper summarizes the preparation methods of ice slurry, including the wall scraping method, undercooling method, vacuum method, fluidized bed method, and direct contact method. The wall scraping method, which has been widely used in industry and commerce, is the main method to design the dynamic ice slurry system between the buffer of fruit and vegetable air conditioning storehouse. Finally, this paper summarizes the characteristics and application of ice slurry precooling and makes a summary and prospect.

1. Introduction

Food is one of the important livelihood industries in China, and it is also an important support to ensure and meet the people's growing consumption needs. Fruits and vegetables are rich in vitamins, cellulose, and more than 10 kinds of minerals, such as calcium, iron, and copper, which can regulate the physiological process of the human body [1]. Therefore, residents' demand for fruits and vegetable increases. At the same time, the residents of vegetable food quality requirements are increasingly high.

As the primary link of cold chain logistics, precooling plays a crucial role in maintaining the fresh quality of fruits and vegetables after harvest, which is indispensable in cold chain logistics. The results show that in the whole refrigeration chain, the loss rate of vegetables without precooling treatment is as high as 25~30% during storage and transportation. In contrast, the loss rate of vegetables with precooling treatment can be reduced to 5~10% [2]. Therefore, precooling can effectively reduce the loss of fruits and vegetables during storage and transportation and maintain the edible quality of fruits and vegetables after harvest.

To reduce the loss of fruits and vegetables after picking, it is necessary to precool fruits and vegetables in time. The temperature and relative humidity in the buffer room of fruit and vegetable cold storage are the basic technical parameters that determine the cooling speed, taste, and commodity value of fruit and vegetable. If the cold storage temperature is too high, the precooling speed is slow, and the effect is poor. Cold storage temperature is too low, which will cause fruit and vegetable frostbite and even cause other physiological diseases. Low humidity in cold storage will accelerate the transpiration of fruits and vegetables and will reduce their taste and commodity value [3]. The design goal of the fruit and vegetable cold storage buffer room is to quickly cool the harvested fruits and vegetables to the storage temperature to ensure their high quality in cold chain logistics. The ice slurry has the characteristics of good flow and heat transfer characteristics, high latent heat storage density, fast load response speed, and safety [4]. It can better meet the conditions of low temperature and high humidity required by precooling fruits and vegetables and is suitable for pre-cooling. This paper mainly introduces the dynamic ice slurry pre-cooling system.

2. Dynamic ice slurry technology

Dynamic ice slurry is composed of tiny ice crystals and solutions, with the diameter of ice crystal particles ranging from tens to hundreds of microns [5]. The solution comprises water and a freezing point regulator such as ethylene glycol, ethanol, or sodium chloride. The mixture has excellent transport properties and can be moved like a normal fluid through pipes or stored in ice tanks. The transient phase transition of ice crystal particles will release a large amount of cold. It can quickly cool down and respond to the change of cooling load, making the unit volume cold capacity of dynamic ice slurry much higher than the cold capacity of the same cold water [6]. Therefore, it can greatly reduce the conveying pipe diameter, the pump power consumption, and the heat exchanger's structure size. In addition, the dynamic ice slurry mixing fluid is safe and pollution-free for the environment. It fully uses the advantages of making ice at night with electric power and saving electricity costs, making the dynamic ice slurry system have broad application prospects in technology and economy.

*Corresponding author's e-mail: 15098886718@163.com

3. Preparation method of dynamic ice slurry

The main working principle of preparing ice slurry is to generate tiny ice slurry particles by external disturbance, such as mechanical scraping after cooling the water solution. In the process of preparation of ice slurry, the most critical factors are the heat transfer efficiency and whether there will be an ice-blocking phenomenon in the process of generating ice crystals.

The most stable ice slurry-making method in the commercial system is wall scraping. Shell and tube-type heat exchangers are usually used for making ice slurry by scraper type. The refrigerant evaporates outside the tube, and the rotary scraper inside the tube rotates at high speed to scrape the ice crystals adhering to the wall surface. The rotary scraper type generally uses plastic as a mechanical scraping blade. The motor drives the plastic scraper on the power shaft to rotate, and the crystals attached to the inner wall of the heat exchange tube are scraped into tiny ice crystals and separated from the wall. The planetary rotary rod type generally uses the rotary rod as a mechanical scraping device. The rotary rod scrapes the crystals on the wall of the heat exchange tube through the rotation, and the rotary rod rotates along the wall of the heat exchange tube to achieve the effect of scraping the entire wall of the heat exchange tube at the same time. Figure 1 shows the scraper ice slurry generator.

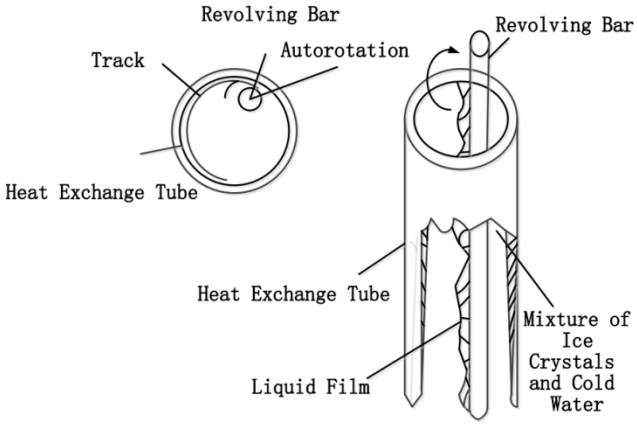

Figure 1 The scraper ice slurry generator

The second preparation method is undercooling preparation. When the temperature of the water or aqueous solution falls below the freezing point, it can remain liquid for a short time, that is, supercooled. The supercooled state is less stable. When a disturbance is given from the outside, such as ultrasound or vibration, the supercooled state is disrupted. Ice crystals are rapidly formed in the supercooled water and mixed with the original solution to form an ice slurry. The working principle of ice slurry prepared by supercooling is shown in Figure 2.

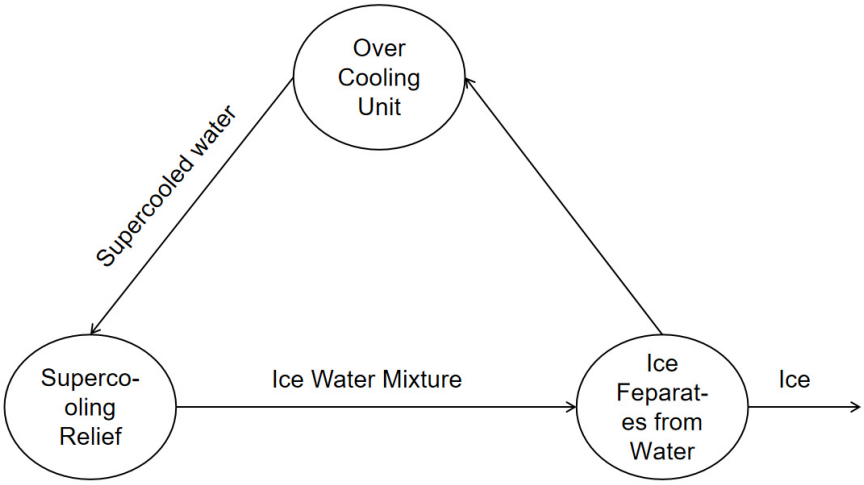

Figure 2 Working principle of ice slurry generation based on supercooled water methods

A solution consisting of water and a freezing regulator (such as ethylene glycol, ethanol, or sodium chloride) slowly enters the ice slurry generator, and the refrigerant changes phase to absorb a large amount of heat. Under the condition of no crystallization on the wall surface, the supercooling degree of the solution can reach 2~3 ℃. Before leaving the evaporator, the solution is physically agitated so that ice crystal particles, known as dynamic ice slurry, can be produced in the outlet section. The concentration of particles in a solution depends on the degree of supercooling.

The third preparation method is fluidized bed preparation. The refrigerant evaporates outside the tube, and the water flows up the tube at high speed. A number of stainless-steel beads with a diameter of 1-5 mm constantly impact the wall surface, aiming to break the ice crystal particles adhering to the wall surface. It can avoid the accumulation of ice crystals and maintain high heat transfer efficiency. The structure design is simple, and the cost is low.

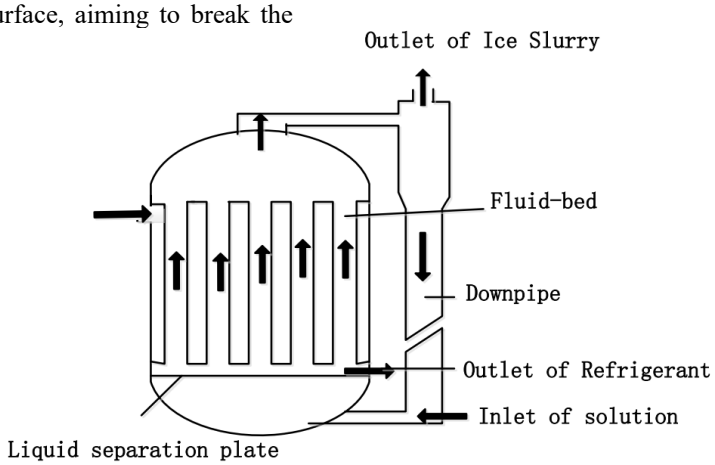

Figure 3 Fluidized bed preparation

The principle of the direct contact method is to use a special nozzle to spray the low-temperature refrigerant, which is insoluble in water, into the ice slurry generator.

Another method is vacuuming jet preparation. Ice slurry was prepared according to the triple point principle. When the ambient pressure of water decreases, the boiling point of water decreases and water will flash in a vacuum environment. Since the latent heat of the vaporization of water is much greater than the heat of freezing, the water absorbs heat in the flash evaporation process, reducing the remaining water's temperature. When the temperature reaches freezing temperature, it condenses into ice crystals.

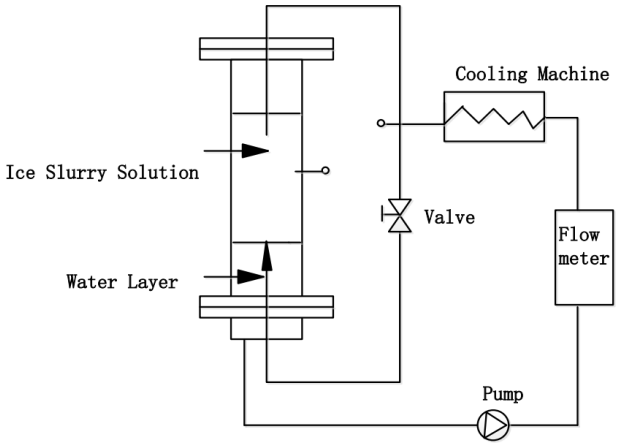

Figure 4 Direct jet preparation of ice slurry

4. Dynamic ice slurry precooling system

Dynamic ice slurry precooling system is a new type of wet and cold preservation technology that uses dynamic ice slurry as cold storage medium and refrigerant [7]. Dynamic ice slurry precooling system includes refrigerant circulation, dynamic ice slurry circulation, and wet and cold air circulation. R717 direct evaporative dynamic ice slurry system is adopted in this project, which is mainly composed of a screw refrigeration compressor, dynamic ice slurry unit, evaporative condenser, water module, ice storage tank, and external water supply pump [8].

After passing through the refrigeration compressor, the refrigerant is compressed into high-temperature and high-pressure refrigerant steam. The refrigerant steam entering the evaporative condenser transfers the heat to the cooling water. After cooling, the refrigerant liquid is condensed into the scraper-type ice slurry generator. Scraper-type ice slurry generator uses wall scraping type to produce dynamic ice slurry. On the outside of the shell and tube heat exchanger, the refrigerant evaporates and absorbs heat, and the rotary scraper inside the shell and tube heat exchanger rotates at high speed to scrape the ice crystals attached to the heat transfer wall and prevent many ice crystals attached to the heat transfer wall.

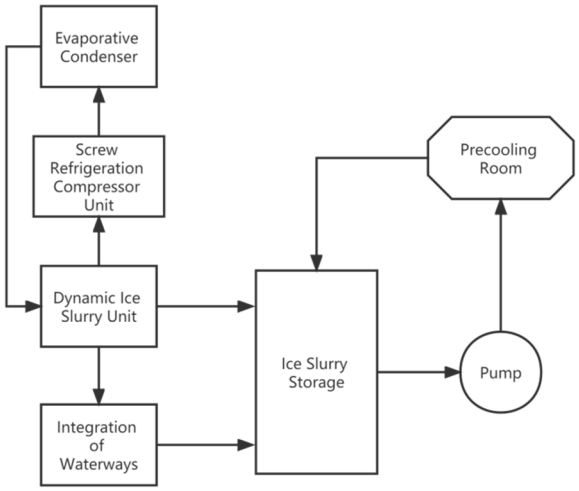

Figure 5 System flowchart of direct evaporative dynamic ice slurry

The dynamic ice slurry generated by the scraper ice slurry generator is stored in the ice storage tank. The dynamic ice slurry can be made at night when the power is low, and the vegetables collected during the day are stored for pre-cooling. At this time, the cold amount required for precooling is provided by the dynamic ice slurry stored in the ice storage tank to achieve the purpose of "peak cutting and valley filling". Because of the density difference between the water and the ice crystals in the dynamic ice slurry, the ice slurry stored in the ice storage tank will be stratified. An agitator is added to the ice storage tank to ensure the uniformity of the ice slurry involved in heat transfer.

The dynamic ice slurry in the ice storage tank is transported to the wet-cooled evaporator by the water pump, and sprayed on the wet curtain through the nozzle. It carries out heat and mass exchange with the air flowing through the wet-cooled evaporator horizontally. The air leaving the wet-cooled evaporator will become the low-temperature and high-humidity wet-cooled air. The processed wet and cold air is sent into the cold storage to quickly pre-refrigerate the vegetables to achieve a better preservation effect and extend the storage and transportation period of fruits and vegetables. After the heat and mass exchange of backwater is sent back to the ice storage tank, a dynamic ice slurry cycle will be formed.

The dynamic ice slurry precooling system comprises an ice-making device and precooling storage. The dynamic ice slurry is stored in the ice storage tank and then pumped by the water pump to the wet cooling evaporator to exchange heat and mass with the air in the storage to complete the precooling of fruits and vegetables.

5. Characteristics and application analysis

5.1. Complete separation of refrigeration and cooling in space

With the help of the cold storage function, the operation of the dynamic ice slurry system solves the problem of the close combination of traditional ice water refrigeration and cooling. That is, no matter how the cold capacity of the workshop changes, the dynamic ice slurry system will run with a full load and efficient ice storage.

5.2. Function of power peak shifting and valley filling

In the normal production process, due to the supply and demand of electric energy cannot be well matched and coordinated in quantity and time, the peak-valley difference of the power system increases, leading to a serious shortage of peak power, resulting in frequent power grid shutdown and power rationing, affecting the daily production and work of enterprises. The dynamic ice slurry system has efficient cold storage capacity, which can easily realize the function of "peak shifting and valley filling". It can efficiently use the low grain price electricity for ice storage and then stop the operation of the refrigeration host during the peak price electricity period. The cooling stored in the valley electricity period provides a cooling load for the process cooling in the peak period and transfers the running time of the refrigeration host.

5.3. Save operating costs and reduce power consumption

The conventional ice water system cannot run continuously and efficiently with a full load, resulting in low COP of the ice water system. The dynamic ice slurry system can ensure the continuous and efficient operation of the refrigeration system with a full load and fully enjoy the preferential price policy of peak and grain products, which can save operating costs and reduce power consumption for enterprises to the maximum extent.

6. Conclusion

This paper summarizes the preparation method and characteristics of ice slurry and studies the application of a dynamic ice slurry pre-cooling system. The pre-cooling technology of ice slurry is a kind of fresh-keeping technology with unique advantages in the fresh-keeping of fruits and vegetables. The wet-cooling technology can make fruits and vegetables quickly drop to a suitable temperature for fruit and vegetable storage. This technology can not only effectively reduce the loss of fruit and vegetable storage and transportation but also maintain the quality of postharvest freshness and improve market competitiveness. Compared with the common refrigeration and cold storage system, the dynamic ice slurry precooling system adds a water pump. Still, its compressor selection capacity is greatly reduced, and the operation cost can be reduced by the use of night time through electricity price.

Due to the development of the technology and the deepening of the understanding of the thermodynamics and thermophysical properties of ice slurry, the application of ice slurry will be more extensive, which will improve the attraction of the technology to potential users.

Acknowledgments

Thanks to the Shandong Institute of Commerce & Technology for the financial support. Thanks to all Refrigeration Equipment Inspection Technical Team members for their help in this paper.

References

[1] Zhang Q, Wang Y., An Y., Wang J., He Z., Zhang H. (2021) Installation and commissioning Technology of dynamic ice slurry System. Clean and Air Conditioning Technology, 04:16-18.

[2] Cao S., Zhang W., Liu A. Current situation of the development of ice slurry ice storage method analysis. Journal of new technology and new products in China, 2021 (5): 65-67.

[3] Wu M., Qin Y., Li G., Shen J., Song X., Zhu S., Han L. (2022). The factors influencing underground coal gasification and evaluation method research progress. Coal science and technology: 1-15.

[4] Yang F., Duan Z., Ma D., Tian T., Fu D., He D. (2020) Progress of coal underground gasification technology. Science and Technology Review, 38(20):71-85. (In Chinese)

[5] Lu W., Liu G., Yu J., Meng L., Teng Z. (2020) Application analysis of dynamic ice slurry system in Dairy Industry. Refrigeration Technology, 40(03):59-63.

[6] Gao R., Zhang Q., Wang Y. (2019) Research status and development trend of ice slurry. Refrigeration Technology, 39(05):65-71. (In Chinese)

[7] Wang C. (2016) Dynamic ice slurry with cold water heat transfer effect analysis. Journal of coal mine safety, 47 (10): 165-167 + 171.

[8] Jiang Y. (2015) Application prospect analysis of dynamic ice slurry cold storage wet cooling technology in fruit and vegetable refrigeration. Refrigeration and Air Conditioning, 15(10):5-9+36.