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Two - period freezing technique of food *

Zhang Jianyi Liu Niansheng
(Xiamen Fisheries College, Xiamen 361021)

Abstract A new technique dividing a common freezing process into two periods is proposed. A higher evaporating temperature is employed in the first period of freezing process and no extra machine is needed. The results show that there is an optimum evaporating temperature during the first period of food freezing, the maximum energy saving can be 35.6% under typical conditions.

Key words food, two - period freezing, energy saving

1 Introduction

As a result of wide application of refrigeration, food industry has been an important section of energy consumption in many countries, while the food chain consumes a very substantial proportion of total primary energy required by a country. For example, the proportion is 15% in Australia, 28.6% in Ireland, 15.8% in the UK and 12% ~15% in the USA[1]. Therefore, energy saving on refrigeration has been an important topic all over the world.

This project uses the original refrigeration plant with two - stage compression, no extra equipment is needed. The new technique is carried out by adjusting the refrigeration plant. Based on the Carnot principle, the principle of the new technique is discussed. The parameters of the novel feezing technique are investigated and optimized by a computer.

According to the condition in China, R717 is adopted as refrigerant. Typical parameters of refrigeration plant are adopted in the program. Two - stage compression refrigeration cycle in closed - type intercooler is a typical scheme used in the food freezing[2] and is selected as an example in this study.

2 The principle of the new process

It is well known that refrigeration means to reduce the temperature. The difference in temperature between the raw material and frozen food is considerable.

For a vapour compression refrigeration cycle, according to Carnot principle, the maximum possible coefficient of performance (*COP*) is:

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$$COP_m = Q_1/W = T_1/(T_2 - T_1) \tag{1}$$

Where Q_1 is refrigerating capacity (J) and W is net work input(J). The temperature t_1 and t_2(absolute temperature T_1 and T_2) are the temperatures of body being refrigerated and the medium absorbing heat respectively.

From equation (1), the work consumed in a refrigeration cycle depends on the difference between working temperature T_1 and T_2. Equation (1) shows that the COP gets low when the temperature range gets large, indicating that a larger amount of power is needed to obtain a certain refrigeration capacity. Conversely, higher COPs can be achieved when the temperature range is smaller.

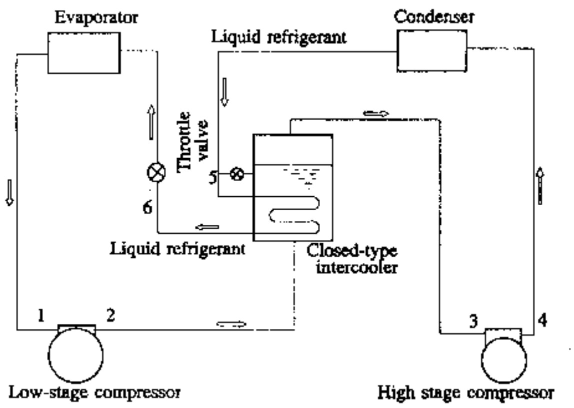

Fig.1 Arrangement of a two-stage compression typical cycle

In the new freezing process, refrigeration is performed in a smaller temperature range in the first period, since a higher evaporating temperature t_e is selected. Then, a part of the refrigerating capacity is obtained at a higher COP or higher efficiency. During the second period, the working condition of the refrigeration plant is similar to that of a common freezing process. The total work consumed in the proposed freezing process is less than that in a common freezing process and energy saving can be achieved.

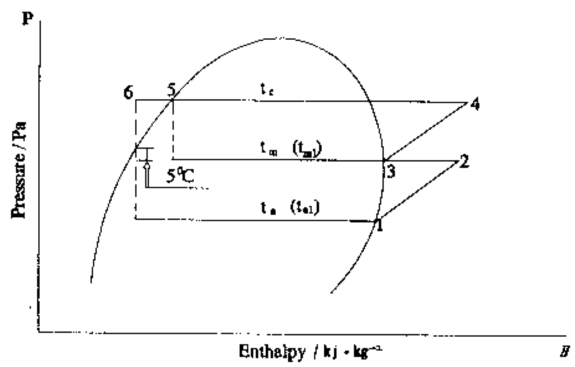

Fig.2 The P-H diagram of the cycle in Fig.1

In order to examine the feasibility of the new technique, it is necessary to look into a typical freezing process in the current industrial practice. After prefreezing treatment, raw material is sent to the air blast freezer, which is the most common method of food freezing. Packaged or un-packaged non-fluid foods will be frozen in air at temperatures ranging −18~−40℃[3]. The product is exposed to an air velocity of approximately 2 or 3 m^3/s. The final temperature of frozen food varies with different foods as well as countries. The range is −15~−30℃[4].

Two-stage compression refrigeration cycle with closed-type intercooler is a typical scheme used in the food freezing[2] and is selected in this study. Figure 1 presents its arrangement of equipment and pipe connection, the P－H diagram of the scheme is shown as Fig.2. The liquid refrigerant flows under condensing pressure via a closed cooling coil in the interstage vessel. In the coil, the liquid is subcooled down to about 5℃ higher than the saturation temperature of intermediate pressure.

The principle, system and equipment of the new freezing process is similar to that of a common freezing process entirely. The difference between the new and common freezing process is only the temperature of the air in the freezer. For the frozen foods, both processes have the same initial and final temperature. Therefore, it is safe to conclude that the new freezing process is feasible.

3 The calculation on the new freezing process

In order to examine the new freezing process quantitatively, the new process should be compared with a typical common process under the same condition. There are three steps in the calculations.

(a) Calculation of the common freezing process. The purpose is to obtain energy consumption of a common process and the capacity of the refrigeration plant.

(b) Calculation of the new freezing process. The aim is to obtain the energy consumption and the freezing time of the new process under the same condition.

(c) Comparison of computed results between (a) and (b). The main features to be compared are the energy consumption and the freezing time.

A typical freezing room with air blast is taken as an example for discussion, and the load capacity of the room is assumed to be 10 000 kg for beef. According to the literature[5], the initial temperature of the beef is 39℃. The precooling temperature of EEC standard is 7℃. The final temperature －18℃ is commonly used in most countries. The total removed heat load Q_f is

$$Q_f = G_f \cdot C_f \cdot (t_{f1} - O) + G_f \cdot (H_{f0} - H_{ff}) \tag{2}$$

where G_f, C_f and t_{f1} are the mass(kg), specific heat (KJ/kg·℃) and initial temperature(℃) of food, respetively. H_{f0} and H_{ff} are the enthalpy of foods at 0℃ and at final temperature.

For an air－blast freezer, if the final temperature of frozen food is －18℃ and the temperature difference between t_e and the food temperature is 10℃, then, $t_e = -18 - 10 = -28$℃. The condensing temperature is set at 35℃, which is a typical design condition in the subtropical area.

Freezing time (T_f) is 20 h. The refrigerating capacity required by a freezer Q_{OH} is given by

$$Q_{OH} = Q_f / (T_f \cdot 3\,600) \tag{3}$$

if Fig.1 is taken as an example, its refrigeration effect q_0(KJ/kg) and the power consumed are

$$q_0 = H_1 - H_6 \tag{4}$$

$$N = G \cdot \triangle H_w \tag{5}$$

where N is the adiabatic power consumed in a refrigeration cycle(kW). G is the mass flow rate of refrigerants(kg/s). $\triangle H_w$ is the work required by a kilogram of refrigerant in the isentropic compression.

The energy consumption (E_c) in a common process is given by

$$E_c = N \cdot T_f \tag{6}$$

for the new freezing process, it consists of two periods. The energy consumption(E_n) of the new freezing process is

$$E_n = E_1 + E_2 \tag{7}$$

$$E_1 = N_1 \cdot T_{f1} \tag{8}$$

$$E_2 = N_2 \cdot T_{f2} \tag{9}$$

where E_1 and E_2 are the energy consumed in the first and second period respectively(kW·H). N_1 and N_2 are the power required in the first and second period respectively(kW), T_{f1} and T_{f2} are the running time in the first and second period respectively(h).

The comparison of energy consumption between the new process and the common process is given by

$$E_s = [(E_c - E_n)/E_c] \cdot \% \tag{10}$$

where E_s is the percentage of energy saving of the new process to the energy of common process.

Moreover, not only the efficiency of plant is improved, but its refrigeration capacity will also increase when the work temperature range of the plant gets smaller. It means that the freezing time of the new process will be less than that of a common process. The comparison of the freezing time required between the new process and a common process is given by

$$T_s = [(T_f - T_n)/T_f] \cdot \% = [(T_f - T_{f1} - T_{f2})/T_f] \cdot \% \tag{11}$$

where T_s is the percentage of freezing time saving of the new process to the energy of common process. T_n is freezing time of the new process.

4 Mathematical model and computer optimization

The performance of the new process varies as the selected evaporating temperature t_{e1} differs. It is necessary to find the relationship between t_{e1} and the performance of the plant in order to decide a suitable t_{e1}.

According to the condition above, it is reasonable to choose -25℃ as the lower limit of variation range of t_{e1}. The upper limit of the variation range of t_{e1} can be set at -5℃, which is high enough for practice.

Cleland proposed some useful mathematical models[6]:

$$H_L = a_4 + a_5 t + a_6 t^2 + a_7 t^3 \tag{12}$$

$$H_v = a_8 + a_9 t + a_{10} t^2 + a_{11} t^3 \tag{13}$$

where H_L and H_v are enthalpy of liquid and vapour refrigerant, respectively.

Enthalpy change in isentropic compression is given by:

$$\triangle H = [c/(c-1)] P_1 \cdot v_1 [(P_2/P_1)^{\frac{c-1}{c}} - 1] \tag{14}$$

where P_1 and P_2 are the suction and discharge pressures, v_1 is the specific volume of vapour in the suction condition and c is the fitted constant.

Quick Basic is employed in the simulation program where a FOR...NEXT loop is used. The control variable is t_{e1}, the step value is 1℃, which is accurate enough in industrial refrigeration plants[7]. Refrigerant R717 is taken as a study object here.

5 Results and discussion

Fig. 3 to 4 are the results of the simulation program. Based on them, the performance of cycle depends on t_{e1}. There is an optimum evaporating temperature(t_{e1}) at which the energy saving of the new freezing process is maximum.

Figure 3 shows the energy saving in the new process to the energy used in the common process as t_{e1} varies. It indicates that the values change considerably as t_{e1} varies. The curve reaches a maximum value when t_{e1} is at −10℃.

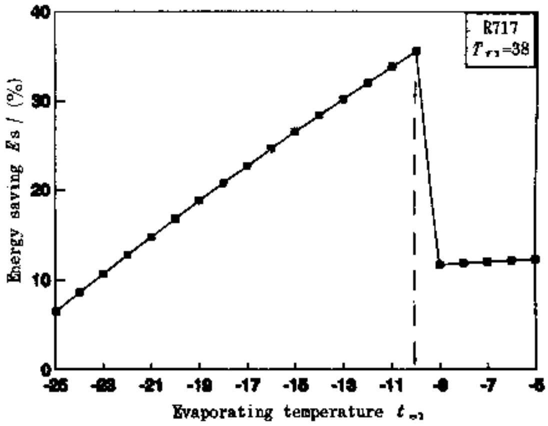

Fig.3 Energy saving of the new freezing process

The time saving of the new process to the time used in the common process is shown in Figure 4, showing that the values change considerably as t_{e1} varies. When t_{e1} changes to −10℃, the curve reaches its maximum.

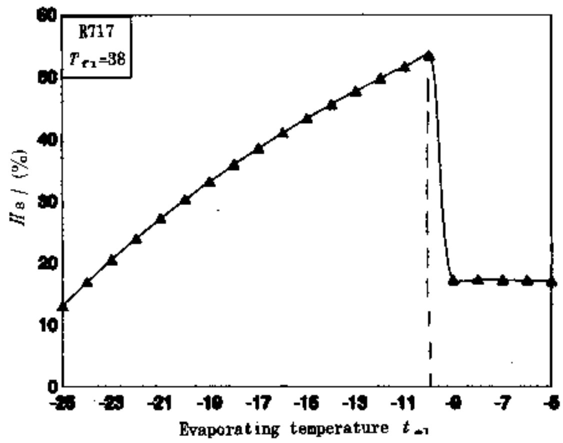

Fig.4 Time saving of the new freezing process

6 Conclusion

According to the analysis presented, the new freezing technique in industrial plants is feasible. With the help of a computer, the results under a definite condition are obtained and presented. Based on the results, the following conclusions may be made:

(1) Compared with a common freezing process, energy savings can be obtained when the new freezing process is employed. There is a maximum energy saving (E_s) as the evaporating temperature t_{e1} varies. The maximum E_s can reach 35.6% with refrigerant R717 under above condition.

(2) There is an optimum evaporating temperature (t_{e1opt}) in the first period of the new freezing process, at which the energy saving E_s is maximum. The optimum t_{e1opt} is −10℃ under above condition.

(3) The freezing time of the new process is less than that of the common process. Compared with the common freezing process, the freezing time saving of the new process can reach about 53% with refrigerant R717 at t_{e1opt} under the presented condition. As a result, the quality of frozen food can be improved when the new process is adopted.

(4) When the new freezing process is employed, the system, both in the first period and the second period, is the same as a common system except the operating parameters.

Based on the calculation above, the benefit of the new freezing process is considerable. But some new problems will appear during the first period of the new process when a normal refrigeration plant adopts the new process, e.g., the balance of the components of system, etc. Therefore, further research is needed before the new process is put into industrial operation.

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食品的两段冻结技术

张建一　刘年生

(厦门水产学院，　361021)

摘　要　在食品冻结中采用2个蒸发温度的新技术，即在冻结的第1阶段采用较高的蒸发温度，提高制冷系数(COP)，在第2阶段中采用较低的蒸发温度以使食品达到所需的最终冻结温度。利用卡诺定理研究该技术中的各项参数并进行优化。结果表明，通过对制冷装置的适当操作和调整可达到节能效果，最大节能值(Es)可达35.6%。

关键词　食品，两段冻结，节能