AUTOMATION SYSTEM FOR A CRYOGENIC FREEZER

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Rezumat. Lucrarea prezintă sistemul de automatizare pentru un congelator criogenic cu azot lichid utilizat pentru congelarea rapidă a produselor alimentare, care foloseşte căldura latentă de vaporizare a azotului lichid şi căldura sensibilă a vaporilor de azot. Modelul de automatizare propus rezolvă partial problema controlului automat al vitezei benzii transportoare. Modelul dinamic oferă date folosind simularea pe calculator. Instalaţia a fost concepută şi executată de autori şi funcţionează în cadrul Laboratorului de Termotehnică al Universităţii "Dunarea de Jos" din Galati.

1. INTRODUCTION

Quick freezing of meat products in a cryogenic freezer consist in the use of evaporation latent heat of the liquid nitrogen, as well as of the sensible heat of the vapors, whose temperature increase up to final temperature of the frozen product.

The use of cryogenic freezing with liquid nitrogen and carbon-dioxide is regarded as the "centuries revolution" in the food area.

The quality of the quick frozen products is superior compared to vapor compression system products. Because today's competition in the food international market concerns more the quality level than the price, quick freezing systems developed continuously, starting from 1960 in the USA and then in Europe. For example, in France (1988) the frozen products consumption was 25.9 kg/year, from which 2 kg were cryogenically frozen. Therefore, need is, that in Romania as well, to be carried-out research in this direction.

2. CONSIDERATION ON THE BAND SPEED AUTOMATIC ADJUSTMENT

The cryogenic freezer is shown in Figure 1 and has the following features:

◊ hourly freezing capacity: 110 kg
◊ dimensions: 5220 × 750 × 1450 mm
◊ weigh: 500 kg
◊ the temp of frozen product: −18 °C
◊ the length of conveyer band: 4.2 m
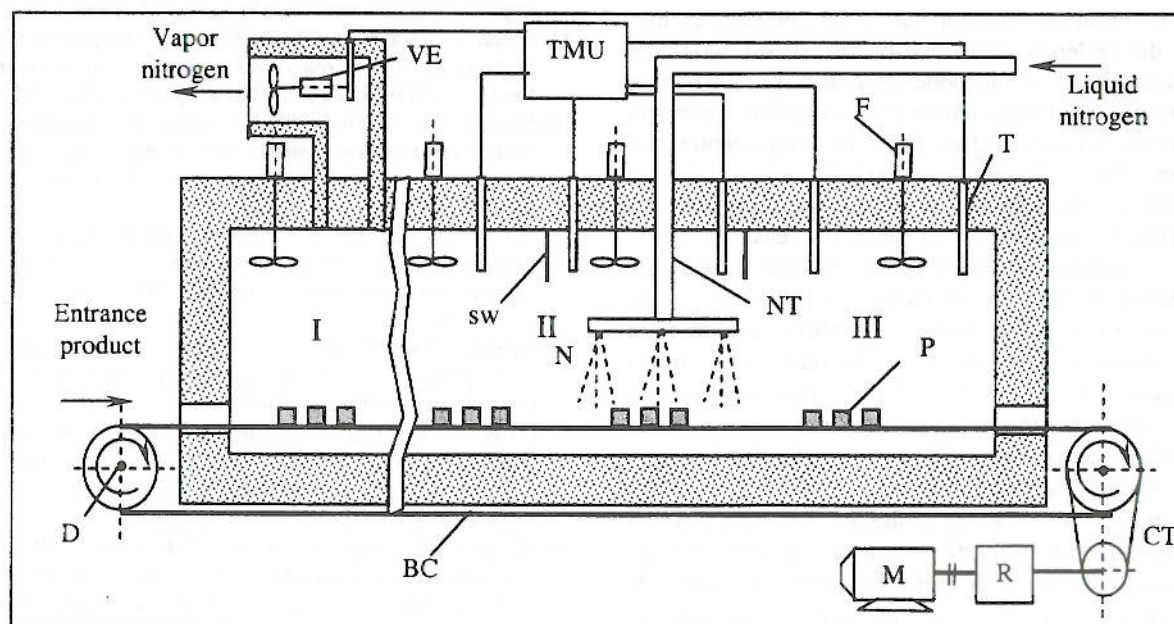◊ speed of the band: 0.44 m/min
◊ freezing time: ≈ 10 min

Fig. 1. Cryogenic freezer:
M – electric motor; P – meat product; BC – belt conveyer; R – worm reducer; CT – chain transmission; F – fan; VE – vapor exhaust fan; N – nozzle; SW – separating wall; NT – nitrogen transfer line; D – drum; TMU – temperature measuring unit; T–thermoresistance; I – pre-cooling area; II – freezing area; III – subcooling area.

Based on the tests carried out on a pork product with a constant thickness (25 mm), one found out that the thermal core temperature of the product ($t_C \leq -18°C$) was achieved depending on the exhausted nitrogen vapors temperature, for constant freezer capacity and sprayed liquid nitrogen flow-rate. Other parameters that can influence the operating conditions of the cryogenic freezer in stationary regime are: outside air temperature, fat contents of the product, the distance among products on the band, the blockage of a forced air circulation fan and product thickness.

If the exhausted nitrogen vapors temperature increases, the nitrogen consumption decreases.

For a vapors temperature of –30 °C, a –18 °C temperature in the core of product is easily achieved. One considered that the exhausted low temperature nitrogen vapors can be used for cooling a temporary food-bank used for product storage prior shipping.

The band speed automatic adjusting system has to operate for a temperature interval of –40 to –20 °C, with a –30 °C reference temperature).

3. ADJUSTING SYSTEM

The main objective for automatic adjusting system is to assure minimum errors for output parameters, without operator intervention. The goal of the adjusting system is achieved if the disturbances are maintained within the previously known limits.

The objective, structure and operation mode of the adjusting system are presented in the next paragraphs. The regulated target is the cryogenic freezer described in the previous paragraph.

The technological purpose is cooling of the product pieces at –18 °C average temperature, with a small temperature variation inside the product, a maximum productivity and a minimum consumption of cooling agent.

Some conditions can be contradictory, so, it is useful to analyze the model of the regulated object, in order to decide the performance limits and required compromises.
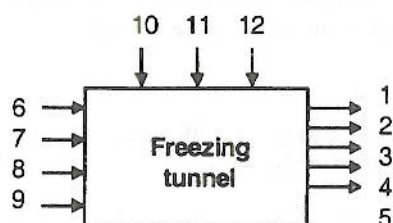

Fig. 2. System's parameters flow chart.

In Figure 2 schematically shows the parameters:
1 – product thermal core temperature when leaving the tunnel.
2 – product surface temperature when leaving the tunnel.
3 – cooling agent outlet vapor temperature
4 – productivity.

5 – average temperature of the cooling-room.
6 – band speed.
7 – initial temperature of the cooling agent.
8 – cooling agent flow-rate.
9 – product density on the conveyer band.
10 – size of the product.
11 – initial temperature of product.
12 – average exterior temperature.

The sizes 1, 2, 3, 4 are process controlled conditions. The average temperature in the cooling-room is an intermediate parameter of the model, and 6, 7, 8, 9 are the input parameters. Of them, the cooling agent initial temperature was definitively fixed when the liquid nitrogen was chosen for the cooling process. The product size (10) represents a perturbance parameter, hard to modify (it's a technological given), but easy to measure, in order to choose the average operating point of the tunnel. The product density on the band is also a technological given (the distance between pieces of the product is 10 mm).

Therefore, only the liquid nitrogen flow-rate and the band speed can be selected as the execution sizes for the system. The last two parameters are disturbances, the most important being the product temperature.

From technological considerations, some of the presented parameters have a small variation range. The productivity represents the product between the speed of the band and the density of product on the band; its value is limited by the flow-rate of liquid nitrogen, if we assume a constant product temperature. The nitrogen flow-rate has an optimum value (in stationary regime) imposed by the tunnel parameters and by the main disturbances, meaning, that for certain product dimensions and for an initial temperature, there is a limit value above the productivity doesn't increase, but the losses increase.

Because the productivity and the efficiency are main parameters for the equipment, is important to choose an operating point for which the agent flow-rate is close to the optimal one, and the band speed provides the specified outlet product parameters. Productivity value results, whose maximum value was limited by choosing the nitrogen flow-rate, considering the efficiency. Product size and inlet temperature are major disturbances, but average exterior temperature is not.

Therefore, in order to achieve its goal, the adjusting system can operate under the following conditions:

• there is a static operation point, chosen considering the efficiency and productivity, that depends on the product dimensions and initial temperature;

• the nitrogen flow-rate and speed of the band are the execution parameters;

• the output parameters are the core product temperature, the product surface temperature when leaving the tunnel, and the temperature of the exhausted nitrogen vapors.

• the quality sizes for adjusting control are: the average temperature of the product output from tunnel and difference between inside and surface temperature of the product.

The simplified dynamic model suggested has the structure presented in Figure 3 where v and $\dot{m}$ are the speed of the band and the nitrogen flow-rate.

The parameters t_1, t_2 are the average output temperature of the product, respectively the output temperature of nitrogen vapor. All these parameters have small variations around the static operating point, therefore one can consider a linear behavior of the system.
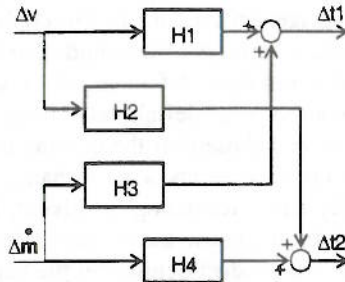

Fig. 3.

Transfer functions are:

$$H_1(s) = \frac{K_1}{T_1 s + 1} \tag{1}$$

$$H_2(s) = \frac{K_2 \cdot \exp(-T_{m2}s)}{T_2 s + 1} \tag{2}$$

$$H_3(s) = \frac{K_3 \cdot \exp(-T_{m3}s)}{T_3 s + 1} \tag{3}$$

$$H_4(s) = \frac{K_4 \cdot \exp(-T_{m4}s)}{T_4 s + 1} \tag{4}$$

The time constants are about few minutes ($T_1 = 3...4$ min, $T_2 = 4...8$ min $T_3 = 3...4$ min). The delay T_{m2} is relative small (below 10 s) while T_{m3}, T_{m4} are between 20...40 sec. Model identification is done each time by the product density on the conveyer band and the inlet temperature. Nevertheless, the variations of these parameters are relatively small. Considering that the nitrogen flow-rate influences on both measurable parameters by means of the delay time, and also the difficulty of regulating this flow-rate, one chose, as the sole execution parameter the speed of the band.
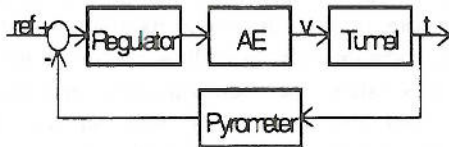

Fig. 4. Speed adjusting flow chart.

The adjusting scheme is presented in Figure 4 where the controlled parameter is the required product

surface temperature when leaving the tunnel, computed (when starting the tunnel) from the required average temperature and the estimated temperature gradient. AE is the motor automation and the pyrometer is the transducer for measuring the external temperature of the product.

Regulator speed control transfer function is:

$$H_R(s) = K_p(1 + \frac{1}{T_1 s}) \tag{5}$$

The size of the integration time constant is also of a few minutes, in order to compensate the main time constant of the H_1 function.

The temperature regulator is a standard one, used for slow processes, but it can also be used a numerical one, with the possibility of recording the stationary regime values, characteristic for each perturbance range; in order to measure the surface temperature of the product when leaving the freezing tunnel, the pyrometer is placed above the conveyer belt, closed to it, aimed to the product surface, as shown in Figure 5.
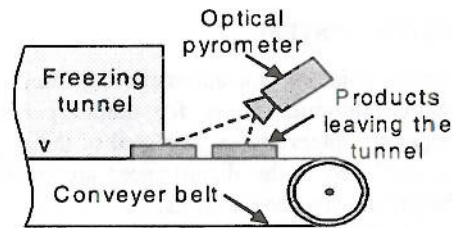

Fig. 5. Products' surface temperature measurement.

The time constant of the pyrometer is neglectible (a matter of seconds)

CONCLUSIONS

Suggested automation design partially solves the problem of conveyer band speed adjusting. To fully solve the problem one need the use of cooling agent outlet vapor temperature as a control input.

Time constants can be found out during testing. The simplified dynamic model allows the obtaining of results by computer simulation, and further investigations could improve the present model.

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