OPERATING EVALUATION OF A COOLER AND A FREEZER USED FOR FREEZING OF SMALL WHEAT BAKERY PRODUCTS

Piotr Mach, Zbigniew Pałacha

WULS-SGGW, Institute of Food Sciences

Summary. The aim of this study was to perform the operating evaluation of a HEINEN arctic a7/12 and a7/24 spiral-belt cooler and freezer used for freezing of small wheat bakery products – kaiser rolls – operating in a Warsaw bakery. Usable heat, heat received from the raw material (net heat), output of electric motors, enclosure heat gain, air infiltration gain, belt cooling heat as well as capacity and efficiency of the cooler and freezer were used to make an operating evaluation of both devices. The cooler with the capacity of 1113 kg/h showed an efficiency of 70.8%, while the efficiency of the freezer with the capacity of 1109 kg/h was only 54.6%. The usable heat in the process of freezing of kaiser rolls was almost 2.5 times greater than the usable heat in the cooling process. Real values characterizing the cooling and freezing process were also determined: time of both processes, temperature distribution, and weight loss in the product. The weight loss of a kaiser roll after the cooling process constituted 8.65% of the mass of the raw product, and after the freezing process it constituted 9.51% of the mass of the raw product. The obtained results were compared with the data of the manufacturer of both devices.

Key words: kaiser rolls, cooler, freezer, operating evaluation

INTRODUCTION

The progress in bakery technology that has been made in recent years is focused on improving products so that they are of the highest quality, repeatable quality, and at the same time convenient and functional in storage and preparation. The introduction of a wide range of bakery products in hotels, bars, at petrol stations, and in small shops forces producers

Zbigniew Pałacha https://orcid.org/0000-0002-8596-8621

✉ zbigniew_palacha@sggw.edu.pl

to use modern technologies [Andrzejewska 2009, Górecki 2005, Lorenz and Kulp 1995, Pałacha et al. 2015, Postolski 2002 and 2007], which will enable the preparation of products depending on the level of demand [Andrzejewska 2008, Hombach 2001, Lösche 2003].

Demand understood in this way is for many of the above-mentioned entities extremely difficult to forecast. Technology that meets such expectations is referred to as "postponed baking" [Lösche 2003, Lorenz and Kulp 1995, Pałacha et al. 2015, Pałacha et al. 2016, Pałacha et al. 2017, Poszyńska 2001, Szwajkajzer 2017]. It consists in separating the dough production, its partial baking or full baking and transferring the last of these stages of production directly to the place of sale [Andrzejewska 2009, Lösche 2003, Poszyńska 2001]. As a result, the consumer has constant access to fresh, often still warm products. In the literature [Andrzejewska 2009, Ambroziak et al. 2002, Cauvain 2004, Giannou and Tzia 2007, Lorenz and Kulp 1995] it is also emphasized that baking outside a bakery requires special dough production technologies. The main goal of the "postponed baking" technology, and especially for this technology of dough production, is to obtain ready-made, already formed products, preserved by partial baking or freezing, or possibly using both of these methods simultaneously [Ambroziak et al. 2002, Cauvain 2004, Giannou and Tzia 2007, Lorenz and Kulp 1995, Le-Bail et al. 2006, Szwajkajzer 2017].

The process of freezing food is most often carried out using the air freezing method. It is one of the oldest freezing techniques. Due to the universality of the method and the devices used, and above all their simple design, ease, confidence, and reliability of use, low labour intensity and high hygiene standard, it is a method widely used in many branches of the food industry [Gruza and Postolski 1974 and 1999, Hombach 2001, Le-Bail et al. 2006, Postolski 2007, Ribotta 2001, Sobczyk 2006, Szwajkajzer 2017, Wolt and D'Appolonia 1984].

In bakery, the number of freezers used is growing from year to year, but there are few publications regarding their operating evaluation. Therefore, it is necessary to study the cooling and freezing process of bread in this respect.

The aim of the study was to perform the operating evaluation of the **artic a7/12** cooler and the **arctic a7/24** freezer. Both devices worked in the same spiral-belt **arctic** system manufactured by **HEINEN**. This system was used to cool and freeze kaiser rolls in a Warsaw bakery.

STRUCTURE AND CHARACTERISTICS OF THE COOLER AND THE FREEZER

The bakery's technical specifications determined the design and location of both devices. The entire production process took place in one hall. At its end, the cooler was placed above the oven. Next to it there was the freezer, which was connected on one side with the cooler, and on the other with a warehouse of frozen products. Both devices were properly insulated and the freezing line was uninterrupted.

The cooling and freezing processes were carried out in spiral-belt devices, with a stream of air of a specified temperature, humidity, and speed, with forced movement, directed against the movement of the frozen product, having contact with the product at every tier of the spiral. Glycol was the coolant. Figure 1 shows a schematic diagram of a spiral **arctic** system, a cooler combined with a freezer.
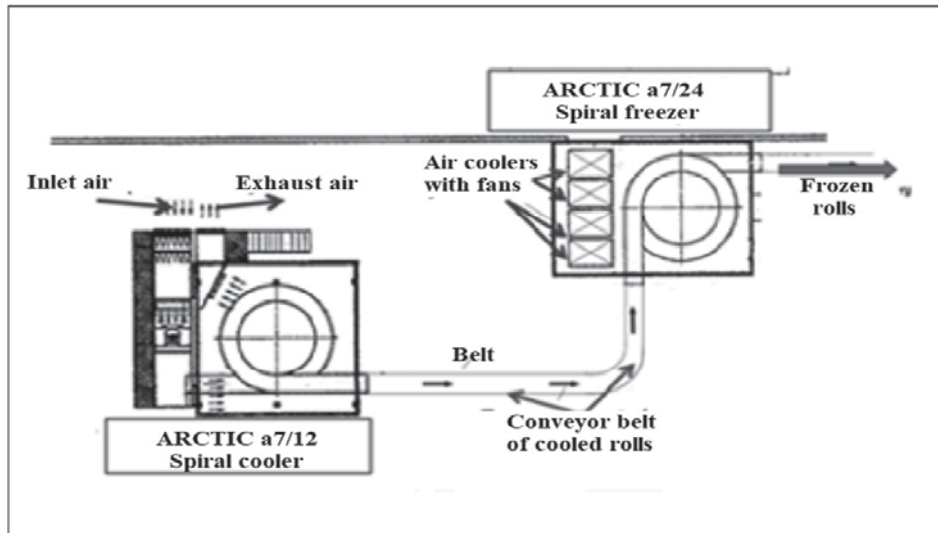
Fig. 1. Diagram of a spiral **arctic** system, a cooler combined with a freezer

Rys. 1. Schemat spiralnego systemu **arctic,** chłodziarki sprzężonej z zamrażarką

Basic technical data of the **arctic A7/12** cooler.

- Length × width × height 7000 mm × 7000 mm × 3600 mm (from elevation)
- Direction of belt movement`   from the bottom to the top
- Infeed height   ~ 3500 mm (from the ground)
- Discharge height   ~ 5800 mm (from the ground)
- Number of tiers   12
- Main drive output   ~ 2.2 kW
- Auxiliary drive output   ~ 1.5 kW
- Belt type   plastic modular
- Power requirement   ~ 4.0 kW
- Connected load   ~ 6.5 kW
- Supply voltage   230 / 400 V, 3-phase, 50 Hz Fans
- Number of fans   1
- Effective output   13 kW

Basic technical data of the **arctic a7/24** freezer.

- Length × Width × Height   8500 mm × 6200 mm × 6400 mm
- Direction of belt movement   from the top to the bottom
- Infeed height   ~ 5800 mm
- Discharge height   ~ 800 mm
- Number of tiers   23.25

- Main drive output   ~ 3.0 kW
- Auxiliary drive output   ~ 1.5 kW
- Belt type   woven stainless steel bars
- Power requirement   ~ 60 kW (without options)
- Connected load   ~ 90 kW (without options)
- Supply voltage   230 / 400 V, 3-phase, 50 Hz
  Fans
- Number of fans   4
- Effective output   4 x 13 kW = 52 kW

MATERIAL AND METHODS

The material for the research consisted of kaiser rolls after a full technological proc-ess. The product was formed, fermented, and partially baked. During each of the ten series of tests, the rolls were made from the same raw materials, according to the same recipe and maintaining identical parameters. Then the product was cooled and frozen by the air freezing method. Table 1 presents the chemical composition of a kaiser roll.

Table 1. Chemical composition of kaiser rolls

Tabela 1. Skład chemiczny bułek kajzerek

Tested feature – Badana cecha	Average value – Wartość średnia
Humidity – Wilgotność [%] *acc. to PN-A-74108:1996*	42.2 ±0.05
Total acidity [degrees] Kwasowość ogólna [stopnie] *acc. to PN-A-74108:1996*	1.4 ±0.05
Total proteins – Białka ogółem (Nx5.7) [% s.s.] *acc. to PN-EN ISO 20483:2007*	13.84 ±0.07
Monosaccharides – Cukry proste [% s.s.] acc. to PN-A-74108:1996	3.3 ±0.2
Fat – Tłuszcz [% s.s.] *acc. to PN-ISO 1444:2000*	6.06 ±0.3%

The scope of the study included collecting all parameters of the cooling and freezing process. Numerical data were collected from places that directly influenced the process and allowed for an unequivocal operating evaluation of the arctic a7/12 cooler and the arctic a7/24 freezer. The following data were collected:
–   the temperature changes in rolls (in the geometrical center and below the surface) sub-jected to the cooling and freezing process. The data were collected with the ELLAB logger number 51 630, recording data every 5 seconds in the temperature range from −50 to 150°C;
–   the speed of air flowing around the product in the cooler and the freezer. Data were collected using an AZ Instrument Corp. instrument, number 9871;

– the air temperature in the cooler and the freezer. Data were collected using an AZ Instrument Corp. instrument, number 9811;
– the humidity in the cooler and the freezer. Data were collected using an AZ Instrument Corp. instrument, number 9861;
– the belt speed, and thus the time of the cooling and freezing process. The data were read from the display of the control panel and confirmed by the record of the temperature distribution measured in rolls.

All parameters indicating the conditions outside the cooler and the freezer were collected, such as:
– the temperature in the hall where the cooler and the freezer were located. Data were collected using an AZ Instrument Corp. instrument, number 9811;
– the relative humidity of the air in the hall in the immediate vicinity of the cooler and the freezer. Data were collected using an AZ Instrument Corp. instrument, number 9861.

The cooling output balance was calculated separately for the cooler and the freezer on the basis of the following formula:

$$Q = b \cdot (Q_N + Q_{SE} + Q_\lambda + Q_W + Q_T) \tag{1}$$

When calculating the cooling output balance for the cooler, the formula (1) takes the following form:

$$Q_C = b \cdot (Q_{NC} + Q_{SEC} + Q_{\lambda C} + Q_{WC} + Q_{TC}) \tag{2}$$

$b = 1.1$ was used for the calculations [Gruda and Postolski 1999].

When calculating the cooling output balance for the freezer, the formula (1) takes the following form:

$$Q_Z = b \cdot (Q_{NZ} + Q_{SEZ} + Q_{\lambda Z} + Q_{WZ} + Q_{TZ}) \tag{3}$$

$b = 1.1$ was used for calculations [Gruda and Postolski 1999].

Individual values of the cooling output balance were calculated from the following formulas:

$$Q_{NC} = \frac{M_C \cdot \Delta ic}{3600} \tag{4}$$

$$Q_{NZ} = \frac{M_Z \cdot \Delta ic}{3600} \tag{5}$$

$$Q_{SEC} = \Sigma N_C \tag{6}$$

$$Q_{SEZ} = \Sigma N_Z \tag{7}$$

$$Q_{\lambda C} = \Sigma F_C \cdot k_C \cdot \Delta t_u \tag{8}$$

$$Q_{\lambda ZZ} = \Sigma F_Z \cdot k_Z \cdot \Delta t_u \text{`} \tag{9}$$

$$Q_{WC} = \frac{V_C \cdot n \cdot \varsigma_{pc} \cdot \Delta i_{fc}}{3600} \tag{10}$$

$n = 0.2$ was used for the calculations [Gruda and Postolski 1999].

$$Q_{WZ} = \frac{V_Z \cdot n \cdot \varsigma_{pc} \cdot \Delta i_{fc}}{3600} \tag{11}$$

$n = 0.2$ was used for the calculations [Gruda and Postolski].

$$Q_{TC} = \frac{M_{Tc} \cdot C_{Tc} \cdot t_{Tkc} - t_{Tpc}}{\tau_c} \tag{12}$$

for polyurethane, PU: C_{Tc} – 1.8 kJ/(kg K) [PN-EN ISO 12524; 2003]

$$Q_{TZ} = \frac{M_{Tz} \cdot C_{Tz} \cdot \left(t_{Tkz} - t_{Tpz}\right)}{\tau_c} \tag{13}$$

for stainless steel: C_{Tz} – 0.46 kJ/(kg K) [PN-EN ISO 12524; 2003]

$$Q_{jc} = \frac{Q_C}{M_{Tc}} \cdot 3600 \tag{14}$$

$$Q_{jz} = \frac{Q_Z}{M_{Tz}} \cdot 3600 \tag{15}$$

$$\eta_c = \frac{1{,}1 \cdot Q_{Nc}}{Q_c} \cdot 100 \tag{16}$$

$$\eta_z = \frac{1{,}1 \cdot Q_{Nz}}{Q_z} \cdot 100 \tag{17}$$

RESULTS AND DISCUSSION

The results of the measurements made during the cooling and freezing of small wheat bakery products are summarized in Tables 2-4. All values contained therein are the averages of ten parallel measurements made.

Table 2. Parameters of the cooling process of rolls

Tabela 2. Parametry procesu chłodzenia bułek

Tested parameter – Badany parametr	Results obtained – Uzyskane wyniki
Relative humidity of the cooling air Wilgotność względna powietrza chłodzącego	54.00 ±0.78%
Cooling air temperature Temperatura powietrza chłodzącego	18.20 ±0.09°C
Cooling air speed Prędkość powietrza chłodzącego	0.80 ±0.07 m/s
Total cooling process time Całkowity czas procesu chłodzenia	18 minutes
Roll temperature at the beginning of the process Temperatura bułki na początku procesu	geometrical centre – centrum geometryczne 91.60 ±3.12°C
	surface – powierzchnia 85.20 ±4.27°C
Roll temperature after the process Temperatura bułki po zakończeniu procesu	geometrical centre – centrum geometryczne 35.70 ±2.35°C
	surface – powierzchnia 31.70 ±3.04°C

Table 3. Parameters of the freezing process of rolls

Tabela 3. Parametry procesu zamrażania bułek

Tested parameter – Badany parametr	Results obtained – Uzyskane wyniki
Relative humidity of the freezing air Wilgotność względna powietrza mrożącego	10.80 ±0.42%
Freezing air temperature Temperatura powietrza mrożącego	–25.30 ±0.11°C
Freezing air speed Prędkość powietrza mrożącego	2.40 ±0.08 m/s
Total process time Całkowity czas procesu	50 minutes
Roll temperature at the beginning of the process Temperatura bułki na początku procesu	geometrical centre – centrum geometryczne 35.70 ±2.35°C
	surface – powierzchnia 31.70 ±3.04°C
Roll temperature after the process Temperatura bułki po zakończeniu procesu	geometrical center – centrum geometryczne –9.00 ±2.71°C
	surface – powierzchnia –16.90 ±2.37°C

Table 4. Weight loss of a kaiser roll

Tabela 4. Ubytek masy bułki kajzerki

Tested product Badany produkt	Average (10 pieces) raw roll weight [g] Uśredniona (10 sztuk) masa surowej bułki [g]	Average (10 pieces) roll weight after partial baking [g] Uśredniona (10 sztuk) masa bułki po zapieku [g]	Average (10 pieces) roll weight after cooling [g] Uśredniona (10 sztuk) masa bułki po schłodzeniu [g]	Average (10 pieces) roll weight after freezing [g] Uśredniona (10 sztuk) masa bułki po zamrożeniu [g]
a kaiser roll kajzerka	69.40 ±0.52	63.60 ±0.70	63.40 ±0.68	62.80 ±0.69
weight loss of a kaiser roll ubytek masy kajzerki [%]		8.36	8.65	9.51

Figure 2 shows the temperature changes in a roll that undergoes the cooling process and then the freezing process.

Figure 2 presents the average, from ten test series, course of temperature changes in rolls subjected to cooling and freezing processes. The record of temperature changes begins when the rolls enter the cooler after leaving the oven. Throughout the cooling process, a steady decrease in temperature was observed both below the surface and in the geometric centre of the tested bread. After 18 minutes of the cooling process, the tem-
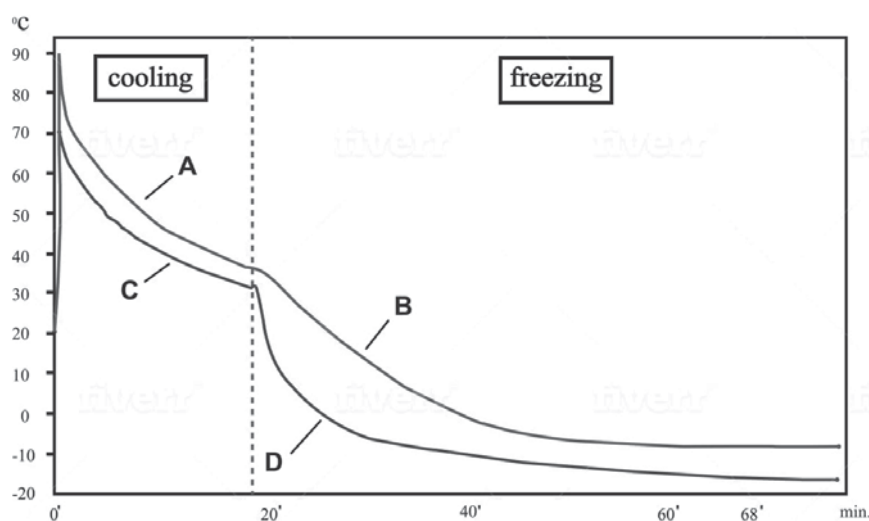

Fig. 2.   Temperature changes in a roll, where: A – temperature changes in the geometric centre of a roll during cooling, C – temperature changes below the roll surface during cooling, B – temperature changes in the geometric centre of a roll during freezing, D – temperature changes below the roll surface during freezing

Rys. 2.   Zmiany temperatury w bułce, gdzie: A – zmiany temperatury w centrum geometrycznym bułki podczas chłodzenia, C – zmiany temperatury pod powierzchnią bułki podczas chło- dzenia, B – zmiany temperatury w centrum geometrycznym bułki podczas zamrażania, D – zmiany temperatury pod powierzchnią bułki podczas zamrażania

perature in the tested rolls decreased at the surface from 85.2°C to 31.7°C, i.e. by 53.5°C, which is a decrease of 37.2%, and in the geometrical centre from 91.6°C to 35.7°C, i.e. by 55.9°C, which is a decrease of 38.9%.

The rolls were in the freezer from the 19th minute. Initially, a rapid decrease in temperature was observed below their surface. The temperature at the surface of the rolls reached 0°C after about 8 minutes. At the geometric centre of the rolls, the temperature was decreasing gently, reaching 0°C after about 20 minutes. After 50 minutes of the freezing process, the rolls lowered their surface temperature from 31.7°C to –16.9°C, i.e. by 48.6°C, which is a decrease of 53.3%. The temperature in the geometrical centre decreased from 35.7°C to –9.0°C, i.e. by 44.7°C, which is a decrease of 25.2%. The beginning of the process of freezing water in a roll began after about 10 minutes at the surface and after about 25 minutes in its geometrical centre, after the rolls were inserted into the freezer.

Table 5 summarizes the numerical values of the output balance of the cooling process, and Figure 3 presents a graphic record of the components of the balance.

Table 5. Numeric values of the output balance in the process of cooling a kaiser roll

Tabela 5. Wartości liczbowe bilansu mocy w procesie chłodzenia bułki kajzerki

No.	Tested parameter	Units	Values obtained
1	Cooler capacity M_c	kg/h	1,113.00
2	Cooling output (net heat received from the raw material) Q_{NC}	kW	42.40 ±3.19
3	Output of cooler electric motors Q_{SEC}	kW	13.70 ±0.00
4	Enclosure heat gain $Q_{\lambda c}$	kW	0.35 ±0.01
5	Air infiltration gain Q_{WC}	kW	0.13 ±0.01
6	Belt cooling heat Q_{TC}	kW	3.25 ±0.30
7	Usable heat Q_C	kW	65.82 ±3.42
	Usable heat Q_{jc}	kJ/kg	212.90 ±11.00
8	Cooler efficiency η_C	%	70.9 ±1.6

In the process of cooling kaiser rolls with cooler capacity of 1113 kg/h, the largest share in the heat balance was that of the cooling output (Q_{NC}), i.e. the net heat that was received from the product. It amounted to 42.40 kW, which constituted a 64.42% share in the output balance. The second item in the cooler output balance was the output of electric motors (Q_{SEC}), which amounted to 13.70 kW, and its share was 20.81%. The third item in the cooler output balance was the heat received during belt cooling (Q_{TC}) of 3.25 kW, and its share was 4.94% (Table5). Other items of the cooler output balance were very small and did not exceed 0.4 kW. The enclosure heat gain ($Q_{\lambda C}$) was 0.35 kW, and its share in the output balance was 0.53%. Air infiltration gain (Q_{WC}) had the smallest share in the cooler output balance. Its value was 0.13 kW, which constituted 0.20% of the output bal-
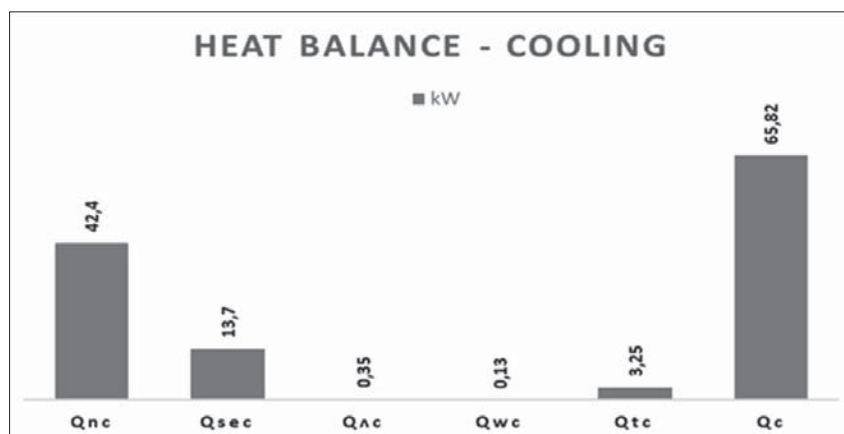
Fig. 3. Individual components of the heat balance of a kaiser roll cooling process

Rys. 3. Poszczególne składowe bilansu cieplnego procesu chłodzenia bułki kajzerki

ance. Small values of the enclosure heat gain indicate good insulation of the cooler. In turn, the low value of the air infiltration gain indicates tight protection of the infeed and discharge of rolls in the cooler.

Generally, the usable heat of the cooler (Q_C) was 65.82 ±3.12 kW, and per 1 kg of the material it was 212.90 ±11.00 kJ/kg. The relatively high efficiency of the cooler (η_C), which amounted to 70.90%, should be emphasized.

Table 6 summarizes the numerical values of the output balance of the kaiser roll freezing process, and Figure 4 presents a graphic record of the balance components.

Table 6.   Numeric values of the output balance in the process of freezing a kaiser roll

Tabela 6. Wartości liczbowe bilansu mocy w procesie zamrażania bułki kajzerki

| No.	Tested parameter	Units	Values obtained
1	Freezer capacity M_Z	kg/h	1,109.50
2	Cooling output (net heat received from the raw material) Q_{NZ}	kW	80.64 ±1.65
3	Output of freezer electric motors Q_{SEZ}	kW	56.50 ±0.00
4	Enclosure heat gain $Q_{\lambda Z}$	kW	2.35 ±0.01
5	Air infiltration gain Q_{WZ}	kW	1.74 ±0.01
6	Belt cooling heat Q_{TZ}	kW	6.40 ±0.21
7	Usable heat Q_Z	kW	162.40 ±1.77
	Usable heat Q_{Jz}	kJ/kg	526.90 ±5.70
8	Freezer efficiency η_Z	%	54.6 ±0.50
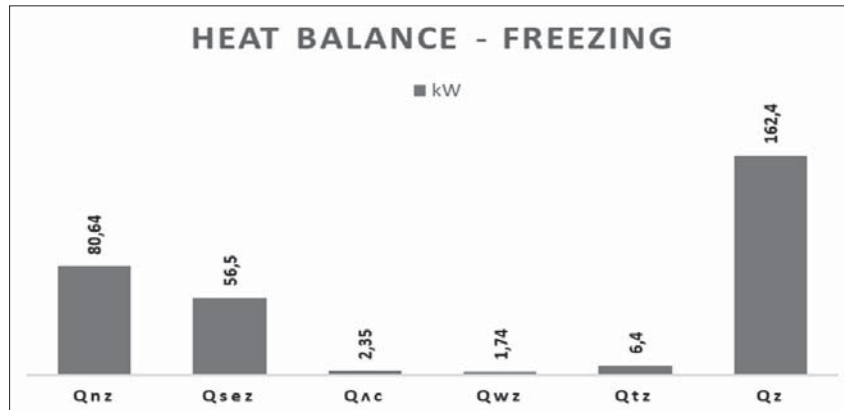
Fig. 4.   Individual components of the heat balance of the kaiser roll freezing process

Rys. 4.   Poszczególne składowe bilansu cieplnego procesu zamrażania bułki kajzerki

In the process of freezing kaiser rolls with freezer capacity of 1109.50 kg/h, the largest share in the heat balance was that of the cooling output (Q_{NZ}), i.e. the net heat that was received from the product. Its value was 80.64 kW, which constituted a 49.66% share in the output balance. The next item in the output balance was the output of freezer electric motors (Q_{SEZ}), amounting to 56.50 kW, whose share was 34.79%. Such a high share in the output balance results primarily from the presence of the main output consumers, i.e. fans usually operating at full power. Therefore, including the full rated output in the balance was a calculation approximate to actual needs [Gruda and Postolski 1999]. The third item in the freezer output balance was the heat received during belt cooling (Q_{TZ}) of 6.40 kW, and its share was 3.94%. The next items of the freezer output balance were the enclosure heat gain ($Q_{\lambda Z}$) of 2.35 kW and the air infiltration gain of 1.74 kW. These values accounted for 1.45 and 1.07% of the freezer output balance, respectively.

Generally, the usable heat of the freezer (Q_Z) was 162.40 ±1.77 kW, and per 1 kg of the frozen material it was 525.90 ±5.70 kJ/kg. The obtained value was approximate to the average value of 506 kJ/kg, which was given for spiral-belt freezers by Gruda and Postolski (1999). Freezer efficiency ($ŋ_Z$) was relatively low and amounted to 54.60%.

Comparing the cooling and freezing processes of kaiser rolls, it is important to note significant differences in the capacity, output balance, and efficiency of both devices.

The difference in the capacity of the cooler (1113 kg/h) and freezer (1109.50 kg/h) resulted from the weight loss of rolls after the cooling and freezing processes (Table 4). It should be emphasized that after partial baking the roll weight was 8.36% lower than the weight of a raw roll. The process of cooling rolls caused a decrease in the roll weight by 0.29 percentage points, and the process of freezing by 1.15 percentage points in relation to the weight of rolls after partial baking. However, the weight of the roll after freezing was 0.86 percentage points lower than the weight of the roll after cooling.

The usable heat in the cooling roll process (Q_C) was almost 2.5 times less than the usable heat in the process of freezing them (Q_Z). On the other hand, the efficiency

of the cooler ($ŋ_C$) was 16.30 percentage points higher than the efficiency of the freezer (Tables 5 and 6).

Significant differences were found in the output balance of both devices. Cooling output (net heat) during cooling rolls was 1.9 times lower than in the process of freezing them. However, the output of the freezer electric motors (Q_{SEZ}) was more than 4 times higher than the output of the cooler electric motors (Q_{SEC}). This difference resulted from both the output and the number of fans used (the cooler – one fan, the freezer – four fans). The belt cooling heat in the cooler (Q_{TC}) was almost 2 times less than the belt cooling heat in the freezer (Q_{TZ}). At the same time, the enclosure heat gain and the air infiltration gain were 6.7 and 13.4 times smaller in the cooler, respectively, than in the freezer. Such large differences resulted primarily from the values of the air parameters inside the cooler and the freezer (the temperature, speed, and relative humidity of the air) (Tables 2 and 3).

The evaluation showed that both the HEINEN arctic a7/12 and a7/24 cooler and freezer used for cooling and freezing kaiser rolls were operating properly.

The manufacturer of the cooler recommended its capacity at the level of 900 kg/h, for rolls with a unit weight of 50 g and reaching the material temperature of 35°C at the end of the cooling process after 21 minutes. The tests confirmed a slightly higher efficiency of the cooling process of kaiser rolls than recommended by the manufacturer. The average final temperature of the product weighing 63.4 g was reached at 33.7°C, with a device capacity of 1113 kg/h and the process time of 18 minutes (Tables 2, 4, and 5). Thus, the average product temperature at the end of the cooling process was 3.7% lower than recommended, with a unit product weight 26.8% higher, the device capacity 23.7% higher, and the process time 14.3% shorter.

The manufacturer of the freezer recommended its capacity at 900 kg/h, for rolls with a unit weight of 50 g and reaching the material temperature of –12°C at the end of the freezing process after 40.7 minutes. The tests confirmed a slightly higher efficiency of the freezing process of kaiser rolls than recommended by the manufacturer. The average final temperature of the product weighing 62.8 g was reached at –13°C, with the device capacity of 1109.5 kg/h and the process time of 50 minutes (Tables 3, 4, and 6). Thus, the average product temperature at the end of the freezing process was 8.3% lower than recommended, with a unit product weight 25.6% higher, the device capacity higher by 23.3%, but the process duration noticeably higher by 22.9%.

CONCLUSIONS

The evaluation showed that both the HEINEN arctic a7/12 and a7/24 cooler and freezer used for cooling and freezing kaiser rolls were operating properly. Higher capacity and lower temperature values of rolls after cooling and freezing processes, with slightly shorter cooling time and slightly longer freezing time than recommended by the device manufacturer, were obtained. The usable heat in the process of freezing kaiser rolls was almost 2.5 times greater than the usable heat in the cooling process. At the same time, the freezer efficiency was 54.6% and was 16.3 percentage points lower than the cooler efficiency.

In order to improve the efficiency of the freezer, further work should be carried out to reduce the electricity consumption of fans. The other values of the freezer heat balance do not raise any objections.

LIST OF SYMBOLS AND INDEXES

Q – usable heat, kW,

Q_C – cooler usable heat, kW,

QZ_Z – freezer usable heat, kW,

b – safety factor

Q_N – cooling output (heat collected from the raw material - net heat), kW,

Q_{NC} – cooling output needed to cool the product, kW,

Q_{NZ} – cooling output needed to freeze the product, kW,

Q_λ – output of enclosure heat gain, kW,

$Q_{\lambda C}$ – when cooling,

$Q_{\lambda Z}$ – when freezing,

Q_W – output of external air infiltration gain, kW,

Q_{WC} – when cooling,

Q_{WZ} – when freezing,

Q_T – belt cooling heat, kW,

Q_{TC} – when cooling,

Q_{TZ} – when freezing,

Q_{jc} – cooler unit heat, kJ/kg,

Q_{jz} – freezer unit heat, kJ/kg,

η_c – cooler efficiency, %,

η_z – freezer efficiency, %,

Q_{SEC} – output of electric motors installed in the cooler, kW,

Q_{SEZ} – output of electric motors installed in the freezer, kW,

M_c – cooler capacity, kg/h,

M_z – freezer capacity, kg/h,

Δi_c – enthalpy difference of rolls before and after cooling, kJ/kg,

Δi_z – enthalpy difference of rolls before and after freezing, kJ/kg,

F_C – surface of enclosure elements (walls, ceiling, floor) of the cooler, m²,

k_C – heat transfer coefficient for a given compartment of the cooler, W/(m² K),

$\Delta t_{už\,C}$ – active temperature difference in a given compartment of the cooler, °C,

F_Z – surface of enclosure elements (walls, ceiling, floor) of the freezer, m²,

k_Z – heat transfer coefficient for a given compartment of the freezer, W/(m^2 K),

$\Delta t_{uż Z}$ – active temperature difference in a given compartment of the cooler, °C,

V_C – volume of the cooler interior, m^3,

n – expected number of air changes per 1 hour,

ζ_{pc} – air density in the temperature of the cooler interior, kg/m^3,

Δi_{fc} – air enthalpy difference inside and outside the cooler, kJ/kg,

V_Z – volume of the freezer interior, m^3,

ζ_{pz} – air density in the temperature of the freezer interior, kg/m^3,

Δi_{fz} – air enthalpy difference inside and outside the freezer, kJ/kg,

M_{Tc} – belt weight in the cooler, kg,

C_{Tc} – specific heat of the belt (polyurethane, PU), kJ/(kg K),

t_{Tpc} – initial temperature of the belt (at the infeed to the cooler), °C,

t_{Tkc} – final temperature of the belt (at the discharge from the cooler), °C,

M_{Tz} – belt weight in the freezer, kg,

C_{Tz} – specific heat of the belt (stainless steel), kJ/(kg K),

t_{Tpz} – initial temperature of the belt (at the infeed to the freezer), °C,

t_{Tkz} – final temperature of the belt (at the discharge from the freezer), °C,

τ_C – cooling time, s,

τ_Z – freezing time, s.

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OCENA EKSPLOATACYJNA CHŁODZIARKI I ZAMRAŻARKI WYKORZYSTANYCH DO MROŻENIA DROBNEGO PIECZYWA PSZENNEGO

Streszczenie. Celem niniejszej pracy była ocena eksploatacyjna chłodziarki i zamrażarki taśmowo-spiralnych arctic a7/12 i a7/24 firmy HEINEN wykorzystanych do zamrażania drobnego pieczywa pszennego – bułek kajzerek, pracujących w jednej z warszawskich piekarni. Do oceny eksploatacyjnej chłodziarki oraz zamrażarki wykorzystano ciepło użyteczne, ciepło odebrane od surowca (ciepło netto), moc silników elektrycznych, zysk cieplny obudowy, zysk infiltracji powietrza, ciepło schładzania taśmy oraz wydajność i sprawność obydwu tych urządzeń. Chłodziarka przy wydajności 1113 kg/h wykazywała sprawność na poziomie 70,8%, natomiast sprawność zamrażarki, przy wydajności

1109 kg/h, wyniosła już tylko 54,6%. Ciepło użyteczne w procesie zamrażania bułek kajzerek było prawie 2,5-krotnie większe od ciepła użytecznego w procesie chłodzenia. Ustalono także rzeczywiste wielkości charakteryzujące proces chłodzenia i zamrażania: czas obu procesów, rozkład temperatury oraz ubytek masy w produkcie. Ubytek masy kajzerki po procesie chłodzenia stanowił 8,65% masy produktu surowego, a po procesie zamrażania 9,51% masy produktu surowego. Uzyskane wyniki porównano z danymi producenta obydwu urządzeń.

Słowa kluczowe: bułki kajzerki, chłodziarka, zamrażarka, ocena eksploatacyjna