World Academy of Science, Engineering and Technology
International Journal of Mechanical and Industrial Engineering
Vol:18, No:12, 2024

Conceptual Solution and Thermal Analysis of the Final Cooling Process of Biscuits in Factory "Jaffa" at Crvenka, in Serbia

Duško Salemović, Aleksandar Dedić, Matilda Lazić, Dragan Halas

***Abstract*—**The paper presents the conceptual solution for the final cooling of the chocolate dressing of biscuit in one confectionary factory in Serbia. The proposed concept solution was derived from the desired technological process of final cooling of biscuit and the required process parameters that were to be achieved, and which were an integral part of the project task. The desired process parameters for achieving proper hardening and coating formation are: the exchanged amount of heat in the time unit between the two media (air and chocolate dressing), speed of air inside the tunnel cooler and the surface of all biscuits in contact with the air. These parameters were calculated in the paper. The final cooling of chocolate dressing on biscuits could be optimized by changing process parameters and dimensions of the tunnel cooler, and looking for the appropriate values for them. The accurate temperature predictions and fluid flow analysis could be conducted by using heat balance and flow balance equations having in mind theory of similarity. Furthermore, some parameters were adopted from previous technology process, such as: inlet temperature of biscuits and input air temperature. A thermal calculation was carried out and it was demonstrated that the percentage error between the contact surface of the air and the chocolate biscuit topping, which is obtained from the heat balance and geometrically 0.67%, which is very good agreement. This enabled quality of the cooling process of chocolate dressing applied on biscuit and hardness of its coating.

***Keywords*—**Air, chocolate dressing, cooling, heat balance.

I. Introduction

COMPANY JAFFA at Crvenka, in Serbia, produces biscuits called: Jaffa, overflowing with jelly with the taste of orange and chocolate. It was necessary to install a device for final cooling of the base of Jaffa [1]. The main purpose of this device and the entire cooling tunnel is to perform the final cooling and hardening of the chocolate mass based on Jaffa biscuits with jelly. It is envisaged that the device is made of high-quality metal sheets, which is thermally insulated, in order to prevent unnecessary wastage and cold air losses. A complete device with a tunnel, precision mechanical circuits and drive electronics should be represented reliable device for carrying out a technological operation of cooling biscuits.

The design of all parts should fully meet the ergonomic conditions and allow workers to work properly during production. All circuits and sub-assemblies must be readily available to all workers who are in charge of approaching and monitoring its work, for the purpose of preventive and concrete maintenance [1].

II. Description of the Device for Definition Cooling of the Jaffa Biscuits

Fig. 1 shows the tunnel cooler „Thermoflow'' as one of the possible solutions for final cooling of biscuit in A.D. „Jaffa" - Crvenka.

Fig. 1 The tunnel cooler „Thermo-flow" (the mid part of the tunnel)

On Fig. 2 it is shown the conceptual solution of the complete device for final cooling of Jaffa biscuit.

A. Elements of the Final Cooling Device for Jaffa Biscuits

1. Control panel
2. Fan with electric motors for air conditioning
3. Upper tunnel
4. Mobile conveyor belt
5. Lower tunnel
6. Air coolers (honeycomb)
7. Valves
8. Water cooler (freon evaporator)
9. Piston compressor
10. Freon refrigerator
11. Pressure valve

1. Upper Tunnel

In the upper tunnel there is a process of exchanging heat between warm Jaffa biscuits that are cooled and handed over the heat to the cold air, that receives heat and heats it on that occasion. The upper tunnel has two cooling zones. The direction of air flow in Zone 1 is contrary to the movement of the biscuits, and in Zone 2 it is in same direction. The upper tunnel should also have air guides. On the outside of the tunnel are provided handles which can regulate the air path through the valve. Air temperature for zone 1 and zone 2 cooling is different. This part of the final cooling device represents the

Duško Salemović is with The Technical College of Applied Sciences, Zrenjanin, Serbia, (e-mail: duskosalemovic@gmail.com)

Aleksandar Dedić is with University of Belgrade, Faculty of Forestry, Belgrade, Serbia (e-mail: alekdedic66@gmail.com).

core of the complete device and will be fully devoted to it in below text. The upper tunnel contains a conveyor belt along which Jaffa biscuits move.

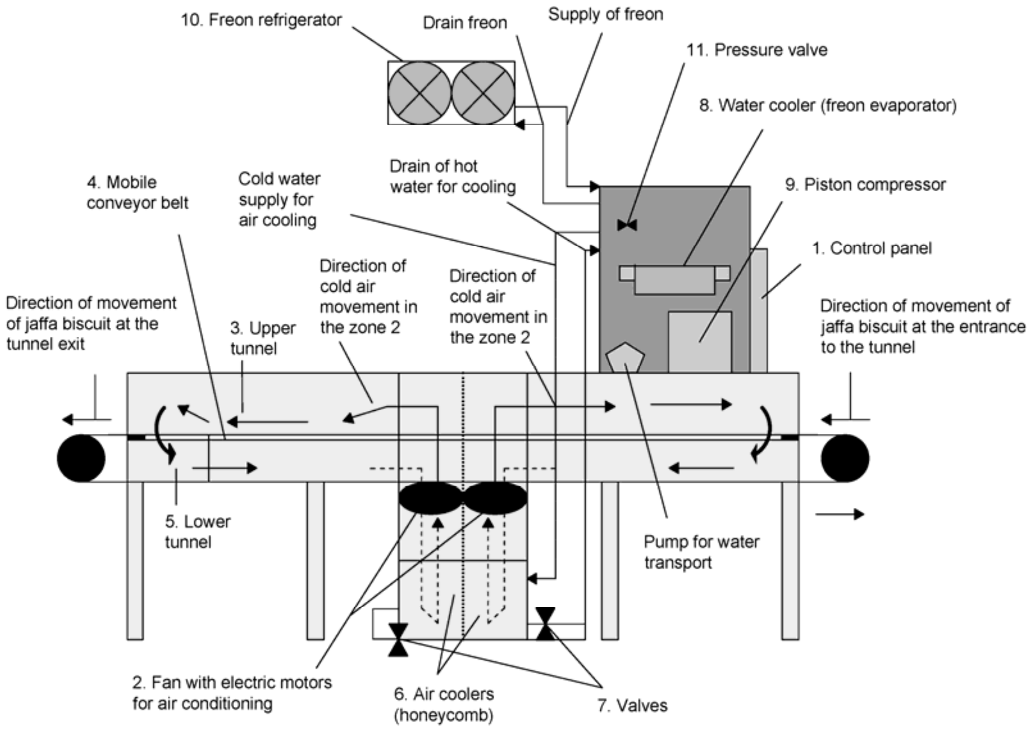

Fig. 2 Complete device for cooling of Jaffa biscuit

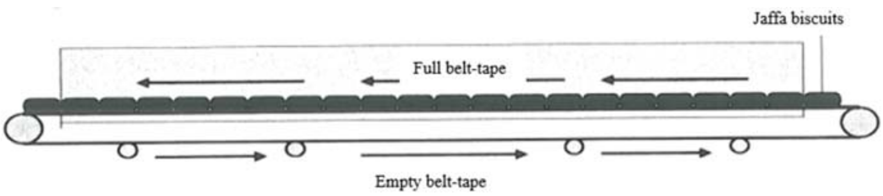

Fig. 3 Representation of the full and empty tape

2. Mobile Conveyor Belt for Biscuits Transporting

Fig. 3 shows the belt-tape conveyer with the direction of its movement. The conveyor belt is designed as a classic ribbon conveyor. Its task is to transfer through the upper tunnel, through which cold air flows, Jaffa biscuits, which in the previous production line are covered with chocolate. During the transport of the product, the final cooling of the chocolate mass is cooled and slowly cured. Below the full belt-tape it is possible to install an electronic scale that would measure the mass of the biscuit and thus indicate errors in the technological process [2]. At the beginning of the return of the belt-tape, a small knife should be installed to remove any remaining chocolate from the tape [3]. Beneath the empty belt-tape are four rollers. Their task is to enable the movement of the tape and ensure its optimal tension. In addition to the lanes on the left and right, appropriate lumbar mechanisms are provided that allow the tape to be restored to the correct road line due to its possible shifting to the side. The tunnel itself is a trapezoidal profile. The back part of the tape is located below the lower tunnel, which means it returns outside the tunnel. The entire estimated length of the tape is 80 m (in both directions). The length of the tunnel is 37 meters.

3. Lower Tunnel

In the lower tunnel, the air cooled by the cookies was warmed up, and it will be washed off by both fans with electric motors. After that, it was directed to the air coolers (heat-exchanger water-air in the form of honeycombs) under the tunnel, in order to cool them and prepare for the new cooling cycle of warm Jaffa biscuits.

4. Maintenance of Equipment

In order to fulfill the requirement of microbiological correctness, it is necessary that the hygiene of the space through which the cake passes is regularly maintained. The construction of a complete device with all its assemblies and subassemblies should allow easy access and cleaning inside the tunnel. The tunnel walls are made in the form of a cover opening up the side of the tunnel upwards, and the shock absorbers make it possible to keep them open for unhindered access to the tape-belt. In this way, workers can easily remove all possible impurities from the transport of biscuits.

III. Description of the Jaffa Biscuit Final Cooling Technology Process

By the endless conveyor belt of the upper tunnel (Fig. 2), from the right to the left, warm and complete Jaffa biscuits, which in zone 1 are cooled in contact with the cold air, which flows from the right (first) fan to zone 1. The air along the upper tunnel flows in the opposite direction from the movement of Jaffa biscuit. The air gently receives the heat from the biscuit, heats it, then goes through the return (bottom) tunnel, passes through the filter and transfers heat to the water, which is then heated. The air is again sucked by the same fan, and goes to the new cycle. There is therefore an intense heat exchange between the Jaffa biscuit and the air that cools them, and the air that cools the water that is heated.

After passing the Jaffa biscuit through zone 1, it further goes through zone 2 in which cold air, driven by a fan (first to zone 2), flows now in the same direction as the biscuit. The air returns through the return (bottom) tunnel and is sucked in the middle of the tunnel (from the side), from the fan (as in Zone 1), passes through the filter and transfers heat to the water, as in the previous case. It is envisaged that the fans are separated by the bulkheads as well as the middle of the upper tunnel from where the air flows to the right (zone 1) and to the left (zone 2), so as not to mix the current. Biscuit, after passing through the tunnel cooler, goes to packaging and storage. The tape returns back to the new biscuit reception.

In Fig. 4, a functional display of the final cooling system of the Jaffa biscuit is given.

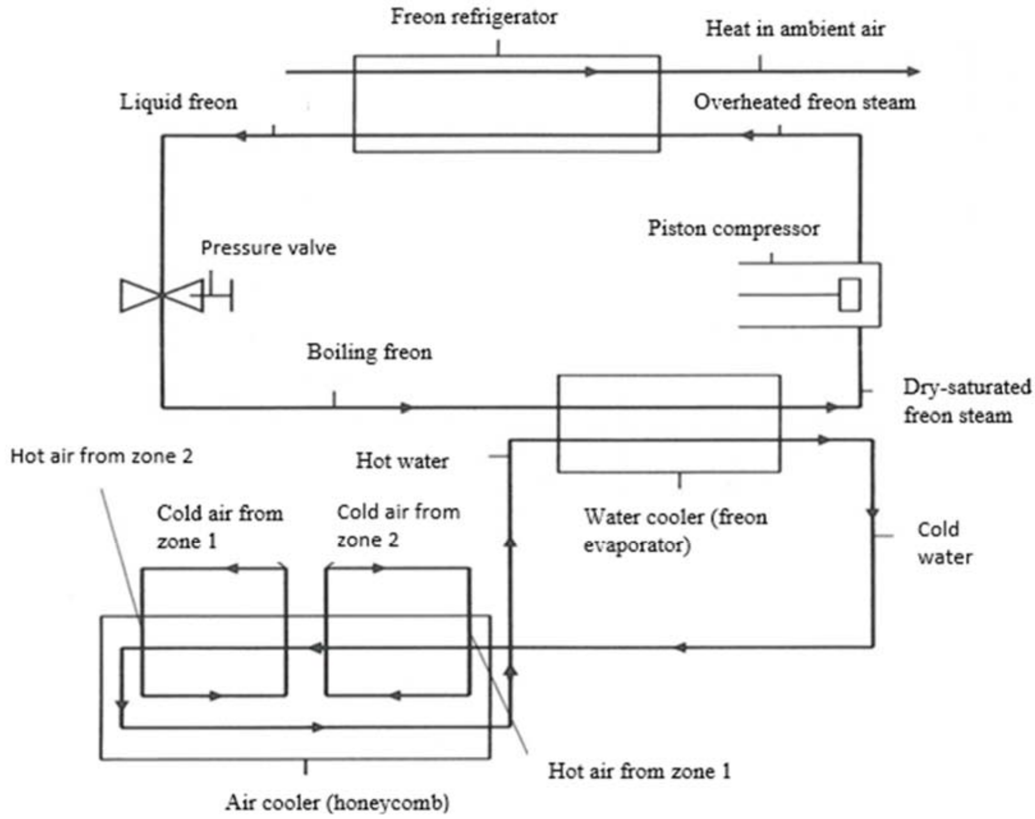

Fig. 4 Functional display of the final cooling system of the Jaffa biscuit

The water that received heat from the air during its cooling is taken from one and the other swapper of a common pipeline into the water cooler (freon evaporator) through the valve, which is leaking in exact quantities. The water cooler is located above the tunnel where freon is used as a working fluid. Freon, which receives heat from it during cooling of cooling water, evaporates. Therefore, the process of evaporation of freon should be timed in a way that all the heat generated from water during cooling is used to convert the boiling fluid (lower limit curve) to the state of the dry-saturated vapor of freon (upper limit curve). Evaporation of the freon takes place at constant pressure. The heat that freon received during the evaporation must pass on some medium. That medium is air outside the factory hall. The problem is that freon evaporates according to the tables at -12 ºC to -7 ºC [4], and the budgetary temperature of the environment for the second climate zone is -5 ºC [5], up to the expected maximum 40 °C, depending on the season. It is necessary to raise the temperature of the dry-saturated freon to a temperature higher than the ambient temperature, in order for it to be able to release the heat received during evaporation. The dry-saturated steam of freon receives a piston compressor, which compresses at a higher pressure and at a higher temperature. On that occasion, the dry-saturated steam goes into the condition of overheated steam.

The overheated freon steam would be taken to the freon refrigerator located outside the hall 1. It would be performed as a multi-stage heat exchanger, where the heated freon steam flows through the tube, while from the outside of the tube ambient air flows by two fans. In the freon refrigerant, the freon cools to the state of the co-steam, so it condenses to the state of boiling liquids, and then cools the liquid phase further. This gives all the heat received to the environment. The entire cooling process of freons is carried out at approximately constant pressure.

In the end, since freon has given heat to the environment, it is necessary to return it to the initial lower pressure. To achieve this, the liquid freon, which returns to the inlet pipe, needs to be passed through the throttle valve, by which its pressure drops to the initial value and it reaches the state of the humid steam or at a lower pressure. On that occasion, the temperature drops further, also to the initial value. Freon is then brought back to the water cooler (freon evaporator), and then it is prepared for a new cycle of hot water cooling and re-evaporation. Therefore, in order for the final cooling of the Jaffa biscuit to proceed continuously, it is necessary to have a separate air-cooling system, in this case water, which constantly receives heat from the air and heats up.

Water cooling is designed with a special Freon apparatus that works on the left-handed Rankin-Claudius circular cycle.

IV. Thermal Calculation of Cooling Process of Jaffa Biscuits

In this chapter, the required physical quantities for Zone 1 will be calculated, characterized by the process of heat exchange between the warm overflow of Jaffa biscuit and the cooler air, which receives the heat from the chocolate overflow. The heat exchange takes place in the tunnel shown in Fig. 5.

The necessary data are:

- heating surface: chocolate overflow of Jaffa biscuit
- heated fluid: air
- flow type: counter-current
- $h = 0.186$ (m): proposed tunnel height
- $D = 0.055$ (m): diameter of Jaffa biscuit
- $H = 0.015$ (m): height of Jaffa biscuit
- $V = \frac{D^2 \cdot \pi}{4} \cdot H = \frac{0.055^2 \cdot \pi}{4} \cdot 0.015 = 0.0000354$ (m^3): volume of Jaffa biscuit troll form
- $m = 0.012$ (kg): mass of Jaffa biscuit
- $\rho_1 = \frac{m}{V} = \frac{0.012}{0.0000354} = 338.983 \approx 339$ (kg/m^3): density of Jaffa biscuit
- $C_1 = 1100 \left(\frac{J}{kgK}\right)$: STC of Jaffa biscuit
- $w_1 = 0.12$ (m/s): velocity of movement of Jaffa biscuit

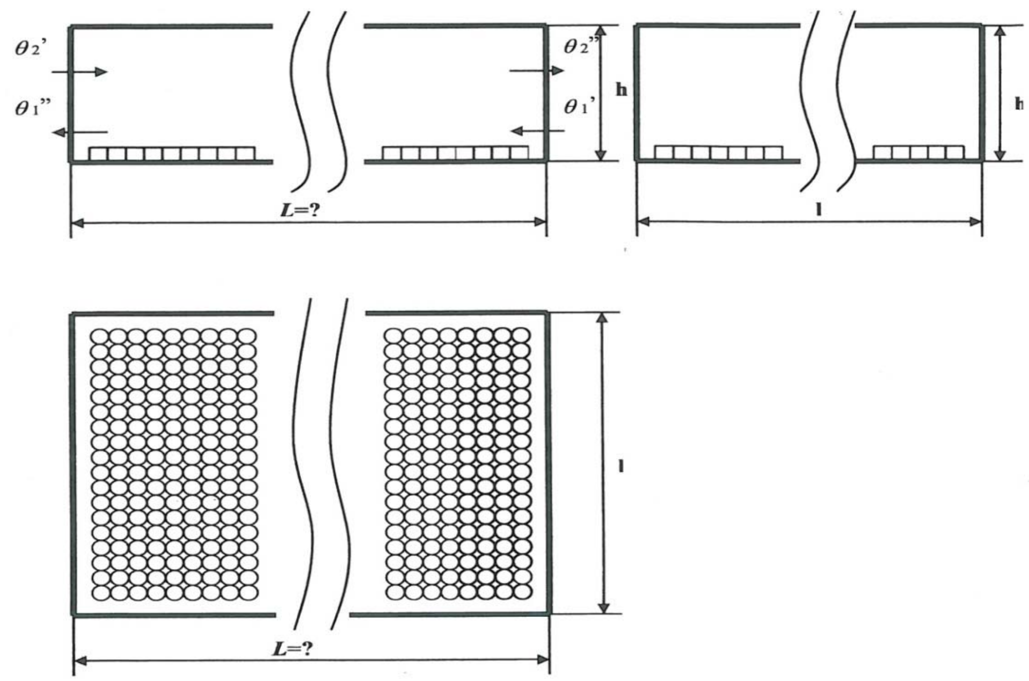

Fig. 5 Appearance of the tunnel for the final cooling of the Jaffa biscuit

- $m = 335$: number of Jaffa biscuits along the length of the lane (L)
- n = 26: number of Jaffa biscuits along the strip width (l)
- $A = \left(D \cdot \pi \cdot H + \frac{D^2 \pi}{4}\right) = \left(0{,}055 \cdot \pi \cdot 0.015 + \frac{0.055^2 \cdot \pi}{4}\right) = 0.0049656$ (m^2): surface of Jaffa biscuit contact with air during cooling
- $L = m \cdot D = 335 \cdot 0.055 = 18.425 \approx 18.5$ (m): required strip length
- $l = n \cdot D = 26 \cdot 0.055 = 1.430 \approx 1.5$ (m): required bandwidth
- $N = m \cdot n = 335 \cdot 26 = 8710$ (pcs.): number of Jaffa biscuits on tape
- $p_{2sr.} = 10^5$ (Pa): medium air pressure

- $\theta'_1 = 29$ (ºC): inlet temperature of Jaffa biscuit
- $\theta''_1 = 26$ (ºC): desired biscuits outlet temperature
- $\theta'_2 = 16$ (ºC): input air temperature
- $\theta''_2 = 20$ (ºC): output air temperature
- $\lambda = 0.157$ (W/(mK)): thermal conductivity of the conveyor belt
- $\delta = 0.003$ (m): predicted thickness of the conveyor belt
- $\Delta\theta = 0.65$ (°C): predicted temperature drop over the thickness of the conveyor belt

The requested sizes to be calculated are:

– A^* (m^2) = ?: the surface of all Jaffa biscuits in contact with the air
– w_2 (m/s) = ?: speed of air
– $\dot{Q}$ (W) = ?: the exchanged amount of heat in the time unit between two media

The average air temperature in the chamber is:

$$\theta_{2sr.} = \frac{\theta'_2 + \theta''_2}{2} = \frac{16+20}{2} = 18\ (°\text{C})$$

It was assumed that there was no significant pressure change along the cooling tunnel, so nominal atmospheric pressure and mean air temperature in the chamber were adopted for budget values from $p_{2sr.} = 10^5 (Pa)$ and $\theta_{2sr.} = 18(°\text{C})$. From the corresponding tables [4], the data for the physical parameter of air were given:

– $\rho_2 = 1.205$ (kg/m^3): density of air
– $C_{p2} = 1005$ (J/kgK): STC of air at p = const.
– $\lambda_{t2} = 0.0259$ (W/mK): thermal conductivity of air
– $v_2 = 15.06 \cdot 10^{-6}$ (m^2/s): kinematic viscosity of air
– $Pr_2 = 0.703$: Prandtl's number

The average temperature of Jaffa biscuit is:

$$\theta_{1sr.} = \frac{\theta'_1 + \theta''_1}{2} = \frac{29+26}{2} = 27.5\ (°\text{C})$$

For this temperature,

– $Pr_z = 0.701$: Prandtl's number in the border layer of air with the Jaffa biscuit topping

The cross-sectional area of the Jaffa biscuit is:

$$A_1 = n \cdot D \cdot H = 26 \cdot 0.055 \cdot 0.015 = 0.021450\ (m^2)$$

The cross-sectional area of the tunnel through which the air flows is:

$$A_2 = l \cdot h - A_1 = 1.5 \cdot 0.186 - 0.02145 = 0.257550\ (m^2)$$

The mass flow of Jaffa biscuit will be:

$$\dot{m}_1 = \rho_1 \cdot w_1 \cdot A_1 = 339 \cdot 0.12 \cdot 0.02145 = 0.872 (\text{kg/s})$$

The heat capacity of Jaffa biscuit is:

$$\dot{W}_1 = \dot{m}_1 \cdot C_1 = 0.872 \cdot 1100 = 959.8446\ (\text{W/K})$$

The Jaffa biscuit part of the heat flux is surrendered by the cooling air and the part by conveying the conveyor belt, so that the heat flux fed to the air in the upper tunnel is:

$$\dot{Q} = \dot{W}_1 \cdot (\theta'_1 - \theta''_1) - \frac{\lambda}{\delta} \cdot \Delta\theta \cdot L \cdot l = 959.8446 \cdot (29 - 26) - \frac{0.157}{0.003} \cdot 0.65 \cdot 18.425 \cdot 1.43 = 1983.27\ (\text{W})$$

The heat capacity of the air is now:

$$\dot{W}_2 = \frac{\dot{Q}}{\theta''_2 - \theta'_2} = \frac{1983.27}{20-16} = 495.82\ (\text{W/K})$$

Mass flow of air will be:

$$\dot{m}_2 = \frac{\dot{W}_2}{C_{p2}} = \frac{495.82}{1005} = 0.493\ (\text{kg/s})$$

The air velocity is:

$$w_2 = \frac{\dot{m}_2}{\rho_2 \cdot A_2} = \frac{0.493}{1.205 \cdot 0.256725} = 1.59 (\text{m/s})$$

Reynolds number is:

$$Re_2 = \frac{w_2 \cdot L}{v_2} = \frac{1.59 \cdot 18.425}{15.06 \cdot 10^{-6}} = 1944866 > 500\,000 - \text{the flow is turbulent}$$

Nusselt's number is [6]:

$$Nu_2 = 0{,}037 \cdot {Re_2}^{0,8} \cdot {Pr_2}^{0,43} \cdot \left(\frac{Pr_2}{Pr_z}\right)^{0,25} = 0.037 \cdot 1944866^{0,8} \cdot 0.703^{0,43} \cdot \left(\frac{0.703}{0.701}\right)^{0,25} = 3418$$

The coefficient of heat transfer is:

$$\alpha_{t2} = \frac{Nu_2 \cdot \lambda_{t2}}{L} = \frac{3418 \cdot 0{,}0259}{18.425} = 4.80\ \left(\frac{\text{W}}{\text{m}^2\text{K}}\right)$$

The mean logarithmic temperature difference will be:

$$\Delta\theta_m = \frac{(\theta'_1 - \theta''_2) - (\theta''_1 - \theta'_2)}{\ln\frac{\theta'_1 - \theta''_2}{\theta''_1 - \theta'_2}} = \frac{(29-20)-(26-16)}{\ln\frac{29-20}{26-16}} = 9.49\ (°\text{C})$$

The contact surface of the two media (air-chocolate dressing) is now:

$$A^* = \frac{\dot{Q}}{\alpha_{t2} \cdot \Delta\theta_m} = \frac{1983.27}{4.8 \cdot 9.49} = 43.538593\ (m^2)$$

From the geometric point of view, considering the proposed conceptual solution, the contact surface of the two media (air-chocolate dressing) would be:

$$A^* = N \cdot A = 8710 \cdot 0.0049656 = 43.250376 (m^2)$$

The matching of the results is quite acceptable, as the percentage error is 0.67%. Fig. 6 shows the temperature of air and biscuit along the tunnel.

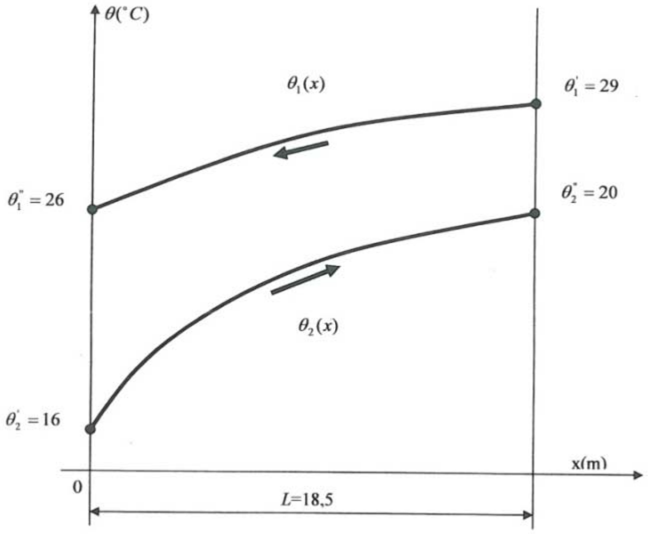

Fig. 6 Graphs of air temperature and chocolate overflow at the entrance and exit from the tunnel

V. Conclusion

From all of this, it can be concluded that the constructively predicted half-length of the 18.5 m cooling tunnel fully meets the required parameters necessary for the technological process of cooling the Jaffa biscuit. The thermal calculation showed a good agreement on the values obtained for the contact surface of two media (air-chocolate overlays), calculated in two different ways: through the heat balance and taking into account the geometric characteristics of the proposed conceptual solution. The desired temperature from the chocolate top at the exit from zone 1 of 26 °C corresponds to the continuation of the cooling process in zone 2, so that the final desired overflow temperature at the zone 2 exit is 23.5 °C. It is still necessary to carry out the techno-economic analysis and choose the optimal solution from the cooling devices present on the market. Certainly, when choosing an optimal solution, it is necessary to take into account the values of the quantities determined by the thermal budget, and especially when choosing a tunnel cooler with good insulating properties.

Acknowledgment

The work was carried out within the project of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, number: 451-03-65/2024-03/ 200169 dated on 05.02.2024.

References

[1] *Internal literature and technical documentation of the factory „Jaffa“*, A.D. Crvenka. (in Serbian)

[2] A. Dedić, D. Lukačev, *Measurement of material mass during transport*, Drvarski glasnik, vol. 2 (6-7), pp. 31-35, 1993. (in Serbian)

[3] M. Gavrilović, *Technology of confectionery products,* II edition, Faculty of Technology, University of Novi Sad, 2003. (in Serbian)

[4] D. Salemović, D. Jašin, *Manual for Process Technique,* The Technical College of Applied Sciences, Zrenjanin, 2008. (in Serbian)

[5] G. Danon, A. Dedić, *Basement of Mechanical Engineering, practicum,* II supplemented and reworked edition, University of Belgrade, Faculty of Forestry, Belgrade, 2011. (in Serbian)

[6] Dj. Kozić, B. Vasiljević, V. Bekavac, *Manual for thermodynamics in SI units,* XII edition, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, 2014. (in Serbian)