EFFECT OF GEOMETRY UPON COOLING CHARACTERISTICS OF WAFER BLOCK COOLERS

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Abstract:
The product formed after the cream is spread between the wafer sheets is called a wafer block. The wafer block can have a minimum of 3 layers (2 sheets, 1 cream) and a maximum of 9 layers (5 sheets, 4 creams). The temperature of the wafer block before entering the cooling tower is 30-35℃. After the cooling process is completed, it cannot be reduced to the outlet temperature (~16℃) and the temperature is not homogeneously distributed. Especially the middle regions are hot. In this paper, the homogeneous temperature distribution is aimed at by using the CFD method. CFD analysis of three predetermined designs was performed using Solidworks / Flow Simulation software. The first design is the one currently used. In the second design, a design improvement has been made to reduce the effect of vortices in dead zones. In the third design, a design improvement was made to positively affect the flow rate in the upper region where the evaporator and fan are located. In the second design, the temperature difference on the wafer block is reduced by 0.02℃ compared to the current design. The third design decreases by 0.13℃ compared to the second design.

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1. INTRODUCTION

When the machinery sector is analyzed, the food machinery sector is one of the largest sub-sectors. Food machinery is a sector that is developing year by year. In the wafer baking oven in the wafer production lines of the food machinery sector, the liquid dough is poured between the molds and baked, and the resulting product is called a wafer sheet. In the following process of the wafer sheet, cream at a 30-40℃ (depending on the customer recipe) temperature is applied on it. A wafer block is a structure consisting of at least two sheets with layers of cream between the sheets [1]. The wafer block can be made with up to 9 layers (5 wafer sheets and 4 creams). The hot cream between the sheets must be reduced to a certain degree to cut the wafer block in the desired dimensions without breaking or falling apart. The wafer blocks are cooled before cutting. The cooling time of the wafer block varies according to the number of sheets and cream configuration. In Fig. 1, there are three types of machines where the cooling process of the wafer block takes place. These are Block Cooling Tunnels, Spiral Cooling machines, and Block Cooling Towers. The block cooling tunnel carries the incoming wafer block on a flat conveyor and performs the cooling process. It is especially advantageous in enterprises with height limits. The spiral cooling machine should be used where the wafer block cannot be rotated during the cooling process. The

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customer does not prefer the first two machines because they take up more space in the factory areas than the block cooling tower. The block cooling tower cools the wafer blocks with shelves arranged in a waterfall from top to bottom. The temperature of the cream spread between the wafer blocks is between 30-40℃. The temperature of the wafer block before entering the cooling tower is between 30-35℃.

Air-cooled chillers are generally used in cooling towers.

a) Wafer Block Cooling Tunnel [2]

b) Spiral Cooling [3]

c) Wafer Block Cooling Tower

Fig. 1. Types of machines where the cooling process of the wafer block takes place

In block cooling towers, hot wafer blocks cannot be reduced to the outlet temperature (~16℃) after completion. However, the temperature on the wafer block is not homogeneously distributed. Especially the center of the wafer blocks cannot be brought to the desired temperature. The cooling capacity can be increased to bring the middle zone to the desired temperature, but high cooling power causes crystallization effects on the product. Crystallization is not preferred as it would adversely affect product quality. Liquid chocolate/cream that has not reached the desired temperature sticks to the cutting blades, accumulates, distorts the dimensions of other products, and is rejected. The geometric tolerance of wafers cut out of dimension changes, and the separation cannot proceed in the product-wide bands called spreading.

The literature search examined many studies on the wafer's cooling processes and equivalent products.

Cream wafer blocks are usually cooled by cold convection air (10-12℃). The humidity of the ambient cooling air must be low. Because; as the temperature of the environment decreases, the relative humidity of the air increases, this means that the wafer product collects moisture on itself. The surface temperatures of the wafer block, which are more in contact with cold air, should be above the condensation point of the cold air environment. When it is below, it collects the moisture of the environment on itself, separating the cream from the wafer [4].

A computational fluid dynamics (CFD) model was developed to see the temperature changes in carcass meat. They validated the proposed model with an experimental system. The presented CFD model enables product quality assessment by identifying critical zones on the product in the cooling system [5].

In the experimental system, the cooling times of liquid praline poured into round molds of equal dimensions with a diameter of 20 mm were examined. It is observed as the area where the temperature change starts in the range of 23-17℃ in the molds. It is seen that 12-13 minutes is sufficient to reduce the praline with a height of 15 mm to 15℃ [6].

As a result of CFD analysis to ensure homogeneous airflow in cooling rooms, the temperature, velocity, and humidity values of the air that provides the main permeability in the cooling environment according to the difference in the orientation angle of the evaporator were examined. As a result, it has been revealed that the airflow is towards the center of the cooling environment, and its position is better at the top center [7-9].

In the CFD study on the temperature distribution of stacked yogurt, the temperature differences in the bottom, and top layers of the yogurt boxes were observed. The main reason for the temperature differences is the high air velocity at the inlet of the fans and the formation of a vortex in the area between the fans due to the position of the fans. For this reason, the airflow in the cooling chamber is distributed in the upper region at a height of 1.5 to 2.5 m. It was observed that a more homogeneous temperature distribution was achieved by changing the position of the fans [10].

Energy efficiency efforts in the dairy sector are important. The costs of dairy producers in Serbia constitute 5-8% of the total cost. In the energy audit conducted in a sample enterprise, electricity consumption is 11-15%, and heat energy is 20-23%. The energy audit method can also be applied to other sectors [11].

Recently, studies on renewable energy sources have increased. In particular, researchers have focused on heat recovery technologies and applications. This study analyzes heat exchangers, the Rankine cycle, and thermoelectric generators. As a result of the study, comparing energy consumption with costs gives better results, and optimizing the heat recovery system is recommended [12].

In a study conducted to understand and measure the factors determining the cooling rate of stored food grains, it was observed that the hygroscopic properties of food grains change the specific heats of grain and air [13].

In food and feed factories, pellet cooling and drying machines are used to remove the temperature and moisture from the pellets. In the study conducted to eliminate erosion in pipes using CFD analysis, increasing the particle size causes an increase in particle sediment [14].

This study chose the computational fluid dynamics (CFD) method for the design and flow improvements to be made on the machine for homogeneous cooling of wafer blocks. The computer simulations were conducted utilizing Solidworks Simulation software.

2. MATERIALS AND METHOD

In this study, homogeneous temperature distribution on wafer blocks is aimed at using the CFD method in a block cooling tower. In Solidworks/Flow Simulation software, the variables that will affect the temperature distributions on the wafer block of the existing design were first defined. Following the determined variables, a preliminary design was made by choosing the method to minimize the temperature differences. A total of three different designs were identified in the study, one of which is exist. At the bottom of the existing block cooling tower, vortices form and there are dead zones with no contact with the product. In the second design, to avoid vortices due to dead zones, a design improvement has been made that will positively affect the flow characteristics. In the third design, a design improvement was made to positively affect the flow rate in the upper region where the evaporator and fan are located.

In current designs, the machine has an evaporator and axial fan. The number of wafer blocks can be increased or decreased according to the machine’s capacity.

The proposed new designs do not affect the capacity of the machine. Fig. 2 shows detailed information about the current design.

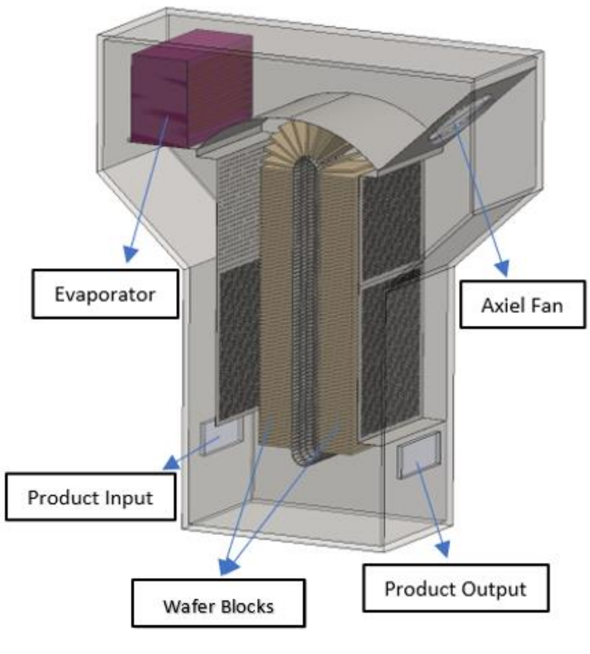
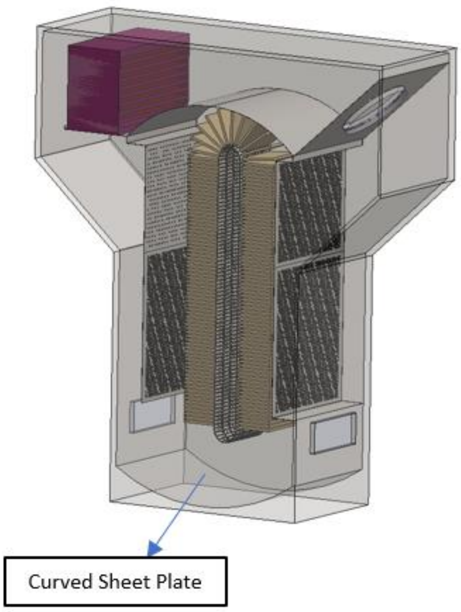
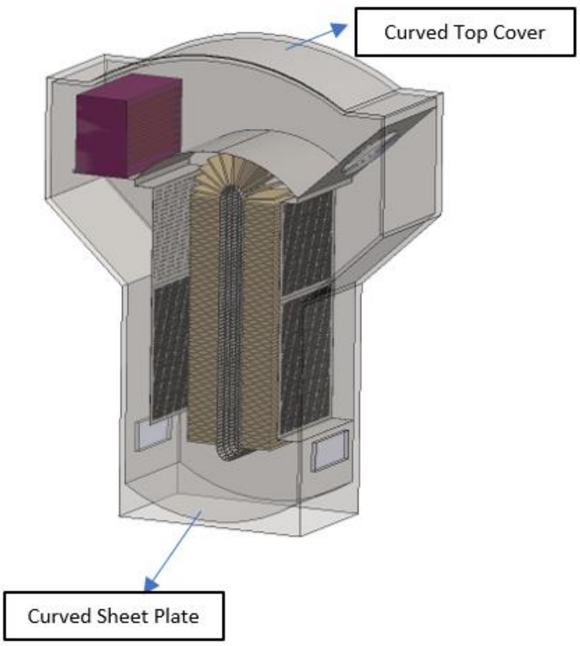


Fig. 2. First design

Fig. 3 shows the design improvements made. In the second design, a curved sheet metal plate was added to prevent vortex formation in the dead zones. In the third design, a curved top cover was added to the area where the evaporator and fan are located to improve the airflow rate of the upper zone.



a) Second design



b) Third design

Fig. 3. The design improvements

The approximate temperature of wafer blocks after the cream spread operation reaches 30-35℃, depending on the ingredients. In the computer simulations, the inlet temperature of the wafer block in the machine is defined as 35℃, while the inside temperature is defined as 10℃. The material in contact with the product in the cooling tower is modelled as AISI 304 material.

In the CFD analysis, it is required to enter the fan curve values containing the performance characteristics of the axial fan in the machine. The values of the fan curve are shown in Fig. 4.

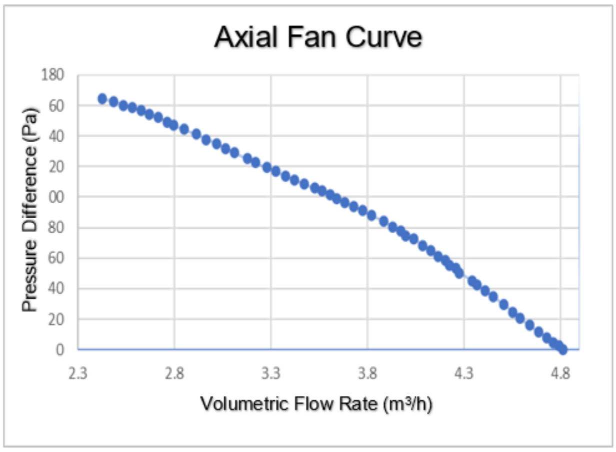


Fig. 4. Axial fan curve

To obtain the temperature and velocity variables of the air, 9 points were identified in the design. The 9 points identified in red are obtained in the machine's center. At 9 points, the temperature and velocity value of the air is obtained. Air temperature and air velocity values will be made for three designs. Fig. 5 shows the points where numerical evaluations were obtained on the cooling tower.

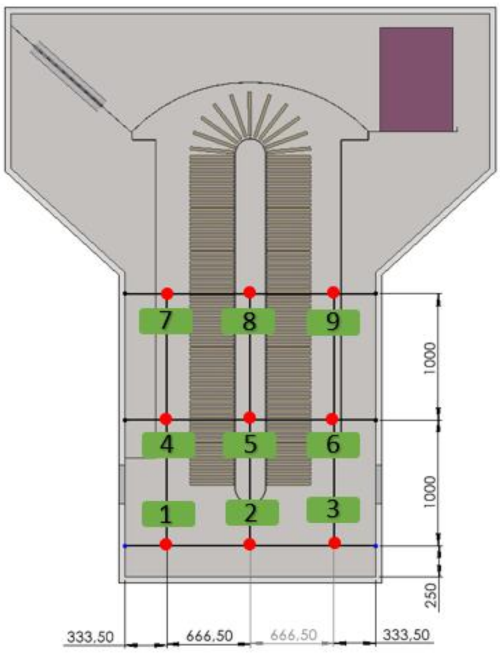


Fig. 5. Cooling tower uvaluated points

The air velocity and temperature effect on the wafer block, which will be determined in the CFD analysis, will be examined. Fig. 6 shows 9 points where numerical evaluations were obtained on the wafer block by using CFD analyses.

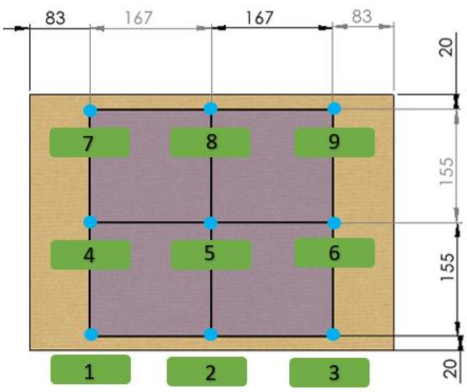


Fig. 6. Points evaluated on the wafer block

3. RESULT AND DISCUSSIONS

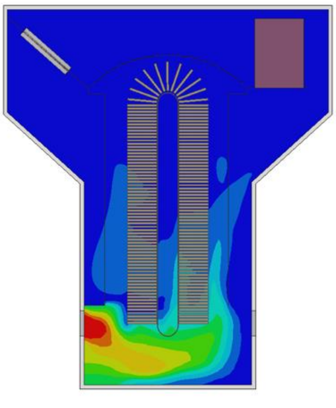
CFD analysis was performed for three designs. The mesh structure of the analyses is given in Table 1.

Table. 1. Mesh structure of the design

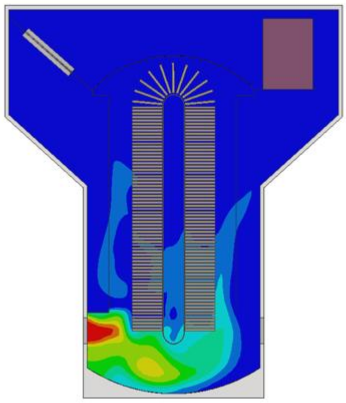
DESIGN	Fluidized cells	Solid cells	Total Cells
First Design	354130	206549	560679
Second Design	355942	207575	563517
Third Design	353520	205807	559327

Time-independent CFD analyses were performed. As a result analysis, three different variables were analyzed. The air temperature distribution inside the cooling tower, air velocity, and temperature distribution on the wafer block was analyzed. The evaluated points inside the cooling tower affect the uniform temperature of the wafer block. Points 1, 2 and 3 in the cooling tower are the areas where the dead zone is located. The evaluated point 5 on the wafer block indicates the temperature of the center of the wafer block.

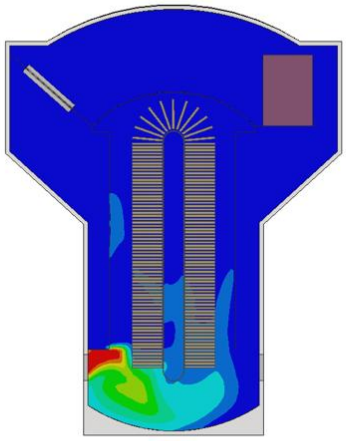
According to the results of CFD analysis for three different designs, the air temperature distributions inside the machine are shown in Fig. 7.



a) First design



b) Second design



c) Third design

Fig. 7. The air temperature distributions inside the machine

The results of the air velocity and temperature values obtained in the cooling tower as a result of analyzes are shown in Tables 2 and 3 respectively.

Table 2. Air velocity values for the three designs

# Point	First Design	Second Design	Third Design
	Velocity (m/s)	Velocity (m/s)	Velocity (m/s)
1	0.653	1.351	1.532
2	0.773	0.619	0.675
3	1.669	2.932	3.147
4	0.406	0.545	0.972
5	1.282	1.031	1.078
6	1.939	1.939	1.561
7	2.641	2.593	2.477
8	2.393	2.391	2.296
9	1.004	1.019	0.869
Average	1.418	1.602	1.623
Standard Deviation	0.79	0.887	0.844

Table 3. Air temperature values for the three designs

# Point	First Design	Second Design	Third Design
	Temperature (°C)	Temperature (°C)	Temperature (°C)
1	20.93	12.74	12.68
2	22.18	19.69	13.28
3	10.22	6.12	6.18
4	9.13	7.99	6.23
5	8.92	8.31	7.42
6	8.06	7.25	7.25
7	7.67	8.83	8.09
8	6.54	6.25	5.96
9	7.65	7.29	6.33
Average	11.25	9.38	8.16
Standard Deviation	5.94	4.33	2.82

The results obtained from 9 evaluated points determined on the wafer block as a result of the analysis are shown in Table 4.

Table 4. Wafer block temperature values for three designs

# Point	First Design	Second Design	Third Design
	Temperature (°C)	Temperature (°C)	Temperature (°C)
1	12.84	11.17	9.49
2	12.76	11.31	9.41
3	12.6	11.36	9.32
4	12.88	11.25	9.48
5	12.79	11.35	9.43
6	12.61	11.41	9.33
7	12.93	11.31	9.5
8	12.86	11.43	9.45
9	12.63	11.48	9.34
Average	12.77	11.34	9.42
Standard Deviation	0.12	0.09	0.07

4. CONCLUSION

The findings and comments resulting from the CFD analysis are summarized below.

- ✓ In the second design developed compared to the existing design, CFD analysis showed that the wafer block's temperature difference (ΔT) decreased by 0.02°C.
- ✓ Comparing the CFD analysis result of the third design with the second design, it was noted that the temperature difference (ΔT) on the wafer block decreased by 0.13°C.
- ✓ Adding curved sheet metal to the cooling tower increases the air velocity in the dead zones, and the air temperature decreases compared to the existing design.
- ✓ In the second and third designs, the temperatures at point 5, the center of the wafer block, decrease as the air velocity and temperature in the dead zones improve.
- ✓ It is seen that the third design is the best design for the homogeneous temperature distribution on the wafer block, which is the aim of the study. However, the current block cooling machine cannot be increased further due to its maximum height in factory layouts. Therefore, the second design was selected as the optimum design.
- ✓ As an output of the study, the temperature differences in the wafer block were reduced by improving the design without increasing the cooling power.
- ✓ In the continuation of this study, parametric optimization or heuristic optimization methods can be used to obtain data that will ensure a homogeneous flow.

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