Department of Biosystems and Agricultural Engineering
MICHIGAN STATE UNIVERSITY

BE 487 - Spring 2025
Biosystems Design Projects

Optimized Cooling for Tillamook Cheddar Cheese (Under NDA)

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Client: Tillamook County Creamery Association **Faculty Advisor: Dr. Ian Hildebrandt**

Background

Market demand for quality cheese is increasing, and the Tillamook County Creamery Association is poised to meet it. Tillamook's high-quality standards must be met without compromise.

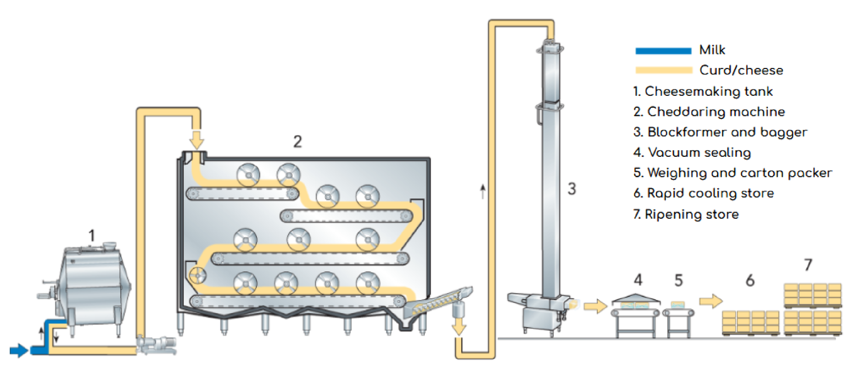

Figure 1: Tillamook's cheese manufacturing system.

After cheese is made, it is sealed and cooled (see Step 6). Cooling takes on average 20-22 hours and presents a bottleneck in the manufacturing process. Improper cooling results in a decrease in product quality and economic value.

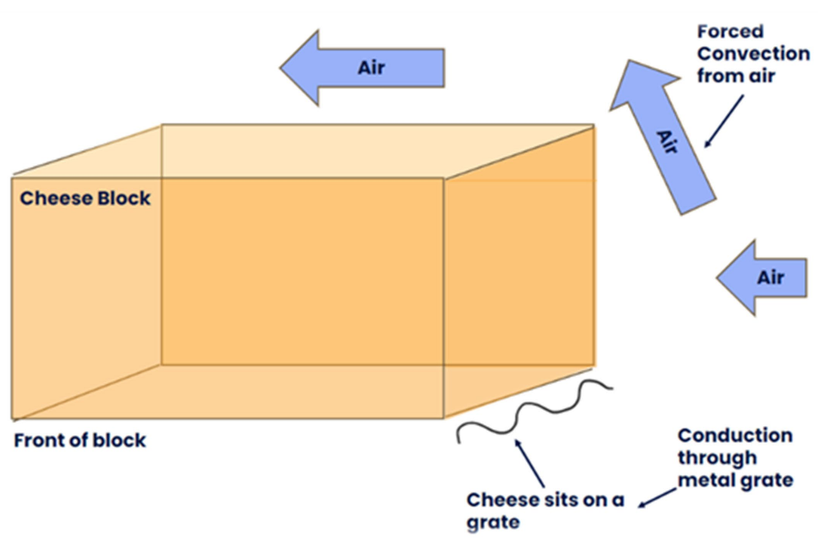

Figure 2: Diagram of heat transfer over surface of cheese blocks..

All blocks are similar to one another in size and composition. They are cooled by convection and transfer their heat to the surrounding cold air of the cooling room.

Problem Statement

Identify and resolve current issues in the cooling process at Boardman plant and determine optimal cooling temperature and air velocity for cheddar cheese.

Objectives

- Develop a heat transfer model to simulate the heat loss of a cheese block during its passage through the cooling room.
- Assess issues with cooling room and identify 3 potential design improvements.
- Perform an economic and energy cost analysis for proposed solution.
- Reduce 11% of cheese blocks downgraded annually.
- Minimize residence time.

Constraints

- Heat transfer model costs must remain under $1,000.
- Costs pertaining to energy usage must remain under $200,000.
- 100% of the cheese must be <60°F when exiting the rapid cooling room.
- Residence time cannot exceed 18 hr.
- Government regulations and safety concerns applicable must be met.

Design Alternatives

- Computational Fluid Dynamics – Simulate fluid flow and heat transfer for entire cooling room.
- Analytical Spreadsheet – Simplistic approximation tool for an individual cheese block's heat transfer.
- Finite Element Method (FEM) - Utilize MATLAB to simulate block heat transfer based upon thermal property inputs.

Selected Design

FEM model in MATLAB was chosen based on accuracy and ability to model.

Model Inputs: air velocity (m/s), residence time (hours), ambient temperature (°F), and cheese block thermal properties.

Current Cooling

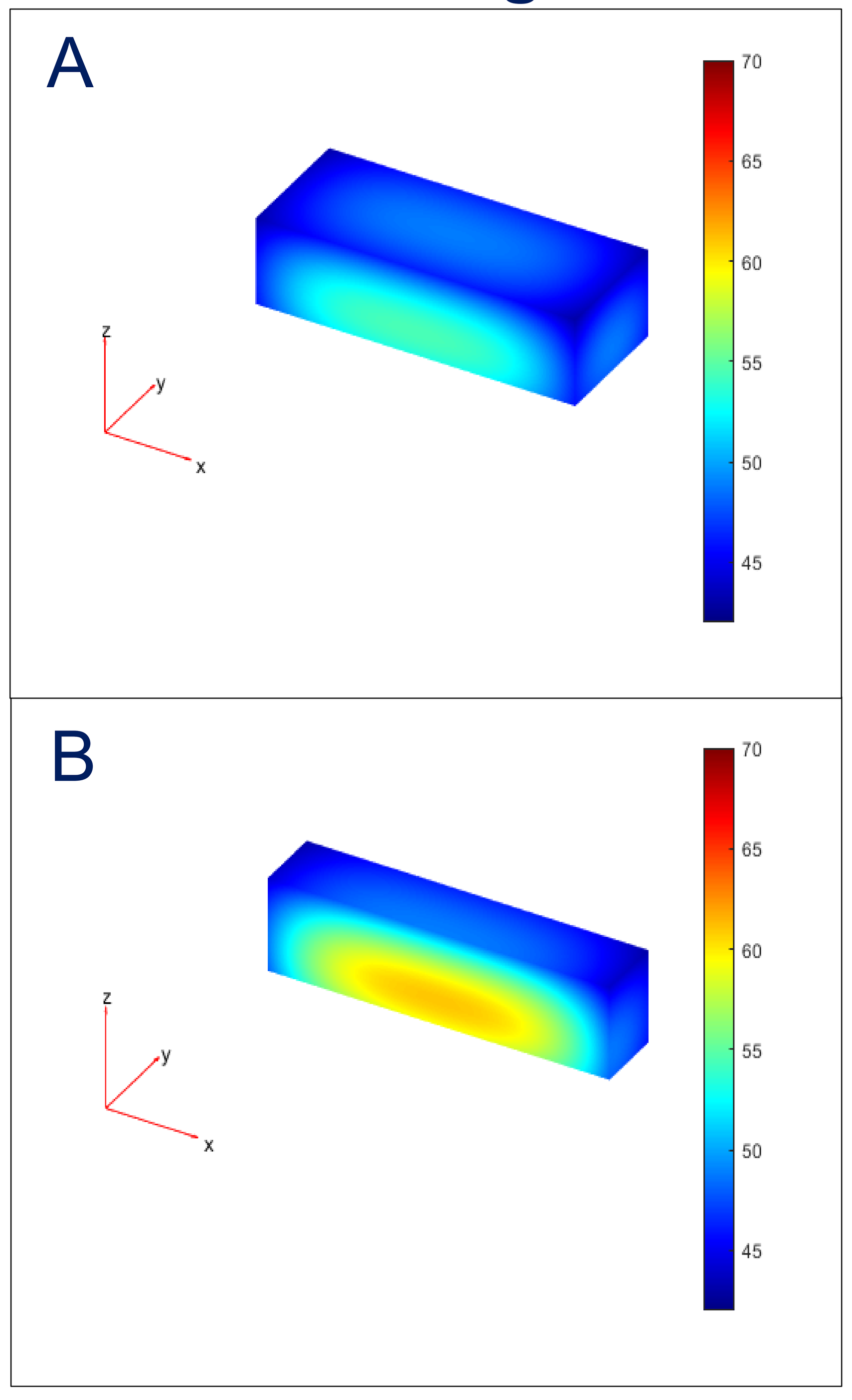

Figure 3: MATLAB modeled heat transfer through cheese block using FEM under current parameters generating a heat map with approximate temperature(°F) values. A represents a whole cheese block, and B represents a cross section of the cheese block.

Solution

Our final solution will achieve an 18-hour residence time.

Current conditions

- Ambient temperature of 41°F
- Air velocity of 3.88 m/s
- Convective coefficient of 9 W/m^2K

Proposed conditions

- Ambient temperature of 37.4°F.
- No change to air velocity nor convective coefficient

This solution can be easily implemented and was the most cost effective.

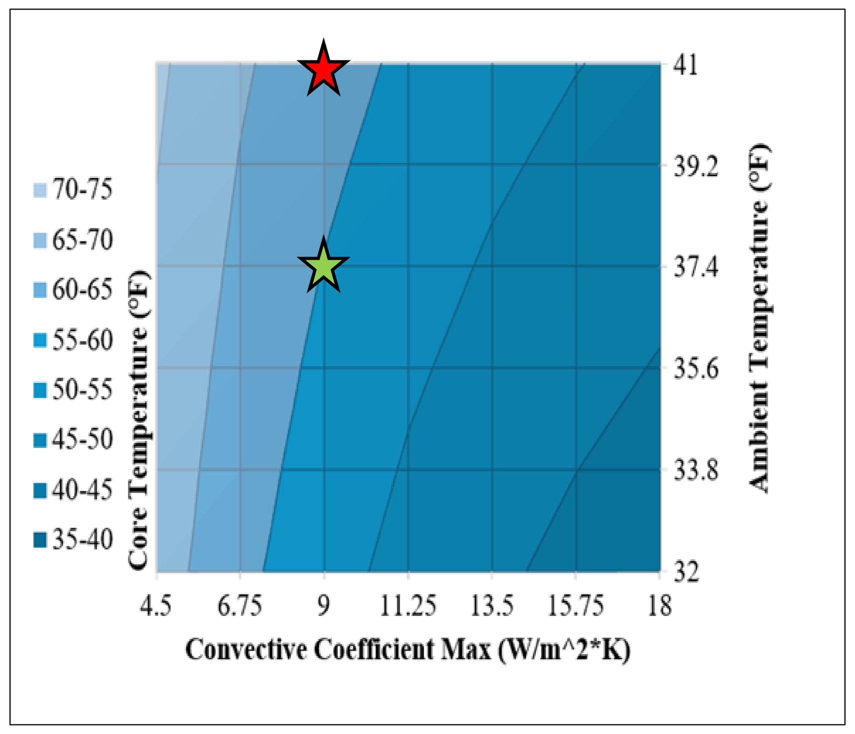

Figure 4: Contour plot for an 18-hour residence time. The red star indicates current parameters and the green star for proposed.

Proposed Cooling

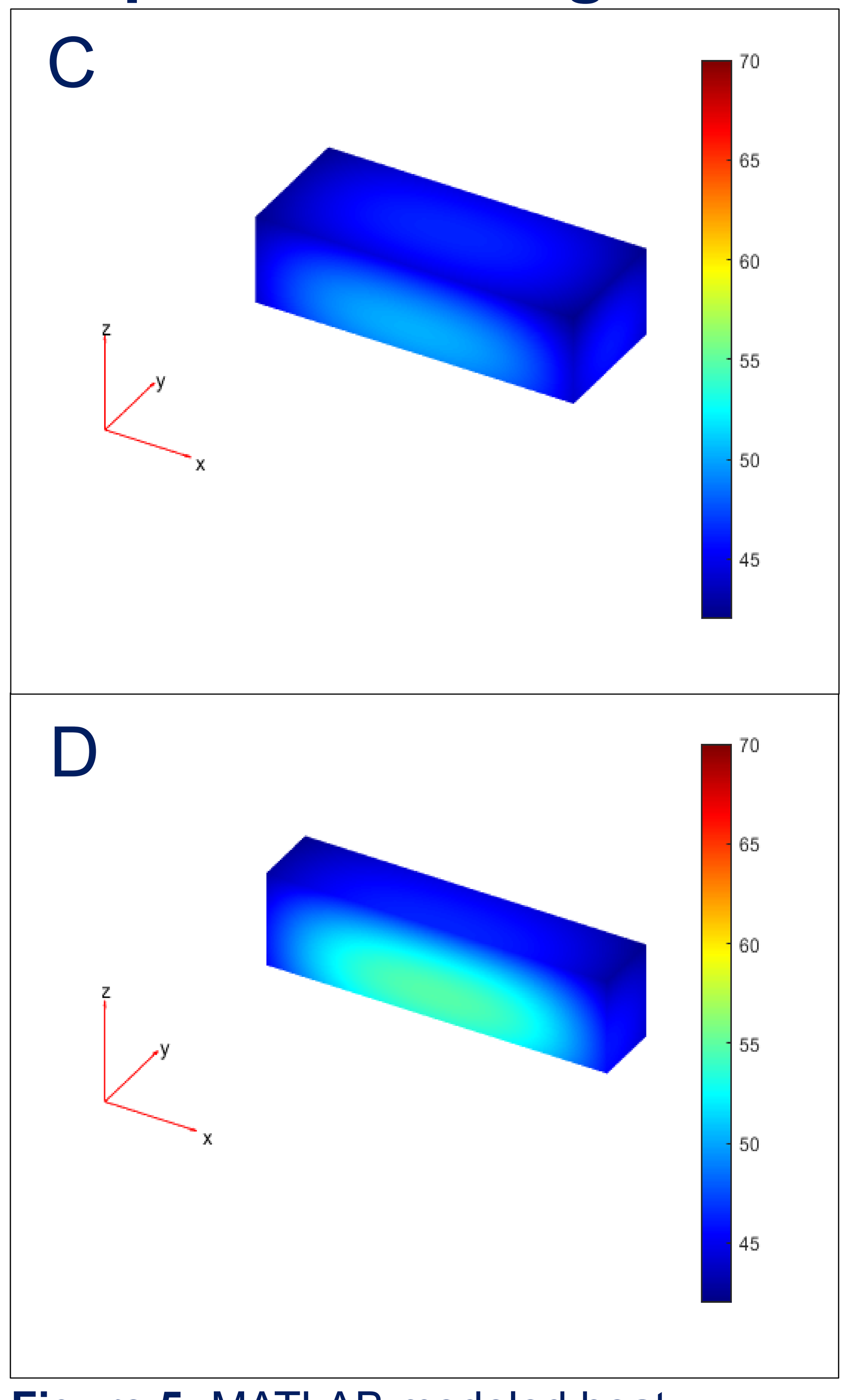

Figure 5: MATLAB modeled heat transfer through cheese block using FEM under proposed parameters generating a heat map with approximate temperature(°F) values. C represents a whole cheese block, and D represents a cross section of the cheese block.

Validation

To better understand the performance of the model, validation was performed. It was determined that the model predicts a higher rate of heat loss than was observed. Due to data size limitations, exact error is uncertain.

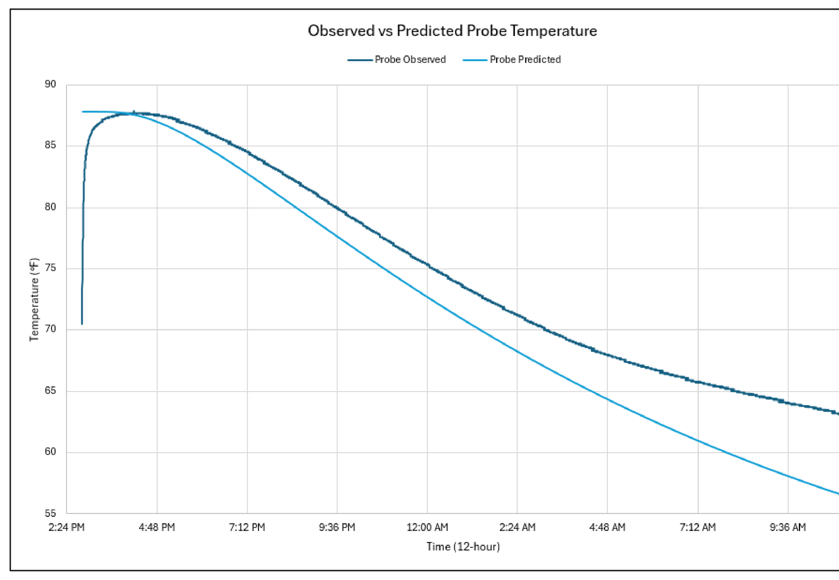

Figure 6: Observed vs predicted cheese block core temperature over time.

Model accuracy can be improved by providing more accurate inputs. Average values for facility specific thermal properties and boundary conditions could be determined. Additionally, the effect of thermal resistance layers could be measured and included.

Economics

- The model accounts for the warmest block in the cooling room.
- The solution presented holds the potential to cool 100% of all improperly cooled blocks.
- This has the potential to save up to ~$130,000 in loss prevention with a ROI of one year.

Table 1: Economic analysis.

Operation	Improperly Cooled Blocks Fixed (%)	Improper Cooling Cheese Loss (blocks)	Potential Loss Prevention ($)
Normal	0	6,215	0
Proposed	100	0	127,895

Energy

- Calculate the difference in annual energy consumption at an ambient temperature of 41°F versus 37.4°F.
- Calculate the energy that must be removed from all cheese blocks produced annually.
- Heat transfer through walls not included due to complex facility layout.

Table 2: Energy analysis.

Operation	Air Temperature (°F)	Final Average Cheese Temperature (°F)	Cheese Cooling Cost ($)
Current	41.0	53.6	29,876
Proposed	37.4	50.9	32,071

Further Recommendations

Any one of the following recommendations/improvements will achieve a 16-hour residence time. The asterisks in table 3 indicate current parameters.

Table 3: Further recommendations.

Recommendation	Air Velocity (m/s)	Ambient Air Temperature (°F)
1	8.75	41*
2	6.05	37.4
3	3.88*	32

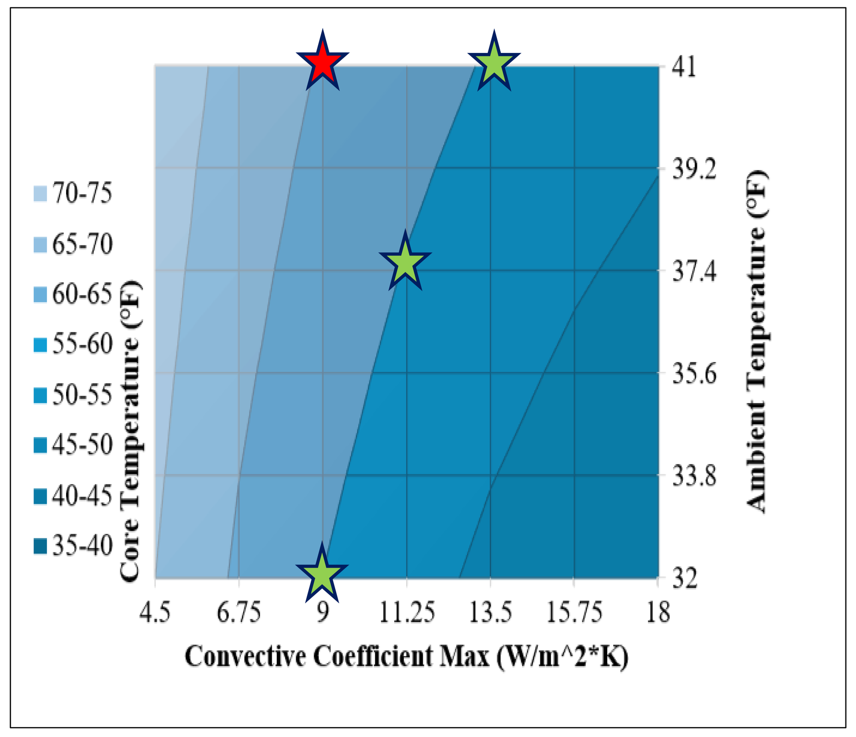

Figure 7: Contour plot for a 16-hour residence time. The red star indicates current parameters and the green star for proposed.

With the 16-hour residence time, concerns about ice crystallization and the freezing point of cheese came to light. Since there is limited knowledge at what temperature the blocks will freeze, the 18-hour residence time was determined to be the solution to preserve cheese quality.

Overall, the final recommendation is to decrease the ambient temperature for a 18-hour residence time.

Next Steps

- More accurate cheese thermal properties can be determined.
- Additional data collection for a more accurate temperature curve.
- Identification of the temperature at which cheese quality degrades.
- Same process can be applied to Tillamook cooling facility.

Acknowledgements

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References

1. Keates, S., & Okereke, M. (2018) *Finite element applications: A practical guide to the FEM process.* Springer. https://doi.org/10.1007/978-3-319-67125-3.