Computational Analysis of Thermal Fluid Dynamics around the Outlet in a Household Refrigerator

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ABSTRACT

Household refrigerators are essential for preserving food quality and maintaining energy efficiency through controlled airflow and temperature distribution. This study utilizes computational fluid dynamics (CFD) to analyze thermal fluid dynamics around the outlet of a household refrigerator and employs a Feed Forward Neural Network (FFNN) to develop an optimized model. The conventional model with only airflow near the upper outlet, causing vortex formation and stagnant zones with inadequate air circulation. In contrast, the AI-optimized model, which positioned an additional outlet at the lower right, effectively minimized these stagnant areas, leading to more uniform airflow distribution throughout the refrigerator. Despite these improvements, further optimization is needed to address remaining inefficiencies and enhance overall cooling performance and energy efficiency.

KEY WORDS

Thermal Fluid Flow, Computational fluid dynamics, Refrigerator

1. INTRODUCTION

The performance of a refrigerator is influenced by its internal temperature distribution and airflow efficiency. For visualizing temperature and flow fields and optimizing design, Computational Fluid Dynamics (CFD) has long been an essential tool.

Recent advancements in artificial intelligence (AI) have introduced new possibilities for optimizing refrigerator design. This study combines traditional CFD techniques with AI-based design optimization to analyze internal temperature characteristics and propose optimal design solutions.

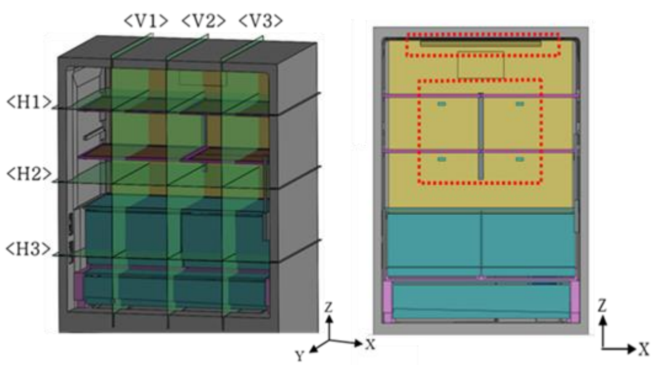

Fig.1: (a) 3D view planes (b) Air outlet location

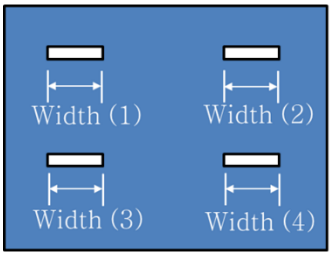

Fig.2: Input variables for widths of four holes

2.Theory and AI Optimization

2.1 Modeling

The interior layout of a household refrigerator is shown in Fig. 1. Fig. 1(a) shows a schematic of the refrigerator cross-sections used for flow observation. Fig. 1(b) visually depicts the positions of the top and side outlets, excluding the door baskets.

2.2 Basic concepts of neural networks

The Feedforward Neural Network has a structure where information flows in a single direction and is widely used for both training and prediction.

An FFNN consists of an input layer, hidden layers, and an output layer, with neurons in each layer connected through weights (w) and biases (b). A neuron is the smallest unit in a neural network, producing an output (y) by computing the weights and biases for the input (x).

2.3 Definition of training data and objective function

The training data uses outlet width as the input, with temperature variance set as the output for each case. The output has a design range of 0–30mm. Fig. 2 visually represents the four input variables.

The objective function (f) minimizes the difference between the maximum and minimum temperature deviations over time, defined as:

$$f\text{=min}(\max(\bar{T}_1,\cdots \bar{T}_N)\text{-}\min(\bar{T}_1,\ \cdots \bar{T}_N) \qquad (1)$$

where $\bar{T}_N$ is the average internal temperature at the N-th sampling location over time.

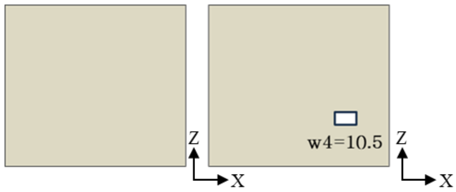

Fig.3: Wall for (a) Base model (b) AI optimization model

2.4 Refrigerator Computational Fluid Analysis

This study conducted analyses using Ansys Fluent 2022R1. The “standard k-ε” turbulence model was applied , with the governing equations for mass and momentum as follows:

Mass Conservation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \quad (3)$$

Momentum Conservation

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \times \vec{v}) = -\nabla \rho + \nabla \cdot \tau \quad (4)$$

Energy Conservation

$$\frac{\partial}{\partial t}(\rho H) + \nabla \cdot (\rho \vec{v} H) = \nabla \cdot (k \nabla T) + \Phi \quad (5)$$

3. Simulation Results and Discussion

3.1 Simulation Results of the Base Model

The VF3X model's original outlet design is shown in Fig. 3(a), with simulation results in Fig. 4. Due to rapid airflow, some areas (V1, V3) experience stagnant air at the top, while others (V2) lack mid-section flow, indicating uneven air circulation and temperature distribution in certain zones.

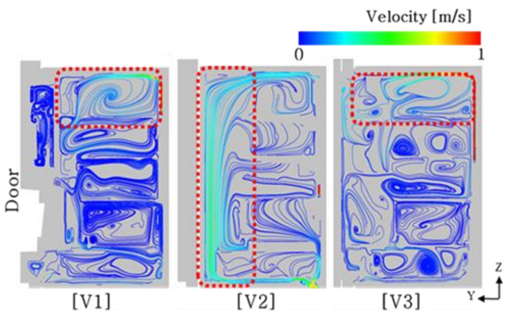

Fig.4: Streamlines in base model showing the stagnant area

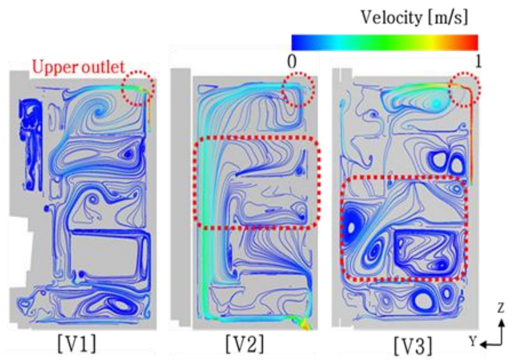

Fig.5: Streamlines in AI optimization model reduced vortexes

3.2 Simulation Results of the AI Model

The AI-optimized outlet design is shown in Fig. 3(b), with results in Fig. 5. The new outlet at the lower right enhances cool air flow to the lower compartments, reducing downward velocity and improving circulation. This results in greater temperature uniformity across the refrigerator, though internal temperature range remains largely unchanged and the average temperature decreases.

4. Conclusion

This study compared the temperature distribution and airflow between the original and AI-optimized refrigerator models. The original model experienced vortices from rapid airflow at the upper outlet, leading to stagnant areas. The AI model effectively reduced these stagnant zones, improving airflow uniformity. Despite, the average internal temperature tended to decrease. Further design optimization is suggested to resolve these issues.

ACKNOWLEDGEMENTS

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