Thermal Analysis of Small Refrigerator Compartment by using CFD

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Abstract: **Refrigeration systems are extremely important in daily life, especially in terms of preserving food, health, and comfort. The objective of this project work is to make some effective changes in the design of a conventional refrigerating system so that performance of the evaporator can be optimized. The effects of the normal and perforated fin on the velocity and temperature distribution at different levels. To make a comparative analysis between various cases of with and without the fin refrigerating system. The analysis and modeling through CFD for refrigerators based on diffusion-absorption is presented as a feasible tool for the purpose of evaluating proposals in the internal design of the refrigerator. The present study considers that significant improvements can be achieved on the thermal profiles, by researching an optimal geometric plate-evaporator, in which the airflow is included as a parameter of great importance in the operability of the refrigerator and therefore, in the preservation of food supplies.**

Keywords: Domestic Refrigerator, Temperature Distribution, Heat Transfer, CFD.

I. Introduction

Refrigeration systems are extremely important in daily life, especially in terms of preserving food, health, and comfort. The basic function of a domestic refrigerator is to preserve the quality of perishable products, and this quality depends on a good refrigerator performance, which is highly linked to temperature distribution and the air flow inside the compartments.

For refrigerators based on vapor compression, several studies have been conducted, particularly focusing on the temperature and air flow distribution of the compartments. In the literature we may find works related to the study of the air speed using the Particle Image Velocimeter technique, along with 3D numeric simulations using CFD software. For instance conducted a numeric study of air flow and heat transfer in a natural convection domestic refrigerator. The development of a model for a frost-free refrigerator where they predict and experimentally compare temperature profiles, obtaining a certain discrepancy in their results. In order to improve the temperature uniformity and the air flow in a natural convection refrigerator. Observed that the temperature distribution depends on the internal geometry of the refrigerator, specifically in the spaces between the refrigerator shelves and the liner bottom wall. The present a numerical simulation of a forced convection refrigerator concluding that the freezer and the fresh food compartment are found in phase (synchronized) with one another. Through simulation the authors proposed a new internal design.

Furthermore, some technologies have emerged in response to the search for alternative refrigeration systems, among them those thermally activated (solar energy, geothermal, residual heat, etc.) that reflect a reduction in greenhouse gases and zero contribution to global warming depending on the type of working fluids. In this field, the diffusion-absorption refrigeration systems are widely used in domestic applications such as hotel rooms as they are quiet and safe.

II. Literature review

Veronica Rodriguez-Martinez et al. [1] This article overviews the technological evolution of residential refrigerators, key national and international regulations covering them, and summarizes the information available to estimate the quality and safety deterioration in foods and beverages stored in them. At present, the national and international government standardized performance tests used to assess residential refrigerators focus on energy consumption. Efforts by refrigerator manufacturers to consider the impact of temperature fluctuation, temperature recovery, extreme ambient temperature, door openings, and other factors affecting temperature control and, thus, food safety and quality need to be harmonized, validated, and implemented as official standardized tests.

Juan M. Belman-Flores et al. [2] this work presents the main behaviors shown in the habits of consumers of domestic refrigerators, which influences the energy consumption of this appliance. This study is based on a series of surveys answered by 200 consumers from four cities in the State of Guanajuato, Mexico. The questions were arranged with the aim of evaluating the general characteristics and usage habits such as refrigerator age, door opening frequency, damper position, load of food supplies, external and internal cleaning habits, and nearby heat sources, among other things.

Diana Pardo-Cely et al. [3] the refrigerator is an essential domestic appliance product and is available worldwide. Additionally, the technologies on which the majority of refrigerators are based involve high energy consumption, and environmental deterioration due to the type of energy input and the use of certain work fluids. Therefore, how refrigerators work is of great interest, and in recent years the development of diverse research in this field has intensified.

O.R Olatunji et al. [4] In this work, a slightly modified 100g R134a domestic refrigerator was retrofitted with limited mass charge (30g) of R600a and LPG refrigerants and tested in different ambient temperature conditions (19, 21, 23 and 25 oC). In conclusion, the investigated energetic characteristics of the system improved with reducing ambient temperature and all conditions with infused hydrocarbon refrigerants attained cabinet temperatures lower than -3 oC in accordance to ISO 8187 recommendation for domestic refrigerators.

Hitesh Kumar et al. [5] This work presents the air flow and temperature distribution through natural convection warmness switch in severally modeled freezer is studied. The freezer and refrigerant compartments is studied for three configurations. The freezer and refrigerant compartments is studied for three configurations. In initial configuration using Plate-evaporator with rectangular finned surface and In second configuration Plate-evaporator while not finned surface and In third configuration Plate evaporator with perforated finned surface.

Araştırma Makalesi et al. [6] In this study, the performance of a diffusion absorption refrigeration (DAR) system using solar energy is investigated experimentally. For this purpose, two types of systems with/without sub-cooling are used for the experiment. Two-phase closed thermosyphon type heat pipes using water as the working fluid are used to utilize solar energy as heat source.

III. OBJECTIVES

There are following target are normal from the present work

1. The objective of this project work is to make some effective changes in the design of a conventional refrigerating system so that performance of the evaporator can be optimized.
2. To study the effects of normal and perforated fin on the velocity and temperature distribution at different level.
3. To make comparative analysis between various cases of with and without fin refrigerating system.

IV. METHODOLOGY

The freezer and refrigerating compartments is studied for three configurations. In first configuration using Plate-evaporator without finned surface and in second configuration Plate-evaporator with finned surface and In third configuration Plate-evaporator with perforated finned surface. The CATIA provides the following approaches for model generation: Creating a solid model within CATIA. The ANSYS-FLUENT software is used for the CFD simulation of the compartment. The conservation equations to steady state were solved for the coupling of the velocity and pressure through a SIMPLE algorithm; a second-order upwind discretization scheme was used for momentum and energy equations and a standard scheme for the pressure. The laminar regime considering the Boussinesq´ s equation in the y-component of the momentum equation was applied. The convergence criteria were 103 for the momentum and continuity equations, $10^{-3}$and 10^{-6} for the energy equation. The convergence was reached with 420 and 380 iterations for the plate evaporator without extended surfaces and the plate with extended surfaces, respectively. Comparison of temperature profiles for different configurations of refrigerating compartment. The freezer and refrigerating compartments is studied for three configurations. The perforated finned surface gives best result.

A. *Software used for the study Catia v5*

For the present work CATIA V5 is used for model design.CATIA V5 mainly used for design. CATIA supports multiple stages of product development (CAx), including conceptualization, design (CAD), engineering (CAE) and manufacturing (CAM). CATIA facilitates collaborative engineering across disciplines around its 3DEXPERIENCE platform, including surfacing & shape design, electrical, fluid and electronic systems design, mechanical engineering and systems engineering.

ANSYS 15.0

For the present work ANSYS 15.0 programming is used. ANSYS Fluent programming is the most-capable computational liquid elements (CFD) device accessible, enabling you to go further and quicker as you advance your item's execution. To convey quick Fluent incorporates very much approved physical demonstrating capacities, precise outcomes over the amplest scope of CFD and multiphysics applications.

B. *FLUENT/CFD:*

Computational fluid dynamics (CFD) is a branch of liquid mechanics that utilizations numerical examination and information structures to take care of and investigate issues that include liquid streams. To reproduce the cooperation of fluids and gasses with surfaces characterized by limit conditions Computers are utilized to play out the required counts. With fast supercomputers, better arrangements can be accomplished.

C. *Steps Of Working Method*

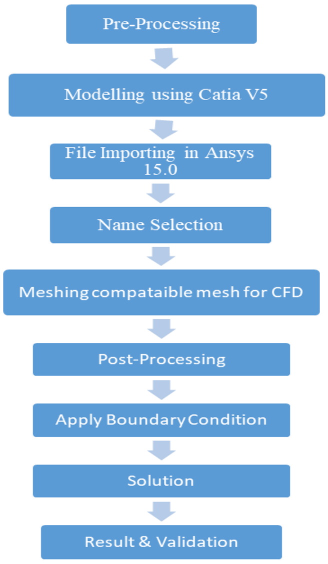


Fig. 1 Setup of working

D. *Governing Equations*

The numerical analysis of the fluid flow of the air is focused to the compartment of the refrigerator defined above. The main objective is to analyze the thermal behavior and velocity distribution generated by the temperature gradient, and to compare the thermal behavior of the reference refrigerator (as it is when shipped out of factory) with the plate-evaporator without extended surfaces proposed here. The following considerations were done for the mathematical model: 1. Incompressible flow 2. Steady state flow 3. Boussinesq model 4. Without thermal load inside the refrigerator 5. Laminar flow regime The density is calculated using the Boussinesq approximation in the momentum equation in y direction. The conservation equations are adapted to the model, considering constant properties and including the Boussinesq's equation in the y-component of the Navier-Stokes equation.

Continuity equation

$$\rho\left(\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}\right)=0$$

Energy Equation

$$\frac{\partial(\rho H)}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho * u_j * c_p * T\right)=\frac{\partial}{\partial x_j}\left(\lambda.\frac{\partial T}{\partial x_j}\right)+S_E$$

Where

- ρ is the fluid mass density,
- **S_E** is the source term.

Momentum equations

Component- x

$$u_x\frac{\partial u_x}{\partial x}+u_y\frac{\partial u_x}{\partial y}+u_z\frac{\partial u_x}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial X}+\frac{\mu}{p}\left(\frac{\partial^2 u_x}{\partial x^2}+\frac{\partial^2 u_x}{\partial y^2}+\frac{\partial^2 u_x}{\partial z^2}\right)$$

Component- y

$$u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}+u_z\frac{\partial u_y}{\partial z} = g_y\beta(T-T_\infty)+\frac{\mu}{p}\left(\frac{\partial^2 u_y}{\partial x^2}+\frac{\partial^2 u_y}{\partial y^2}+\frac{\partial^2 u_y}{\partial z^2}\right)$$

Component- z

$$u_x\frac{\partial u_z}{\partial x}+u_y\frac{\partial u_z}{\partial y}+u_z\frac{\partial u_z}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial z}+\frac{\mu}{p}\left(\frac{\partial^2 u_z}{\partial x^2}+\frac{\partial^2 u_z}{\partial y^2}+\frac{\partial^2 u_z}{\partial z^2}\right)$$

E. *Material Properties*

Properties of the air inside of the compartment

Table 1: Properties of the materials

Material	Density[kg m^{-3}]	Specific Heat[J kg^{-1} K^{-1}]	Thermal conductivity[W m^{-2} K^{-1}]	Viscosity [kg/m-s]
Air	1.22	1006.43	0.24	$1.78x10^{-5}$
Al	2719	871	202.4	-

F. *Steps of Working*

1. Collecting information and data related to the Refrigerator system.
2. A fully parametric model of the Refrigerator system is generated using CatiaV5
3. Model obtained in Step 2 is analyzed using ANSYS 15.(FLUENT),
4. Manual calculations are done.

5. Finally, we compare the results obtained from ANSYS

G. *Steps of ANSYS Analysis*

The different analysis steps involved in ANSYS are mentioned below.

Preprocessor the model setup is basically done in preprocessor. The different steps in pre-processing are

Building the Model

The CATIA provides the following approaches for model generation: Creating a solid model within CATIA. The commercial refrigerator used in this study was of small capacity (0.03 m^3) as seen in Fig. 2. The external dimensions of the experimental refrigerator were 0.4 m 0.35 m 0.50 m (width x depth x height) and the wall thickness was approximately 0.037 m. Inside the refrigerator there was an aluminum plate with rectangular fins, which was directly in contact with the evaporator tube, and by this means, the heat transfer was achieved in the food compartment. The plate consisted of 19 fins and was 0.3 m 0.3 m. In case of perforation fin .the diameter of the circle is 0.026m.

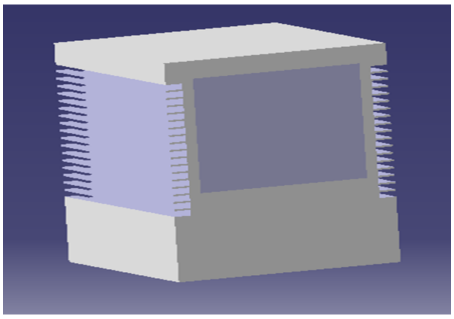


Fig. 2 Refrigerator model in CATIA V5

H. Meshing

Case-1

ANSYS Meshing includes intelligent, general-purpose, automated high-performance type of product. It delivers the most suitable work for exact, proficient Multiphasic arrangements. A work appropriate for a particular investigation can be created with a solitary mouse click for all parts in a model. For the master client who needs to tweak on it give full controls over the alternatives used to create the work are accessible. The energy of parallel preparing is consequently used to decrease the time you have to wait for mesh generation. The mesh created in this work is shown in fig. No.3. the total Node is generated 102720& Total No. of Elements is 478747for Refrigerator with fin.

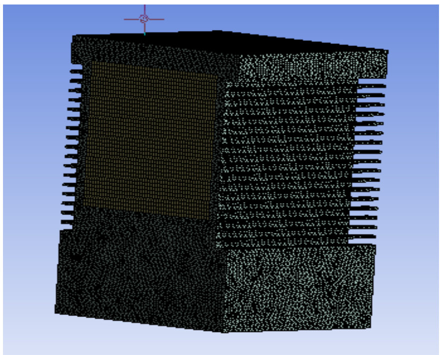


Fig. 3 Meshing: Total No. of Nodes: 102720& Total No. elements: 478747.

Case-2

The mesh created in this work is shown in figure No.4. The total Node is generated 169407& Total No. of Elements is 156198for Refrigerator without fin.

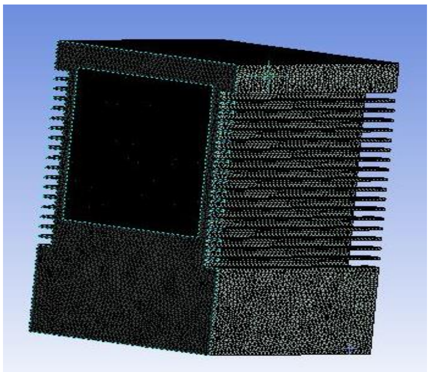


Fig. 4 Meshing: Total No. of Nodes: 169407& Total No. elements: 156198.

I. Defining Name Selection

In name selection first select the cold surface in Fig 5

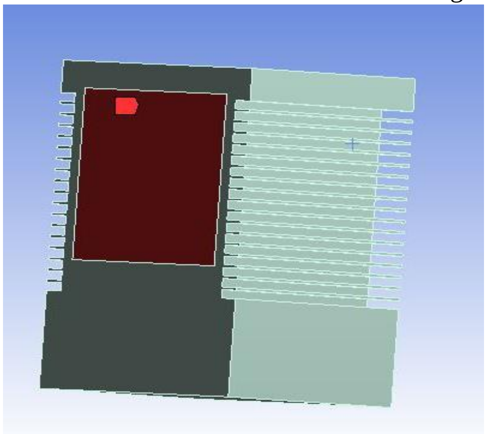


Fig. 5 Cold wall selection

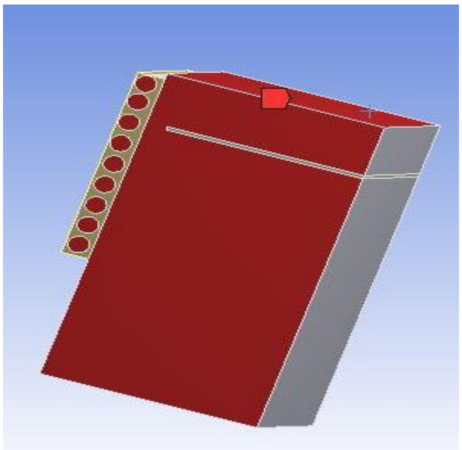


Fig. 6 air domine selection

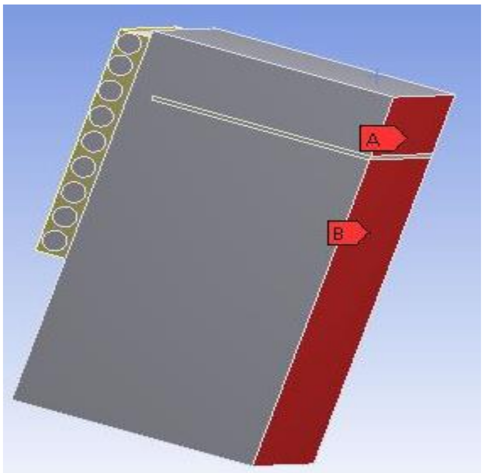


Fig. 7 hot wall selection

J. *Defining Material Properties*

For any kind of analysis material property are the main things which must be defined before moving further analysis. There are thousands of materials available in the ANSYS environment and if required library is not available in ANSYS directory the new material directory can be created as per requirement. For present work aluminum used as a material of fin. The material properties of the present case are as: Density: 2719 kg/m3, Is thermal conductivity: 202.4 W/m-K, Specific Heat: 871 J/kg-K[1],

K. *Boundary Condition*

The boundary conditions applied to the compartment take into account the temperature in all the walls, considering an average temperature according to experimental test. The temperature of door is 286k and the temperature of evaporator plate is 273k according to experimental result.

- fin -
    - Material- aluminum

- Cold wall
    - Temperature- 273
- Hot wall
    - Temperature-286

After applying the proper boundary condition the simulation is run. And the results were recorded.

L. *CFD Analysis*

CFD analysis may use to determine temperature distribution and other thermal capacity that may vary over the time. Various heat transfer application, heat treatment problems, Condenser coils involve CFD analyses. The function tool for define the equation or describing the curve and then apply the function as a boundary conditions.

M. *CFD Simulation of the Compartment*

The study was carried out using ANSYS FLUENT tool. The steps for the analysis are shown below

- Import the stp file in the ANSYS FLUENT module.
- After importing the stp file in ANSYS, open design modular of the ANSYS FLUENT and created the named selection of the parts refrigerator.

Case-1.

Fig. 8 shows the temperature distribution in the vertical plane for the plate-evaporator without finned surface.

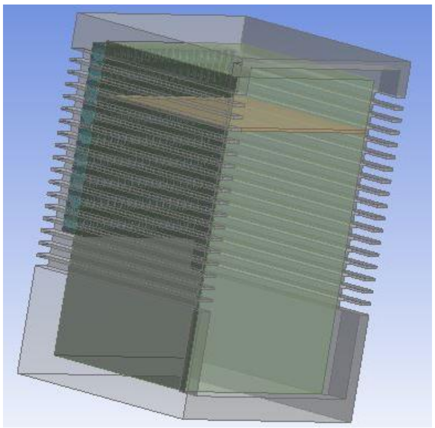


Fig. 8 Plate-evaporator without finned surface

a. *Contour For without fin refrigeration system*

The result of CFD analysis of with fin refrigerator. The contour in Fig.9 shows the temperature distribution in the refrigerator. The bottom of the refrigerator low temperature and the upper part of the refrigerator is higher temperature in compartment. In this case Plate-evaporator with finned surface is used. The Plate-evaporator without finned surface increase the temperature distribution in compartment. In this case, it can be seen that the temperature distribution does not change significantly by showing in vertical direction a cooler zone in the bottom of 280.634 K and an upper region with a higher temperature of 281.928 K. It can be seen that most of the behavior is relatively low temperature (Blue zone). Hence, the temperature obtained experimentally with three thermocouples located over this plane (upper, middle, lower) shows an average of 281.243 K. With these results an adequate acceptability for the developed model can be determined in this work.

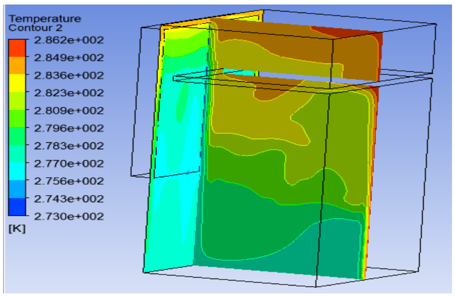


Fig. 9 Temperature Contour for refrigerator

b. Contours For without fin refrigeration system

Another part of the analysis in the compartment is the velocity distribution generated by the temperature gradient. Fig. 10 show the velocity distribution for the same cases mentioned above. The higher speed is located on the side walls and the bottom of the compartment, which include areas of the extended surface. The position of the shelf influences the flow field, principally because the shelf in the lower position causes an upstream retention (for instance, the red1 and yellow ones near the door), supporting the uniformity of temperature in this space of the compartment. For this case, the average velocity at the middle plane is 0.0077 m/s.

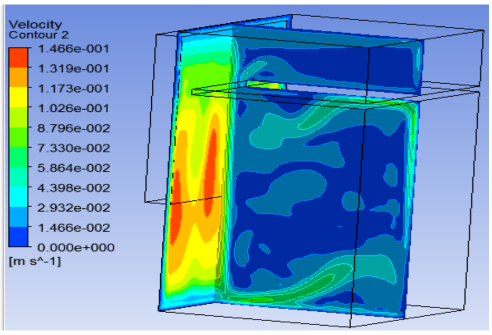


Fig. 10 Velocity contour

Case-2.

c. CFD analysis of Plate-evaporator with finned surface

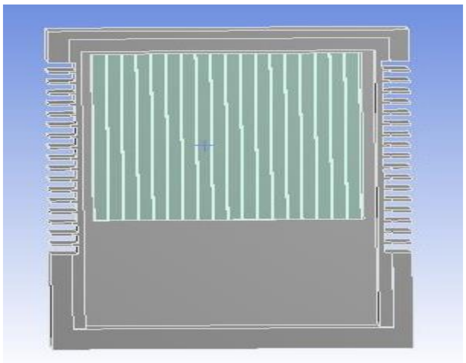


Fig. 11 Plate-evaporator with finned surface

d. Contours For Plate-evaporator with finned surface.

In this case, it can be seen that the temperature distribution does not change significantly by showing in vertical direction a cooler zone in the bottom of 275.235 K and an upper region with a higher temperature of 284.417 K. It can be seen that most of the behavior is relatively low temperature (Blue zone). Hence, the temperature obtained experimentally with three thermocouples located over this plane (upper, middle, lower) show an average of 278.77 K. With these results an adequate acceptability for the developed model can be determined in this work.

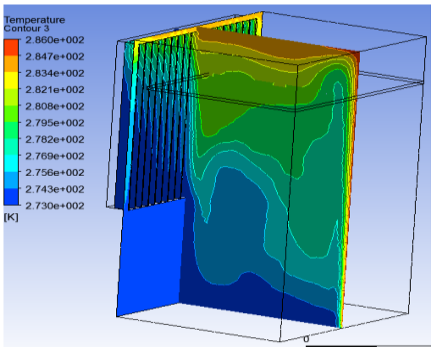


Fig. 12 Temperature Contour for Plate-evaporator with finned surface

e. Contours For Plate-evaporator with finned surface.

For this case, the average velocity at the middle plane is 0.005259 m/s.

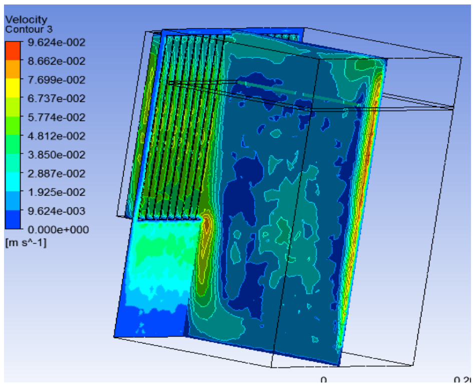


Fig. 13 Velocity contour for Plate-evaporator with finned surface

N. Calculation

C_p=871 j/kgk $m=4.96\times10^{-3}$ kg/s Q_{bp}=65w
base paper

T_p=273k T_{air1}=281.91k T_{air2}=278.09k T_{air3}=277.73k

$$Q=mC_p(T_{air}-T_p)$$

Q_1=38.49 W (without fin)

Q_2=21.98 W(with fin)

Q_3=20.43 W(perforated fin)

$$COP=Q/Q_{bp}$$

COP_1=0.59 COP_2=0.33 COP_3=0.31

V. Results

CFD results are obtained in order to study the temperature and velocity fields inside the domestic frost-free refrigerator. This results concern simulations which shows heat transfer by convection between the internal walls of freezer and refrigerating compartments.

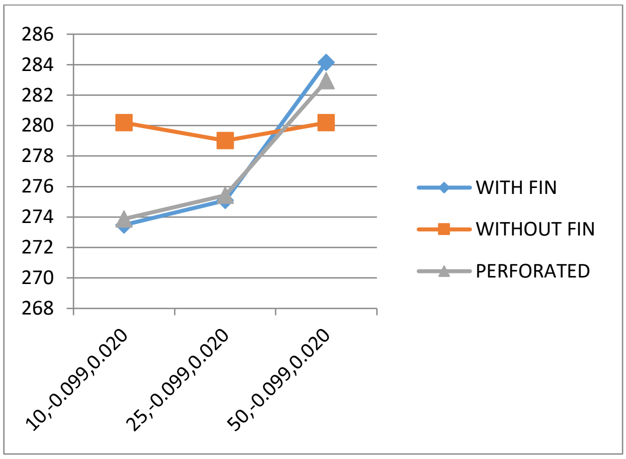
Table 2: Maximum and Minimum Temperature Obtained From Analysis

Refrigerator	With finned	Without finned	Perforated finned
Minimum Temperature	277.560 k	279.972k	277.410 k
Maximum Temperature	283.160 k	283.750 k	282.1680 k

Table 3: Comparison of COP

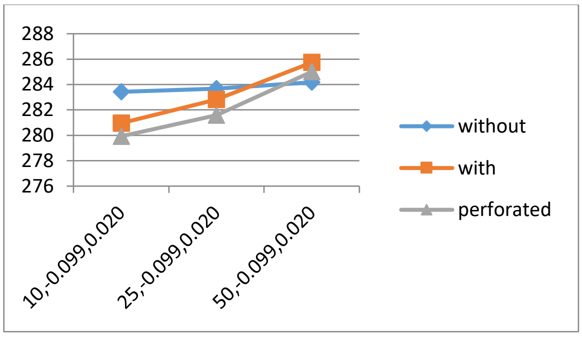
Refrigerator	T_p[K]	T_{airc}[K]	Q_{evop}[W]	COP
Without finned	273	281.92	38.49	0.59
With finned	273	278.14	21.98	0.33
Perforated finned	273	277.73	20.43	0.31

A. *Minimum temperature graph*



Graph 1. Minimum temperature in the refrigerator compartment at different point.

B. *Maximum temperature graph*



Graph 2 Maximum temperature in the refrigerator compartment at different point.

VI. Conclusion

CFD simulation of air flow and heat transfer is carried out within the freezer and refrigerating compartment of a domestic frost-free refrigerator. Three configurations are studied in the compartments with and without finned and perforated finned. Temperature distributions in the freezer model confirm the theory that there is stratification, a warm zone (higher temperature) at the top and a cold zone at the bottom.

1. The average temperature maintained in the freezer and refrigerating compartment is about 273k and 282k respectively.
2. In refrigerating,
   - Temperature in without finned system – 276.62k K to 284.94 k
   - Temperature in with finned system – 276.396 k to 283.68 k
   - Temperature in with finned system – 275.60 k to 282.15 k
3. An analysis of the energy performance of the refrigerator according to the design of the plate-evaporator was conducted, and the results showed minimal differences.
4. Whatever the configuration studied (empty with/without shelves, loaded with products) for this type of refrigerator, the air temperature at the top of the refrigerator is about 5 C higher than the average air temperature, and therefore it is important to avoid placing sensitive products in this position.
5. While perforated finned demonstrated maximum Temperature distributions and providing higher cooling effect.
6. Finally, the analysis and modeling through CFD for refrigerators based on diffusion-absorption is presented as a feasible tool for the purpose of evaluating proposals in the internal design of the refrigerator. The present study considers that significant improvements can be achieved on the thermal profiles, by researching an optimal geometric plate-evaporator, in which the air flow is included as a parameter of great importance in the operability of the refrigerator and therefore, in the preservation of food supplies.

A. Future Scope

The present work concerned just the update of Fins of evaporator plate from the purpose of warmth exchange rate. There are some conceivable proposals which might be feasible for reception in future.

1. CFD investigation was led to test the temperature distribution of different finned.
2. The CFD simulation developed by our work can be further used as a tool to study the influence of operating conditions on the temperature and velocity fields: the

evaporator temperature (parameter related to the thermostat setting by the consumer), the dimensions of the evaporator (parameter related to design) and the percentage of product-occupied volume in the refrigerating compartment.

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