Studying strategies for air distribution inside a refrigeration chamber under partial load conditions

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Abstract

This article is describes a study about the air flow distribution inside a refrigeration chamber, using computational fluid dynamic (CFD) simulation. The software used to perform this study was Fluent 14, from Ansys. The main objective was to study the air flow inside a cold chamber and the influence of air deflection and other strategies to achieve a better efficiency in air flow, under partial load product conditions. Special attention was given to the situation when a small quantity of product is located in a small part of the chamber. Measurements of temperature and air velocity were made inside the cold chamber, to validate the model. The results demonstrate that the air recirculation inside the refrigerated chamber, when loaded by a reduced quantity of product, is strongly influenced by the localization of product and localization of evaporator. To this situation the best air circulation of interior air is achieved by the introduction of an air deflector outside the evaporator

1. Introduction

It is know that in conservation of products inside a cold chamber, one of the most important aspects to considerer is the correct distribution of inside airflow [1]. This correct distribution of air is fundamental to keep the products at the desired conservation temperature. In the past, many strategies have been studied and applied with the objective of keeping a good air distribution inside the cold chamber. This good air flow distribution should be achieved keeping low energy consumption. Also other parameters like correct air velocity and correct humidity are very important to keep the products under correct conditions of refrigerated storing. To achieve this multiple purpose some strategies have been used in the past, like the choosing the correct type of evaporator, the utilization of air deflectors inside and changing the localization of the products inside the cold chamber. In this study particular attention was given to the situation when a reduced quantity of product is located in small part of the chamber. The studied cold store is a refrigerated chamber used in the conservation of milk products and derivatives and the interior set point temperature is 4ºC.

2. Cold Store description

The studied refrigeration cold storeis used in the conservation of milk products and derivatives and the set point temperature in the interior is 4ºC. The cold chamber has the following dimensions: 1.21m wide, 2.02m heightand 2.02m depth. The evaporator used inside is an air forced convection one, with one axial air ventilator (400 mm wide, 350 mm long and 280 mm height).Inside there is alight box with dimensions (110x110x200 mm), placed 220mm from the lateral wall and 1300 mm from the wall upside. Figure 1 shows a photo of the studied refrigeration chamber and the 3D model created.

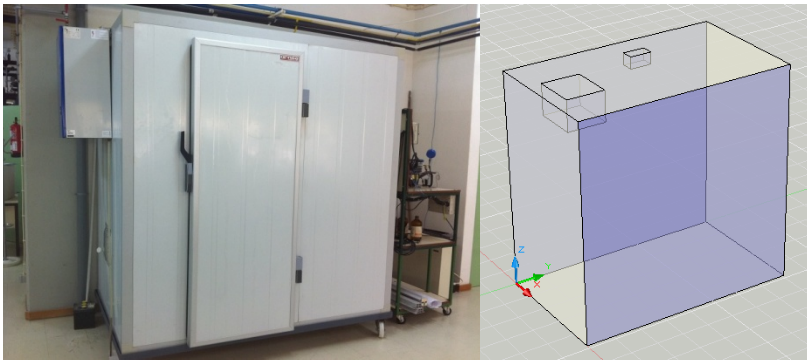

Figure 1 –The real cold chamber and model used in simulation (case 1)

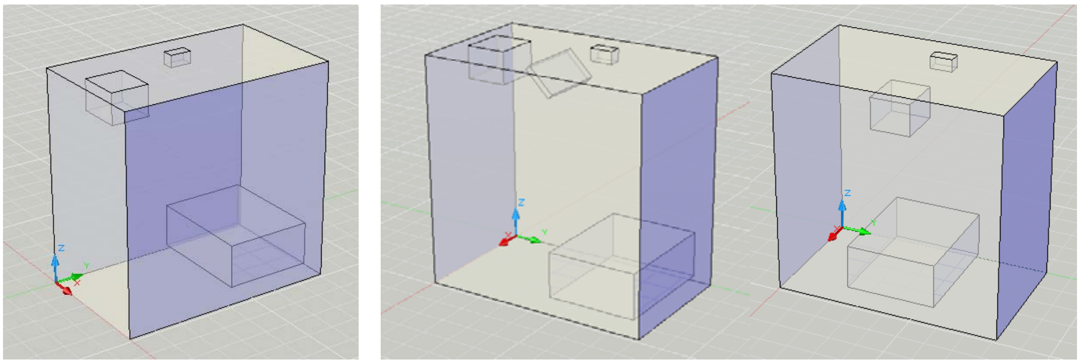

Figure 2 – The other refrigeration chamber case studies considered (case 2, case 3 and case4)

3. Simulation work

The CFD software used was Fluent from *ANSYS14*. *Fluent* software is a computational program which allows the numerical simulation of fluids flow and heat transfer in complex geometries. The 3D chamber geometry was created in *AutoCAD*.In *Meshing* a tetragonalmesh was created, with 94216 control volumes and 30871 nodes.For the other cases studied slight changes were needed to adjust the mesh at the new body's presents in the chamber[3][4][5].

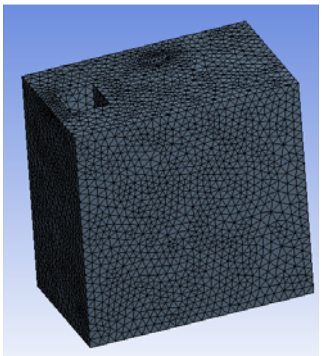

Figure 3 – Grid used in simulation

Concerning the mesh quality the follow results were obtained: an average element quality of 0.61; an average aspect ratio of 3.71 and an average skewness of 0.26.The solver used was pressure-based, the formulation velocity was absolute type and the regime was stationary. The energy model used was the viscous k-epsilon, with two equations, with the sub modelRNG. The other parameters of the energy model were left as default.Regarding the boundary conditions, the chamber limits were defined as solid walls, the outlet of the evaporator was considered as a velocity inlet and the inlet of the evaporator was considered as a pressure outlet. The outlet velocity of the evaporator was defined as 2.19m/s and the temperature as 275K. These values were obtained with real measurements in the real cold chamber studied.In the solution method considered in the simulation was the Least Squares Cell Based. The monitors used were the residuals, with the default values; a residue of 1 x 10^{-6} for energy and 0.001 to all the other.

To the model validation, measurements were made inside the cold chamber in the points represented in figure 4.

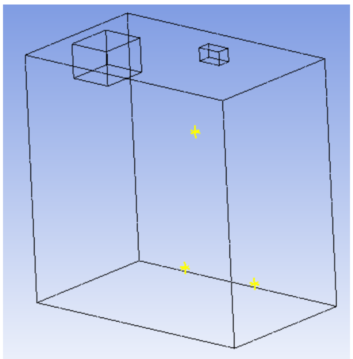

Figure4 – Localization of the measurement pointsused in model validation

The parameters measured weretemperature and air velocityin several points inside the chamber. The equipment used to perform the measurements was athermo-anemometer KIMO VT 300. Some of the measured points were considered to calibrate the numeric model. These points are shown in figure 4. Figure 5 shows the correlation graphic between the measured and the calculated values by the numeric simulation.

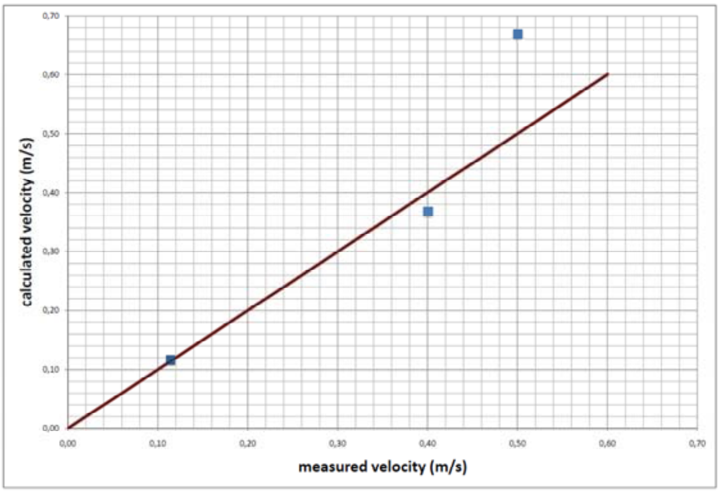

Figure 5 – Correlation between measured and simulated values

By the analyses of results of the model, and comparing with the values of real measurements obtained in the refrigerated chamber, is possible to observe a good correlation between the results of the model and the measurements. The difference between measured and calculated values was 3%, 9% and 25% (from left to right on graphic).

After the model calibration a pack volume was introduced in the model to simulate de refrigerated products inside the chamber. 320 test packages of 1 kg (50x100x200mm), according to standard ISO 29953-2 (2005) [2] were introduced. This situation of introduction of a small quantity of product will be designated as case 2. Also two other cases were considered in this study, with the correspondent model implementation. Case 3 considers the introduction of air deflectors after the evaporator blow, to improve air recirculation and temperature harmonization and the collocation of both the product and evaporator in the centre of the chamber (evaporator attached to the ceiling).

4. Results

The simulation results for the four cases studied are shown in the next figures. The velocity magnitude is represented as contoursin planes YZ and XZ.Figure 7 shows the result for the original situation (case 1).

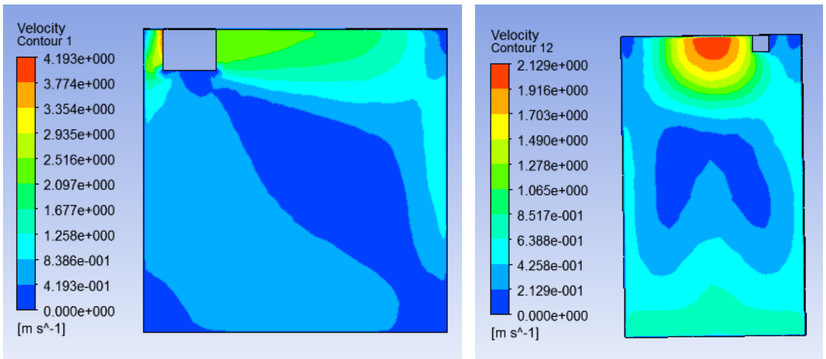

Figure7 – Velocity magnitude contours for case 1 (YZ and XZ plans respectively)

By the analysis of the velocity magnitude contour of plane YZ (located in the centre of the refrigerated cold store) it is possible to see the air stagnation in the centre of the cold chamber. It is also possible to see that air is not equally distributed inside the chamber. We can also verify that the air velocity is slightly smaller than it should, be because the blow air velocity leaving the evaporator doesn't promote anefficient circulation of air in the entire refrigeration chamber.

Figures 8 shows the results for the Case 2, refrigeration chamber with same configuration as in the base case, but with a reduced quantity of product inside the chamber.

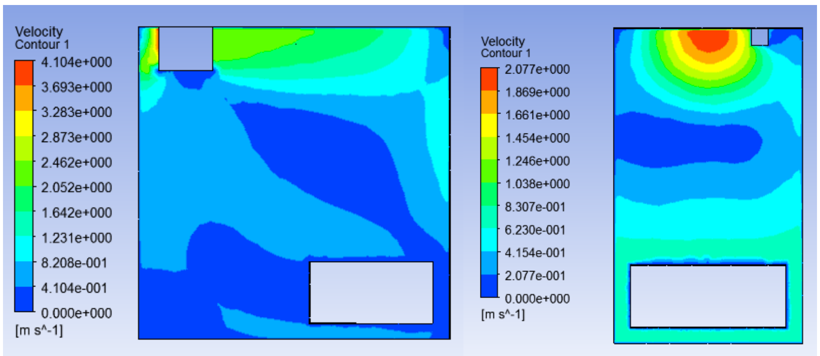

Figure 8 – Velocity magnitude contours for case 2 (YZ and XZ plans respectively)

It is possible to see the influence of the product on velocity distribution inside the chamber.The presence of the small quantity of products in the corner of the refrigeration chamber conduces to a perturbation in the air flow, destroying the recirculation scheme.This conduces to poor temperature distribution inside the chamber, and it's consequently degradation of interior refrigeration conservation conditions to the products.

The 3rd case studied (case 3) considers a deflector in front of the evaporator outlet. Figure 9 shows the results for this case.

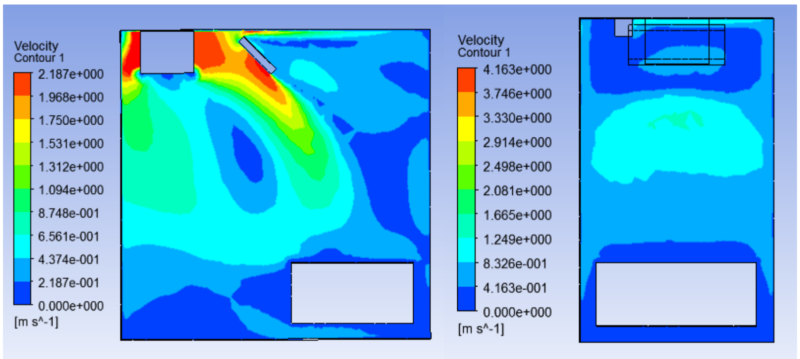

Figure 9 – Velocity magnitude contours (YZ and XZ plans respectively)

By the analysis of the velocity magnitude contours it is possible to verify the influence of the deflector on the velocity distribution insidethe chamber. Contours are now more heterogeneous, conducting to better homogeneous temperature distribution inside.It is visible that the deflector improves the flow distribution inside the chamber, especially in the centre where the velocity magnitude is no longer zero.

The results obtained for case 4 (refrigeration chamber with centred evaporator and product) are shown in Figures 10.

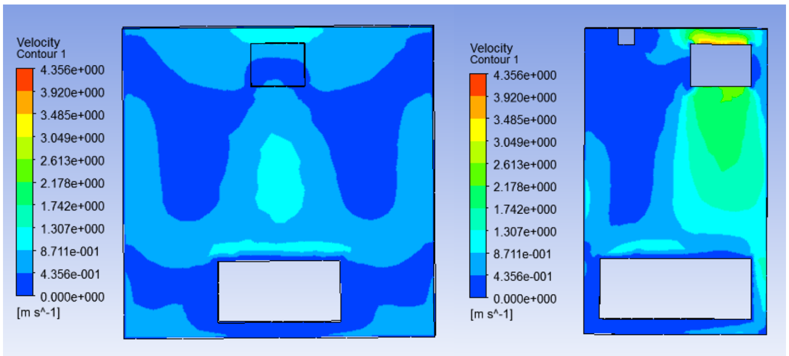

Figure 10 – Velocity magnitude contours (YZ and XZ plans respectively)

By the analysis of the velocity magnitude contours of case 4, it is possible to verify that in this case the products have now a bigger influence on the velocity distribution at the lower level of the chamber. Near zero velocity regions are biggerin this solution.It is also visible by the analysis of velocity contours in plane XZ that a very bad circulation scheme is achieved for this solution in this plane.

5. Conclusions

By the analysis of the results we can conclude that for this particular situation, the location of product inside the chamber and the evaporator location are important items that influence the air recirculation and air distribution. Case 3 shows that air recirculation inside the chamber is improved when an air deflector is strategically placed after the air leaving the evaporator. It is also possible to conclude that as the product acts as a barrier to air flow recirculation, the location of the product inside the chamber is a key factor to achieving efficient ambient conditions inside the chamber. Special attention should be given to this factor, to obtain good recirculation of air and good temperature distribution. In this work, the three cases studied (with a reduced quantity of product) conduce to poor profile in recirculation air. However the best situation seems to be the case 3, when an air deflector is introduced outside the evaporator. Also other situations like product centred in the chamber, with spacing from the floor should be tested in the future. It is also possible to conclude that Fluent is a good tool for this kind of applications. Fluent achieves good performance in studies concerning the best air distribution inside refrigeration chambers filled with products.

References

[1] Coca, E.L. (2000), "*Poupanças energéticas em instalações frigoríficas*". O Instalador. Nº48, pág. 49-58
[2] ISO 29953-2 (2005) standard, Refrigerated display cabinets - Part 2:Classification, requirements and test conditions
[3] Training Manual - Introduction to FLUENT, 2009, Release: 12.0.
[4] Training Manual - Meshing Application Introduction, 2009, Release: 12.0.
[5] ANSYS FLUENT 12.0/12.1 Documentation, 2009, Release: 12.1.

[1] Beckman, WA, Klein, SA, Duffie, JA. *Solar heating design, by the f-chart method.* Wiley. New York, 1977
[2] Incropera F, DeWitt DP. *Fundamentos de Transferencia de Calor*. Prentice Hall. Méjico, 1980