THE GREADIENT OF TEMPERATURE ANALYSIS IN A REFRIGERATED DISPLAY CASES FOR FOOD PRODUCTS PRESERVATION

ANALIZA GRADIENTULUI DE TEMPERATURA ÎNTR-O VITRINĂ FRIGORIFICĂ PENTRU PĂSTRAREA PRODUSELOR ALIMENTARE

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Abstract. *Computational fluid dynamics (CFD) is a powerful numerical tool that is becoming widely used to simulate many processes in the food industry. Recent progression in computing efficacy coupled with reduced costs of CFD software packages has advanced CFD as a viable technique to provide effective and efficient design solutions. In the present paper we show by CFD techniques the modelation and simulation of a maintaining processes of some agro-food products at low temperature (0-4°C) into refrigerated display case by temperature gradients determination. CFD simulation has the advantage of virtually testing of temperature distribution into interior space of refrigerated display case before introducing the real food products for being kept into. CFD method is important because could show simultaneously the temperature in two or three dimensions on different regions from the display case, which is practically impossible to do by classical methods (temperature measuring with temperature transducers).*

Rezumat. *Calculele de dinamica fluidelor (CFD) reprezinta o unealta numerica puternica ce devine larg utilizata la simularea multor procese din industria alimentara. Progresele recente din domeniul calculatoarelor cuplata cu reducerea costurilor pachetelor de programe CFD au propulsat CFD ca pe o tehnica viabila sa furnizeze solutii eficiente in proiectarea propriu-zisa. In acest articol este prezantata prin tehnica CFD modelarea si simularea unui process de mentinere a produselor agroalimentare la o temperature scazuta (0-4°C) intr-o vitrina frigorifica prin determinarea gradientilor de temperatura. Simularea CFD are avantajul de a proba virtual distributia de temperatura in spatiul interior al vitrinei frigorifice inainte de a introduce in mod real produsele alimentare pentru pastrare in vitrina. Metoda CFD este importanta deoarece poate arata temperatura in doua sau trei dimensiuni simultan pe mai multe regiuni din interiorul vitrinei, ceea ce este practic imposibil prin metode clasice de masurare a temperaturii cu traductoare de temperatura.*

INTRODUCTION

With the purpose to maintain the agro-food products at a low temperature for a long time period, it is necessary the maintaining of a low and uniform temperature into refrigerated display case.

Vertical open display cases are widely used in supermarkets. The use of refrigerated display cases allows good visibility and ensures free access to stored food for shop costumers. A virtual insulation barrier called the air curtain is developed by the recirculation of air from the top to the bottom of the case [1].

This is a nonphysical barrier between cold air in the case compartments and the warm shop environment. As the air curtain falls from the inlet at the top of the case, it entrains cooled air from the back of each case compartment. This air passes over all the food products resulting in heat transfer from the food to the air, which allows the food to be maintained at a predefined temperature. Heat transfer also occurs between shop environment and the air curtain. This causes the temperature of the air curtain to increase and reduces the effectiveness of the air curtain in the lower compartments of the display case [2].

The study air curtains are necessary because these are easily disturbed of air circulation in front of the display case or the shop costumers. This disturbed create "hole" in the aerodynamic air curtain and even if they are short time manage to an inefficient seal arouse an increase of temperature in inside display case with a extra energetic consumptions for cold products preservations.

Numerous CFD studies on the ability of the air curtain to maintain food at a predetermined temperature have been conducted over recent years [3, 4].

The considerable advances made through the CFD modelling of display cases in the last few years will undisputedly lead to improving their efficiency, and thus strengthen their link in the chilled food chain.

FORMULATION OF THE PROBLEM

The display case cabinet of the investigation is a vertical open display unit (figure 1) with four shelves for refrigerating food.

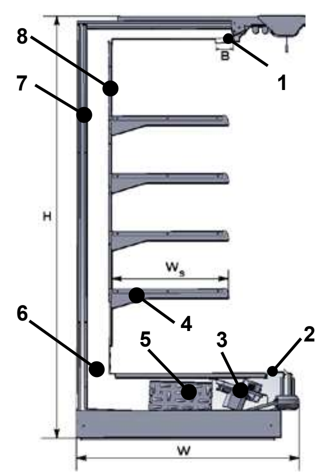

Fig.1. Cross section of a typical one air curtains vertical display case:
1- discharge air grille (DAG) (honeycomb); 2 - return air grille (RAG); 3 – fan; 4 – shelfs; 5 – evaporator; 6 - rear duct; 7 - insulating layer; 8 - rear grille.

In a vertical open display case, air is forced to flow through an evaporator which is situated on the base of the case by suitable fans located on the front of the evaporator in the case. A small fraction of the cooled air is feed into the case through the perforated plate at the back of the case, while the bulk of cold air is blown through one linear discharge air grille (honeycomb) to form one air curtain. The temperature of the inner part air curtain is lower than that of the outer part air curtain, and the profile velocity of the inner part air curtain is lesser than that of the outer part air curtain. The air curtain and air infiltration from the external medium is recirculated through the return grill and is positioned at the base of the display case.

CFD SIMULATION OF REFRIGERATED DISPLAY CASES

CFD simulation of a refrigerated display case with four shelves, with the purpose to establish the temperature gradient, supposes several steps of engineering designing.

First step is the pre-processing for which the purposed geometry is drawn in three dimension and then discretizated with a node network necessary for temperature distribution calculation. In the second step boundary conditions and equations solvers are introduced for temperature distribution calculation into the processed geometry from the first step. After the calculus is finished, the obtained results are processed in post-processing step where graphs, temperature and speed distribution, concentration distribution, etc. can be visualized. After the evaluation of the obtained results, if the temperature distribution (uniform distribution), which is the purpose of this study, it isn't accordingly, the redesign study is restarted, with pre-processing step, and the refrigerated display case geometry is remodeled till the desired geometry is obtained.

Pre-Processing step

The geometry of the three purposed sections for simulation has been taken from a 3D refrigerated display case assembly drawing in SolidWorks software (figure 2).

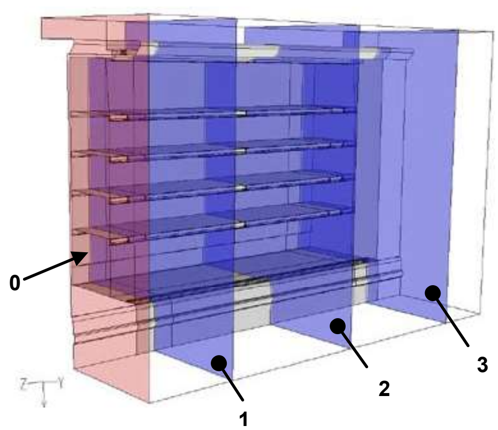

Fig. 2. Supporting and transporting units:
0- lateral plane velocity input; 1- left cross section; 2- middle cross section; 3- right cross section**.**

With the purpose to simulate 3D geometry, the processing (calculus) step would last too much time, and it was referred to simplification assumptions, considering that thermal transfer phenomenon in volume is about the same with the one in sections unfolded. It generates three sections in two dimensions, for parts form volume, considered to have an uneven temperature gradient distinguished by experimental tests in cold test room.

Depends on their position in the refrigerated display cases referred to the test room wall through a laminar air flow goes in with a speed of about 0.2 m/s, these three sections are recognized as left (L), middle (M) and right (R).

The two dimensional predictive models were created using GAMBIT software. The surfaces of the three sections L, M, R have been discretizated in GAMBIT with a structurated mesh that consists of parallelepiped network (figure 3).

The used knots number in discretization was of 254060. The knots were distributed with higher consistency in the interest zone of the air curtain and internally refrigerated display case, dropping off exponential in consistency toward the outward walls of test room. The boundary conditions were imposed in Gambit and completed with functions and values in FLUENT.

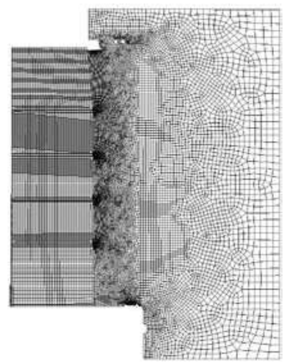

Fig. 3. *Cross section with mesh at the vertical display case*

Processing step

2D models for the three sections have been introduced and calculated with Fluent v6.3 a commercially available CFD code what uses the finite volume technique. So for the DAG region was introduced polynomial pre-definite function for the suitable speed profile of each cross section, completed with the variation function of temperature. The speed profiles and temperature function have been initially experimental determined into the testing room.

In the test room (the outward region refrigerated display cases) it was introduced initial temperature of 25 °C. Knowing as in outward zone of refrigerated display cases in the tangent plan air flow with speed of 0.18 - 0.2 m/s (according to standard tests EN 441), initial boundary condition in the DAG was completed with a turbulent intensity of 2.66, 1.83, 2.16 % for the cross section L, M, R, in harmony with the hydraulic diameter.

In consent with user guide from FLUENT level to the turbulence intensity is considered low around value of 1 % and highly heaved to 10%.The simulation being unsteady was imposed a time step size equal with the time measurements of 0.2 second, number of time steps 1800 and maximum iteration per time step 10. In this kind the time for simulation is 6 minutes and a total number of iterations 18000 realized at a time computation for about 12 hours.

Post-Processing step

The simulations results for one three cross sections are processed through the temperatures profile distribution at one time considered of be the most disadvantageous, namely when it observes a strong interaction of respective infiltration of temperature increases in the lower shelves region refrigerated display cases.

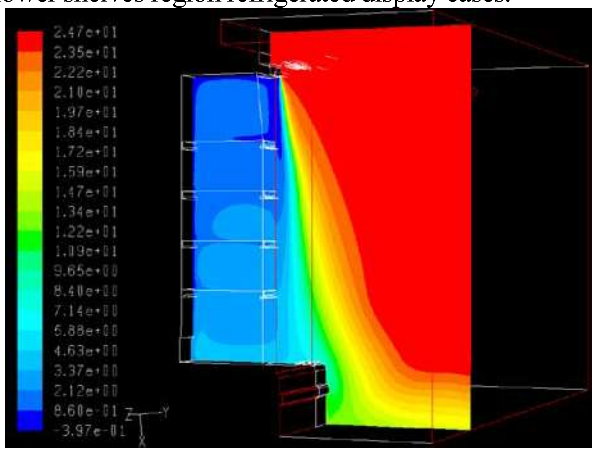

Fig. 4. Temperature distribution in the left cross section [°C] at 360 s time

The relative position function of working cross section toward the side section of the test room where input air with a speed 0.18 m/s can do the regions differentiation from refrigerated display cases where the air curtain an achieves the role of seal toward the outside environment.

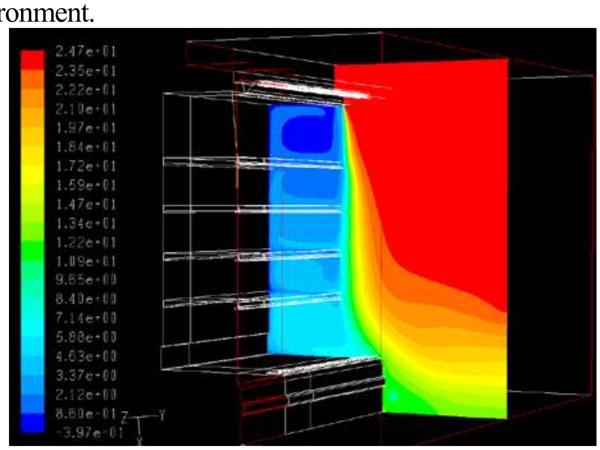

Fig. 5. Temperature distribution in the middle cross section [°C] at 360 s time

Uneven of temperature gradient with preponderant in R plan (figure 6) of inferior shelves, and also in L and M plan respectively (figures 4, 5) leads to a constructive reoptimization of refrigerated display case geometry. Uneven temperature gradient into inferior shelves region leads to the keeping of agro-food products at a higher temperature than the one assessed by normative.

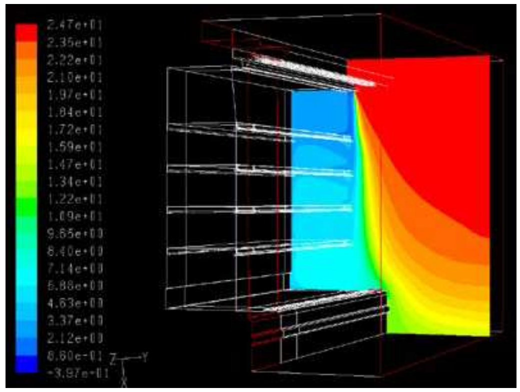

Fig. 6. Temperature distribution in the right cross section [°C] at 360 s time

CONCLUSIONS

The advantage of 2D simulation in different transversal sections of the refrigerated display case offers a good interpretation of the simulation results in a reasonable calculation time for the actual technique, compared to the same precision level and the density of the discretization but into a three-dimensional space of the refrigerated display case. The obtained results by simulation in the purposed variant are agree with the measurements made for the temperature and for the speed. This correlation between simulation and experiments has been validated by the obtained experimental results with the temperature and speed transducers positioned in front of each shelf that indicates the temperature and speed distribution on the whole air curtain height.

It can be concluded from tests and CFD simulations that a reoptimization of refrigerated display case geometry is more than necessary, and the way of calibrated CFD simulations by experiment leads to a time economy during the projection process and it is more easily from the point of view of costs, compared with other testing methods and visualization of temperature and speed gradient, for example Thermo Scan and PIV (Particle Image Velocimetry) that cannot be applied into closed study domains.

The mention of a more uniform distribution of temperature into opened refrigerated cabinets is an actual desideratum that can improve the quality of keeping by cold of food products for a long period.

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