THE USE OF CFD TO IMPROVE THE PERFORMANCE OF REFRIGERATED CABINETS FOR FOOD PRODUCTS PR ESERVATION

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Maintaining food temperatures below critical values is the key to maximizing the high quality warranty life of refrigerated food products. The paper presents a comprehensive CFD (Computational fluid dynamic) method which can be used to optimize and redesign the performance of refrigerated display case. CFD modelling 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). The CFD simulations applied for a refrigerated cabinets with four shelves were initial calibrated with experimental dates, while later the dates obtained by simulation were compared with the experiment in other measure points from refrigerated cabinet inside. In this kind was realized an error level testing of CFD simulation. The obtained results were of ± 5% error, which is an accepted level in the field of heat transfer and fluid flow.

***Key words**: CFD –refrigerated food products* **-** *vertical refrigerated cabinet*

The design on computer became indispensable to the engineering field in order to develop and to realize new useful equipments for food industry. The inclusion of CFD (Computational Fluid Dynamics) into the design field made possible the simulation of more processes from food industry as follows: refrigeration, cold display and storage, ventilation, drying, sterilisation, mixing. 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 and redesign. The CFD application into optimization projects of refrigerated display cases with four shelf is motivated by high temperature variations of the foods in the bottom region of the refrigerated display cases, and of the high energetically consuming as well referred to one kilogram of food kept at cold (0-4°C) for 24h. Vertical open refrigerated cabinets are widely used in supermarkets. They can not only store various foods, but also have the advantages of good display and easy getting of products stored. In a vertical open display case are one or more virtual forced air curtains with the role of barriers between the refrigerated food inside the case and the ambient air in the store. 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.

However, the entrained ambient air into the air curtain is the largest energy loss. According to some estimates, 72-75% of the cooling load is constituted by infiltration of ambient air cross the curtain, and energy calculations preformed by the refrigeration industry have found the air curtain entrainment load can be as high as 90%. Since refrigeration accounts for roughly 50% of overall supermarket electricity consumption, air curtain entrainment plays a large role in supermarket energy usage. In addition, the high humidity levels of the entrained air accelerates the frosting of the evaporator coils (reducing their heat transfer and increasing the required frequency of defrost cycles). Therefore, minimizing the ambient air entrainment into the display case is critical to the overall system performance and efficiency. Extensive tests by Evans et al. [3] have led to the conclusion that the warmest specimens are located in the front. Further, Foster et al. [4] observed a variation in the product temperature between left and right. A review by Smale [5] brings out complementary role played by CFD analysis to testing. It demonstrates the ability of CFD to capture temperature critical domains, which again occur in the front and top layers of the stock. Several CFD studies of refrigerated cabinets exist notable among them are the ones from Cortella and co-workers [1, 2].

Starting from the literature studies [1-5], in the present paper we describe the experiments realized on a refrigerated display cases and the CFD simulation for the air curtain in 3D (three dimension) on a refrigerated cabinets with four shelves and the experiments realized for this. We compared the obtained values by simulation with the obtained experimental ones and we succeeded to realize a gauging of CFD simulation. The advantages offered by the CFD simulation and their gauging with the experiment are, first of all, the reducing of the costs and of the necessary time to optimize geometry for refrigerated cabinets through repeated experiments.

MATERIAL AND METHOD

In a vertical refrigerated cabinets with four shelves used for refrigerating food preservation, air is forced to flow through an evaporator which is situated on the base of the cabinets by suitable fans located on the front of the evaporator in the cabinet. A small fraction of the cooled air is feed into the cabinet through the perforated plate at the back of the cabinet, while the bulk of cold air is blown through one linear discharge air grille (DAG – honeycomb type) to form one air curtain. The air curtain and air infiltration from the external environment is recirculated through the return grill (RAG) and is positioned at the base of the refrigerated cabinets.

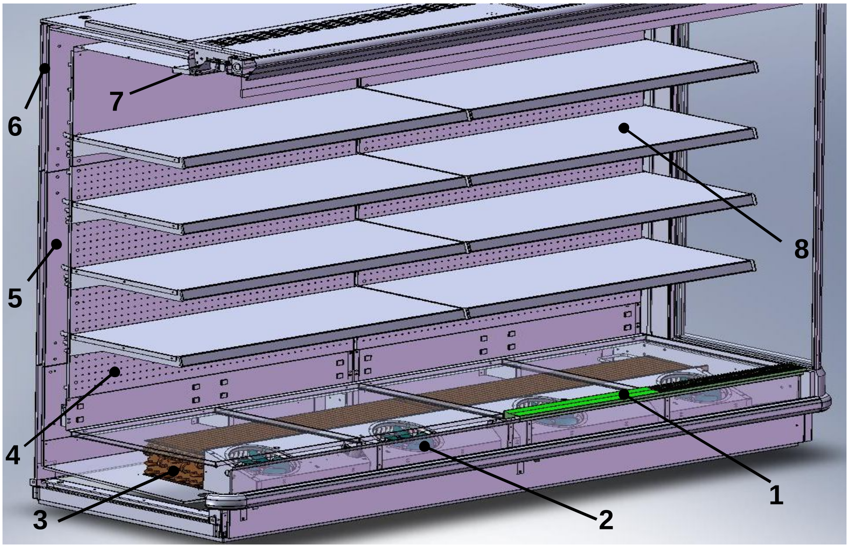

Figure 1 **Refrigerated cabinet with four shelfs**
1- return air grille (RAG); *2* - fan; *3* – evaporator; *4* – rear grille; *5* – air canal; *6* - insulating layer; *7* - discharge air grille (DAG) (honeycomb); *8* - shelfs.

A prototype of the refrigerated cabinets has been tested at the climatic test room, built in accordance with the EN441/4 Standard. Therefore, the ambient temperature was settled at 25°C and 60%, while the air in the room moved parallel to the longitudinal axis of the unit at uniform velocity 0.2 m/s. Figure 2 show the scheme of the experimental facility and the position of the display case in the test room.

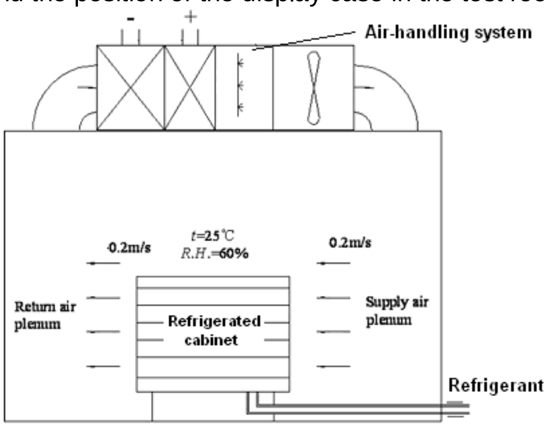

Figure 2 **Position of the refrigerated cabinets in the test room**

Position for the velocity, temperature and humidity transducers at the DAG (*fig.3*) was realized after a first CFD simulation. Transducers correct position is very important for accuracy further CFD simulation.

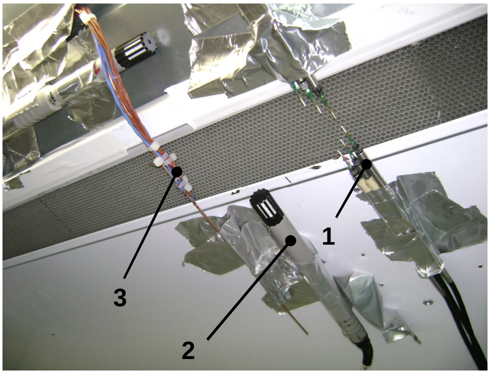

Figure 3 **Transducers position to the DAG**
1-velocity; *2* - humidity; *3* –temperature.

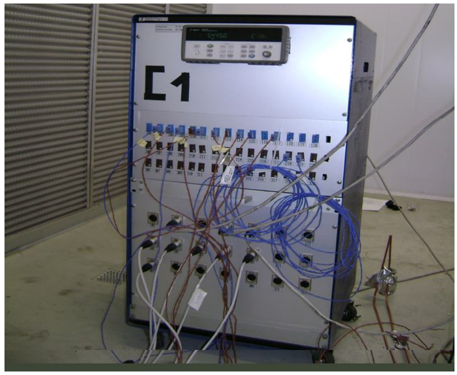

Figure 4 **Unit Acquisition**

CFD METHODS

CFD method is now used as an analytical modelling method for solving the flow of fluids and thermal analysis. This comes to filling the experimental method for the design of modern refrigerated cabinets. This method integrated into modern design system of the equipment from food industry makes possible the obtaining of some qualitative results *(fig. 5)*.

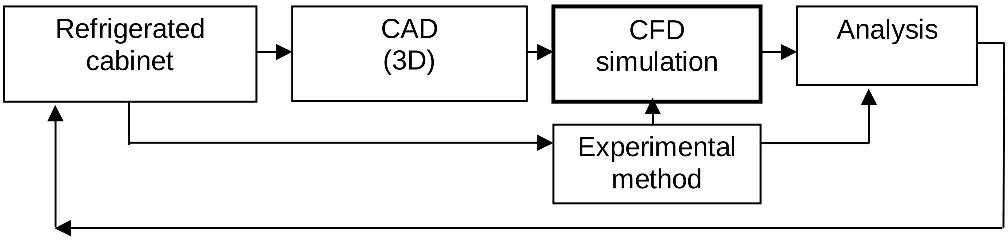

Figure 5 **Method integrated design**

First step in the CFD simulation is the *pre-processing* for which the purposed geometry is drawn in three dimension and then discretizated with a node network necessary for velocity and temperature distribution calculation.

Processing is the second step in simulation where boundary conditions and equations solvers are introduced for temperature and velocity 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 velocity distribution, concentration distribution, etc. can be visualized. After the analysis of the obtained results, if the temperature and velocity distribution are correct for this study, it isn't accordingly, the redesign study is restarted, with pre-processing step, and the refrigerated cabinets geometry is remodeled till the desired geometry is obtained.

RESULTS AND DISCUSSIONS

The experimental results obtained with traducers for speed profile at DAG *(fig. 6)* and for temperature profile *(fig. 7)* are filtered with a soft realized in C++ which are processed further into a mathematical software *(fig. 8)*, *(fig. 9)*, necessary for the obtaining of some polynomial functions. The obtained polynomial functions of 10 orders for speed profile at DAG are introduced into processing step of CFD simulation with Fluent software.

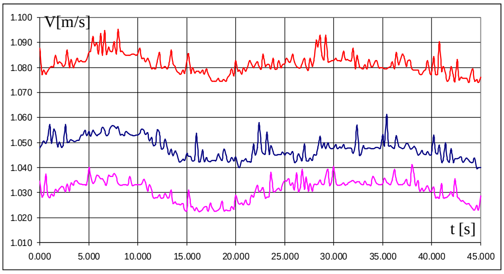

Figure 6 **Velocity profile**

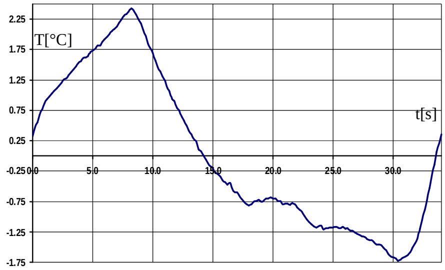

Figure 7 **Temperature profile**

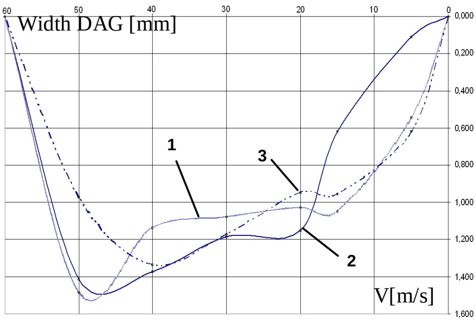

Figure 8 **Velocity profile functions (DAG)**
1 - left; *2* - middle; *3* - right.

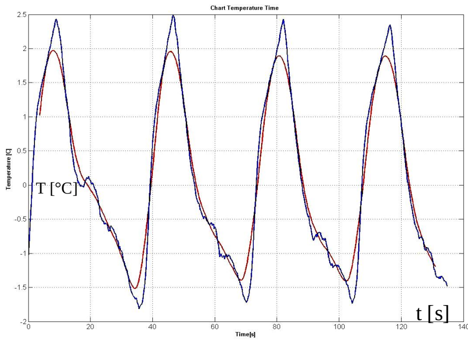

Figure 9 **Temperature profile functions (DAG)**

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 cabinets in the tangent plan air flow with velocity of 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 three cross sections (left, middle, right). 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 36 hours. The calculation system has been a Pentium IV with a CPU DualCore 6600 2.4 GHz and 4GB RAM.

The obtained results have been processed into post-processing stage from CFD simulation. For a better understanding of the obtained results it was proceeded to a combination of the method of representation of the flowing at air curtain level through flow lines and temperature gradient distribution through colours *(fig. 10), (fig. 11)*. It can be seen from the two presented figures (front and bottom view) a higher temperature at the bottom region of the refrigerated display cases with about 4-5°C over the imposed level by EN ISO 23953-2 standard and also a distribution of the flow air which indicate a high turbulence degree.

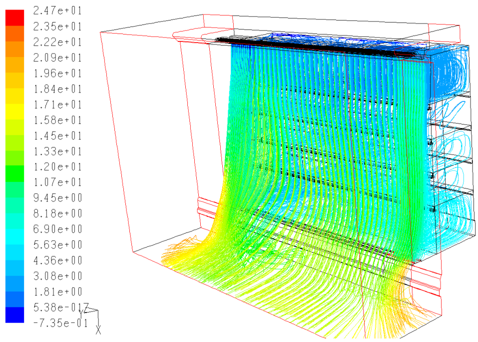

Figure 10 **Temperature air curtain front view**

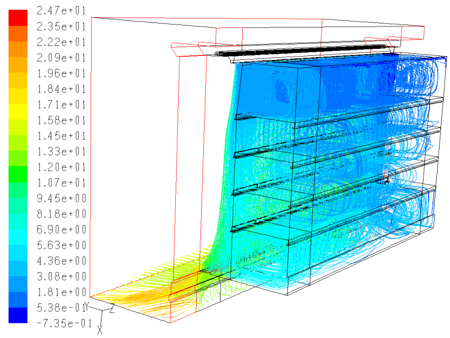

Figure 11 **Temperature air curtain bottom view**

CONCLUSIONS

In the present paper we purposed a modern integrated design of refrigerated cabinets used in food industry by CFD method. The CFD analysis was exemplified by simulation of a 3D refrigerated cabinets model having as the reference basis the recommendations and the experience of other researchers in this field, introducing as the originality element unsteady computation with the velocity profile variation and temperature of air curtain at the discharge air grille (DAG). The advantage of 3D simulation offers a good interpretation of the simulation results in a reasonable calculation time for the actual technique. The obtained results by simulation in the purposed variant are agree with the measurements made for the temperature and for the velocity. This correlation between simulation and experiments has been validated by the obtained experimental results with the temperature and velocity transducers positioned in front of each shelf that indicates the temperature and velocity distribution on the whole air curtain height.

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