A Review on Quantification of air flow heat and mass transfer in cold stores CFD model

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***Abstract*—The understanding of the flow field inside the cold store is very important to food storage at low temperatures. Transport phenomena, comprising airflow, heat and mass transfer, are key processes in refrigerated storage. This paper gives a review of approaches to modeling transport phenomena in food bulks, packages and stacks.A transient three-dimensional CFD model was developed to calculate the velocity, temperature and moisture distribution in an existing empty and loaded cool store. The dynamic behavior of the fan and cooler was modeled. The model accounted for turbulence by means of the standard k-3 model with standard wall profiles. The model was validated by means of velocity, air and product temperature. The airflow model is based on the steady state incompressible, Reynolds-averaged Navier-Stokes equations. The turbulence is taken into account using a k-α model. The standard as well as the Renormalization-Group (RNG) version of the k ÿ "model is investigated.The forced-circulation air cooler unit is modeled with an appropriate body force and resistance, corresponding to the characteristics of the fan and the tube-bank evaporator. The model was capable of predicting both the air and product temperature with reasonable accuracy.**

***IndexTerms*—Cold store; Modeling; CFD; Heat transfer; Mass transfer, Speed; Air, Temperature; Humidity.**

I. INTRODUCTION

A uniform cooling and cold storage of fresh produce are di cult to obtain in industrial cooling rooms because of an uneven distribution of the airflow. The airflow distribution is dependent on the produce, the cooling medium, the geometry and characteristic of the cooling room. The velocity distribution can be determined based on the conservation equations for mass and momentum. An analytical solution can be found only in simple cases. The variables can be examined experimentally, but this is a tedious, costly, time-consuming method and furthermore, it is only applicable to existing storage rooms. It can, hence, notbe used to optimize the storage room in an early phase of the design. With the increasing availability and power of computers together with efficient solution algorithms and processing facilities, the governing fluid-flow equations can now be solved numerically. The technique of Computational Fluid Dynamics (CFD), which uses computers for solving fluid-flow problems, is very powerful and spans a wide range of industrial and non-industrial application areas. Several user-friendly software packages are available such as PHOENICS, CFX, and STAR-CD, FLUENT/FIDAP.

Refrigerated foods can either be stored in large bulks or in smaller units or packages. A wide range of packages are used in practice, constructed from a variety of materials, with many different designs and ranging in size. Then, packages are stored in particular arrangements as to optimize air penetration. Transport phenomena in such systems are complex and mathematical models aid the understanding and design of refrigerated storage systems.

One of the main aims in designing storage enclosures is to ensure a uniform targeted temperature and humidity in the stored bulk products. The intricate transport mechanics and the complex geometry of a fully loaded cool store make it difficult to determine the optimal configuration andoperation parameters of the store in an empirical way. A model-based approach can prove to be advantageous for design purposes with small added cost. With the increasing availability and power of computers together with efficient solution algorithms and processing facilities, the technique of Computational Fluid Dynamics (CFD) can be used to solve the governing fluid flow equations numerically. A first step towards modeling cool stores loaded with agricultural products is representation of the heat and mass transfer inside bulk storages of agricultural products. Many models have been proposed with different levels of complexity such as uniform air-product temperature, thermal equilibriumand internal temperature gradient with mass transfer incorporated . Airflow has been studied in ventilated enclosures for food preservation and processing. To study the non-uniform temperature and moisture of a loaded cool store, only a few models have been proposed in the last 10 years. These models are limited to a two-dimensional one-phase model, or distributed dynamic model with only validation for temperature at two locations in the cool store. Van Gerwen and Van Oortused CFD to model 3D airflow and heat transfer in a refrigerated room for agricultural products and studied the effect of different configurations on the cooling effectiveness. However, no detailed information of the model, or the validation was reported. Mass transfer was not modeled in most of the cases. Hoang et al. used CFD to model 3D airflow, heat and mass transfer in an industrial cool store for chicory roots. The latter was validated for the air temperature only (air velocity and product temperature were not validated).

The aim of current work is to develop validated CFD models for vacuum cooling of porous foods to allow simultaneous prediction of temperature profile and weight loss to provide better understanding of the mechanism of cooling and aid in the improvement of design and operation.

II. LITERATURE REVIEW

X. H. Hao, Y. L. Ju[1] "Simulation and analysis on the flow field of the low temperature mini-type cold store" In this research paper the understanding of the flow field inside the cold store is very important to food storage at low temperatures. In this paper, the CFD simulation on the flow field for low temperature cold store with air forced supply mode is presented. The turbulence flow of three-dimensional steady incompressible viscous fluid is analyzed using finite volume method and standard K e two-equation. The temperature and velocity fields of this cold store are simulated, analyzed and compared. The simulation results show that the velocity and temperature fields are evidently influenced by the cross section from the ground, and the optimal cross section is also given in this paper.

Pieter Verboven, D. Flick, B.M. Nicola, G. Alvarez[2] "Modeling transport phenomena in refrigerated food bulks, packages and stacks: basics and advances" In this research paper transport phenomena, comprising airflow, heat and mass transfer, are key processes in refrigerated storage. This paper gives a review of approaches to modeling transport phenomena in food bulks, packages and stacks. Darcye-Forchheimer porous media models have been successfully used. Ergun theory was found not directly applicable when foods are stored in packages, which cause flow confinement and vent hole resistance, invalidating traditional theory. Heat and mass transfer in food bulks has been modeled using single- and two-phase models. Suggested modifications were demonstrated to not be generally valid, leaving much scope for further development of models for refrigerated system design. Direct CFD approaches were shown to be successful alternatives to achieve this goal.

A.M. Foster, M.J. Swain, R. Barrett, S.J. James[3] "Experimental verification of analytical and CFD predictions of infiltration through cold store entrances" In this research paper Measurements of infiltration through different size entrances of a cold store at two different cold store temperatures were taken and compared against established analytical models andcomputational fluid dynamics (CFD) models. The analytical and CFD models generally tended to over predict the infiltration. The analytical model developed by Gosney et alprovided the closest comparison with the various experiments. The CFD models were more accurate than the fundamental analytical models but less accurate than those based on a semi-empirical approach. For the experimental configurations examined, CFD offered no real advantage over these empirical analytical models. If the conditions were such that the infiltration rate changed with time or if door protection devices (e.g. air curtains) were used, CFD would become much more advantageous in predicting infiltration.

Da-Wen Sun*, Zehua Hu[4] "CFD simulation of coupled heat and mass transfer through porous foods during vacuum cooling process" In this paper, a numerical simulation by using a computational fluid dynamics (CFD) code is carried out to predict heat and mass transfer during vacuum cooling of porous foods on the basis of mathematical models of unsteady heat and mass transfer. The simulations allow the simultaneous prediction of temperature distribution, weight loss and moisture content of the meats at low saturation pressure throughout the chilling process. The simulations are also capable of accounting for the effects of the dependent variables such as pressure, temperature, density and water content, thermal shrinkage, and anisotropy of the food. The model is verified by vacuum cooling of cooked meats with cylindrical shape within an experimental vacuum cooler. A data file for pressure history was created from the experimental pressure values, which were applied in the simulations as the boundary condition of the surface temperature.

M.L. Hoang*, P. Verboven, J. De Baerdemaeker, B.M. Nicolaõ[5] "Analysis of the air flow in a cold store by means of computational fluid dynamics" Airflow inside a cold store is investigated using computational fluid dynamics. The airflow model is based on the steady state incompressible, Reynolds-averaged Navier-Stokes equations. The turbulence is taken into account using a k € model. The standard as well as the Renormalization-Group (RNG) version of the k ÿ " model is investigated. The forced-circulation air cooler unit is modeled with an appropriate body force and resistance, corresponding to the characteristics of the fan and the tube-bank evaporator. The finite volume method of discretization is used. The validation of the model has been performed by a comparison of the calculated time-averaged velocity magnitudes with the mean velocities measured by means of a hot-®lm type omni-directional velocity sensor. A relative error on the calculated air velocities of 26% was observed. The RNG k ÿ " model does not help to improve the prediction of the recirculation. Both a finer grid and enhanced turbulence models are needed to improve the predictions.

H.B. Nahor, M.L. Hoang, P. Verboven, M. Baelmans, B.M. Nicolaı [6] CFD model of the airflow, heat and mass transfer in cool stores" In this research paper, a transient three-dimensional CFD model was developed to calculate the velocity, temperature and moisture distribution in an existing empty and loaded cool store. The dynamic behavior of the fan and cooler was modeled. The model accounted for turbulence by means of the standard k-3 model with standard wall profiles. The model was validated by means of velocity, airand product temperature. An average accuracy of 22% on the velocity magnitudes inside the empty cold store was achieved and the predicted temperature distribution was more uniform than predicted. In the loaded cold =

N.J. Smale, J. Moureh, G. Cortella[7] " A review of numerical models of airflow in refrigerated food applications" In this research paper Temperature homogeneity in most food refrigeration systems is directly governed by the airflow patterns in the system.Numerical modeling of airflow provides an opportunity to develop improved understanding of the underlying phenomena influencing system performance, which can lead to reduced temperature heterogeneity and increased effectiveness and efficiency of refrigeration systems. With the rapid advances in computational power of recent years, the use of Computational Fluid Dynamics (CFD) techniques in this application has become popular. This paper reviews the application of CFD and other numerical modeling techniques to the prediction of airflow in refrigerated food applications including cool stores, transport equipment and retail display cabinets.

III. CONCLUSION

There has been considerable effort put into the numerical modelling of airflow in refrigerated food applications in recent times. As the power of computers has increased, so too has the sophistication of these models. Dynamic CFD simulations have become more frequently performed, as they have the use of turbulence models other than the widely used k-€ model.

The k-€ model has been shown not to be sufficiently accurate for use in many applications; however, implementation of more sophisticated alternatives has not yet been widely reported. With further increases in the availability of computational power, the implementation of these models will become more widespread. Research determining the required sophistication of the turbulence model for a given application is an area sure to receive much attention in coming years.

The use of a porous media approach to simplify complex geometries has also become popular in recent times; however, this approach is unlikely to be sufficiently accurate for many products. A multi-scale approach where detailed investigations of product stacks using CFD are used to develop models of the macroscopic behavior of these systems is another area for future research. CFD continues to have difficulty in accurately reproducing experimental results, and issues concerning grid dependency and turbulence model selection remain. Therefore, operator judgment continues to play a major part in the reliability of simulation results and implementation by experienced operators aware of the impact of the turbulence model, discretization scheme and boundary conditions is required to obtain reliable results.

The application of airflow modelling techniques to food refrigeration systems provides an opportunity to develop improved understanding of the underlying phenomena, to reduce ventilation and temperature heterogeneity and increase the efficiency and effectiveness of refrigeration systems. These potential benefits ensure that numerical modelling will continue to receive considerable attention and evolve in the coming years.

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