Scientific quarterly journal ISNN 1429-7264

Agricultural Engineering

2014:1(149):73-81

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.149.008

# COMPUTATIONAL FLUID DYNAMICS CFD AS AN INNOVATIVE TOOL FOR SIMULATION OF THE SMOKE DRYING PROCESS AND FOR MODELING THE STRUCTURAL ELEMENTS OF A SMOKE-DRYING CHAMBER[1]

Mariusz S. Kubiak[a*], Marek Jakubowski[a], Włodzimierz Dolata[b]

[a]Department of Food Industry Processes and Facilities, Koszalin University of Technology
[b]Department of Engineering and Production Processes Design, Poznan University of Life Sciences
[*] *Contact details: ul. Racławicka 15-17, 75-620 Koszalin, e-mail: mariusz.kubiak@tu.koszalin.pl*

ARTICLE INFO

*Article history:*
Received: October 2013
Received in the revised form: December 2013
Accepted: February 2014

*Keywords:*
Computational Fluid Dynamics (CFD)
simulation model
smoking chamber
smoke-drying process
power nozzles construction

ABSTRACT

*This paper elaborates upon the use of Computational Fluid Dynamics (CFD) tools in the engineering practice as an integral part of progress of the chemical engineering of smoke-drying taking into consideration the technical progress and smoke-drying methods. The use of tools connected to CDF modeling allowed collecting crucial information concerning the performed process of smoke-drying for the assortment geometrically shaped similarly to a piece of oval ham. A single truck chamber was a base construction for solutions of the suggested modification of the powering elements (nozzles) as well as for computer model geometry of the structure of an empty chamber and a full chamber itself. Discretization has been made in ANSYS Mechanical APDL 12.1 software and on this basis a model of the suggested solution for construction of power nozzles as well as nozzles spreading the smoke substance inside the smoking chamber has been prepared. On the basis of simulating models and received feedback we can unequivocally say, that more advantageous conditions of spreading the smoke substance in the smoking chamber had been found. The tests performed in real conditions with the use of modified power nozzles in comparison to a classic arrangement confirm dependences obtained during simulation.*

## Introduction

The objective of the smoking process in the technological aspect is to fix and provide the smoke-dried products with highly specific sensory properties and to remove the water part and antimicrobial properties of the produced components of smoke, mainly phenols (Sikorski and Kołakowski, 2010). However, vagueness of definition does not reflect a complex and balanced smoking technology. The smoking process depends on many

[1]Scientific research funded with funds for education within 2010-2013 as a research project no NR12 0125 10

factors e.g. smoke components (wood species and its form used for production of smoke, manner and speed of wood combustion), temperature, moisture and density of the produced smoke (Tóth and Potthast, 1984; Bratzler et al., 1969) and indirectly on the speed and the manner of providing and flow (distribution) of the smoke mixture inside a chamber and the structure and distribution of supply nozzles (Sikorski and Kołakowski, 2010; Kubiak and Jakubowski, 2010a, 2013).

The increasing awareness concerning ecology and health influenced the progress in the entire smoking technology including development of smoking treatment techniques and methods. A modern production practice, regardless the food processing branch aims at searching for solutions which enable reduction of costs at the simultaneous maintenance of the technological regime (Kubiak, 2012). With time and due to cultural changes and the progress in technical thinking, smoke-drying has become a finely refined process and has taken a new generation form (Wilms, 2000; Kubiak, 2012). The need to meet the raising quality requirements, including health requirements at maintaining a traditional nature of the smoked product was emphasised (Sikorski and Kołakowski, 2010; Kubiak and Jakubowski, 2013).

During smoke-drying the smoke particles constantly move influenced by diffusion forces (Brownian motion), gravitational, convectional, centrifugal, electrostatic forces, etc. Particularly great function is performed by Brwnian motions, which are the main reason for coalescence, coagulation and deposition of smoke particles on the product. An approximate diameter of a single particle of smoke is 0.08-0.15 µm and the density of the smoke mixture and its medium (air) is within 0.02-1.30 $g \cdot cm^{-3}$ (Šimko, 2009; Sikorski and Kołakowski, 2010; Sikorski, 2004). Proper placement of the feeding nozzles and guidance of the smoke mixture direction of propagation allows achieving its uniform distribution, as well as reduction of pollution resulting from the preservation process.

## Objective of the paper

The objective of the research was to use one of many available numerical modeling methods (CFD) to obtain information related to improvement of the smoking process, by better propagation of smoke mixture inside the chamber, while having regard to the geometrical shape of the batch.

## Material and methods

The subject of the study was a KWP-1et type single-trolley chamber by Pek-Mont Sp. z o.o. (fig. 1a, b) with the overall internal dimensions of the working part: length – 1,440 mm, width – 1,200 mm, height – 2,950 mm. The choice was a result of the fact, that such chambers are currently in use in small to medium size factories, where production is oriented toward diverse groups of meat products, smoking of which requires the ability to instantly change conditions under which the process is carried out (PEK-MONT, 2010; Kubiak and Jakubowski, 2010a, 2010b).

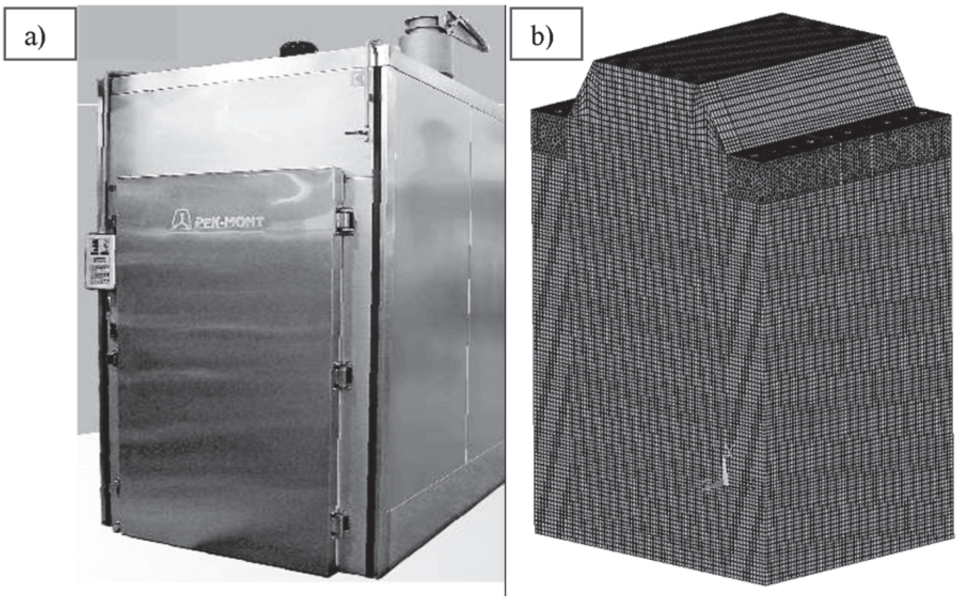


*Figure 1. Single-trolley smoke and cooking chamber of Pek-Mont Sp. z o.o. company: a – general view (www.pekmont.pl), b – geometrical model of the inside with a discretization grid*

Based on the actual data, a basic (classic) model of the internal space of the chamber was prepared. The entire geometry of the computer model of the empty chamber structure (with classic and modified system of nozzles) and its discretization was made in ANSYS Mechanical APDL 12.1 (ANSYS Mechanical, 2010) software. At the construction of the finite elements grid, a tetragonal element of Fluid 142 type available in the software library was applied (ANSYS Mechanical, 2010). In the simulation analysis geometry of a batch similar to filling in actual conditions was used: an oval shaped product. Dimensions of a single item from the batch corresponded to average dimensions characteristic for the product. The used geometry and distribution itself constitutes in simulation some kind of simplification related to assumption of regular and uniform dimensions of the processed batch. A generated grid for the base (a classic system of supply nozzles) and the suggested solution (a modified structure of supply nozzles: long nozzles up to 15 cm from the floor) for an empty and loaded chamber were within the number of elements which were respectively approx. 1, 250, 000 - empty chambers (fig.2 a-c) and approx. 1, 500, 000 – loaded chambers (fig. 2 b-d).

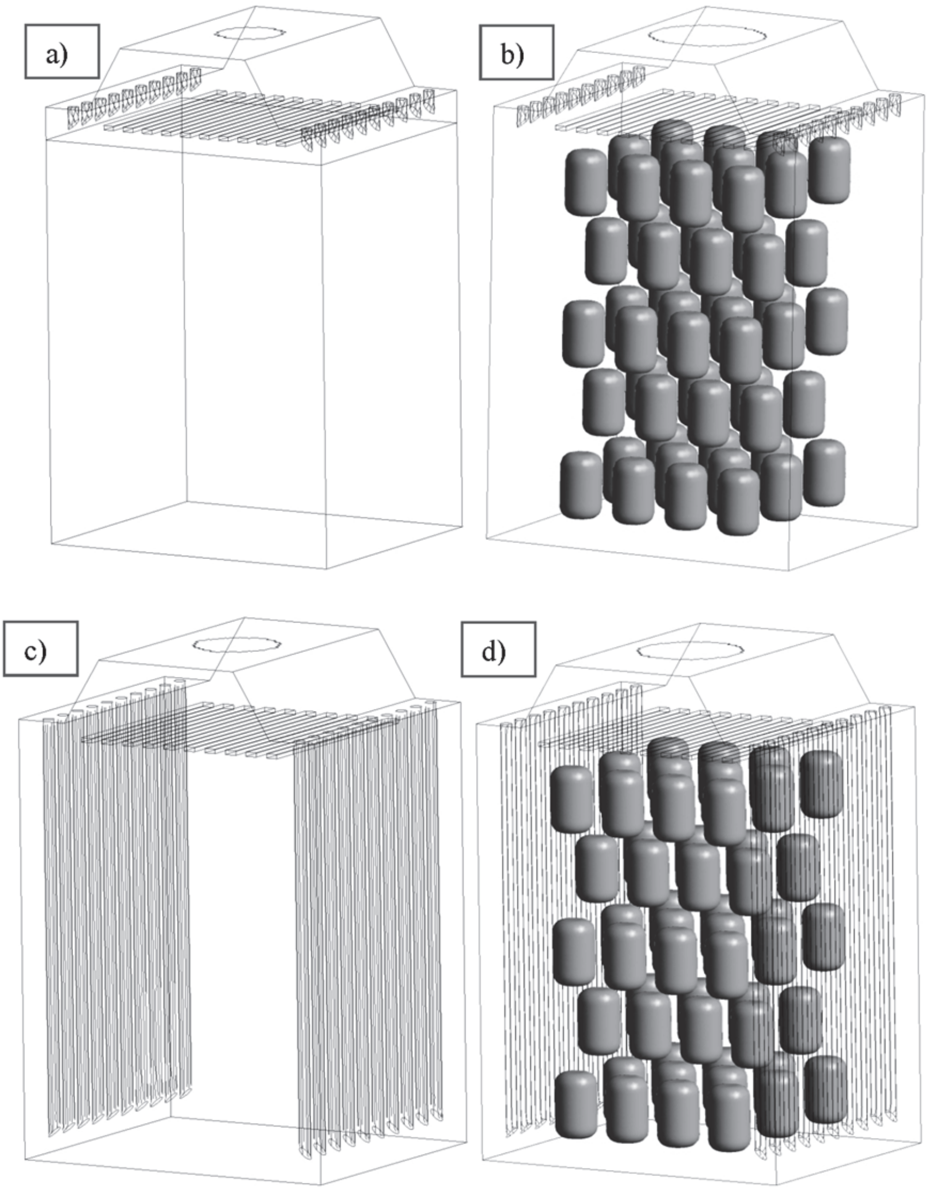


*Figure 2. Generation of grid for empty chamber and with batch: a,b – base (classic) and c,d – modified structure of supplying nozzles*

The prepared models were then fed into the preprocessor of CFX program, in which boundary and initial conditions, corresponding to the conditions and parameters of the actual smoking, were declared. The next phase for the performed simulational analyses was to feed the prepared models into the solver module and commence the simulation (ANSYS CFX, 2010).

In this paper the phrase "smoke mixture flow" inside the smoking chamber is used interchangeably with "motion" and "propagation", which is dictated by the definitions comprising domain-specific nomenclature.

## Research results

Generated graphic files of the finite elements grids enable presentation of data in the form of maps of flow velocity distribution (movement) in spaces of the analysed chambers (classic and the suggested modification) and the analysis of tracking of the dispersed phase particles. Presentation in the form of velocity distribution maps enabled processing of the output values of the parameters specifying the motion of the mixture.

Velocity distribution in the entire space of the internal chamber filled with a batch for the classic variant (basic) and with a modified structure of supplying nozzles has been presented in figure 3.

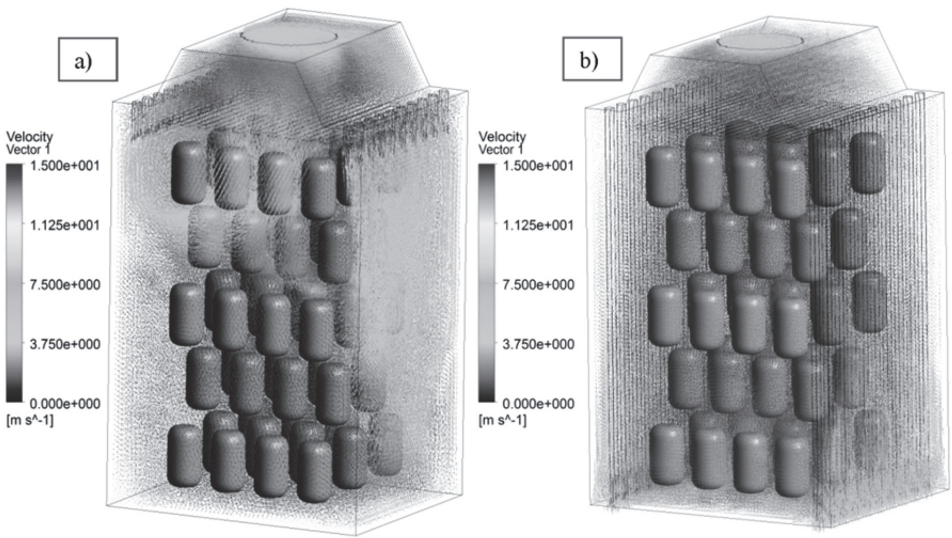


*Figure 3. Space maps of distribution of flow speed (movement) vectors in smoke single-trolley chamber with batch: a – base (classic), b – of modified structure of supplying nozzles*

The compared distribution of the flow velocity of mixture in the smoking chambers in both variants of structure proved considerable variability, which proved lack of flow symmetry despite equal distribution of feeding nozzles (fig. 3 a-b).

The presented velocity maps (fig. 3a) may indicate considerable irregularities of the smoke mixture flow in the entire space of a chamber loaded with a batch. Obstacles in the form of particular pieces of a batch explicitly prove the problem of irregular propagation with the smoke mixture and thus the possibility of technological faults e.g. insufficient or excessive smoking with a classic arrangement of supply nozzles. Figure 3b, which depicts the proposed longer feeding nozzles, shows better velocity distribution, which leads to more even propagation.

The dispersed phase particles tracking analysis performed to better portray the differences of smoke mixture flow, allows to locate the areas of its concentration. This allows to recognize the areas with insufficient propagation conditions, which impact the correctness of the smoking process. Figures 4a-b present smoke particles motion path for the analyzed variants of nozzles feeding the smoke mixture. In both cases it was assumed that smoke particles which come in contact with any of the chamber walls or the batch items settle onto their surfaces.

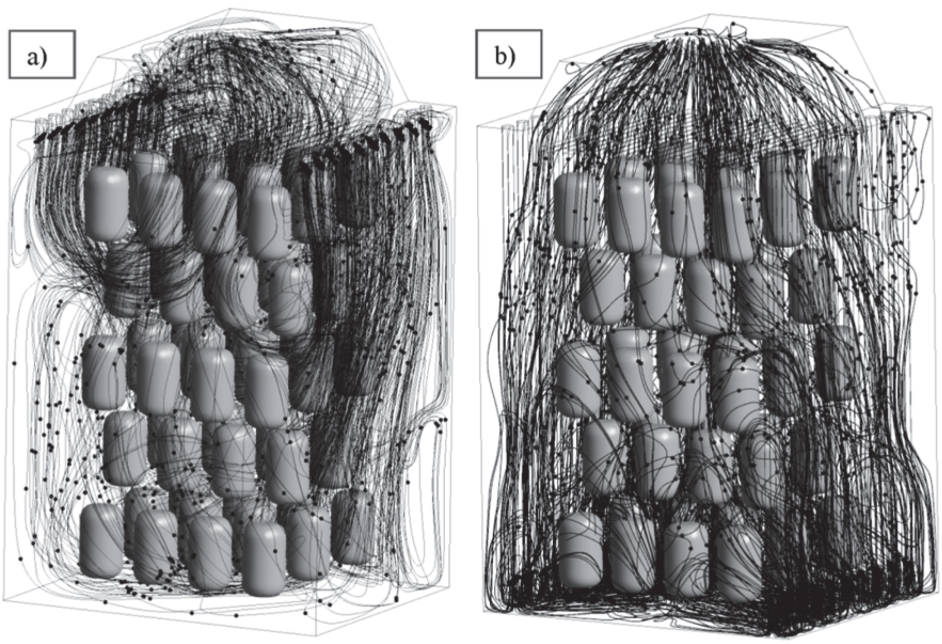


*Figure 4. Tracking of smoke particles in smoke single-trolley chamber with batch: a – base (classic), b – of modified shape of supplying nozzles*

Comparing the results of the smoke particles tracking in the chamber with a classic (basic) structure and with a batch it may be stated that the so-called “blank spaces” of the smoke mixture concentration occur (fig. 4a). Those “blank spaces” (zones) prove the thesis about the unfavorable smoke mixture propagation conditions with this type of nozzle arrangement, which can further impact the final product. A different situation is observed when the modified nozzles are used (their length up tp 15 cm from the floor). In the suggested arrangement of supplying nozzles, a more favourable movement of smoke mixture is emphasised both in the bottom as well as in the central part of the smoking chamber, which improves concentration and conditions of the smoke propagation. Including lower values of the smoke flow velocity both in simulation conditions as well as in real conditions, better conditions for smoking may be obtained in the form of a longer contact of smoke with the processed raw material (regardless its geometry, size or even shape).

## Conclusions

1. The developed and tested model and results obtained based on calculations constitute a valuable tool for persons, who in the production practice deal with the smoking process. It concerns both technologists who guard the conditions of the correct course of the technological process as well as deisgners of smoking chambers for searching for new solutions in optimization of the complex smoking process.
2. The tested model showed stability, which allows, after extending the computational power of the working station, declaring the multi-phase flow and including additional factors, which affect the smoking process.
3. It is also possible to modify the batch’s geometry, nozzle placement, which allows performance of simulational analyses for different load variants.
4. The aim of the presented simulational model is to be a tool for seeking new structural solutions to the feeding nozzles of the smoking chamber, and also other elements which can improve the smoking process.

## Acknowledgements

The authors would like to express their gratefulness towards PEK-MONT Ltd. from Bielsk in Plock county for their valuable content-related advice during the research on possible alterations to the structure of smoking chambers, and the use of simulation software for this purpose. The authors also would like to extend their gratitude to Zakład Przetwórstwa Mięsnego I.Z. Grabowscy S. J., where the real-world industry-scale research took place, which allowed verification of the outputs of the simulation analyses.

## References

Ansys CFX 12.1 (2010). *Dokumentacja programu*.

Ansys Mechanical 12.1 (2010). *Dokumentacja programu*.

Bratzler, L.J.; Spooner, M.E.; Weatherspoon, J.B.; Maxey, J.A. (1969). Smoke flavor as related to phenol, carbonyl and acid content of bologna. *Journal of Food Science*, *34*, 144-148.

Jakubowski, M.; Kubiak, M.S. (2013). Analiza symulacyjna przepływu powietrza w komorze wędzarniczej o zmodyfikowanym rozmieszczeniu dysz zasilających. *Inżynieria i Aparatura Chemiczna*, *52*(3), 183-184.

Kubiak, M.S. (2012). Nowoczesne rozwiązania konstrukcyjne stosowane w komorach wędzarniczo-parzelniczych, *Postępy Techniki Przetwórstwa Spożywczego*, *40,* 83-86.

Kubiak, M.S.; Jakubowski, M. (2010a). Model symulacyjny warunków przepływu w komorze wędzarniczej. *Postępy Techniki Przetwórstwa Spożywczego*, *1*, 55-57.

Kubiak, M.S.; Jakubowski, M. (2010b). Trójwymiarowa analiza symulacyjna CFD rozkładu pola prędkości przepływu mieszaniny dwufazowej w komorze wędzarniczej, *Nauka Przyroda Technologie*, *4*(5), 1-11.

Kubiak, M.S.; Jakubowski, M. (2013). CFD simulations as a supporting tool of process and construction optimization in food industry production practice: the case study of a single truck smoking chamber. *Italian Journal Food Science*, *25*(3), 251-254.

PEK-MONT Sp. z o.o. (2010). Materiały wewnętrzne firmy (www.pekmont.pl).

Sikorski, Z. E.; Kołakowski, E. (2010). Smoking, *in Handbook of Meat Processing* (Ed Toldrá F.), Chapter 12. Wiley-Blackwell, Oxford, UK, 231-245.

Sikorski, Z.E. (2004). Traditional smoking. in. *Encyclopedia of meat sciences,* Jensen W.K., Devine, C.; Dikeman, K. (Eds.), (1265-1277). London: Elsevier.

Šimko, P. (2009). Polycyclic Aromatic Hydrocarbons in Smoked Meats. *Safety of Meat and Processed Meat Food Microbiology and Food Safety*, (Ed Toldrá F.), (343-363). chapter 13. Springer Science, Business Media, LLC.

Tóth, L.; Potthast, K. (1984). Chemical Aspects of the Smoking of Meat and Meat Products. *Advances in Food Research*, 29, 87-158.

Wilms, M. (2000). The developing of modern smokehouses – Ecological and economical aspects. *Fleischwirtschaft International*, *4*, 8-13.

## COMPUTATIONAL FLUID DYNAMICS (CFD) INNOWACYJNE NARZĘDZIE DO SYMULOWANIA PROCESU WĘDZENIA ORAZ MODELOWANIA ELEMENTÓW KONSTRUKCJI KOMORY WĘDZARNICZO-PARZELNICZEJ

**Streszczenie.** Omówiono Computational Fluid Dynamics (CFD) w praktyce inżynierskiej jako integralną część postępu w całej inżynierii procesowej wędzenia z uwzględnieniem rozwoju technik i metod przeprowadzania obróbki wędzarniczej. Wykorzystanie narzędzi związanych z modelowaniem CFD pozwoliło na uzyskanie istotnych informacji dotyczących przeprowadzanego procesu wędzenia dla asortymentu o kształcie geometrycznym zbliżonym do szynki (myszka). Komora jednowózkowa stanowiła konstrukcję bazową dla rozwiązań proponowanej modyfikacji elementów zasilających (dysz), jak również geometrię modelu komputerowego samej konstrukcji komory pustej i z wsadem. Dyskretyzacja została wykonana w programie ANSYS Mechanical APDL 12.1 i na jej podstawie stworzono model o proponowanym rozwiązaniu konstrukcji dysz zasilających i rozprowadzających mieszaninę dymu wewnątrz komory wędzarniczej. Na podstawie modeli symulacyjnych i uzyskanych z nich wyników można jednoznacznie stwierdzić, że osiągnięto korzystniejsze warunki rozprowadzenia mieszaniny dymu w komorze wędzarniczej. Przeprowadzone w warunkach rzeczywistych badania z wykorzystaniem zmodyfikowanych dysz zasilających w porównaniu z klasycznym układem potwierdzają zależności uzyskane z symulacji.

**Słowa kluczowe:** Computational Fluid Dynamics (CFD) model symulacyjny, komora wędzarnicza, proces wędzenia, konstrukcja dysz zasilających