25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-1555
COMPUTATIONAL ANALYSIS OF LAMINAR FLOWS IN A POROUS MEDIUM COMPOSED OF CORN COBS

Hélio Ribeiro Neto
Pedro Ricardo Corrêa Souza
Ítalo Augusto Magalhães de Ávila
Amanda de Sousa Martins
Isadora Zechin de Oliveira Toniello
Elias de Matos Guimarães
Federal University of Uberlândia, Av. João Naves de Ávila 2121, Campus Santa Mônica. Uberlândia, MG, Brazil, CEP: 38400-902
heliorine@hotmail.com, eng.pedro.ricardo@gmail.com, italo.ufuracing@gmail.com, amandamartins@metaej.com.br, isadora-toniello@metaej.com.br, eliasguimaraes@metaej.com.br

Felipe Camargo Rosa
Cinthia Vieira Golfi Andriazzi
Fabrício Gobbo Ferreira Filho
Monsanto do Brasil Ltda. BR 452, km 149 Zona Rural 38405232 - Uberlândia, MG - Brazil
felipe.c.rosa@monsanto.com, cinthia.v.andriazzi@monsanto.com, fabricio.gobbo.ferreira.filho@monsanto.com

Aristeu da Silveira Neto
Federal University of Uberlândia, Av. João Naves de Ávila 2121, Campus Santa Mônica. Uberlândia, MG, Brazil, CEP: 38400-902.
aristeus@ufu.br

Abstract. *The purpose of this work is to investigate the heat transfer inside and outside a fully loaded cart with corn spikes. To do so a well known commercial CFD code was used to model the fluid flow inside and outside a porous media with thermal energy transfer. The aim of this paper is to validate the chosen models with an experiment conducted in the field and open the possibility to design an efficient colling system for this application.*
Keywords: *CFD, URANS, Porous Media, Corn Spikes*

1. INTRODUCTION

Companies that produces maize seed must transport the live ears from the field to the seed treatment site. These live seeds exhibit biological activity that can transform stored chemical energy into thermal energy. The transportation is done using trucks or carts that carry approximately 25 tons of spikes. The sides of the trucks can be impermeable, slatted or screened. The carts are covered by tarpaulins to avoid the fall of spikes during the trip. When the sides are ripped or screened, the withdrawal of thermal energy by moving air relative to the moving cart is facilitated.

The temperature inside the spike load tends to increase due to the biological activity of live grains. When the beans reach a temperature of 40 ř C they die, losing their ability to germinate. This warming becomes more intense when the carts remain in place for a long enough time. On average the temperature increases by 1 °C / hr.

The pin-loaded cart can be physically modeled, considering a porous medium. The air that permeates the pores, either by natural convection or by forced convection, exchanges thermal energy with the spikes, usually removing energy from the spikes. When the carts are stationary, there is basically natural convection. In this flow condition it is found that the heating rate is of 1 °C / hr. On very hot days the cart is loaded with heated spindles, for example at 35 ° C. In that case, when the load reaches the site it is already at 38 ° C, for example. This means that if the cart remains stationary for more than an hour, its core reaches the limit mark. Thus, companies often must discard full loads or otherwise dispose of them. This was the motivation to start a project involving MFLab-FEMEC-UFU aiming thermal control of spike loads.

The solution to this problem requires the design of a load cooling system, which must use forcing convection inside the spindle load. This is an example of an engineering problem whose solution can be faster and cheaper with the use of computational simulation of the flow.

This work is about mathematically, numerically and computationally modeling of flows in a porous medium. The physical characteristics, such as porosity, permeability, specific mass, thermal conductivity, thermal capacity, were determined analyzing samples of the porous medium. Some of the information was obtained in publications of other authors,

Figure 1. Physical model of the problem: Cart loaded with spikes inside a rectangular domain.

Silva (2008), Pinto (2016), Araujo (2016), Rama (2004), César Corrêa and De Sousa e Silva (2014). The most delicate question to be answered was which flow regime? Laminar or turbulent? In this article we present the procedure elaborated for the determination of the regime. The comparison between the results obtained through computational experimentation and the results obtained through material experimentation is presented.

2. PHYSICAL MODEL

The physical model is represented in Figure 1. It is a cart whose interior is laden with ears of corn. The analysis domain extends far away on the sides and top of the load so as to be able to impose the boundary conditions. In all planes, zero speed and ambient temperature conditions were imposed.

3. MATHEMATICAL DIFFERENTIAL MODEL

Three-dimensional incompressible flows with thermal energy transfer are mathematically described by a system of five partial differential equations containing: Mass balance (Eq. 1), Linear momentum balance in the three directions (Eq. 2) and Thermal energy balance (Eq. 5). Additional equations may be present for this system to close the turbulence when the flow is not laminar. These equations will be described in the next sections.

3.1 Fluid-dynamic model

The differential mathematical model is based on the principles of mass balance, linear momentum balance and thermal energy balance. These balances are performed in a way that takes into account the influence of the porosity and the permeability of the medium. The differential equations are presented below:

The equations below describe the behavior of a continuous, incompressible Newtonian fluid in a porous medium. In order to obtain the mass balance and momentum balance equations in a non-porous medium, one must define the variable γ as being equal to 1 and the variable C_0 as being equal to zero. The equation 1 models the mass balance:

$$\frac{\partial\left(\gamma\rho_f\right)}{\partial t}+\nabla\cdot\left(\gamma\rho_f\vec{v}\right)=0, \tag{1}$$

where ρ_f is the specific mass of the fluid, $\vec{v}$ is the velocity vector of the fluid, t is the time, and γ is the porosity of the porous medium.

The equation 2 models the balance of the momentum:

$$\begin{aligned}\underbrace{\frac{\partial}{\partial t}\left(\gamma\rho_f\vec{v}\right)}_{\text{Local acceleration}}+\underbrace{\nabla\cdot\left(\gamma\rho_f\vec{v}\vec{v}\right)}_{\substack{\text{Advective}\\\text{transport}}}=\underbrace{-\gamma\nabla p}_{\substack{\text{Pressure}\\\text{Gradient}}}+\underbrace{\nabla\cdot\left(\gamma\mu\left(\nabla\vec{v}+\nabla\vec{v}^T-\frac{2}{3}\nabla\cdot\vec{v}\,\mathbf{I}\right)\right)}_{\substack{\text{Diffusive}\\\text{transport}}}+\\+\underbrace{\gamma\rho_f\vec{g}}_{\text{Gravity}}-\underbrace{C_0\left|\vec{v}\right|^{C_1-1}\vec{v}}_{\substack{\text{Transformation due to}\\\text{the porous media}}},\end{aligned} \tag{2}$$

in which p is the pressure, μ is the dynamic viscosity of the fluid, $\mathbf{I}$ is the identity matrix, $\vec{g}$ is the gravity vector C_0 and C_1 are constants adjusted experimentally. These constants were obtained in the work Eduardo *et al.* (2002). The authors present a graph of loss of charge as a function of fluid velocity for different grains. The curve for corn with straw was used. The curve data were extracted and a curve fit was made to obtain the constants C_0 and C_1. The constants obtained are:

$$C_0=363,9615, \tag{3}$$

$$C_1 = 1,9482. \tag{4}$$

3.2 Thermal Model

For simulations in which the porous medium and the fluid are considered to be in thermal equilibrium, conductive flow in the porous medium uses an effective conductivity and the transient term includes the thermal inertia of the solid region of the medium:

$$\frac{\partial}{\partial t}\left(\gamma\,\rho_f\,E_f\,+\,(1-\gamma)\,\rho_s\,E_s\right)+\nabla.\left(\vec{v}\,\left(\rho_f\,E_f+p\right)\right)=S_s+\nabla.\left[k_{eff}\nabla T\right], \tag{5}$$

in which γ is the porosity of the medium (0.65), ρ_f is the specific mass of the fluid; (1.225 $kg\,m^{-3}$), ρ_s is the specific mass of the solid; (1037.225 $kg\,m^{-3}$), E_f is the thermal energy of the fluid, E_s is the thermal energy of the solid, $\vec{v}$ is the velocity vector, S_s is the chemical energy transformation in thermal energy; (198 $W\,m^{-3}$), k_{eff} is the effective conductivity of the porous medium; ($6.13455\,10^{-2}\,W\,m^{-1}\,K^{-1}$) and T is the temperature of the porous medium.

The effective conductivity of the porous medium can be found as follows:

$$k_{eff} = \gamma k_f + (1-\gamma)\,k_s, \tag{6}$$

where k_f is the thermal conductivity of the fluid; ($2.42\,10^{-2}\,W\,m^{-1}\,K^{-1}$), and k_s is the thermal conductivity of the solid. ($1.3033\,10^{-1}\,W\,m^{-1}\,K^{-1}$) de Andrade *et al.* (2004). For the determination of the thermal conductivity of corn, the lowest value found in de Andrade *et al.* (2004) was used. The lowest value is the most critical, since the higher the conductivity the faster the thermal energy propagates in the medium.

4. COMPUTATIONAL MODEL

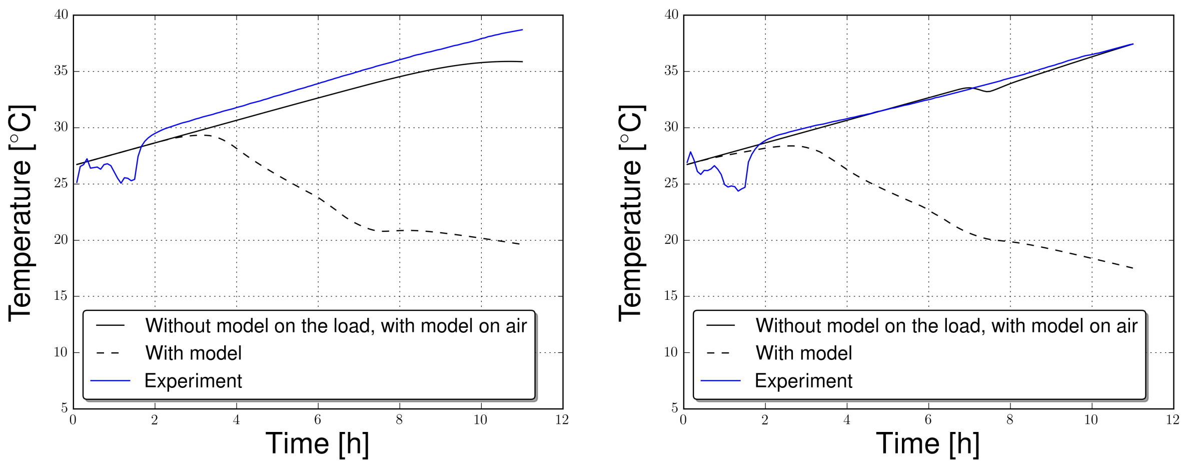
An Unsteady Reynolds Averaged Navier-Stokes (URANS) approach was used in this work to solve the incompressible transient equations shown in previous section for a three dimensional domain. These equations were solved with a second order accuracy through a Finite Volume formulation employed in ANSYS® Fluent software. The velocity-pressure coupling was done with SIMPLE and the convergence criteria at each time step fixed in 10^{-4}. The realizable k-ϵ turbulence closure model was used and the final result obtained when the simulation time reached 11 hours.

5. RESULTS

In this work two CFD simulations were made, the first one considers the flow regime to be turbulent both inside and outside the cargo and in the second the flow regime is considered laminar only within the porous media (inside the cargo).

In order to choose witch of the above consideration would be more realistic, an experiment was conducted. It consisted of inserting temperature probes on specific points across the cargo. Six probes were put inside the cargo and one left outside to measure ambient temperature.

The measures started at 6PM and ended at 6AM on the next morning. With these measurements the results were compared with the simulations and the results are presented on Fig 2. It is observed, by comparing the experimental and simulation curves, that considering the flow laminar inside the cargo has a better agreement with the experimental results.



Probe 3 Probe 4

Figure 2. Temperature in probes for both CFD simulations and the experiment.

Analyzing Fig 2 made clear that the natural convection flow inside the porous media should be considered laminar. With these results the chosen computational model and it's simplifications are validated and therefore can be used to simulate a forced convection flow aiming the design of an efficient cooling system.

6. CONCLUSION

In the present work, the physical, mathematical and computational modeling of non-isothermal flows in porous media was presented. Simulations were performed to analyze the turbulence model influence on the flow dynamics and the thermal energy transport.

The numerical results were compared with an experiment conducted by the authors. It was possible to conclude that the natural convection flow inside the porous media must be considered laminar. This conclusion will be considered on future works to simulate a forced convection flow aiming the design of an efficient cooling system.

7. ACKNOWLEDGEMENTS

The authors acknowledge with gratitude the support and collaboration of Bayer Brazil in this work. The authors are thankful to the Brazilian Research Agencies FAPEMIG and CNPq (INCT-EIE) and to CAPES and Petrobras S.A. for the financial support provided for this research.

8. REFERENCES

Araujo, P., 2016. *Estudo das propriedades termofísicas da fibra de coco minimamento processadas visando aplicação como isolante térmico*. Intech Open.

César Corrêa, P. and De Sousa e Silva, J., 2014. *Estrutura, composição e propriedades dos grãos*. ISBN 978-85-62032-00-4. doi:10.13140/2.1.3511.6164.

de Andrade, E.T., Couto, S.M., de Queiroz, D.M. and Peixoto, A.B., 2004. "Determinação de propriedades térmicas de grãos de milho". *Ciênc. agrotec. [online]*, Vol. 28, pp. 488–498. doi:10.1590/S1413-70542004000300002.

Eduardo, M., Moreira, R., Cavalcanti Mata, M. and Duarte, M., 2002. "Porosidade intergranular de produtos agrícolas". *Revista Brasileira de Produtos Agroindustriais*, Vol. 4, pp. 79–93. doi:10.15871/1517-8595/rbpa.v4n1p79-93.

Pinto, J., 2016. *Possible aplications of Corncob as a raw insulation material*. Intech Open.

Rama, J.P.F., 2004. *Eco–paineis construídos a partir de madeira e resíduos de palha/casca de arroz*. Dissertação de mestrado, Universidade de Coimbra. URL `http://hdl.handle.net/10316/38631`.

Silva, J., 2008. *Secagem e armazenagem de produtos agrícolas*. Aprenda Fácil, 2nd edition.

9. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.