Introducing Natural-Convective Chilling to Food Engineering Undergraduate Freshmen: Case Studied Assisted by CFD Simulation and Field Visualization

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ABSTRACT: A computational fluid dynamics (CFD)-assisted didactic activity has been applied to Food Engineering freshmen aiming at introducing basic concepts of process modeling and simulation towards the food industry. Evoking natural convection, a relatively simple case study was proposed involving two initially room temperature porous samples (identified as two fruits) that were placed inside a refrigeration chamber. Three different configurations were suggested for placing such warmer samples so that students were asked to order them with respect to their chilling capability, that is, to their ability to chill samples as fast as possible. Freshmen's written answers were collected before CFD was used to simulate and visualize each distinct chilling scenario. Accordingly, a finite-volume FORTRAN simulator for transport phenomena in domains fully or partially filled up with porous matrix was used to help compare each chilling performance. Among all possible combinations, answer

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distribution is presented and discussed in the light of freshmen's scholar background as well as based on the way natural convection concepts were introduced.

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INTRODUCTION

Along the food chain, Food Engineers' activities include design, processing and quality control, to name a few. Hence, Food Engineers should be acquainted with food constituents, their reactions with the surroundings as well as internal reactions and sources for their deterioration, comprising structural, chemical, biochemical, and microbiological factors. Familiarity with food preservation processes and technologies is also an interesting and required feature.

Besides engineering criteria for process or equipment design, Food Engineers should bear in mind what happens to raw material and their transformation. In view of that, Food Engineers should grasp not only Mathematics, Physics, Chemistry and (basic) Biology but also Engineering Sciences applied to food industry such as Transport Phenomena, Refrigeration, Unit Operations, Biotechnology and Bioengineering (the first two being of particular interest to this work).

In competitive scenarios either on local or worldwide basis, it is essential for engineers to be minimally able to face and solve problems of any sort, regardless their specialization. Arora [1] shares similar opinion while da Silva et al. [2] cite the requirement for qualified and versatile professionals with solid academic background. Collis [3] adds further skills to modern engineers' education, paying special attention to the ability of continuously introducing improvements and innovations into process or equipment.

Considering the Food Engineering undergraduate program offered at the Faculty of Animal Science and Food Engineering, University of Sao Paulo (FZEA/USP, Brazil), courses aim at comprising as many areas covered by such engineering branch as possible. Particularly, the first-term course named ''Introduction to Food Engineering'' intends to provoke freshmen's interest towards their forthcoming professional education by, for example, introducing basic notions of industrial food preservation and processing technologies. Such course counts on the participation of many staff members of the Food Engineering Department, FZEA/USP, and it takes advantage of their distinct academic background. Among topics covered by the course, the present work is specifically interested on foodstuff preservation through chilling (refrigeration), which is a process profoundly based on transport phenomena.

TRANSPORT PHENOMENA EDUCATION: CHALLENGES AND SIMULATION SUPPORT

When engineers solve problems, they usually face some sort of mass transfer, production of certain energy form or exchange of given chemical species through distinct phases. Transport processes occur simultaneously but for didactic reasons or due to their inherent complexity they are individually presented for the sake of understanding, formulation and solution. Therefore, it has been customary to group mass, momentum and energy transfers into separate Transport Phenomena courses (e.g., Fluid Mechanics, Heat Transfer and Mass Transfer).

da Silva et al. [2] assign some challenges to Fluid Mechanics education for Mechanical Engineering students inasmuch as it demands their familiarity with several physical phenomena besides a fine grasp of calculus. The same rationale can be straightforwardly extended to Food Engineering undergraduate education as concepts of Physics, Calculus, Differential Equations and Solid Mechanics are desired and welcome pre-requisites as well.

Related to the respective conservation principle, transport phenomena modeling leads to a somewhat complex equation set. In practice, solutions rely on simplifying assumptions or regular geometries, which unfortunately tend to push problems away from reality. da Silva et al. [2] pointed to the fact that many physical considerations and hypotheses are frequently evoked at Fluid Mechanics education. Such is a thoughtful issue for teachers to talk about with students in order to prevent the later from supporting the conclusion that coefficients should be invariably introduced so as to bring ideal solutions back to real world.

As discussed by Gad-El-Hak [4], the capacity to properly suggest simplifications and assumptions demands an academic maturity yet not well developed by typical undergraduate students. Hence, it is worth arguing whether such ability could be forestalled or accelerated in initial courses. Specifically, an interesting aspect to be verified has to do with students' capacity to conceive models for problems they are asked to solve. Stepping further into the matter, the abovementioned investigation could start right from scratch by targeting engineering freshmen.

Problem solving usually relies on modeling so that, based on their own background and skills, engineers try to identify features that allow problem description as close to reality as possible. Such identification and description stages correspond to physical−mathematical model elaboration. Once such modeling steps have been accomplished, solution methodologies are then investigated, adopted and even optimized based on some appropriate criteria (e.g., technological, economical, or environmental criteria).

Transport phenomena modeling and solution evoke conservation principles for mass, momentum and energy as well as additional expressions (i.e., constitutive equations) in order to match the number of equations to the number of unknowns. Despite counting on simplifications, integral formulation of such principles allows engineers to solve many problems with reasonable accuracy, which can be convenient if there is only interest on the overall system behavior.

On the other hand, differential formulation of conservation principles leads to (partial) differential equations and detailed understanding might be achieved by solving those equations. Nonetheless, there is a price for the advantage of analytical solutions obtained this way, namely, there are only few cases for which one is able to deduce solutions for the governing differential equations, besides accounting for difficulties related to proper description of boundary or initial conditions. In order to deduce analytical solutions, simplifying hypotheses are then put forward, which may jeopardize solution quality, accuracy or applicability.

Experimental data are certainly valuable for process assessment or equipment design as they benefit from the most wanted attribute of depicting real behavior. Yet, there are situations where field or laboratory data acquisition might be at risk due to safety concerns, technological constraints or economic aspects (i.e., costly human or material resources). For those scenarios, mathematical modeling and numerical simulation may play an important role and engineers should be aware of and familiar with their potential.

Initially used for academic purposes, numerical simulation has experienced a notable evolution and become a powerful tool for process or equipment design, performance prediction and optimization in several engineering branches. In principle, relatively complex transport phenomena can be tackled via modeling and simulation, taking into account effects sometimes neglected or ignored. For example, irregular geometry and time-varying processes might be rapidly solved with confidence and accuracy, evoking fewer simplifying assumptions.

Most simulators are implemented from numerical discretization of governing equations. Based on the remarkable development of computational fluid dynamics (CFD), the possibility of solving full Navier−Stokes equations may not only broaden but also modify Fluid Mechanics education at Engineering courses [5]. In particular, CFD might be properly used in conjunction with graphical tools (post-processors), allowing the visualization of velocity (flow), pressure and temperature fields, for example. Yet, just like the fact that experimental data along with scarce analytical solutions are important (or crucial) for numerical validation, it is worth reminding that classes at didactic laboratories are indispensable for Fluid Mechanics education [2].

Bearing in mind food preservation by chilling as well as aiming at introducing basic concepts of natural convection, the present work reports a numerical simulation-assisted didactic activity applied to Food Engineering freshmen, which were enrolled at the aforementioned course ''Introduction to Food Engineering'' at FZEA/USP. Conscious of the fact that freshmen's background is unlike to comprise deep knowledge on Transport Phenomena or Refrigeration, such didactic activity recalled an allegedly habitual situation, namely, foodstuff chilling inside a cold chamber (i.e., inside a refrigerator).

"PROCESS SIMULATION" AS A LECTURE FOR "INTRODUCTION TO FOOD ENGINEERING" COURSE

Along the lines of Food Engineering scope and interests, each staff member contributes to the course ''Introduction to Food Engineering'' through invited lectures based on with his (her) own research experience and viewpoint. With respect to the activity reported in the present work, ''Process Simulation'' was the topic proposed and accepted for the lecture.

Recognizing and Discussing the Relevance of Industrial Processing

The aforesaid lecture was in fact among the initial ones according to the course program, which thus inspired extra care. In view of that, the lecture started by discussing the conceptual difference between *phases* and *states* of matter. It was stressed that the later are more inclusive than the former as there may exist many states in a given phase, each state being uniquely related to a well-defined set of physical properties.

The idea of *process* was introduced in line with the necessity or interest on changing one or another property (i.e., changing states) of a given matter sample. The following definition was then put forward: “process is a *planned* operation or set of operations promoting physical and/or chemical *transformations* to obtain *products of interest* from selected or available *resources* (either raw material or energy forms).” A somewhat deeper conversation was carried on the role of Food Engineers regarding the previous words in italics.

As an attempt to call students’ attention to the importance of food processing, they were asked to name products made from guava (a typical Brazilian fruit), apart from the fresh fruit itself. The resulting list included seven industrially processed products and, for 1 kg of each product, students were asked to rank those industrialized guava-made products according to the final price as paid by consumers at supermarkets. Almost all products were correctly ordered thus showing that freshmen are indeed conscious that distinct technologies tend to add value to final products, from industrial processing up to foodstuff preservation devices.

An issue that equally came about was the relevance of not only *know-how* but also *know-why* for process engineering. Commonly classified as chemical, thermal or mechanical (besides biological concerning foodstuff), processes are modeled through mass, momentum and energy balances, often coupled to each other. At this point, usefulness of computational methods was highlighted as means to obtain detailed knowledge, which is frequently imperative for process or equipment design, scale-up and optimization.

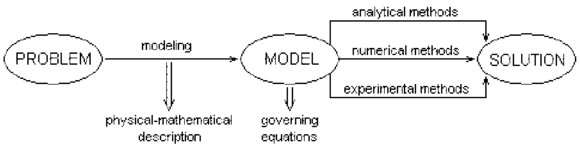

Figure 1 Usual procedures and methods for solution of engineering problems.

Introducing Modeling and Simulation of Industrial Processes or Equipments

Sketching usual steps for problem solution in the so-called Exact Sciences, Figure 1 was shown to students so as to encourage a discussion on distinct solution methods for Engineering problems, comparing their advantages and disadvantages (as argued earlier in Transport Phenomena Education: Challenges and Simulation Support Section). Special attention was paid to modeling, including the very perception of what a model is about. Three relatively simple industrial equipments were then called to mind and students were asked to mathematically describe each one of them in terms of relevant physical properties. Identification of entailed physical properties was part of the exercise and Table 1 summarizes the equipments and the corresponding models proposed by the students.

It was stressed that such was a quite simple (but realistic!) modeling practice, comprising a drill of process or physical phenomenon identification followed by its representation through equations. It was also pointed that, besides fundamental laws or physical principles, a model encompasses equations describing distinctive material properties (constitutive equations) as well those describing operational conditions (boundary and initial conditions).

The rationale behind process numerical simulation was introduced based on the industrial engineer’s necessity or interest on quantifying operational conditions. Among the advantages of research and

Table 1 Discussing Modeling Concepts With Food Engineering Freshmen: Correspondence Between Real Industrial Equipment and Proposed Model

Equipment or process	Physical nature	Physical property	Model proposed by freshmen
Conveyor belt	Mechanical	Linear velocity	Constant speed linear motion
Agitator mixer (impeller)	Mechanical	Angular velocity	Constant speed angular motion
Refrigeration chamber	Thermal	Heat load	Sensible or latent heat equation

development (R&D) activities assisted by computational simulators implemented from consistent and validated mathematical models, the following were discussed:

- Financial provisions to cover (habitually numerous) new design, scale-up and optimization tests might be greatly saved;
- Difficult-to-measure process parameters might be effortlessly investigated;
- Process behavior under non-tested, prevented, unwanted or dangerous conditions might be easily predicted and assessed; and
- The computational simulator might be always improved or extended by up-to-date or more accurate information (e.g., model constants or empirical correlations).

On the other hand, important restrictions were brought into discussion as, for example:

- Necessity to validate the computational simulator against available analytical results and/or experimental or operational data; and
- Difficulties related to the proper mathematical description or implementation of complex phenomena as well as of boundary or initial conditions (as an attempt to make the simulator as comprehensive as possible).

As far as developing numerical simulators is concerned, existing methodologies were briefly pointed out such as finite-difference method (FDM), finite-element method (FEM), finite-volume method (FVM) and artificial neural networks (ANN). Due to the availability of relatively cheap high-performance computers allied to numerical methods of increasing robustness and efficiency, it was commented that computational techniques to simulate interesting applications have not only intensified but also expanded to several distinct areas, including (but not restricted to) energy production, environmental phenomena, equipment design, weather forecast, thermal comfort, aeronautics and astronautics, oil reservoir engineering, biotechnology [6] and, last but not least, food engineering [7,8].

CASE STUDY: NATURAL-CONVECTIVE CHILLING OF TWO "FRUITS" IN A "REFRIGERATOR" CHAMBER

After introducing basic concepts of mathematical modeling and numerical simulation, a relatively simple chilling case study was put forward. Aiming at early setting students' focus, the "food engineering" problem was described and students were asked to think about solutions while important additional concepts and information would be concurrently provided.

Introducing Natural Convection to Food Engineering Freshmen Aided by Simulation

The proposed process entailed two porous samples initially at a higher temperature. Eventually, those samples would be placed inside a small chamber to be chilled. As an attempt to associate such process to freshmen's everyday life experience, the two samples were identified as two fruits whereas the chamber was referred to as a refrigerator partition (particularly bearing in mind the refrigerator design where upper freezer is not a separate compartment from the rest).

Chamber geometry was defined as a square closed cavity of side $L = 0.35$ m. From the thermodynamic standpoint, top horizontal surface was assumed as isothermal and kept at colder temperature while the remaining (bottom horizontal and side vertical) enveloping surfaces would be adiabatic. For the sake of simplicity, the two samples were treated as two small squares of side $l = L/5 = 0.07$ m, both with constant porosity ε and initially at $\Delta T = 10°\text{C} = 10$ K above the temperature of the top surface. Figure 2 sketches the case study proposed.

With the intention of demonstrating the important role played by natural convection, it was presumed that the chamber was not initially cold, that is, "the refrigerator has not been turned on yet." At the start, inner air temperature was hence higher than the top surface temperature and the same $\Delta T = 10°\text{C} = 10$ K temperature difference was effortlessly assumed. Prior to placing the samples into the chamber, a primary procedure would be to chill inner air itself. Without placing the two samples inside, a hypothetical (and quite unrealistic) inner air chilling

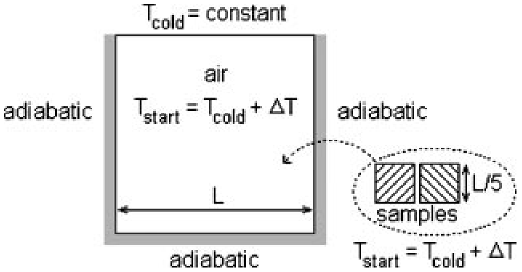

Figure 2 Geometry and physical conditions of foodstuff chilling problem proposed to Food Engineering freshmen.

was intentionally simulated in which air would be *rigorously standing still*.

Accordingly, in order to simulate such time-dependent pure conductive heat transfer an existing FORTRAN (standard 90/95) CFD simulator for transport phenomena within domains partially or fully filled up with porous material was employed [9]. Following the FVM, governing equations are discretized on staggered grids while pressure−velocity coupling is achieved through SIMPLER method [10]. The reader should refer to [11] for further information about the FVM-CFD simulator.

Due to the moderately low thermal diffusivity of air and to the absence of convection, the ‘‘cold front’’ emanated from the top cold surface experienced only a short diffusion into the motionless inner air below, as expected. Figure 3A shows the isotherms corresponding to the final dimensionless temperature distribution for a given simulation time period. Some interesting points were stressed and explored with freshmen as, for example, the conductive quality of the heat transfer process and the fact that the ‘‘cold front’’ propagates parallel to the top cold surface by virtue of the vertical adiabatic walls and the lack of air motion.

Conversely, initial inner air chilling was simulated considering the same time interval but this time accounting for natural convection and assuming laminar and incompressible air flow. As expected, numerical results were notably different so that inner air became completely cold at the end of the simulation time, that is, top surface temperature was practically achieved throughout the domain. For such natural-convective process, it was worth pointing to the following results:

- Contrary to conduction-dominant observations (previous simulation), convective air currents caused irregular patterns for the ‘‘cold front’’ propagation, as depicted in Figure 3B for a given intermediate simulation time instant;
- With the help of CFD animation, streamlines were then defined, calling freshmen’s attention to appearance, size, intensity, orientation (clockwise or counterclockwise) and collapsing of recirculation cells, as shown in Figure 4 related to the same instant of the dimensionless temperature distribution presented in Figure 3b.

Aiming at process understanding, velocity field visualization (via corresponding velocity vectors at some points in the domain) was included into both streamlines and temperature field animations. Based on the ideas already mentioned and discussed, a ‘‘food engineering’’ problem was proposed to the students concerning natural-convective chilling of the two porous samples, specifically with respect to their relative position inside the chamber.

Application of Numerical Simulation to Solve the Proposed Chilling Problem

Although full details about modeling and simulation were not presented to freshmen, it is worth mentioning that a Darcy−Brinkmann−Boussinesq approach

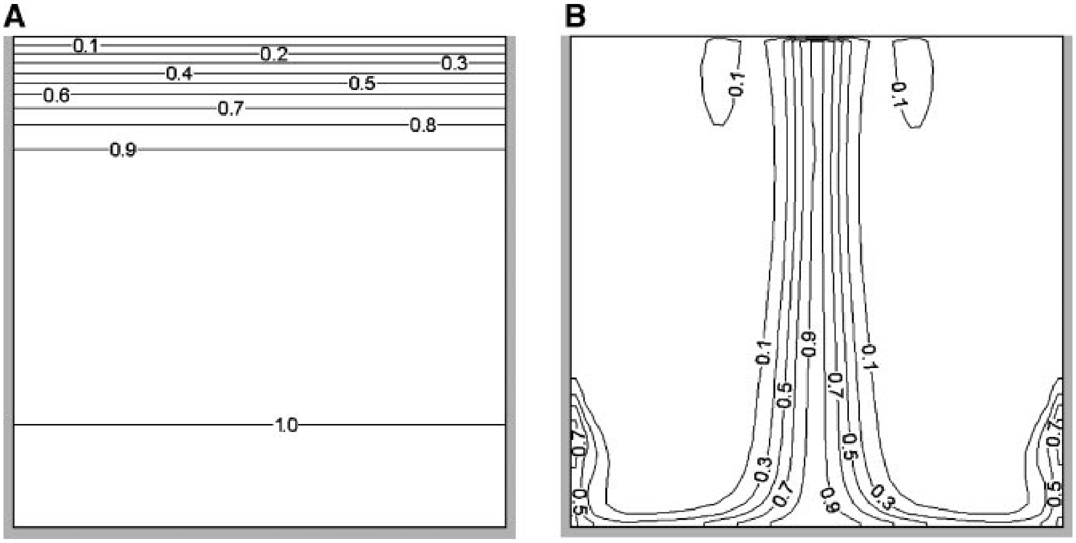

Figure 3 Temperature field inside the chamber: (A) final distribution disregarding natural convection; (B) distribution at an intermediate time instant including natural convection.

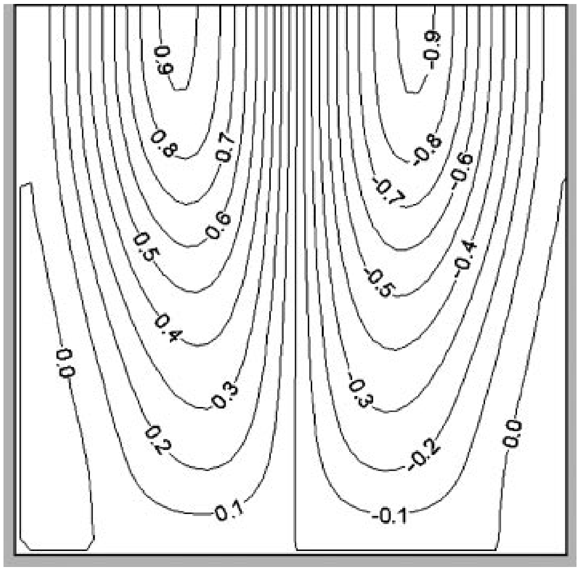

Figure 4 Convective streamlines (showing recirculation cells) inside the chamber at an intermediate time instant.

was adopted, including natural convection based on laminar and incompressible flow. In order to simulate time-varying chilling of the porous samples inside the chamber, the following governing equations are numerically implemented (discretized) following a dimensionless formulation into the FVM simulator:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{1}$$

$$\begin{aligned}&\frac{\partial U}{\partial \tau}+U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}\\&=\frac{\Gamma^n}{\mathrm{Re}}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right)-\frac{\partial P}{\partial X}-\frac{nU}{Re\,Da}\end{aligned} \tag{2}$$

$$\begin{aligned}&\frac{\partial V}{\partial \tau}+U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}\\&=\frac{\Gamma^n}{Re}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)-\frac{\partial P}{\partial Y}-\frac{nV}{Re\,Da}+\frac{Gr}{Re^2}\theta\end{aligned} \tag{3}$$

$$\frac{\partial \theta}{\partial \tau}+U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\Lambda^n}{Re\,Pr}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \tag{4}$$

Dimensionless primitive variables are defined as:

$$\begin{aligned}&X=\frac{x}{L},\quad Y=\frac{y}{L},\quad U=\frac{u}{u_0},\quad V=\frac{v}{u_0},\\&P=\frac{p}{\rho_0 u_0^2},\quad \theta=\frac{T-T_0}{\Delta T},\quad \tau=\frac{t}{t_0}\end{aligned} \tag{5}$$

where u and v are the velocity components along the Cartesian coordinate directions x and y respectively, p is pressure, T is temperature, and t is time. Reference values for inner air velocity, density, and temperature are respectively u_0, ρ_0, and T_0 while the scale value for time is $t_0 = L/u_0$.

Dimensionless groups—Reynolds, Darcy, Grashof, and Prandtl numbers—follow their usual definition, respectively:

$$Re=\frac{u_0 L}{\upsilon},\quad Da=\frac{K}{L^2},\quad Gr=\frac{g\beta\Delta T L^3}{\upsilon^2},\quad Pr=\frac{\upsilon}{\alpha} \tag{6}$$

where υ is the kinematic viscosity of air, K is the permeability of both porous samples, g is gravity acceleration, and α is the thermal diffusivity of air. In line with the original version of the simulator [11], the dimensionless parameter n indicates whether transport phenomena take place inside ($n = 1$) or outside ($n = 0$) the porous samples. Auxiliary dimensionless parameters include $\Gamma = \tilde{\upsilon}/\upsilon$ and $\Lambda = \tilde{\alpha}/\alpha$ to measure bulk-to-air ratios (i.e., porous medium-to-open air ratios) for kinematic viscosity and thermal diffusivity, respectively.

Apart from previously cited values for L and ΔT as well as typical air property values (ρ_0, α, β, and υ) for $T_0 = 10°\mathrm{C} = 283$ K, representative values for u_0 and K were adopted in order to obtain $Re = 2000$, $Da = 10^{-15}$, $Gr = 10^8$, and $Pr = 0.72$, in addition to $\Gamma = 1$, $\Lambda = 0.1$, and $0 \leq \tau \leq 20$. Furthermore, at process start ($\tau = 0$) it was assumed that porous samples were placed inside the chamber at $\theta = 1$ while inner air was initially at rest ($U = V = 0$) as well as cold ($\theta = 0$).

Dimensionless boundary conditions comprise:

- No-slip condition ($U = V = 0$) at all vertical and horizontal solid surfaces;
- Adiabatic bottom horizontal and vertical walls ($\partial\theta/\partial X = 0$ or $\partial\theta/\partial Y = 0$); and
- Isothermal (cold) top horizontal wall ($\theta = 0$).

Assuming that the whole chamber (“refrigerator”) is already cold at the temperature of the top horizontal wall, three configurations for placing the porous samples (“fruits”) were proposed, as depicted in Figure 5. Stressing that exactly the same simulation time would be used, freshmen were asked to rank such distinct configurations with regard to chilling efficiency, the most efficient configuration being defined as that one resulting in larger overall temperature reduction at simulation completion. Accordingly, each student was given a piece of paper with the abovementioned question and orienting one

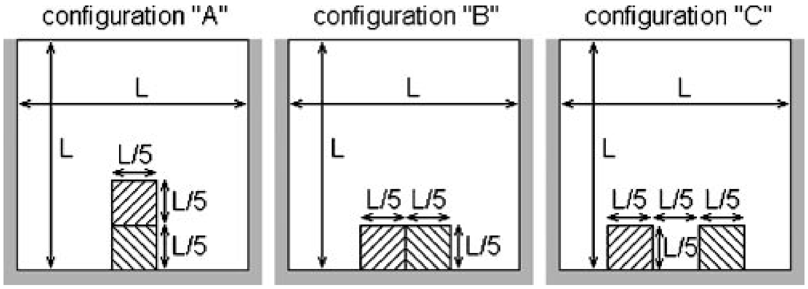

Figure 5 Three suggestions for placing the two samples inside the chamber (all configurations are horizontally centered onto the chamber base).

to assign numbers to each configuration, being "1" for most efficient, "2" for intermediate and "3" for worst performance.

After a few minutes for deliberation, written answers were collected and Table 2 shows their distribution as a function of different possibilities (configuration ranks). It is worth noting the numerous options for possibilities ranking configuration "*C*" as the most efficient one (i.e., possibilities 5 and 6 added together $= 39.5\% + 48.8\% = 88.3\%$ of all answers). Approximate answer counting was accomplished by asking freshmen to raise their hands according to their choices so that it was verified that configuration "*C*" was in fact expected to be the most efficient one. CFD animations were shown for each numerical simulation, comprising visualizations of both flow (streamlines) and temperature fields (velocity vectors presentation included in both).

Figure 6 presents the final temperature distribution obtained for the simulation of each configuration. By visual inspection, freshmen agreed that configuration "*C*" achieved indeed the best performance (in line with majority's expectation), followed by configuration "*A*" whereas configuration "*B*" was the least efficient one.

From a quantitative perspective, chilling performance of each configuration might be assessed by means of an average dimensionless temperature θ_{average} (including both samples), evaluated through the following integration:

$$\theta_{\text{average}} = \frac{1}{A}\int_A \theta \mathrm{d}A = \frac{1}{A}\int_A \theta(X, Y)\mathrm{d}X\mathrm{d}Y \quad (7)$$

where *A* is the total dimensionless area occupied by both porous samples (it would obviously correspond to the total volume for a three-dimensional case study). Considering that the FVM simulator discretizes the solution domain, the previous integral is numerically assessed through discrete summations so that the following results were obtained:

$$\theta_{\text{average},A} = 0.556,$$
$$\theta_{\text{average},B} = 0.654, \quad \theta_{\text{average},C} = 0.079$$

thus confirming the qualitative (visual) judgment as well as the choice made by most freshmen about the efficiency of configuration "*C*."

Several students who ranked configuration "*C*" as the most efficient agreed that their choices were influenced by the fact that such configuration results in the larger overall exposed area, which is indeed imperative for heat transfer. However, recalling Table 2, it is interesting to note that possibility #6 (configuration "*B*" as intermediate) received only

Table 2 Distribution of Freshmen's Written Answers to the Proposed Foodstuff Chilling Problem

Possibility	Performance of configuration *A*	Performance of configuration *B*	Performance of configuration *C*	Number of answers	Percentage of answers
# 1	Best	Intermediate	Worst	1	2.3
# 2	Best	Worst	Intermediate	1	2.3
# 3	Intermediate	Best	Worst	2	4.7
# 4	Worst	Best	Intermediate	0	0
# 5	Intermediate	Worst	Best	17	39.5
# 6	Worst	Intermediate	Best	21	48.8
Blank answers				1	2.3
Total				43	100

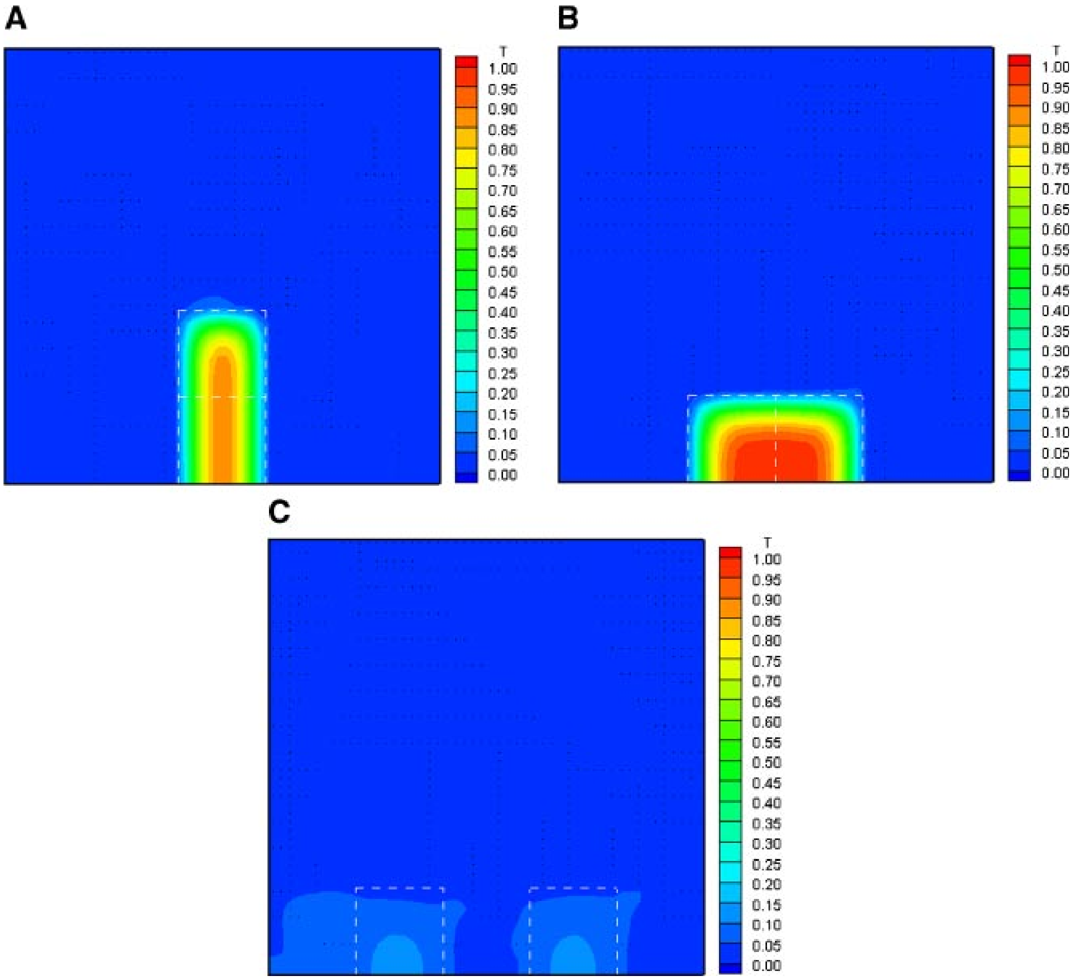

Figure 6 Final temperature distribution for each proposed configuration (“A,” “B,” and “C”).

few more indications than possibility #5 (configuration “*A*” as intermediate). A possible explanation for such opinion partition might rely on the fact that configuration “*A*” results in a larger exposed area besides being relatively closer to the cold top surface.

CONCLUDING REMARKS

Numerical simulation has become an important tool for process engineering. Provided that simulators are implemented based on comprehensive mathematical models, they might be confidently applied to real-world (thus complex) problems. A recent trend in top technology development is to properly combine distinct solution methods (i.e., analytical, experimental, and numerical) aiming at successful equipment design, scale-up or optimization, which is potentially advantageous in competitive marketplaces.

Opportunities to help students familiarize with such useful and powerful tool should be explored at most. In view of that, activities similar to the lecture given as part of the course “Introduction to Food Engineering” are always welcome as they can be fruitful. Application of numerical simulation (particularly CFD) in Transport Phenomena education might become very interesting as modern graphical post-processors allow unique visualization of flow (velocity), pressure, temperature and species concentration fields.

Accordingly, simulation-assisted didactic activities may complement and benefit not only theoretical concepts habitually exposed in lecturers but also experimental activities accomplished at didactic laboratories. One may go further and propose that experimental didactic activities in cooperation with those performed at a didactic computational (numerical simulation) laboratory could comprise a course or a course sequence named, for example, “Numerical and Experimental Methods for Transport Phenomena.”

One may also claim that theory related to Fluid Mechanics (or to Transport Phenomena in general) demands an academic maturity from students. However, it is up to teachers to reduce such gap separating students from necessary physical and mathematical skills and knowledge whenever possible. The activity here reported points to a possible roadmap towards such goal, by evoking and exploiting phenomena taken from students' everyday life experience, postponing a deeper discussion, explanation, formalization and technological application to a later instance.

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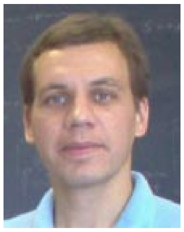
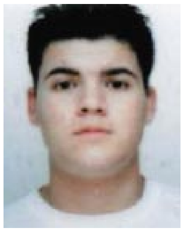
BIOGRAPHIES



José A. Rabi received his BSc in applied physics in 1995 from the University of São Paulo, Brazil; MSc in mechanical engineering with an emphasis on aerodynamics, propulsion, and energy in 1998 from the Aeronautical Institute of Technology, São José dos Campos, Brazil; and PhD in mechanical engineering with an emphasis on thermal and fluid engineering in 2002 from the University of Campinas, Brazil. He served as a postdoctoral fellow with an emphasis on transport phenomena in porous media in 2003–2004 at the University of Calgary, Canada. His current research interests include the mathematical modeling and numerical simulation of food engineering and biotechnological processes and equipment using finite-volume methods, IMSL routines, or lattice-Boltzmann models.



Rodrigo B. Cordeiro is a senior-level undergraduate student pursuing a BEng in food engineering at the University of São Paulo, Pirassununga, Brazil. His current research activities include the mathematical modeling and numerical simulation of extraction of natural products in fixed bed using supercritical carbon dioxide.

Alessandra L. de Oliveira received her BEng in food engineering in 1994 from the State University of São Paulo, São José do Rio Preto, Brazil; MSc in food engineering with emphasis on thermodynamic modeling using equation of state in 1997 from the University of Campinas, Brazil; and PhD in food engineering with an emphasis on supercritical fluid extraction in 2001 from the University of Campinas. Her current research interests include thermodynamic modeling of high-pressure phase equilibrium data, extraction of natural products using supercritical and conventional methods, and frozen food processing.