NUMERICAL SIMULATION OF SPRAY DRYERS

R C Favalli[(*)(**)], M M Pimenta[(***)], J O A Paschoal[(*)]

[(*)]IPEN - Instituto de Pesquisas Energéticas e Nucleares, Brazil
[(**)]Instituto de Física da Universidade de São Paulo, Brazil
[(***)]Escola de Engenharia Mecânica da Universidade de São Paulo, Brazil

SUMMARY

Nowadays, the spray drying technique is largely employed in the ceramic tile industry due to the improved powder properties. However, the optimization of the system is generally empirical and experimental tests demand a certain amount of money. The simulation of such systems through mathematical and physical modelling can then be used as a powerful tool to improve the process, while the influence of many parameters on both the continuous and disperse phase can be studied. In this paper, the interaction is presented between the drying air and the atomized alumina slurry for mixed and concurrent types of gas flow. The gas velocity and temperature profiles after the droplet injection are also calculated. Air humidity, temperature and trajectories of droplets are some of the variables solved by the program.

1. INTRODUCTION

The spray drying technique is widely employed in the chemical, food, pharmaceutical and ceramic industries[1, 2, 3, 4, 5]. Specifically in the ceramic tile industry, this process is used to evaporate the water added to aid the grinding process of the raw material and to homogenize the additives[6, 7]. The main advantage of adopting such a process is the resulting powder flowability, since the granules obtained keep the spherical shape of atomized droplets; the quality of the final product is directly affected by the granule sphericity, while transportation and compaction are improved. Though the ceramic tile production method is very well established, the optimization of the system is generally empirical. Besides, experimental tests demand time and money.

In view of this, the aim of the present work is to simulate, through mathematical and physical modelling, the behaviour of the drying system for several sets of operating conditions. It can be a tool to improve and optimize the drying process of any kind of slurry, with computer time being its sole cost. The earlier simulations were made in an integral form and the influence of different parameters on gas flow and atomized droplet history were difficult to study. Nowadays, refined mathematical models can be employed in the simulation of such systems due to the fast development of computer processing and storing capacities; it allows not only predicting gas velocity and temperature profiles and droplet behaviour but also the influence of several parameters on the properties of the dried material.

This paper presents the influence of the drying media (hot air) on the history of an atomized alumina slurry for mixed and concurrent types of gas flows. It also takes into account the changes in the gas profiles due to the droplets injected into the system. Alumina slurry is a representative material and it has been chosen for simplicity, nevertheless any kind of slurry material can be used if its thermodynamic and transport properties were given. The mathematical models are based on a set of coupled partial differential equations and describe the behaviour of both phases, continuous and disperse; this system of equations does not have an analytical solution and thus must be solved numerically.

In the next section, a brief description of the mathematical and physical modelling, as well as the computational domain and boundary conditions, are presented. The results and their discussion are in section 3, followed by the work conclusions in section 4.

2. COMPUTATIONAL FLUID DYNAMICS

As long as the mathematical model used to simulate spray drying systems is a set of coupled partial differential equations which have no analytical solution, a numerical scheme is required. The adopted procedure to solve such a system of equations is the control volume method developed by Patankar[8].

The gaseous phase is simulated by the equations of continuity, Navier-Stokes, conservation of energy and water vapour, which respectively give mass, velocity, temperature and humidity of the gas[9]. Calculated profiles are obtained before and after the injection of the slurry. For the disperse phase, the simulation is carried out setting a discrete distribution of droplet diameters (called computational particles), each representing a percentage of the total mass loaded into the system. Mass, momentum and heat transfer models between the phases provide the granule mass, and consequently their diameter, velocity and temperature along their trajectories, as well as residence time and humidity of each class of computational particle[10, 11, 12].

2.1 COMPUTATIONAL DOMAIN

Figure 1 shows the computational domain. It represents the right half of an ordinary spray drying chamber of concurrent flow, schematically illustrated in Figure 2.

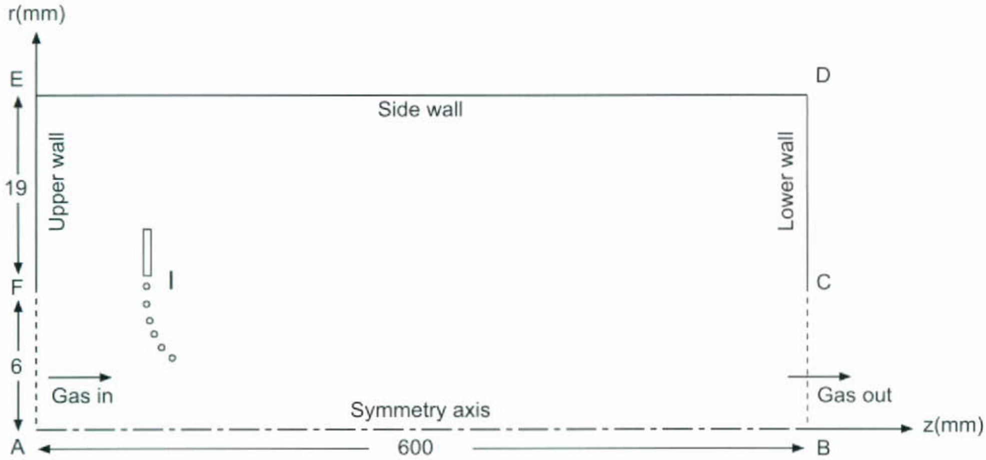

Figure 1: Computational domain of a spray drying chamber.

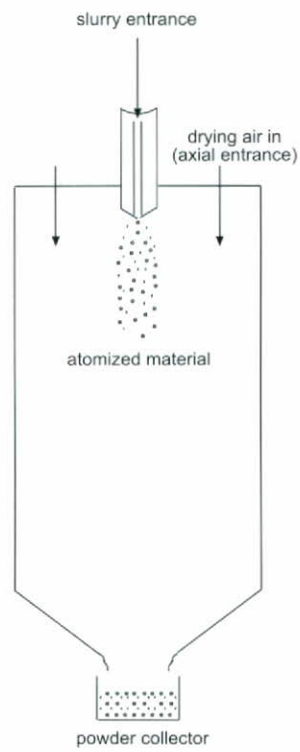

Figure 2: Spray drying chamber of concurrent flow.

The drying air enters through section AF and it flows throughout the chamber, dragging the droplets injected in position I. Contact between the hot air and the atomized slurry leads to the evaporation of droplet moisture content. Both gas and granules exit through BC. The symmetry axis is indicated by AB.

2.2 BOUNDARY CONDITIONS

Based on the computational domain just set out, the initial and boundary conditions are established. At the line AF, the chamber entrance, the gas temperature is set to 310°C and its axial velocity to 2 m/s; the radial component of velocity is chosen as zero. The gas flow rate for these values of gas input diameter gives a velocity of 13.5 l/min. The initial air humidity is zero, but it can be set according to the environmental data.

Symmetry conditions must be kept at AB, so that $\partial h/\partial r=0$, $\partial u/\partial r=0$, $v=0$, $\partial cw/\partial r=0$ are specified respectively for enthalpy, axial velocity, radial velocity and air humidity.

At the chamber exit (BC), it is assumed that $\partial h/\partial z=0$, $\partial u/\partial z=0$, $\partial v/\partial z=0$, $\partial cw/\partial z=0$. At the walls the velocity and the air humidity are set to zero while the temperature is based on experimental data.

Point I indicates the position at which the droplets are injected in the chamber; in the schematic of the domain it is perpendicular to the symmetry axis and its associated injection angle is 0°. Nevertheless, point I can be located anywhere in the computational domain. The droplet velocity at the injection point is 2.5 m/s and droplet temperature is 25 °C. The alumina slurry flow rate is taken as 3% of the gas flow rate, i. e., 0.4 l/min.

Adopted initial values were based on the ones given by Crowe[11]; however, their values can be easily and directly changed.

3. RESULTS AND DISCUSSION

Solving the governing equations for the gas and the particles, the influence of the continuous phase on the disperse one, and vice-versa, can be studied. The alumina slurry is injected in three different sizes: 30, 40 and 50 μm. A 0.4 l/min feed rate and a 50% initial water mass content are set. Figure 3 presents the trajectories of droplets injected concurrently and parallel to the chamber axis. They deviate from their original injection angle since, after a relaxation time, the particles follow the stream lines (see Figure 7).

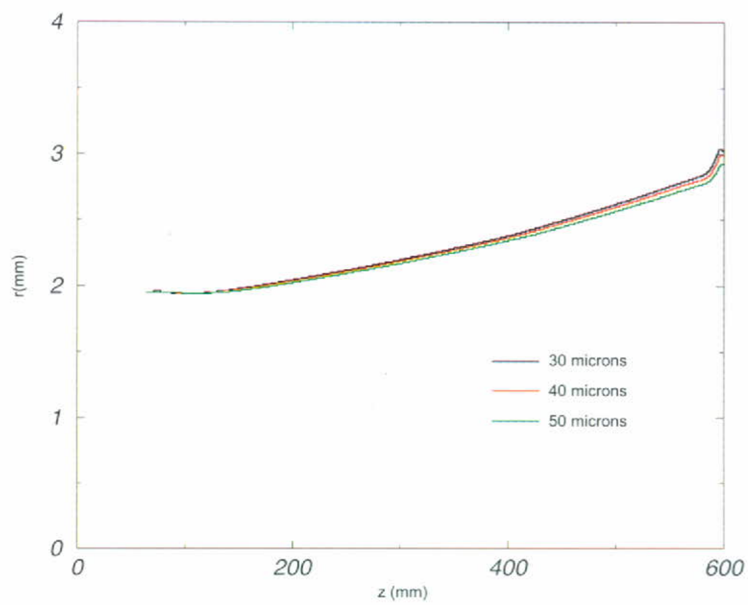

Figure 3: Droplet trajectories inside the drying chamber. Concurrent flow with injection angle of 90° (nozzle tip parallel to the chamber axis).

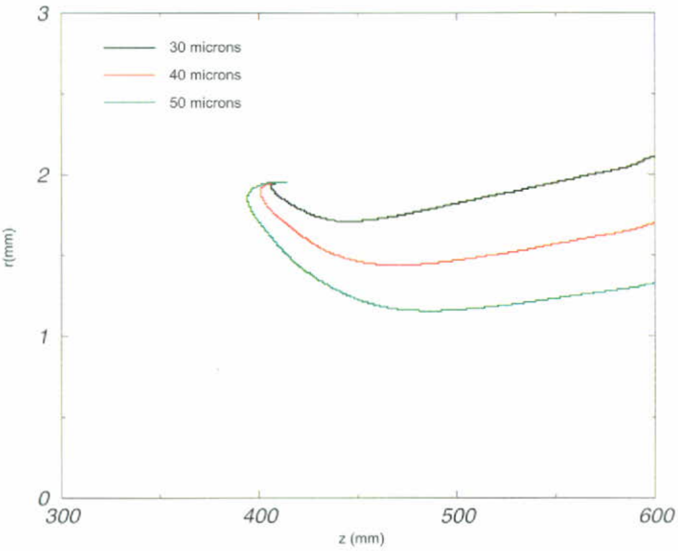

Figure 4: Droplet trajectories inside the drying chamber. Mixed flow with injection angle of 270º (nozzle tip parallel to the chamber axis).

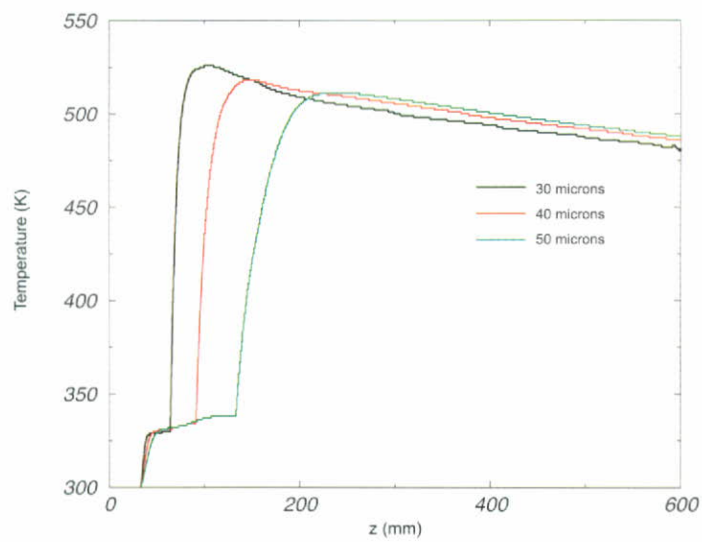

Figure 5: Droplet temperature along their trajectories inside the drying chamber.

By a simple change in the injection point position and angle, it is possible to simulate mixed flow type of drying; the droplet trajectories for this situation are shown in Figure 4. In the beginning, as the gas is introduced at the top and the droplets at the bottom of the chamber, the flow is countercurrent and the particles go up until the gas flow drags them along, now in a concurrent flow type, back to the bottom of the drying chamber. The slight deviation of the droplets is also due the stream lines of the gas.

Figure 5 presents droplet temperatures along droplet travel inside the drying chamber for concurrent flow. Many applications take advantage of this type of flow, when heat sensitive material is to be dried since a thin film of water envelops it during the very first phase of the process. It begins to evaporate at approximately 40°C; and granule temperature will only rise when the water content reaches the critical point, i. e., there is only enough residual water to fill the pores of the granule but not to cover its surface. Droplet temperature profile for mixed flow presents a similar behaviour. As can be seen, this aspect of drying is very well simulated by the computer program (Figure 5).

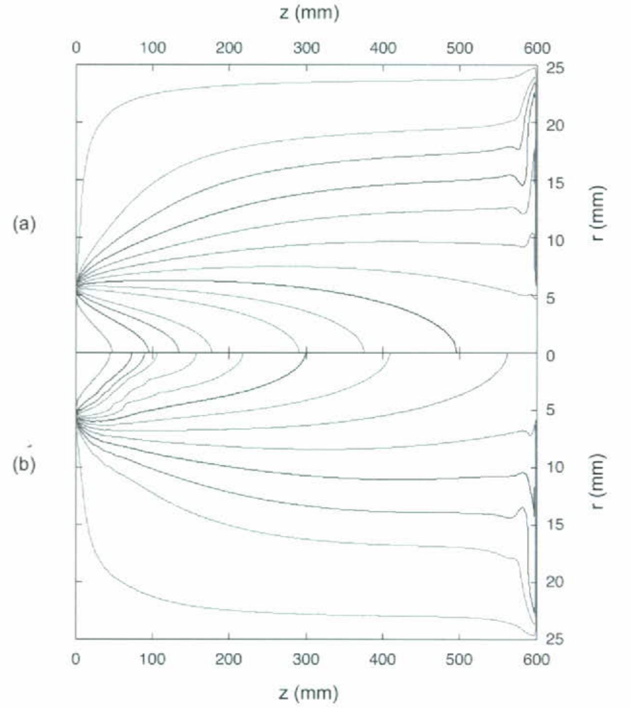

Figure 6: Air isotherms (a) before and (b) after the droplet injection. Inner line of 580 K, decreasing in intervals of 10 K.

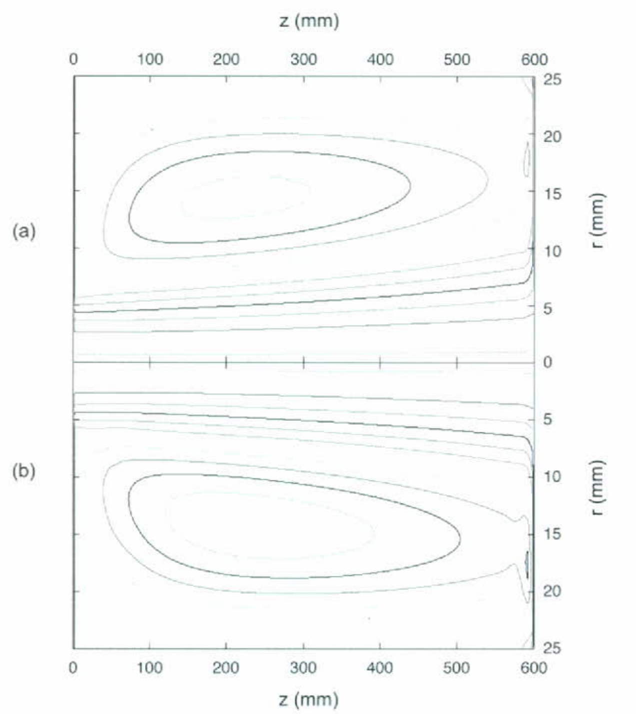

Figure 7: Air stream lines (a) before and (b) after the droplet injection. Inner line (the nearest to the symmetry axis) of 0.001 g/s, increasing in intervals of 2×10^{-2} g/s.

The calculated particle residence time is on average 0.6 s for concurrent flow and 0.2 s for mixed flow; the reason for this difference of residence time in concurrent and mixed flows is the location of the injection point and consequently different distances for the particles to reach the chamber exit; the reduction on droplet diameter is about 45%, i. e., a 50 μm droplet injected generates a granule of 30 μm approximately.

Gas isotherms before and after the injection of droplets is depicted in Figure 6; The temperature is mainly reduced near the injection point due to the heat transfer between the continuous and disperse phase as can be noted by the retraction of the lines in this region. The decrease in temperature is about 5 to 7% in the chamber axis region for this set of operating conditions. The velocity profile, Figure 7, is less affected than temperature profile, which is surely due to the assumed low feed rate of the alumina slurry.

Air humidity gets higher after droplet introduction into the drying chamber due to

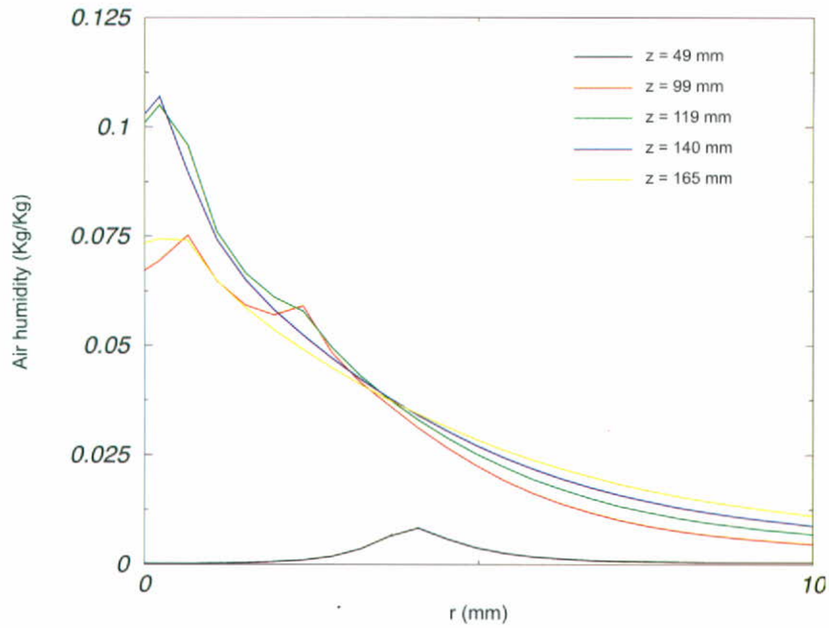

Figure 8: Air humidity after the droplet injection. Radial profiles (40 ≤ z ≤ 200 mm).

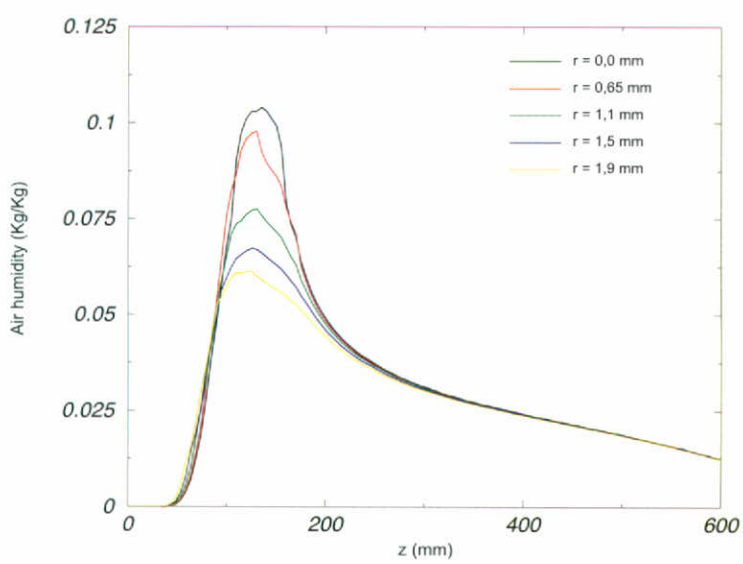

Figure 9: Air humidity after the droplet injection. Axial profiles (0 ≤ z ≤ 5 mm).

water evaporation of the slurry, as indicated by absolute humidity rising from zero up to 0.1 kg water vapour/ kg dry air, even for a small alumina slurry feed rate. Figures 8 and 9 presents the absolute humidity plotted, respectively, in radial and axial directions.

4. CONCLUSIONS

Mathematical modelling and simulation of spray drying process as developed here can be used as a powerful tool to guide system optimization, since it allows the most important parameters to be studied, with computer time being its sole cost. In this paper, the interaction between the drying air and the atomized alumina slurry for mixed and concurrent types of gas flow is presented. Droplet trajectories for both types of flow are calculated, then enabling the influence of continuous on disperse phase to be qualitatively estimated. Furthermore, the program calculates droplet temperature along droplet path in the chamber, their residence time, residual moisture content and the granule diameter for each size of injected droplet. Gas temperature, velocity and humidity profiles are generated before and after the material injection. Thus, the influence of the atomized slurry on the gas profiles can be satisfactorily analysed. Temperature decreases due to the heat transfer between phases, and air humidity rises because of slurry water evaporation. The dependence of one phase on the other is clearly evidenced by the numerical results obtained in this work.

ACKNOWLEDGEMENTS

Financial support through a scholarship to R C Favalli is gratefully acknowledged.

REFERENCES

[1] R. B. KEEY. Theoretical foundations of drying technology, volume 1 of Advances in drying, chapter 1. Hemisphere Publishing Corporation, 1980.

[2] C. STRUMILO AND T KUDRA. DRYING: principles, applications and design, volume 3. Gordon and Breach Science Publishers, 1986.

[3] K. MASTERS. Applying spray drying to ceramics. American Ceramic Society Bulletin, 73(1):63-72, 1994.

[4] F. D. SHAW. Spray drying: A traditional process for advanced applications. Journal of the American Ceramic Society Bulletin, 69(9):1484-1489, 1990.

[5] D. L. HOUK. Spray drying in metal industries. Journal of Metals, 37:24 27, June 1985.

[6] J. O. A. PASCHOAL. Projeto plataforma para a indústria de revestimento cerâmico. Relatório final, Centro Cerâmico do Brasil – CCB, São Paulo, July 1999.

[7] A. P. F. GORINI AND A. R. CORREA. Cerâmica para revestimentos. BNDES Setorial, 10:201 251, September 1999.

[8] S. V. PATANKAR. Numerical heat transfer and fluid flow. McGraw Hill, 1980.

[9] R. C. FAVALLI. Simulação de tochas de plasma de arco não transferido. Dissertação de mestrado, Instituto de Física, Universidade de São Paulo, BR, 1997.

[10] C. T. CROWE, M. P. SHARMA AND D. E. STOCK. The Particle-Source-In- CELL (PSI-CELL) model for gas-droplet flows. Journal of fluids Engineering, pages 325-332, June 1977.

[11] C. T. CROWE. Modeling spray-air contact in spray-drying systems, volume 1 of Advances in drying, chapter 3. Hemisphere Publishing Corporation, 1980.

[12] R. C. BIANCHINI. Modelagem e simulação de processos a plasma para o tratamento de organo clorados. Dissertação de mestrado, Universidade de São Paulo, Instituto de Física, BR, 2000.