NUMERICAL SIMULATION OF AN INDUSTRIAL SPRAY DRYER

[1]Renata Cristina Favalli, [2]David Gosman, [3]Peter Fereday
[4]Marcos de Mattos Pimenta, [5]José Octavio Armani Paschoal

[1] IPEN – Instituto de Pesquisas Energéticas e Nucleares, Brasil, renata.favalli@gmail.com
[2] Imperial College, Londres, Reino Unido
[3] Pilkington's Tiles Group PLC, Reino Unido
[4] Departamento de Engenharia Mecânica da Escola Politécnica, USP, Brasil
[5] IPEN – Instituto de Pesquisas Energéticas e Nucleares, Brasil

ABSTRACT

This paper presents a three dimensional simulation of an industrial scale spray dryer employed by ceramic tile industries through the use of Computational Fluid Dynamics (CFD) techniques. A previous work presented in Qualicer 2002 [1] showed the preliminary results of a laboratory scale spray dryer simulation in two dimensions. Therefore, the present work represents a significant improvement on the subject of numerical simulation of spray dryers employed by these industries.

*The geometry, operating and initial conditions of the dryer at Pilkington's Tiles were modelled and simulated using the CFD code STAR-CD, from Computational Dynamics - Adapco Group. The mesh generation was done in two steps. First, the geometry of the chamber and the surface mesh were built with STARdesign. Second, this surface was imported into STAR-CD where the volume mesh was trimmed using Pro*Am. Both STARdesign and Pro*Am are from CDAdapco Group.*

After defining a suitable type of mesh, the calculations for the interaction air-droplets were initiated. The suspension was assumed to be pure alumina for simplicity, but whenever possible and available, the properties of the actual suspension were employed. Results from the simulations include velocity and temperature profiles of the air flow inside the spray dryer chamber before and after the injection of the ceramic slurry. The influence of droplets injection on the gas acceleration and cooling in the whole drying chamber is presented. Calculated parcels track inside the dryer is also showed in this paper.

1. INTRODUCTION

The aim of this work was to model and simulate an industrial scale spray dryer employed by ceramic tile industries through the use of Computational Fluid Dynamics (CFD) techniques. The literature reveals that little attention was given to this type of dryers. The most similar works on the drying of ceramic suspensions were done by Kadja and Bergeles [2], who simulated the drying of coal suspension, and by Liang et al [3], who simulated the drying of individual droplets of mono-disperse silica suspension. However, numerical simulation of spray dryers is broad and is already making use of CFD tools to develop new equipment designs [4] and to analyse new types of processes as for example super-heated steam drying [5], reactive drying [6] and pulsating flow drying [7]. Vast research is made on food product drying, especially on dairy products, to obtain more suitable models for this process [8], [9], [10], [11], more experimental data [12], as well as computational experiments of product drying [10], [11], [13], [14], [15], [16].

An A/S NIRO Atomizer equipment installed in the 1980's at Pilkington's Tiles, Poole, UK is the dryer simulated here. The air inlet is at the top of the chamber and the air flow of hot air is made approximately parallel to the axis by L-shape vanes. The slurry is injected at mid chamber height by pressure nozzles in a fountain mode. The air is pumped out through a protruding pipe at the side of the chamber, passing by the cyclone and filter to retain finer granules, to finally be released to the atmosphere. The material collected by the cyclone is returned to the bottom of the dryer to be stored with the rest of the produce. The domain of interest for the simulations is the drying chamber only. STAR-CD, STAR*design* and Pro*Am, all from Computational Dynamics - Adapco Group, were respectively the software employed in the numerical simulations, spray dryer virtual design and computational mesh generation.

Results from the simulations include velocity and temperature profiles of the air flow inside the spray dryer chamber before and after the injection of the ceramic slurry. In the study case presented here, droplets of alumina suspension were injected using 12 nozzles symmetrically displayed inside the dryer. The influence of droplets injection on the gas acceleration and cooling in the whole drying chamber is presented. Calculated droplets/granules trajectories inside the dryer are also showed in this paper.

For the model validation, however, it is necessary to compare simulated results with experimental data, which is unfortunately not available in the literature. Hence, a great effort must be done by the ceramic tile community towards the establishment of a database for spray dryers of ceramic slurry as well as for wet and dry material properties. With a validated model, improvements on the operation and design of spray drying systems could be made through the use of CFD tools with relative easiness, cutting down on the number of experimental runs that would be otherwise necessary to optimize the system.

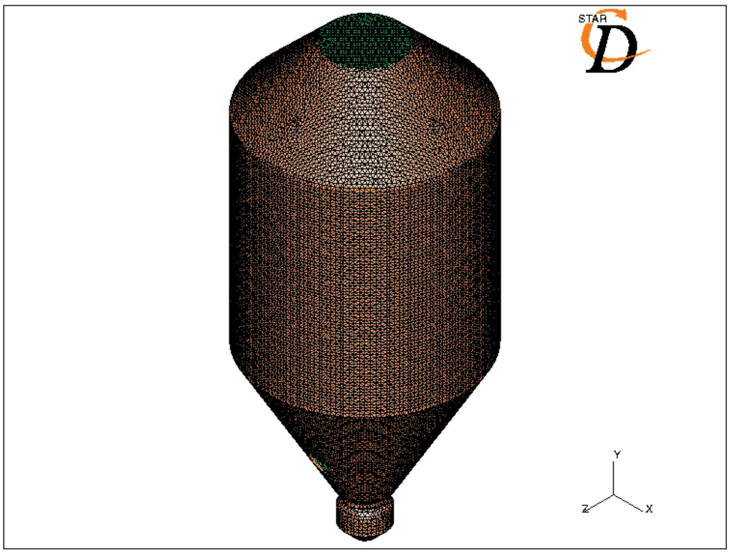

Figure 1. Meshed domain of the drying chamber.

2. COMPUTATIONAL DOMAIN AND MESH

In the dryer operating at Pilkington's Tiles, the air exhausts through a pipe on the side of the chamber, implying on an asymmetric geometry and as a consequence in a three-dimensional computational domain. The software STAR*design* was used for the chamber design, while the automated volumetric mesh was built with Pro*Am, both from CD-Adacpo Group. Picture 1 is the meshed chamber domain used in the simulations. Picture 2 is a detail of the volumetric mesh inside the chamber; in this hybrid grid, hexahedral elements are concentrated in the central region of the domain and the tetrahedral are placed near the wall of the chamber as to adapt to the cut faces.

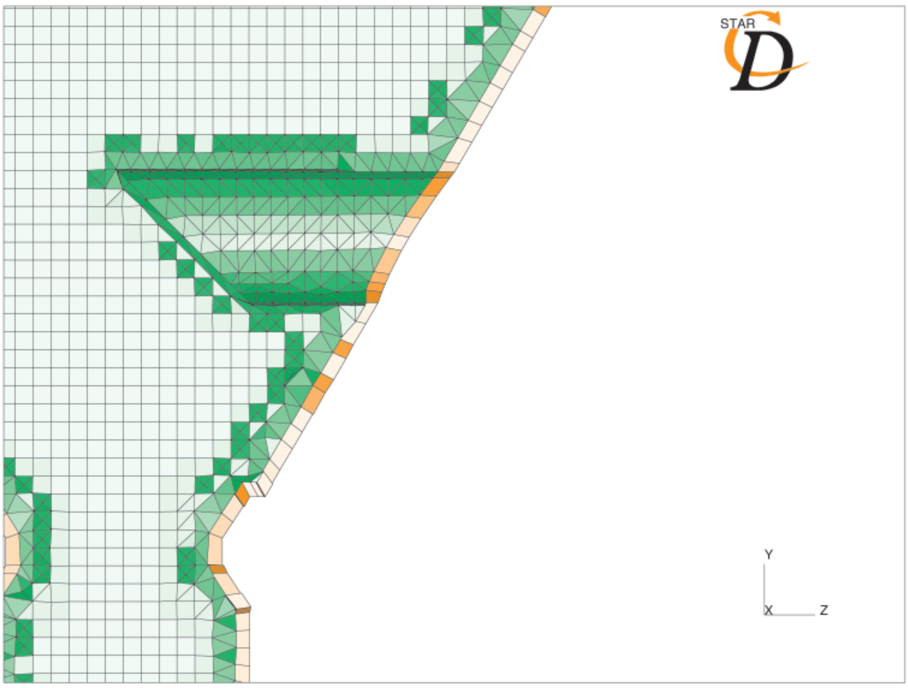

Figure 2. Detail of the volumetric mesh inside the chamber..

3. GAS FLOW BEFORE DROPLETS INJECTION

Velocity magnitude is seen on Pictures 3 and 4. Picture 3 presents this velocity at the upper part of the chamber, in x equal to half of the chamber's diameter. It can be seen on this picture that a small recirculation zone appears near the walls due to the expansion on the chamber's diameter. The local minimum for the velocity magnitude in this region of the chamber is zero because of the influence of the walls on this variable, whilst the local maximum is about 1.5 m/s, which is boundary condition for gas velocity at the inlet.

At the bottom of the chamber, Picture 4, it is observed greater gas velocity gradients, between 0 and 17 m/s, and this is due to the diameter of the exhaustion pipe being smaller than the gas inlet diameter. There was not much variation of the temperature profile at this point worth to be mentioned.

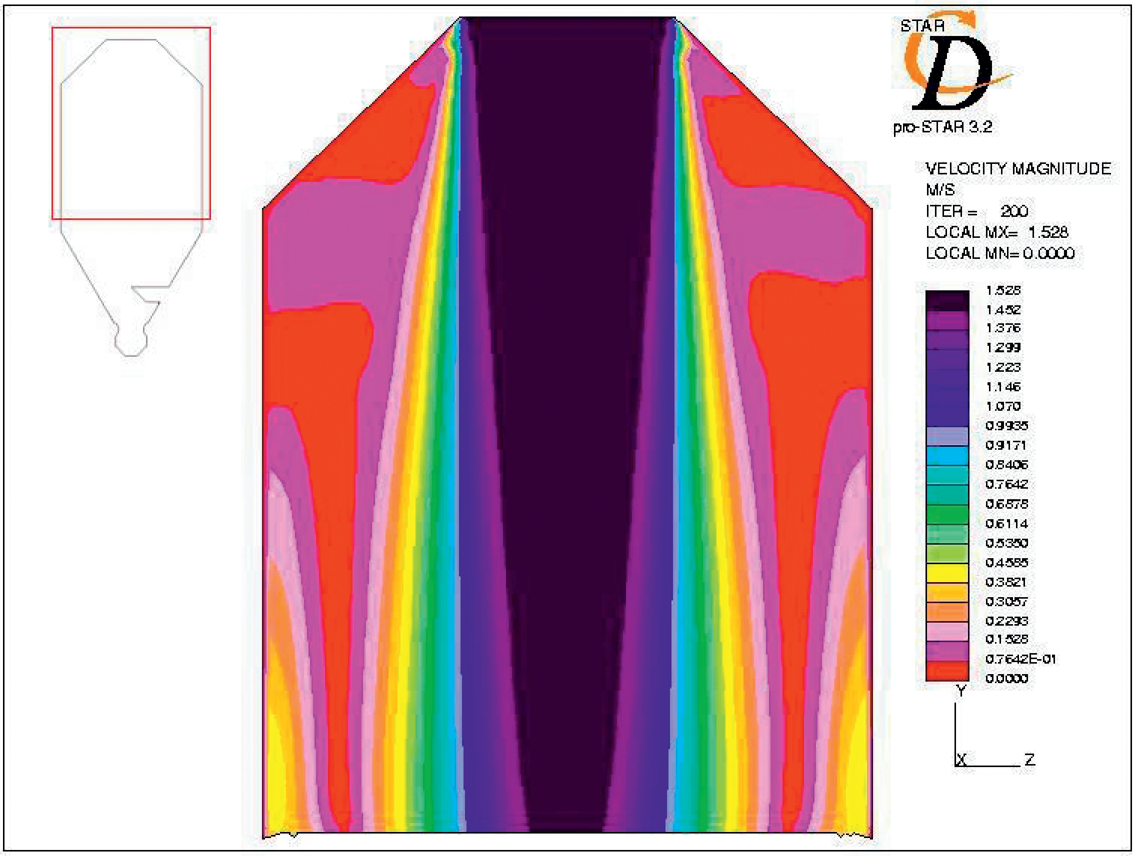

Figure 3. Velocity magnitude at the inlet region.

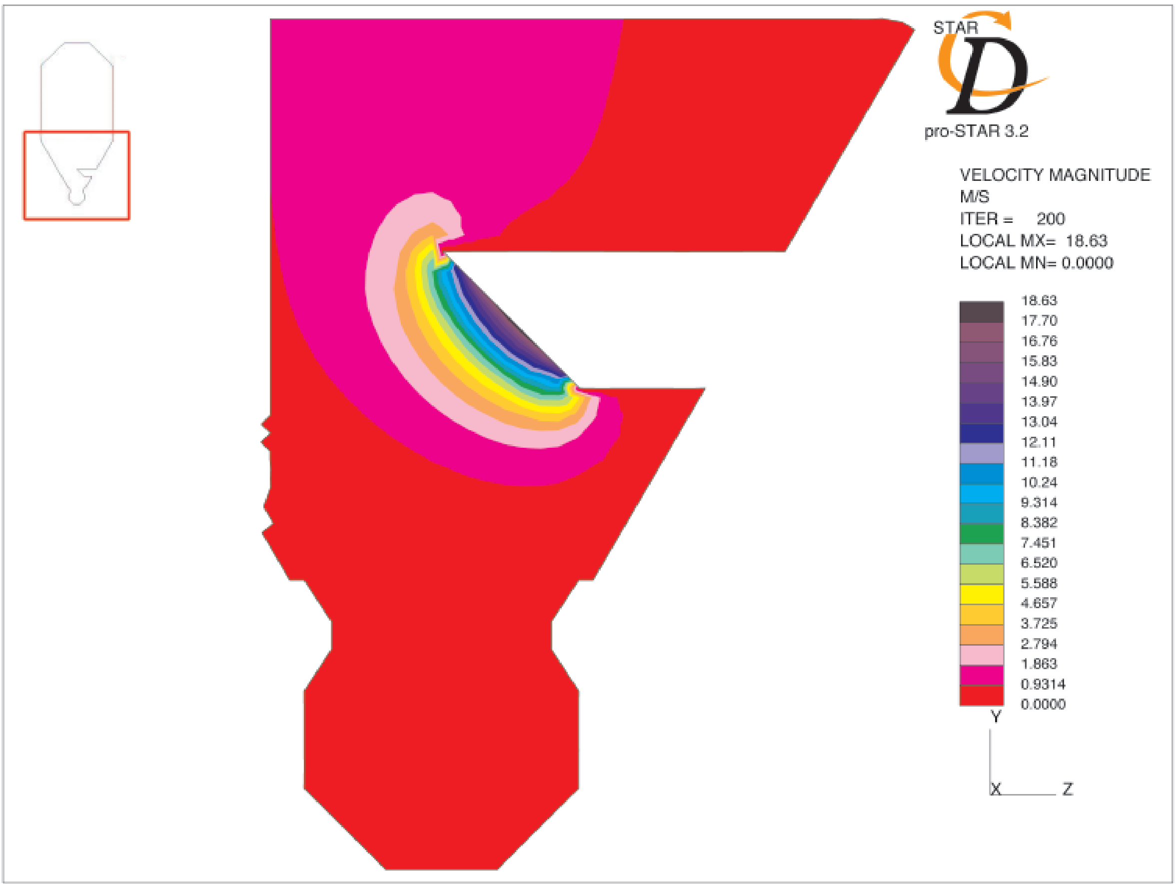

Figure 4. Velocity magnitude at the outlet region.

4. DROPLETS INJECTION

Droplets of alumina suspension were injected using 12 nozzles symmetrically displayed inside the dryer. The operating and boundary conditions for the drying air are: flow rate of 8 m^3/s, with intake parallel to the y axis, and temperature of 963 K. The slurry flow rate is 0.001 m^3/s, mean diameter of 250 µm and moisture content of 30%. A small portion of the drying air (10% of the total amount) is assumed to be leaving through the bottom of the chamber to avoid deposits of particles on that region.

The velocity profiles are shown on Pictures 5 and 6, which are, respectively, a view from the top of the chamber at injection height and a transverse cut passing through the axis, detailing the injection region. The influence of droplets injection on the acceleration of drying gas is clearly seen on these pictures. Gas velocity reaches a local maximum of almost 3 m/s.

Pictures 7 and 8 are the calculated temperature profiles plotted transversely through the dryer axis and a detail of such plot at the slurry injection region. The changes on this profile are also more drastic near the injection points, as expected. Temperature falls to values as low as 700 K, indicating local gas cooling of about 30%.

Calculated particle tracks can be seen in Pictures 9 and 10. The first plot is a view from the top of the chamber and the twelve injection points are visible, identified by the red to yellow vectors (8 to 16 m/s on the scale) which indicate greater speeds. At the middle of this picture, a concentration of green and light-blue vectors (5 to 13 m/s, approximately) indicate the exit of the granules through the protruding pipe at the lower region of the chamber. A frontal view of the tracks is presented on the latter picture, where some injection points are visible and so is the height at which slurry is injected. Droplets are injected upwards but are soon dragged by the gas coming from the top of the chamber, as well as by gravity, to the bottom of the dryer where most of them exit the system. It can also be seen that a small part of granules are being discharged through the protruding pipe, indicated, again, by the green and light-blue vectors.

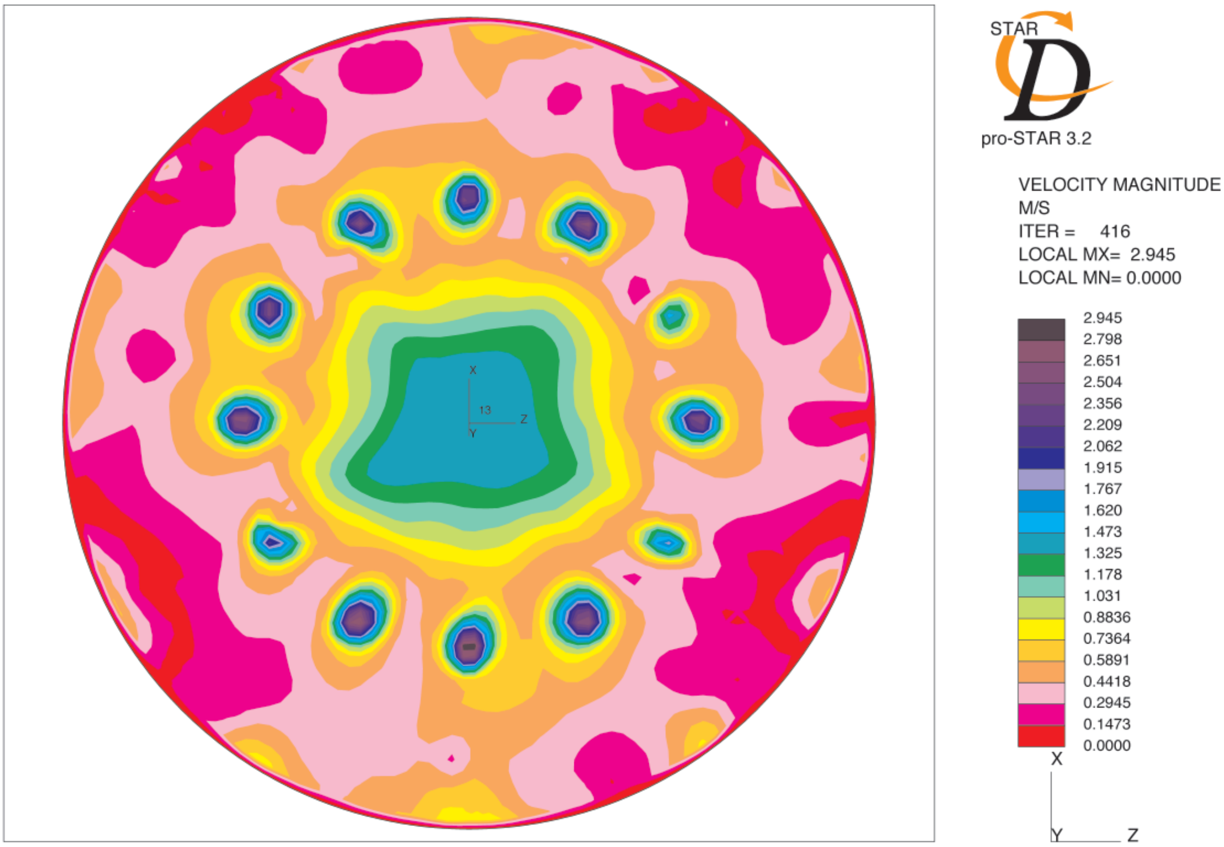

Figure 5. Velocity magnitude. Top view of the injection region..

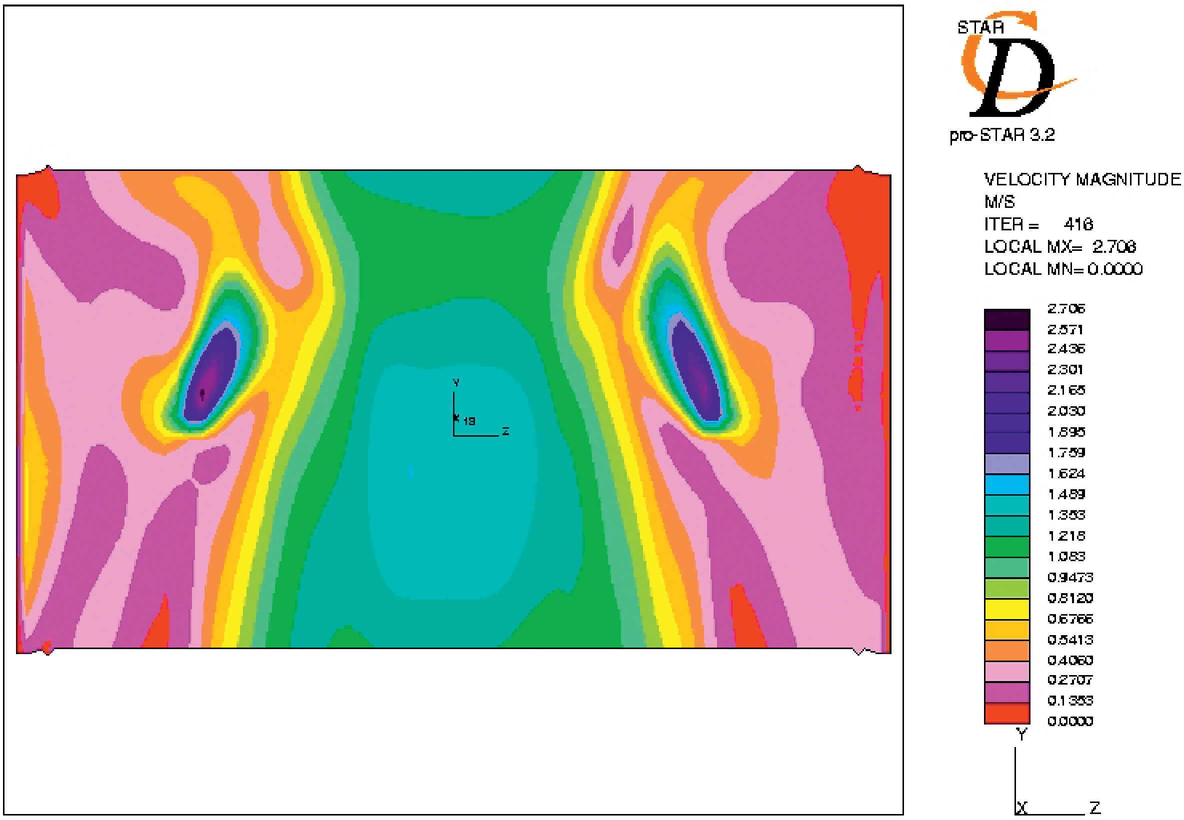

Figure 6. Velocity magnitude profile at the injection region.

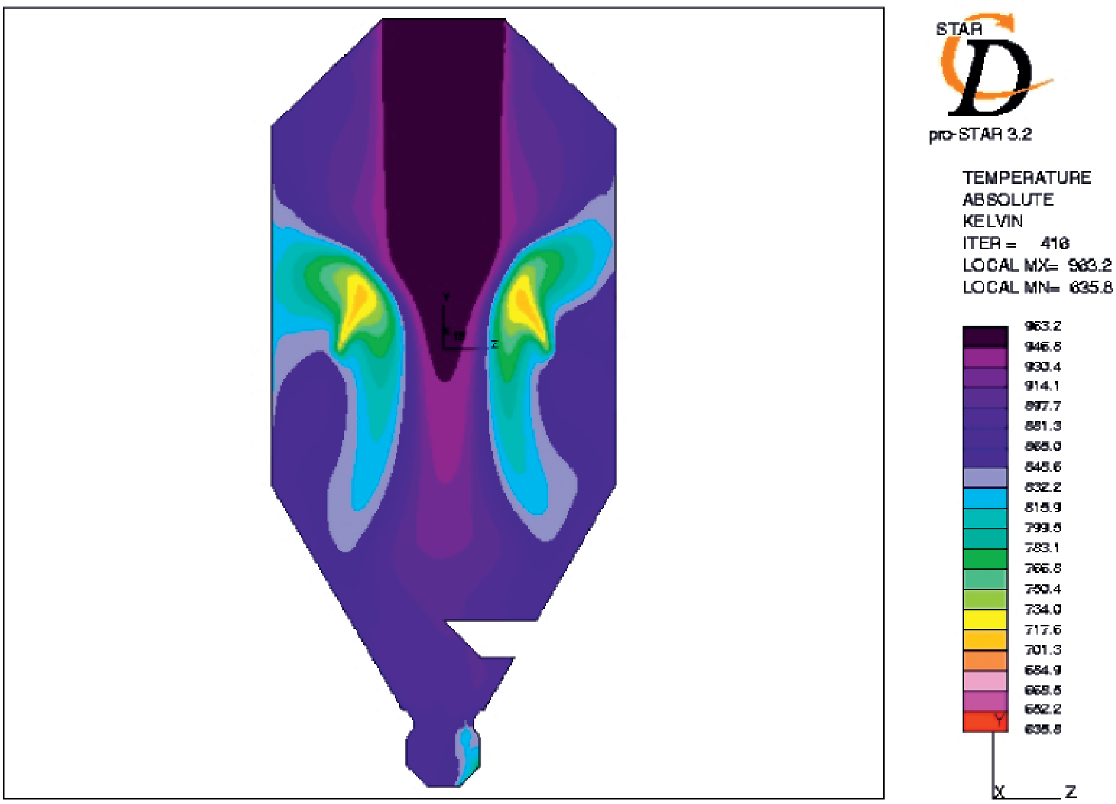

Figure 7. Temperature profile at the axis of the chamber, after injection of droplets.

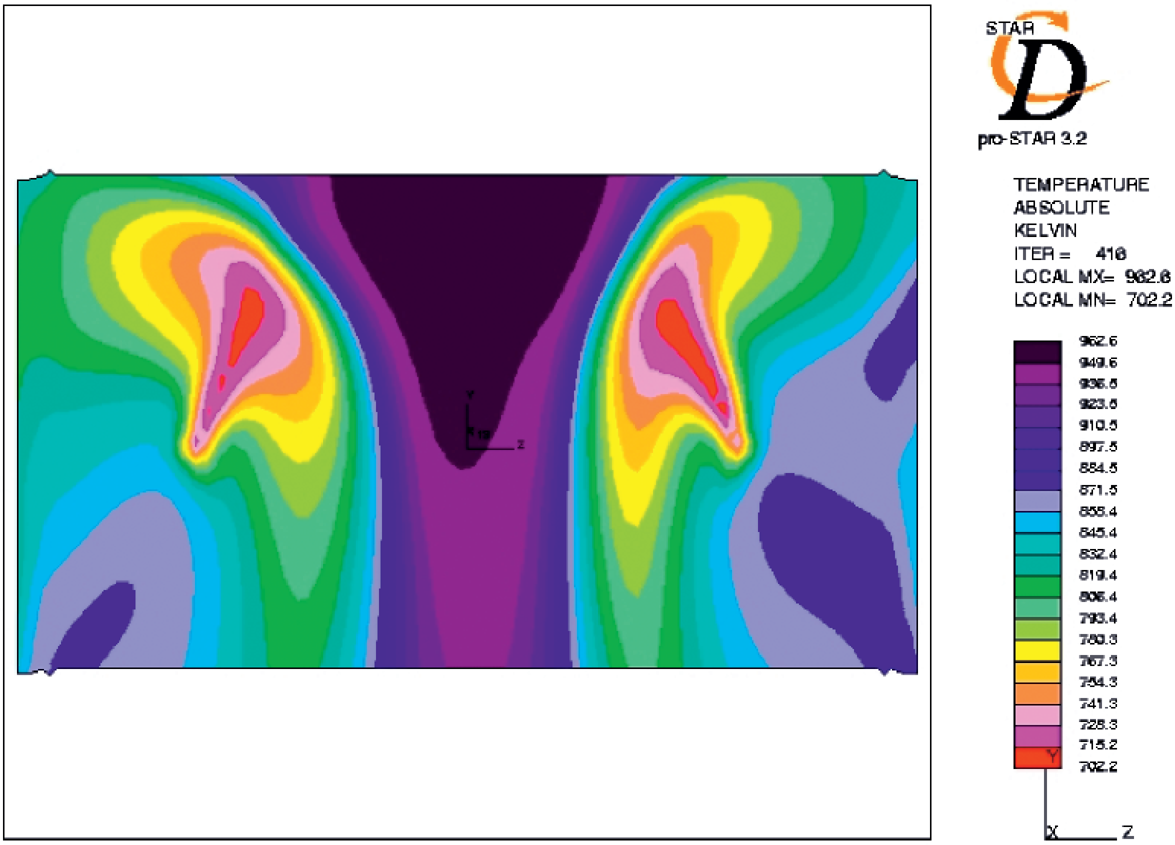

Figure 8. Temperature profile near the injection region.

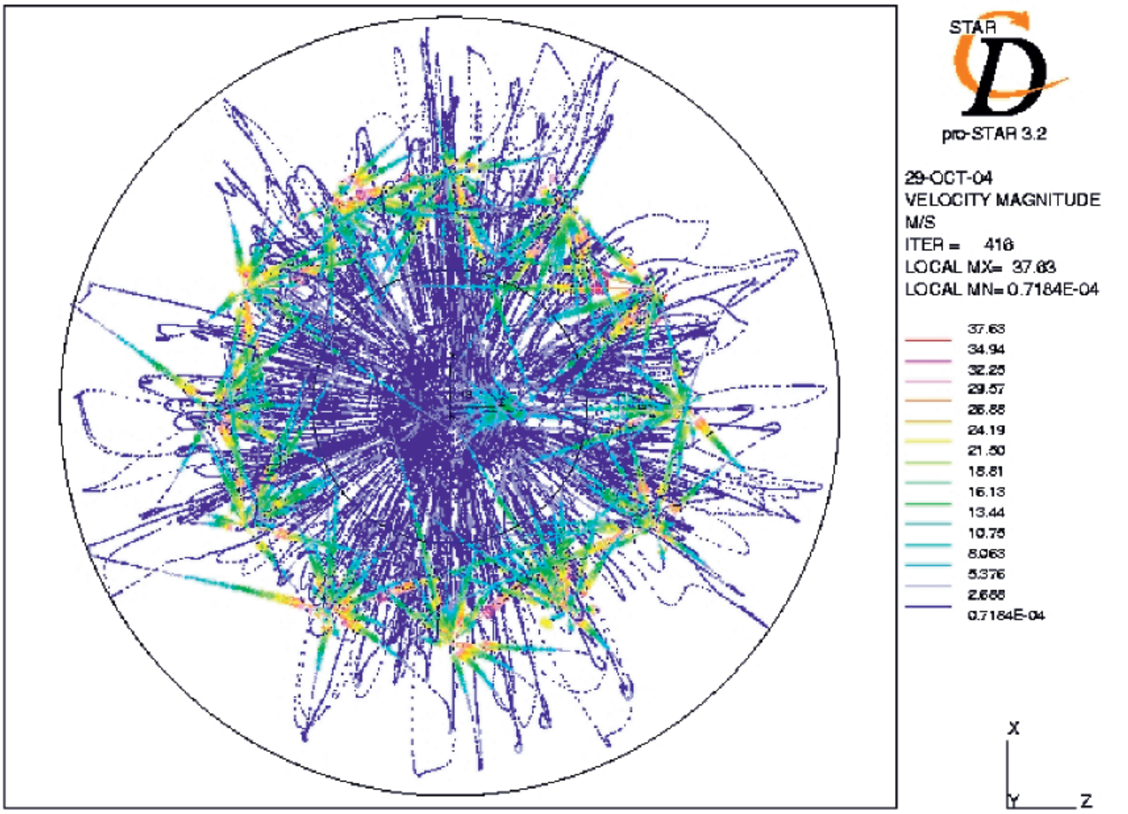

Figure 9. Droplets trajectories. Top view.

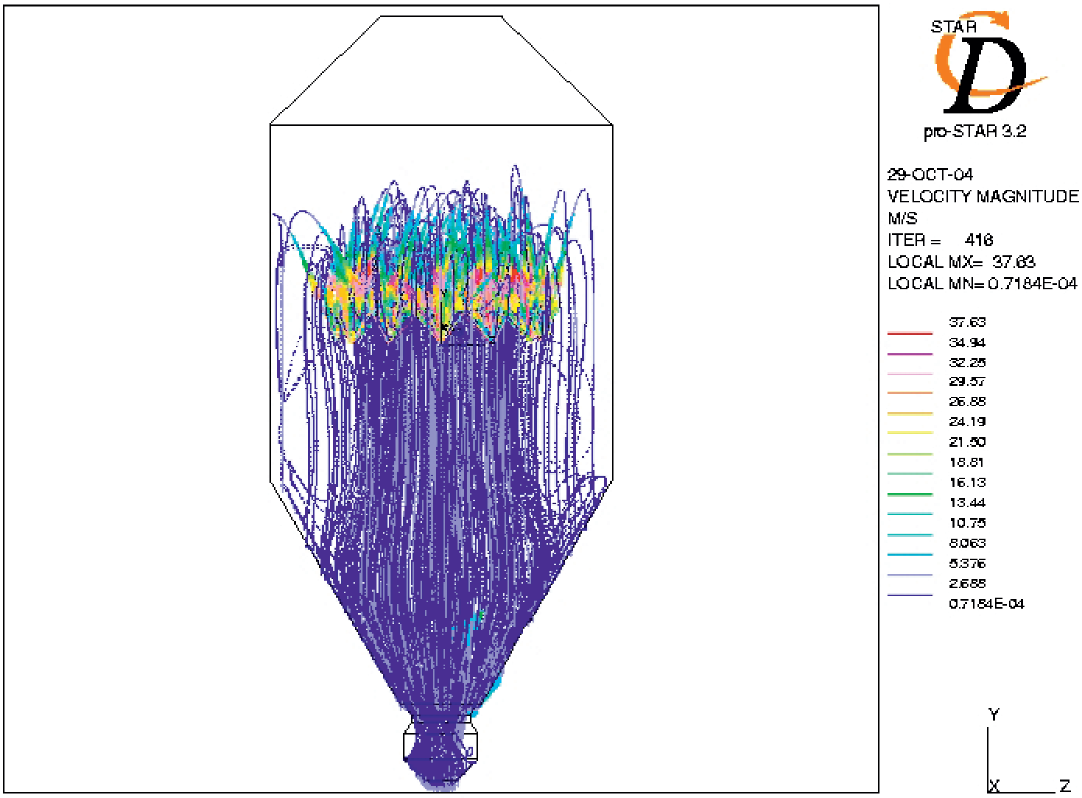

Figure 10. Droplets trajectories. Front view.

5. FINAL REMARKS

The aim of this work was to simulate a large scale spray dryer employed by the ceramic tile industry. Dryer geometry and operating conditions were kindly supplied by Pilkington's Tiles Group.

After choosing the mesh that best fitted the domain, the simulations with the drying system of alumina slurry in hot air began. Alumina slurry was chosen as a representative material but whenever possible the properties of the actual suspension were employed. To avoid problems with the temperature field, that are caused by the accumulation of granules at the bottom of the chamber, it was necessary to establish a continuous gas flow through the bottom since a steady state hypotheses was assumed for the drying process.

Qualitative results for the velocity and temperature profiles, as well as for the droplets trajectories were obtained for the drying of a ceramic suspension through CFD analyses. Comparison of simulated results with experimental data is required to validate the model.

Analyses of equipment design and operating conditions with a validated model can be carried out in order to optimize the spray drying system, keeping to a minimum the number of experimental tests that and therefore reducing the time and costs to develop improved systems.

ACKNOWLEDGEMENTS

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