Modelling Spray Drying Process in a Counter-Current Pilot-Scale Drying Tower

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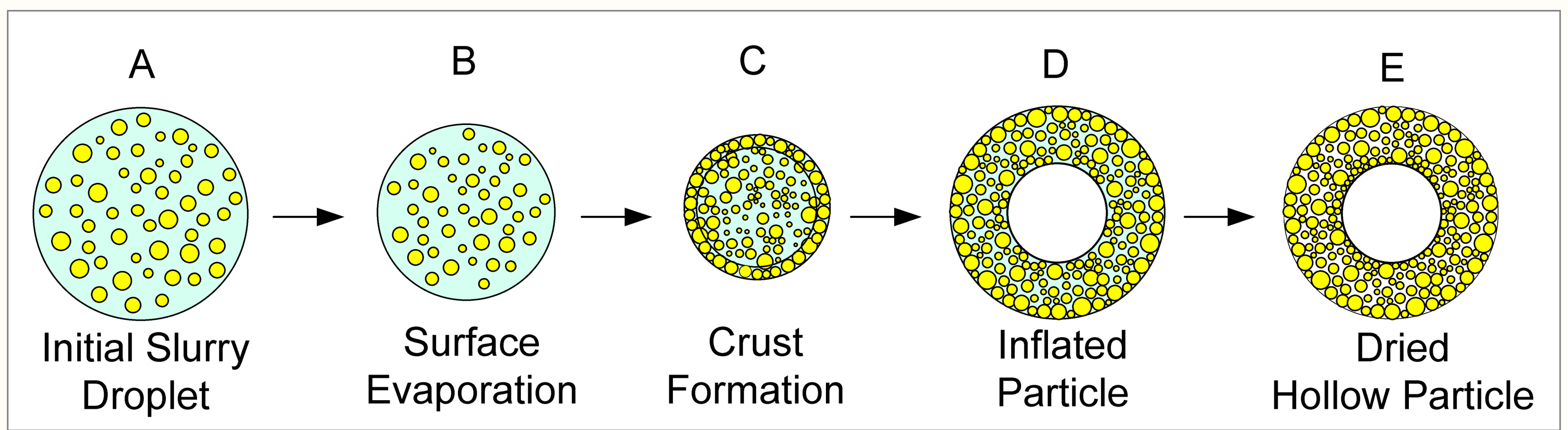
1. Summary

- CFD and plug flow modelling is used to study heat, mass and momentum transfer in a pilot-scale counter-current spray drying tower.
- The droplets/particles have a range of sizes (100-2300 μm).
- A semi-empirical droplet drying model is used for droplet drying kinetics.
- The transport processes are very dependent upon the droplet/particle sizes.
- A compartmental model will be developed which solves the complex interactions of the two phases in a computationally efficient manner.

2. Introduction

- Spray drying is used for the manufacture of a wide variety of particulate products including food, chemical, pharmaceutical and household products.
- Spray drying process modelling is very challenging due to the difficulty associated with integrating transport processes between the droplets/particles with highly complex turbulent swirling gas flow.
- CFD and plug flow modelling approaches are used to model detergent slurry spray drying process and a comparison is made between the two models.

3. Droplet Drying Kinetics

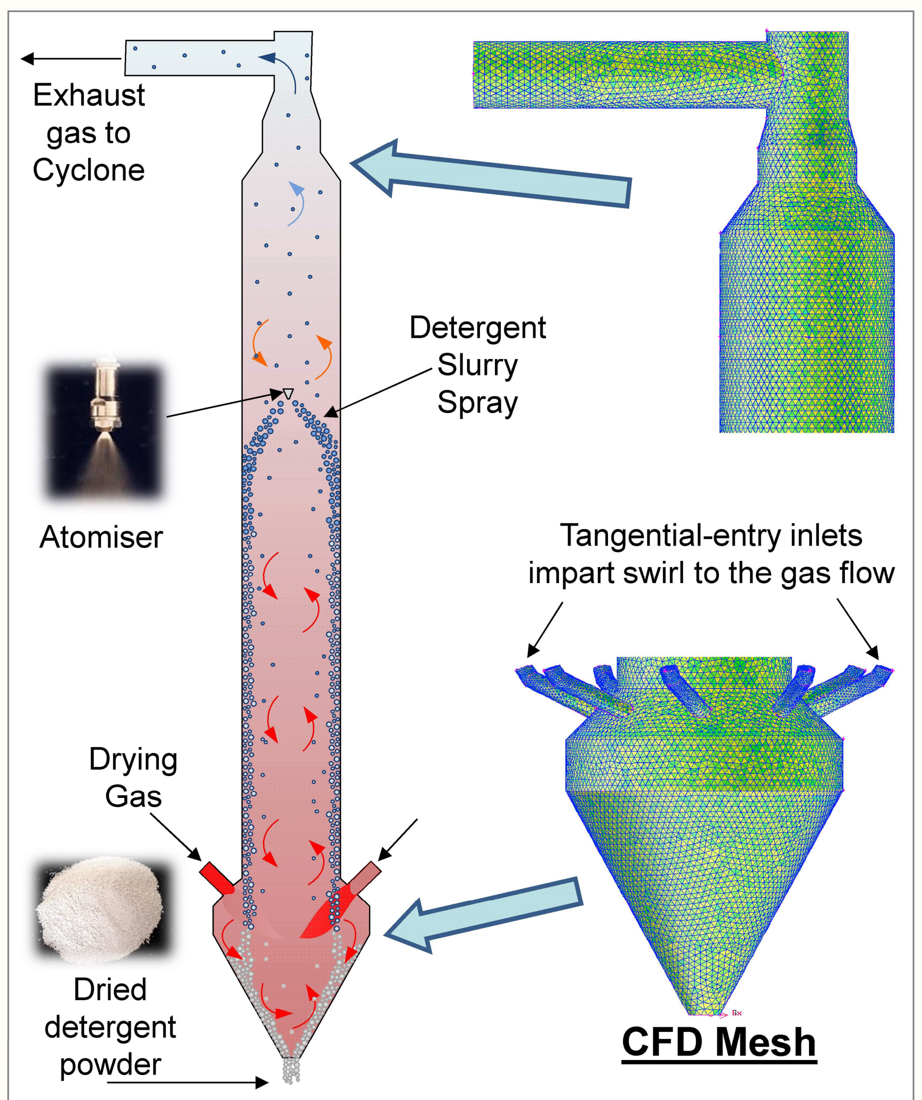


Slurry Droplet Drying Mechanism

- Droplet drying is modelled using a semi-empirical single droplet drying model developed by P&G [1].
- The model is based on a full numerical model by Hecht and King [2].
- Drying takes place in three stages:
  - A-B: Saturated surface drying.
  - C: Internal moisture diffusion controlled drying.
  - D: Heat transfer controlled drying at the slurry boiling point followed by particle inflation.

4. Modelling Methodologies

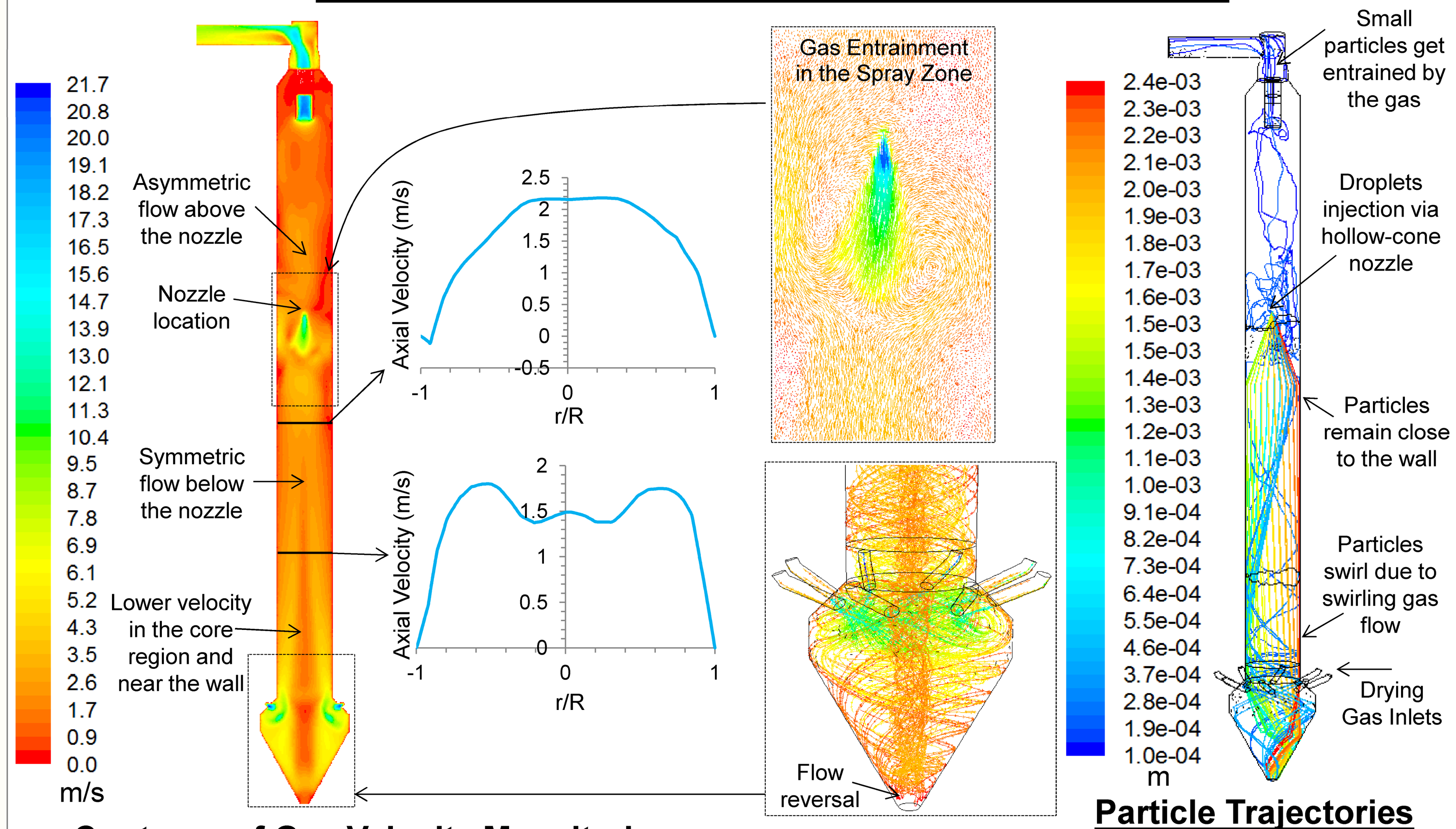
- A multiphase 3D **CFD** simulation in the steady state is carried out using Fluent v. 12.
- The Reynolds-stress turbulence model with the Eulerian-Lagrangian approach is used.
- A mesh comprising 1.3×10^6 tetrahedral cells is used.
- The restitution coefficient is a linear function of moisture content.
- Details of **CFD** methodology can be found in Ali *et al.* [3].
- The **Plug Flow** model considers heat, mass and particulate phase momentum transfer along the tower height.
- In the **Plug Flow** model, the minimum particle velocity is set to terminal falling velocity.
- The **Plug Flow** model is solved using an algorithm developed within MATLAB.



Spray Drying Tower Schematic

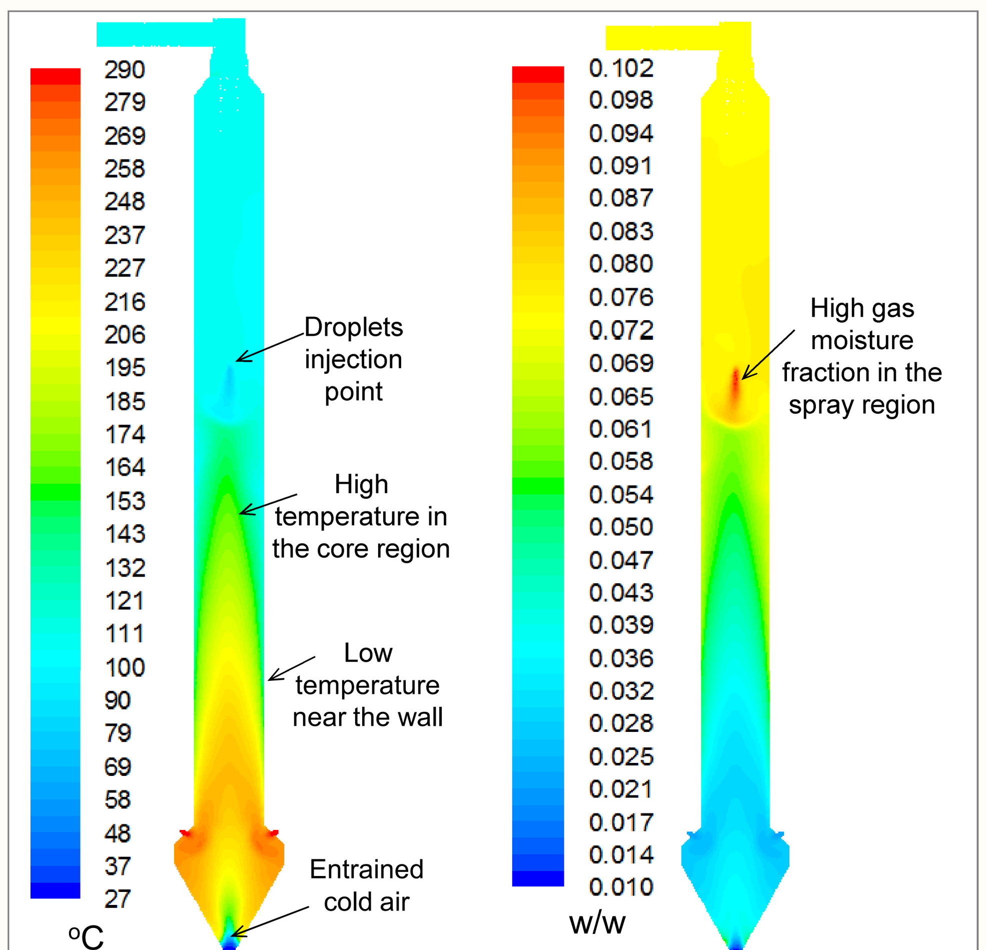
5. Simulation Results

Gas Profiles and Particle Trajectories Obtained from CFD



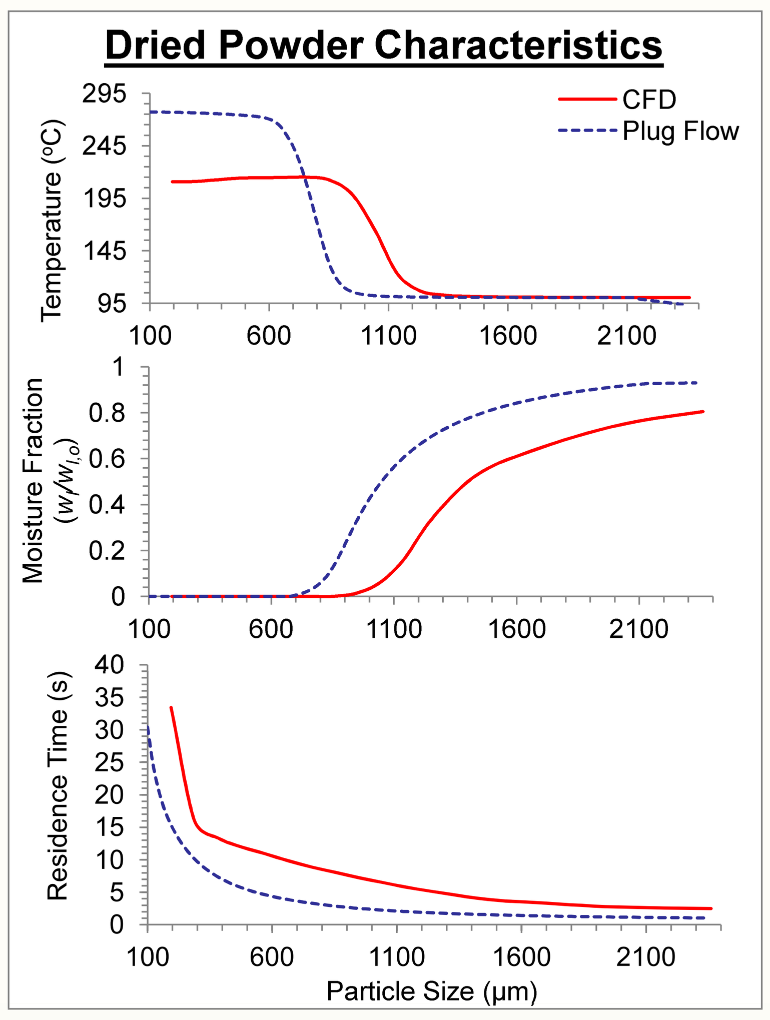
Contours of Gas Velocity Magnitude **Particle Trajectories Coloured by Diameter**

- Low gas velocity persists near the wall and particles move close to the wall.



Gas Temperature **Gas Moisture Fraction**

Dried Powder Characteristics



6. Conclusions

- The plug flow model under-predicts the particle residence times as the minimum velocity is limited to terminal velocity and particle-wall interaction and interaction with turbulence is ignored.
- The plug flow model under-predicts heat and mass transfer compared to the CFD model.
- The particle outlet temperature, moisture content and residence times vary significantly with size and hence, good estimations of the initial droplet size and inclusion of coalescence and agglomeration are important.

7. Future Modelling Strategy

- A compartmental model will be developed with the participation of Process Systems Enterprise Ltd, Procter and Gamble, Novozymes A/S and the University of Leeds and support from the Technology Strategy Board.
- The model will be based on the air flow profiles and residence time distributions obtained from CFD.
- It will consist of a series of well mixed and plug flow zones and include agglomeration kernel to account for change in particles sizes.
- The model will be used to optimise spray drying operation in a computationally efficient manner.

References

1. Hecht, J. P. (2012). Personal communication. Newcastle Technical Centre, United Kingdom.
2. Hecht, J. P. and King, C. J. (2000). *Ind. Eng. Chem.*, vol. 39, pp. 1766-1744.
3. Ali *et al.* (2013). 8th *International conference on multiphase flows*, Jeju, Korea (to be presented in May, 2013).

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