A global coating quality model for top-spray fluidized beds : spray sub model

Mike Vanderroost, Frederik Ronsse, Jan Pieters, Koen Dewettinck

In: **Proceedings of the 6th International conference on Simulation and Modelling in the Food and Bio-industry (FOODSIM 2010), 167-170.**

To refer to or to cite this work, please use the citation to the published version:

Vanderroost, M., Ronsse, F., Pieters, J.G., Dewettinck, K. (2010). A global coating quality model for top-spray fluidized beds : spray sub model. Proceedings of the 6th International conference on Simulation and Modelling in the Food and Bio-industry (FOODSIM 2010), June 24-26 2010, Brangança, Portugal, 167-170.

A GLOBAL COATING QUALITY MODEL FOR TOP-SPRAY FLUIDIZED BEDS: SPRAY SUB MODEL

Mike Vanderroost
Frederik Ronsse
Jan Pieters
Koen Dewettinck
Department of Biosystems Engineering
Ghent University
Coupure links 653
B 9000, Ghent
E-mail: mike.vanderroost@ugent.be

KEYWORDS

Model, Coating Quality, Fluidized Bed.

ABSTRACT

Fluidized beds are amongst others used in industrial applications for coating particles. Little research has been performed in developing a quality model for a coating process. A quality model is able to predict the quality of the process in terms of coating thickness and uniformity and the occurrence of unwanted side-effects, including agglomeration, attrition and spray loss. The quality of the coating process in a fluidized bed is largely determined by the spray characteristics and the particle motion. A new quality model was developed for the coating process in a top-spray fluidized bed. The first step in the development of the new model was the creation of an accurate spray sub-model that describes the movement and the heat and mass balances of the droplets in the coating process. The second step was the creation of a particle sub-model that describes the movement and the heat and mass balances of the particles in the fluidized bed. The third and final step will be the development of the global coating quality model by combining the spray and the particle sub model. Experimental validation of the spray sub-model has already been carried out and is presented in this paper.

INTRODUCTION

Fluidized bed coating is a technique that is used for the coating of solid particles and is often used in the food and pharmaceutical industry. In a fluidised bed coating reactor three interacting phases (solid particles, air, and droplets containing the coating material) can be distinguished (figure 1). The particles are fluidized by heated air that is coming from the bottom of the reactor. A nozzle placed above the fluidised bed sprays coating material towards the particles in the form of small droplets. While travelling through the bed, the particles and the droplets exchange heat and mass with each other, with the air and with the reactor wall. To predict the quality of the coating process, the global coating quality model needs to be able to describe the droplet and the particle behaviour in the fluidised bed. Therefore, a spray sub-model and a particle sub-model were created. Both models will be merged into the final global coating quality model. The main objective of this paper is to discuss the spray sub-model and its experimental validation.

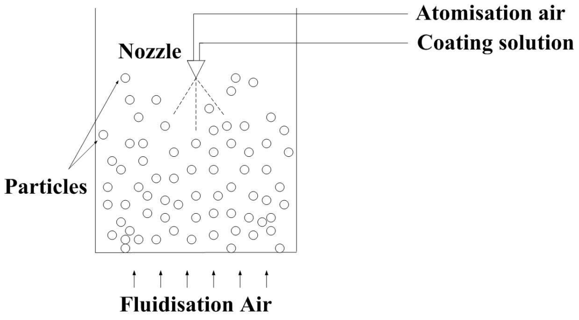


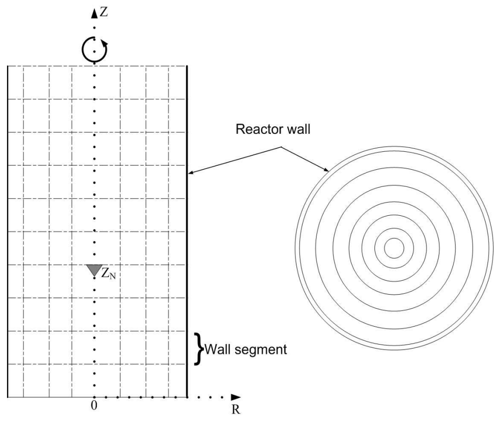
Figure 1: Fluidized bed coating reactor

MATERIAL AND METHODS

Model description (spray sub model)

Reactor

The fluidized bed reactor was modelled as a 2D axisymmetric volume which is divided in cylindrical shell control volumes (figure 2).



(a) **(b)**

Figure 2: Discretisation of the reactor into control volumes: (a) Side View, (b) Top View

Droplets

In the spray sub-model, two types of droplets were considered. First, there are the droplets that move freely in the reactor. They originate from the nozzle and have a measured statistical distribution for the angle when leaving the nozzle. They are characterized by their temperature, position, velocity and diameter. Second, there are the droplets that move downwards on the wall after collision with the wall. They are characterised by their temperature and position. It was assumed that after collision the complete droplet gets the shape of a disc and moves down the wall.

Gas phase

The atomisation flow originating at the nozzle was modelled as a jet flow (Figure 3).

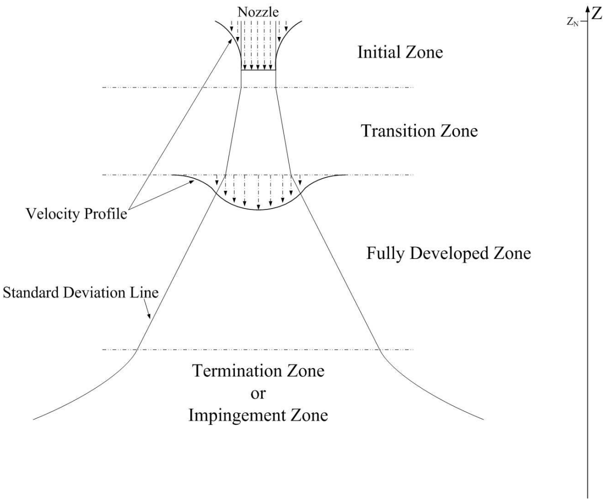


Figure 3: Atomisation or entrainment flow

The development of a jet flow is described by a Gaussian velocity profile with an increasing standard deviation with increasing distance to the nozzle, while the central velocity decreases with increasing distance to the nozzle (Zue 1999). When no atomisation flow is used, it is assumed that the motion of the droplets at the nozzle will develop an entrainment flow that is modelled as a jet flow with a velocity that is a fraction of the maximum velocity of the droplets originating at the nozzle.

Thermodynamics

The dynamic heat and mass transfer model, developed by Ronsse *et al.* (2007), was used to describe the dynamic interaction between the different phases in the fluidised bed.

Model description (particle sub model)

By applying fluidisation air in a fluidised bed reactor, the particle bed gets the properties of a boiling liquid. Bubbles are created at the bottom of the reactor and move upwards through the bed (Figure 4).

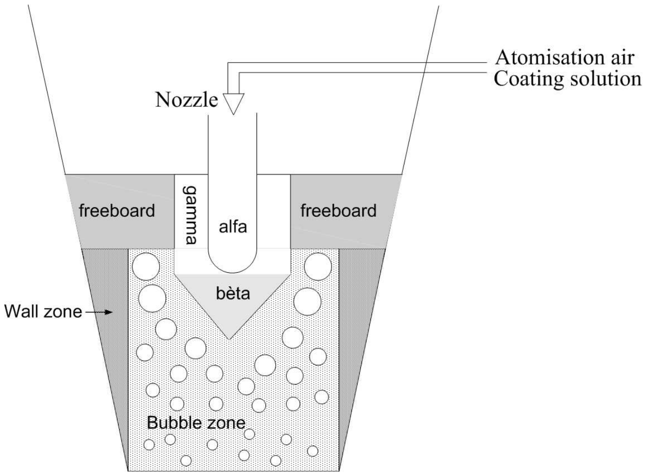


Figure 4: Particles behaving like a boiling fluid

Three different zones were defined in the fluidised bed: the bubble zone, the crater zone and the wall zone.

Bubble zone

In this zone, the bubbles originating at the bottom of the reactor, move through the bed. The bubbles are responsible for the upward motion of the particles.

Crater zone

When atomisation air is supplied at the nozzle, a crater arises in the fluidised bed. This zone was divided in three sub-zones: the alfa zone, the beta zone and the gamma zone.

In the alfa zone, it is reasonable to assume that particles, bubbles and fluidisation air will not occur due to the high pressure of the atomisation airflow. At the bottom of this zone, the atomisation flow velocity is zero, meaning that at this point all the atomisation flow is dissipated in the radial direction.

Beneath the alfa zone, a zone of higher particles densities is assumed to exist due to the pressure of the atomisation flow. This is the bèta zone. Bubbles will not enter the bèta zone and are forced to move around it, as can be seen in figure 4. This means that in the bèta zone only the emulsion phase will occur.

In a region around the alfa zone, the gamma zone is defined. In this zone, the radial dissipated atomisation air will be deflected upwards due to the resistance of the fluidised bed and the reactor wall. In this zone, a turbulent mixture of atomisation air and fluidisation air entrains particles from the bèta-zone at the bottom and carries them upwards. This implies that the gamma zone is a dilute region of particles.

Wall zone

The small inclination of the wall is the driving force for the downward motion of the particles in a zone close to the wall. Since the gas velocity near the wall is close to zero and since particles are forced in the direction of the wall because of the atomisation air, higher particle densities will occur in this region. Hence, in the wall zone there will be no fluidisation and particles will start to move downwards. Since bubbles follow the path of least resistance, it is clear they will not occur in this zone.

To facilitate the modelling of the particle motions and collisions, a hexagonal closest packing lattice is introduced in the model. This means that the particle motion is discretised and that a time consuming algorithm to check for overlapping particles is not needed. (figure 5).

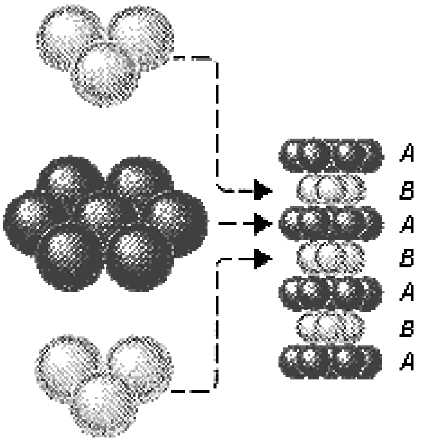


Figure 5: a hexagonal closest packing lattice of spheres

Average particle velocities in the bed are calculated based on conservation of mass in each horizontal cross section of the reactor.

Model description (global coating quality model)

In the new quality model the spray and particle sub models are combined. This, however, requires an accurate description of the interaction between the droplets and the particles to be able to predict coating thickness, coating uniformity and agglomeration. Therefore, the surface of the particles was divided into a certain number of zones on which droplets could spread after collision (figure 6).The area of an elementary zone was calculated using the spreading diameter of a droplet colliding on a solid surface (Werner et al. 2007).

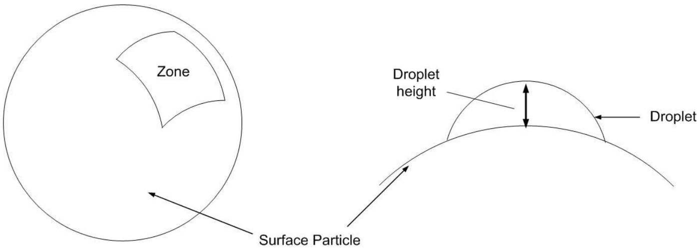


Figure 6: Droplet spreads over an elementary zone on the surface after collision

Experimental Setup (spray sub model)

The experimental setup used for the validation of the spray sub-model is shown in figure 7. The reactor used in this experiment was a large PVC tube with a height of 3.00 m, a diameter of 0.50 m and a wall thickness of 0.01 m. Fluidisation air was simulated using a fan.

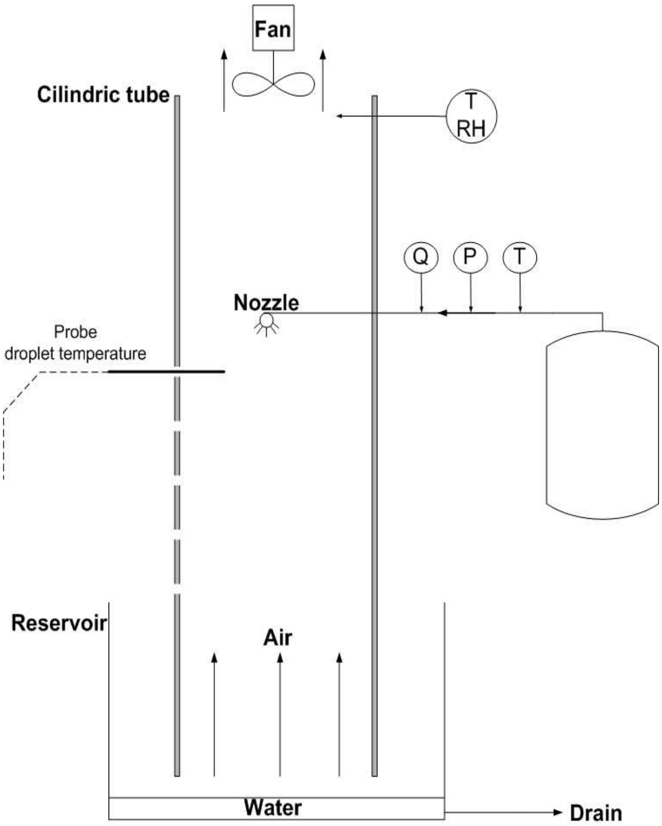
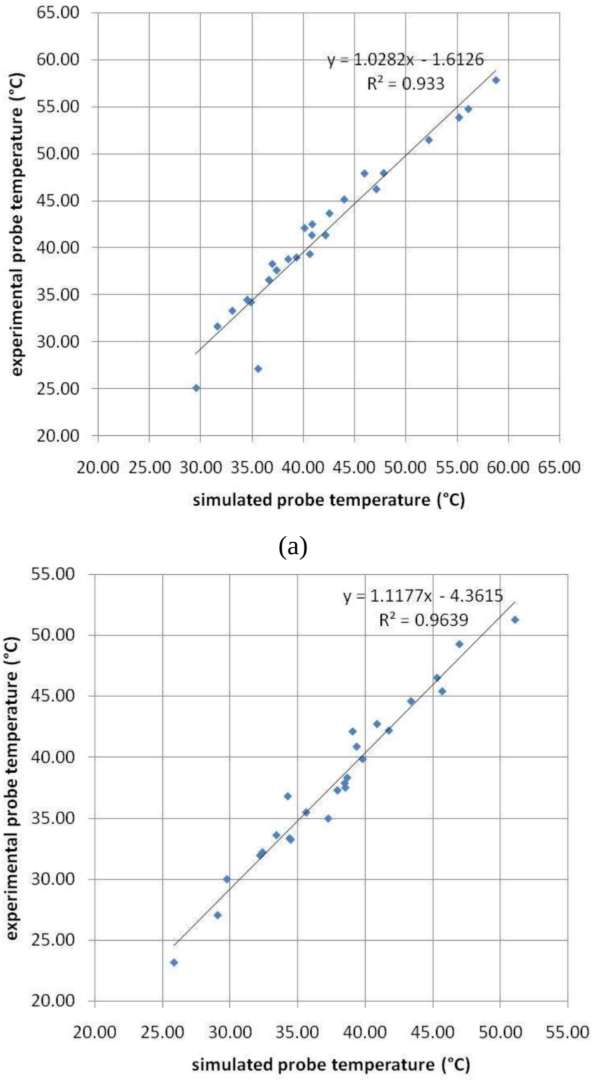


Figure 7: Schematic overview of the experimental setup

A nozzle (Schlick 553 $G^{3/8}$) was placed at a height of 2.50 m in the centre of the reactor. The liquid sprayed was tap water. To reduce fluctuations in the flow rate and to minimise and control the temperature of the liquid feed, the water was lead through a boiler before being sent to a nozzle. For validation of the heat and mass transfer of the droplets, the spatial temperature distribution of the droplets inside the reactor was measured with a T-type thermocouple probe. In addition, the temperature and the humidity of the air leaving the reactor were measured to validate the global heat and mass transfer inside the reactor. The experiments were carried out under different conditions.

RESULTS AND DISCUSSIONS

From figure 8 it can be seen that there was good agreement between the simulations and the experimentally determined temperatures. Linear regression analysis showed that a close-to-linear relationship exists for both radial positions. The same conclusion can be drawn for the temperature of the air leaving the reactor at the top. Since the relative humidity of the outlet air in the experiments was in all cases close to 100%, it was expected that the outlet air temperature resulting from the simulations would also be close to the wet bulb temperature. In figure 9 it is shown that this was the case. The deviations are acceptable and can be explained by relatively large errors in the measurement of the inlet air temperature (± 0.5 °C) and humidity (± 2%) and in the measurement of the outlet air temperature (± 0.3 °C) itself.



(a)

(b)

Figure 8: Experimental (vertical axis) and simulated (horizontal axis) probe temperatures at 0.02m (a) and 0.07m (b) from the central axis

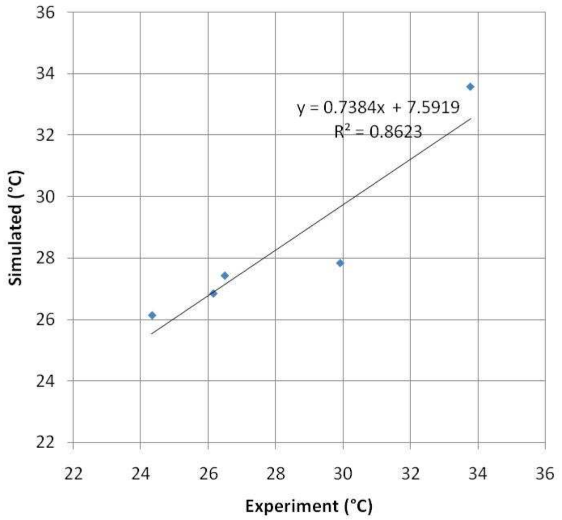


Figure 9: Correlation between the experimental and simulated temperature of the outlet air

CONCLUSION

The spray sub-model was able to predict the air and droplet temperatures and the air humidity. Further research involves the further development of a particle sub-model and the combination and integration of both sub-models into a global coating quality model. Currently, the particle sub-model is being developed.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the financial support of the Special Research Fund (BOF) of the Ghent University.

REFERENCES

Ramkrishna, D. 2000. “Population Balances, Theory and Applications to Particulate Systems in Engineering” Academia Press, ISBN 0-12-576970-9.

Ronsse, F.; Pieters, J.G. and Dewettinck, K. 2007. “Combined population balance and thermodynamic modelling of the batch top-spray fluidised bed coating process. Part I—Model development and validation.” Journal of Food Engineering 78 (2007) 296–307.

Ronsse, F.; Pieters, J.G. and Dewettinck, K. 2007. “Combined population balance and thermodynamic modelling of the batch top-spray fluidised bed coating process. Part II—Model and process analysis.” Journal of Food Engineering 78 (2007) 308–322.

Vadiraj Katti and S.V. Prabhu. 2008. “Experimental study and theoretical analysis of local heat transfer distribution between smooth flat surface and impinging air jet from a circular straight pipe nozzle.” International Journal of Heat and Mass Transfer 51 (2008) 4480–4499.

Werner, S.R.L.; Jones, J.R.; Paterson, A.H.J.; Archer, R.H.; Pearce, D.L. 1999. “Air-suspension coating in the food industry: Part II — micro-level process approach.” Powder Technology 171 (2007) 34–45.

Yue, Z. 1999. “Air jet velocity decay in ventilation applications.” Installationsteknik, Bulletin n°48, ISSN 0248-141X.

AUTHOR BIOGRAPHY

MIKE VANDERROOST was born in Zottegem, Belgium, and graduated at the Ghent University where he studied Engineering Physics and Biomedical Engineering. He obtained his degrees in 2003 and 2005. During his whole education, he had a pronounced interest for physics. After working a few years as a nuclear physicist and as an advisor to the federal police department, he returned back to an academic environment to do scientific research.