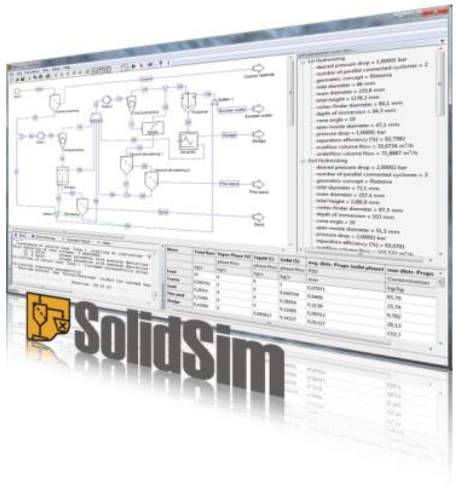
Simulation of a Fluidized Bed Spray Granulation Pilot Plant GF/ProCell 25 with the Flowsheet-Simulation Software SolidSim



ABSTRACT

Fluidized bed spray granulation is commonly used for the production of dust-free and free-flowing powders with well-defined particle size distributions. A typical spray granulation process consists of a fluidized bed spray granulator with an external classification and grinding circuit. In the present contribution the application of the flowsheet simulation system SolidSim for the modeling and simulation of a spray granulation pilot plant GF/ProCell 25 operated at Glatt Ingenieurtechnik Weimar is shown. For the adjustment of the model parameters measurements from the pilot plant are used. The model developed describes the pilot plant with a reasonable accuracy.

INTRODUCTION

In the chemical, pharmaceutical and food industries fluidized bed spray granulation is a commonly used technology to produce dust-free and free-flowing powders with well-defined particle size distributions and particle shapes. The basic idea of the process is to spray a suspension or a solution into a fluidized bed. When contacting the particles in the fluidized bed the liquid droplets spread and partly penetrate into the particles. The fluidization air evaporates the solvent, leaving a layer of solute on the surface of the particle. Continuous fluidized bed granulators are usually sub-divided into several zones, which are operated at different air speeds and temperatures, e.g. granulation in the first and second section, drying in the third and cooling at the end of the process chamber.

Nowadays, software tools for the flowsheet simulation of industrial processes are commonly used for design, simulation, balancing, troubleshooting and optimization purposes (Schuler, 1995). However, the applications are normally restricted to fluid processes, since the established simulation systems are not able to describe bulk solids in an adequate way. In order to fill this gap, the flowsheet simulation system SolidSim has been developed with a special focus on the description of bulk solids (Hartge, 2006). SolidSim provides a wide range of solids processing unit operations, such as sieving, milling, agglomeration, granulation etc. in an easy to use simulation environment.
The present contribution shows the first experiences of Glatt Ingenieurtechnik GmbH with SolidSim and its application to the simulation of a fluidized bed spray granulation process with an external classification and grinding circuit. The simulation model was trained based on measurements from the pilot-plant GF/ProCell 25 operated at Glatt Ingenieurtechnik GmbH in Weimar.

FLOWSHEET SIMULATION OF SOLIDS PROCESSES / SOLIDSIM

In a simulation flowsheet, the process under investigation is represented by models of different processing units (granulator, screen, mill etc.), which are linked by material and energy streams to form a network. An example is given in Fig. 1, which shows a flowsheet of a urea granulation process. Flowsheet simulation is then the numerical solution of material and energy balances and the determination of intensive state variables based on of the interconnected mathematical models for the different process steps.

SolidSim is a Microsoft Windows® based flowsheet simulation system especially designed to model and simulate complex solids processes. It can be used to predict the performance of processing plants or to investigate plant extensions, modifications or designs time- and cost-efficiently. Using SolidSim established methods in the field of fluid process simulation like computer-aided process optimization can also be applied to processes which involve solids. SolidSim allows to setup the flowsheet by drag & drop in an easy to use graphical user interface (see Fig. 1) and provides algorithms to solve the material and energy balances. Furthermore, SolidSim contains a model library covering a wide range of process units.

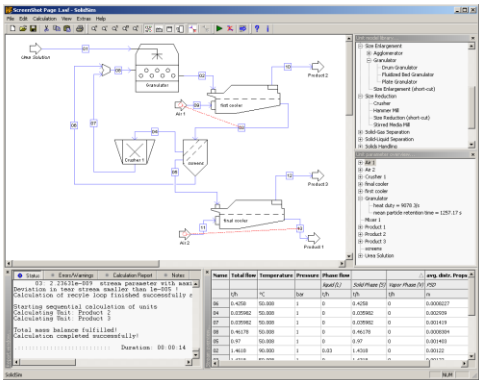


Fig. 1. The main window of the SolidSim simulation system.

SIMULATION OF THE PILOT PLANT

In the present work SolidSim was applied to the modeling and simulation of a continuous spray granulation process of dextrose monohydrate in a pilot plant GF/ProCell 25 as it is operated at Glatt Ingenieurtechnik GmbH in Weimar.

The pilot plant

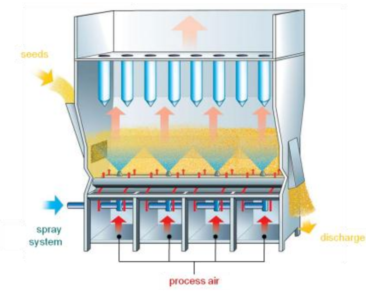


Fig. 2. Schematic drawing of the GF/ProCell 25 pilot plant.

The schematic layout of the pilot plant is given in Fig. 2. In the present case the granulator is not subdivided into different zones. The suspension is sprayed from the bottom by use of four two-component-nozzles into the fluidized bed. All nozzles are operated at the same spray rate. Hence, it can be assumed that the granulator is operated as one process camber with an uniformly temperature profile over the length of the apparatus. An electric heater is used for the conditioning of the inlet air. The airflow through the heater and the fluidized bed can be adjusted by a rpm-controlled blower. In order to control the particle size distribution of the material leaving the granulator a sifter at the granulators' outlet is used. The product from the granulator is then feed to a two-deck screen. To realize an easier bulk handling the coarse and fine particles obtained by screening are milled subsequently by use of a rpm-controlled pin mill. The milled particles are then recycled as seed particles to the granulator. The middle fraction is the product of the overall spray granulation process.

Measurements

At steady-state operation of the process the mass flows and particle size distributions of the different material streams were measured. The mass flows were determined by using a continuous mass sampling at a specified time range. Unfortunately, the samples were not exactly taken at the same time. So fluctuations of the measured flows are unavoidable. The particle size distribution of the material leaving the granulator as well as the particle size distributions of the bed material and product fraction of the screen was determined by sieve analysis of the samples taken. The particle size distribution of the milled material has been determined by use of an optical particle size analyzer. Besides this, the volume flow, temperature and humidity of the process and exhaust air were measured also.

Furthermore, pictures of the product granulates were taken (see Fig 3.) It can be seen that besides the pure granulation also agglomeration took place in the granulator.

The heat loss of the pilot plant was also determined during the measurements. Therefore, the plant was operated under non-loaded operating conditions (no spraying, no bed mass) at different gas flows and temperatures while the temperature of the exhaust air was measured. For this measurement the atomization air was also considered.

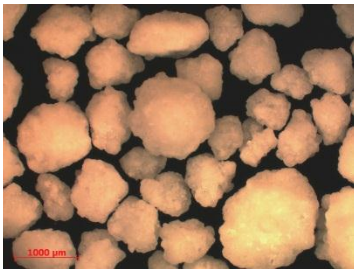


Fig. 3: Dextrose monohydrate granulate product particles.

The SolidSim simulation model

The fluidized bed spray granulation process described above was modeled in detail using SolidSim as shown in Fig. 4. In addition to the granulator, the screen and the mill, the model also includes the process air conditioning.

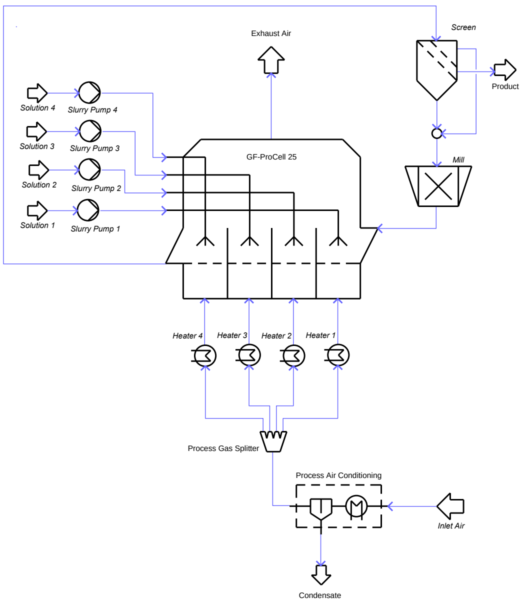


Fig. 4: SolidSim main flowsheet of the granulation pilot plant GF/ProCell 25.

For the modeling of the mill and the screen, models from the SolidSim model library were used. The screen is described by a separation curve according to Rogers (Rogers, 1982), while the mill is modeled according to Bond's law (Bond, 1952).

The measurements from the plant show that besides granulation also agglomeration effects have to be considered for the description of the GF-ProCell 25. So it is not sufficient to describe the granulator by use of the SolidSim granulation model, since this model assumes pure granulation of the particles. By use of a so-called sub-flowsheet the GF-ProCell 25 was described as a combination of a pure agglomeration and pure granulation. It was assumed that the major part of the fine particles at the inlet of the ProCell participate in agglomeration, while a mixture of agglomerated particles and coarse particles from the feed of the ProCell were granulated. For the description of the agglomeration step as well as for the description of the granulation step a CSTR-model is used. Beside the growth of the particles also the classification at the ProCell's discharge is considered within the sub flowsheet as shown in Fig 5.

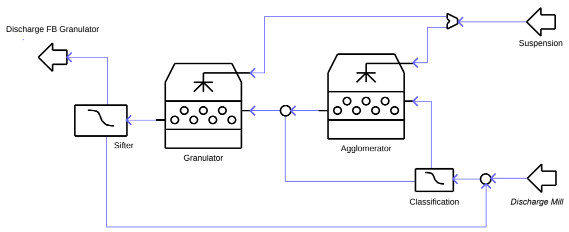


Fig. 5: SolidSim sub flowsheet of the GF/ProCell 25.

Two modes of operation have to be distinguished with regard to the air conditioning: Either fresh air is used for the fluidization or the exhaust air is recycled. The latter mode of operation is used if it is necessary to remove the vaporized solvent from the exhaust air. In this case the exhaust air stream is dehumidified by solvent condensation and subsequent separation. In order to recover the heat of the exhaust air stream the condensation is done by use of a heat exchanger. Similar to the sub-flowsheet for the description of the ProCell a sub-flowsheet for the modeling of the process air conditioning as shown in Fig. 6 has been defined. The air conditioning is modeled as a two-step heat exchange with subsequent condensate separation. In the present work only the fresh air operation without dehumidification was investigated.

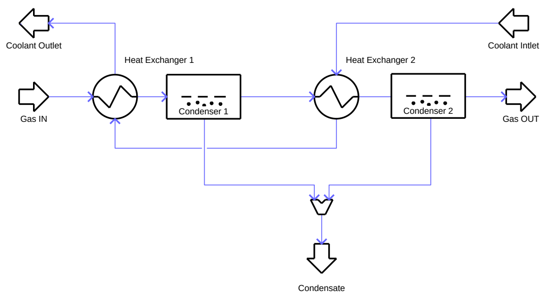


Fig. 6: SolidSim sub flowsheet of the process air conditioning.

Adjustment of the model parameters

Many of the models used to describe solids processing units are more or less empirical. In order to get reliable results from a flowsheet simulation it is often necessary to adjust model parameters to measured data. Because measured values are always erroneous to some degree, in the first step a data reconciliation calculation has to be performed. Based on the reconciled data that fulfils the balance equations the adjustment of the model parameters can be done by use of numerical optimization methods (Reimers, 2008).

In the present work a data reconciliation step was performed in order to eliminate measurement errors from the measured data from the pilot plant. Based on the reconciled data the model parameters of the granulator, the screen and the pin mill were adjusted by use of the SolidSim parameter adjustment tool. Several datasets (mass flows and corresponding particle size distributions for the inlet and outlet streams) were used as basis for the adjustment. The agglomeration unit used in the sub-flowsheet for the ProCell is modeled according to the general formulation of the particle population balance for lumped open systems. Several kernels were tried out and it turned out that the sum kernel (Golovin, 1963) provides the best results.

Simulation results

With the trained model the mass flow, particle size distribution, moisture and temperature of all streams in the flowsheet can be calculated. As an example the measured and calculated particle size distribution of the product stream leaving the process are given in Fig. 7. It shows that the model is able to calculate the product particle size distribution with a reasonable accuracy.

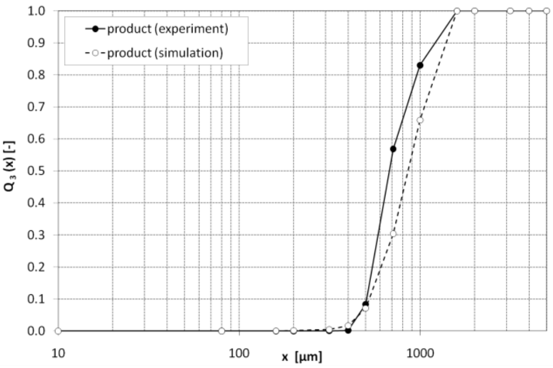


Fig. 7: Measured and calculated particle size distribution of the product stream.

Besides the particle size distribution of the product also the particle size distributions of all intermediate streams are calculated by the simulation model. Fig. 8 shows the measured and calculated particle size distributions of the bed material within the ProCell and the material leaving the ProCell via its discharge. Again, the calculated and measured particle size distributions are in good accordance. The same is true for the particle size distribution of the milled material as shown in Fig. 9

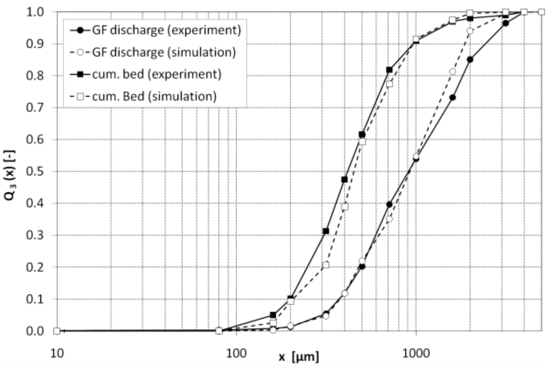


Fig. 8: Measured and calculated particle size distribution for the discharge and bed material of the GF/ProCell.

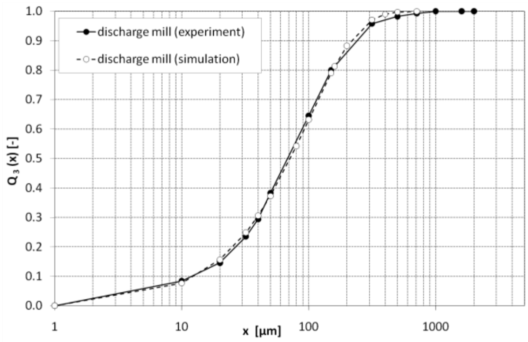


Fig. 9: Measured and calculated particle size distribution of the milled material.

For the calculation of the temperature and moisture of the exhaust air also the atomization-, shifter- and pneumatic transport gas were considered. Additionally, the heat loss of the granulator apparatus was determined to be 4 kW and considered during simulation. The deviation of measured and calculated temperature is about 3K, which can be explained by fluctuation of the inlet air conditions, e.g. gas flow or temperature. The moisture of the exhaust air is predicted with a deviation of approximately 0.4 g_{water}/ $kg_{dry\ air}$ which means an accuracy of about 3%. Altogether the calculated and measured values are in good accordance.

CONCLUSIONS

The developed SolidSim model for the fluidized bed spray granulation process allows for simulation of the process with a reasonable accuracy. SolidSim proved to be a versatile tool for the modelling of complex apparatuses as well as complex processes.

One of the major advantages of SolidSim was the fast and less error-prone process model set-up compared to manual spreadsheet calculations. The advantage becomes even more evident, if many apparatuses are linked in a complex network and if process modifications should be evaluated. Also the computer aided adjustment of model parameters to measured data is very easy and compared to the manual adjustment much faster.

In prospective studies the knowledge of the simulated spray granulation process will be verified based on a scale-up for a production plant. Thus a more reliable plant design might be possible and the risk can be limited.

NOMENCLATURE

$Q_3(x)$	cumulative-mass-distribution	-
x	particle diameter	m

REFERENCES

Bond F.C.. (1952), The third theory of comminution, Min. Eng., Vol. 4, pp: 484–494.

Golovin, A.M., (1963), The solution of the coagulation equation for raindrops, Sov. Phys. Dokl., Vol. 8: pp. 191-193

Hartge E.-U., Pogodda M., Reimers C., Schwier D., Gruhn G.,. Werther J.(2006), Flowsheet simulation of solids processes, KONA, Vol. 24: pp. 146–158

Reimers C., Werther J., Gruhn G. (2008), Flowsheet simulation of solids processes - data reconciliation and adjustment of model parameters, Chem. Eng. Proc., Vol. 47 pp: 138–158.

Rogers R. (1982), A classification function for vibrating screens, Powder Technology, Vol. 31, pp: 135–137.

Schuler, H. (1995), Prozesssimulation, VCH, Weinheim.