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Application of Global Sensitivity Analysis As Preparatory Step for Reduction of a Drying Model of Pharmaceutical Granules

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A shift from batch towards continuous manufacturing is nowadays gaining interest in the pharmaceutical industry (Leuenberger, 2001). However, this transition requires detailed knowledge of all consecutive unit operations in a continuous manufacturing line in order to design adequate control strategies for guaranteeing product quality at all time. One hereby relies on in-process measurements of critical process and product parameters and real-time adjustment of input variables. Given the complexity of the system, the knowledge development can be facilitated by developing mechanistic models of the multi-phase systems in the process (Mortier et al., 2011). The importance of using mechanistic models and system-based approaches in a Process Analytical Technology (PAT) and a Quality By Design (QbD) context has been acknowledged (Sin et al., 2008; Gernaey et al., 2012). Modelling efforts only started recently in this field. The ultimate objective of this effort is to develop a validated model describing the continuous drying of pharmaceutical wet granules in a six-segmented fluidized bed drying unit, which is part of a full continuous from powder to tablet manufacturing line (ConsiGma™, Collette™, GEA Pharma Systems). A calibrated and validated model describing the drying behaviour of a single pharmaceutical granule in two subsequent phases has already been developed (Mortier et al., 2012). In the first drying phase the evaporation of water from the droplet free surface takes place. When the radius of the wet particle equals the radius of the dry particle, the second drying phase initiates. Water inside the particle then evaporates at a rate which is much lower compared to the first drying phase.

This single granule drying model is subsequently to be embedded in a Population Balance Model (PBM), allowing the description of the evolution of the moisture content for a population of granules with distributed moisture content (internal property of the PBM). The PBM is to contain a continuous negative growth term describing the drying process. The single granule drying model can serve for this purpose, but is too complex to be integrated as such in the PBM (also bearing in mind that the PBM needs potential coupling with a hydrodynamic CFD model in the future). Therefore, a model reduction of the single granule drying model is to be performed. Prior to this step, a global sensitivity analysis (GSA) is applied as a powerful tool to determine the most important parameters and model inputs that need to be retained in the reduced model, hereby accounting for the entire global domain of degrees of freedom. This contribution gives a detailed description of this GSA to illustrate its usefulness.

The Global Sensitivity Analysis (GSA) methodology used was a Monte Carlo (MC) simulation followed by a statistical analysis for both drying phases, since the behaviour of both phases is very different and might be sensitive to other model constituents. A Latin Hypercube sampling technique from uniform distributions was used to generate the degrees of freedom used in the MC simulation (McKay et al., 1979). Five degrees of freedom were preselected (gas temperature, gas flow rate, gas humidity, gas pressure and initial granule temperature). These were chosen on the basis of their sensitivity in a local sensitivity analysis (evidenced earlier in Mortier et al. (2012)) and the fact that they can be manipulated during the operation of the dryer. A preselection also keeps the sample size of the MC analysis reasonable (2000 samples were generated). An uncertainty range for each degree of freedom was determined based on physical limitations of the dryer and physical reality. Each combined set of degrees of freedom was evaluated (MC shot) and the growth term for the first and second drying phase was calculated. Comparing the different sets of degrees of freedom it is obvious that the chosen combination of degrees of freedom for the sensitivity analysis has an influence on both drying time and behaviour. The output of the MC was further processed using a linear regression analysis at different time instants in both drying periods using the so-called Standardized Regression Coefficients (SRC) method (Saltelli et al., 2004; Saltelli et al., 2008).

As the drying model reaches no steady state, the moisture content for both drying phases has to be compared after a certain time has elapsed. The average moisture content for one simulation would be another way of selecting an output to perform the linear regression with the parameters that have been varied. For the first drying phase the output was evaluated after 3 s. An R of 0.97 was obtained, which is above the recommended value of 0.7 indicating that the linear regression model explains a large portion of the observed variance induced by the variance in the degrees of freedom. The SRCs are a robust and reliable measure of sensitivity, even for non-linear models and are used to rank the degrees of freedom according to their sensitivity (Saltelli et al., 2004; Saltelli et al., 2008). They represent the fraction of the variance observed in the MC results that can be explained by the variance imposed by the degree of freedom. The SRC of the gas temperature was found to be 0.93, clearly higher than the SRCs for the other degrees of freedom (ranging between 0-0.29). This indicates that gas temperature is by far the most influential degree of freedom in the first drying phase regardless of the values of the other degrees of freedom. For the second drying phase two time instants were selected: respectively 1 and 11 seconds after the start of the second drying phase. After 1 s the R was 0.75, while after 11 s the R dropped to 0.54 indicating strong non-linear behavior for which the applied GSA method is no longer valid (other GSA techniques should be used here, but this was considered to be outside the scope of this work). For this reason, the output after 1 s was used to rank the degrees of freedom. The gas temperature with an SRC of 0.87 was again found to be the most sensitive degree of freedom.

Since the gas temperature was found to be by far the most sensitive degree of freedom for both drying phases, this input

variable was selected to perform the reduction of the full drying model.

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