498c Passivity Based Inventory Control of Particulate Systems

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In this paper we will describe the application of passivity based inventory control for size distribution control in particulate processes. The theory we present can be applied to a wide range of processes modeled with classical population balance techniques. In the paper we will describe the development of a control system for an industrial fluidized bed solar-grade silicon production process, which is presently at the pilot plant evaluation stage. Our model has been calibrated against data obtained from the pilot-scale fluidized bed reactor. The control system has not yet been tested industrially. Simulation studies and robustness results will be presented in the paper.

During the production of solar grade silicon in a fluidized bed reactor, silane gas (SiH_4) thermally decomposes into hydrogen gas and two different types of solid silicon. The heterogeneous silane decomposition produces crystalline silicon on the surface of existing silicon. Homogeneous decomposition produces amorphous silicon powder, which aggregates to form new particles, is scavenged by existing particles, or is exhausted with gas flowing through the system. Existing kinetic models have been used to determine relative amounts of heterogeneous and homogeneous decomposition. These models cannot predict whether the powder contributes to particle nucleation and growth or whether it escapes as loss. The loss of powder determines the process yield and is consequently an important design parameter. In fact the overall success of the process depends on careful control of yield losses since the market price of silicon powder is considerably lower than that of solid silicon.

We have developed a population balance model of the silicon process which tracks the creation, growth, and agglomeration of particles. The nucleation and condensation kinetics have been included, and these allow us to model how the yield depends on operating conditions using one adjustable parameter. This parameter will be estimated using on line parameter adaptation via a state observer. The model predictions have been calibrated so that model predictions of size distributions match industrial pilot plant data.

A feedback-feedforward control system based on the inventory control method has been developed to stabilize the process at different operating conditions. The inventory balance controller is designed so that the total hold-up of silicon is kept constant. Seed and recirculation rates control the size distribution so that it tracks its setpoint within the feasible range of operation. The overall stability of the control system including state and parameter estimation is analyzed using passivity and L_2 stability theory based on thermodynamic storage functions derived from statistical mechanics.