

$$\begin{aligned}
\frac{d\tilde{x}_0}{d\tilde{t}} &= -\tilde{x}_0 + (1 - \tilde{x}_3) \text{Dae}^{\frac{-F}{\tilde{y}^2}}, \\
\frac{d\tilde{x}_1}{d\tilde{t}} &= -\tilde{x}_1 + \tilde{y}\tilde{x}_0, \\
\frac{d\tilde{x}_2}{d\tilde{t}} &= -\tilde{x}_2 + \tilde{y}\tilde{x}_1, \\
\frac{d\tilde{x}_3}{d\tilde{t}} &= -\tilde{x}_3 + \tilde{y}\tilde{x}_2, \\
\frac{d\tilde{y}}{d\tilde{t}} &= \frac{1 - \tilde{y} - (\alpha - \tilde{y})\tilde{y}\tilde{x}_2}{1 - \tilde{x}_3} + \frac{u}{1 - \tilde{x}_3},
\end{aligned} \tag{4.37}$$

where $u = (c_0 - c_{0,s}) / (c_{0,s} - c_s)$. The dynamic model (4.37) can be combined with a state observer and nonlinear model-based control according to eqn (4.32) and assuming a measurement of the zeroth moment of the CSD to obtain:⁹⁶

$$\begin{aligned}
\frac{d\omega_0}{d\tilde{t}} &= -\omega_0 + (1 - \omega_3) \text{Dae}^{\frac{-F}{\omega_4^2}} + L_0 (\tilde{x}_0 - \omega_0), \\
\frac{d\omega_1}{d\tilde{t}} &= -\omega_1 + \omega_4\omega_0 + L_1 (\tilde{x}_0 - \omega_0), \\
\frac{d\omega_2}{d\tilde{t}} &= -\omega_2 + \omega_4\omega_1 + L_2 (\tilde{x}_0 - \omega_0), \\
\frac{d\omega_3}{d\tilde{t}} &= -\omega_3 + \omega_4\omega_2 + L_3 (\tilde{x}_0 - \omega_0), \\
\frac{d\omega_4}{d\tilde{t}} &= \frac{1 - \omega_4 - (\alpha - \omega_4)\omega_4\omega_2}{1 - \omega_3} - \frac{1}{2} \frac{R^{-1}(\omega)L_{\bar{g}}V(\omega)}{1 - \omega_3} + L_4 (\tilde{x}_0 - \omega_0), \\
u &= -\frac{1}{2} R^{-1}(\omega)L_{\bar{g}}V(\omega)
\end{aligned} \tag{4.38}$$

Dynamic simulations of a process model and closed-loop system (4.38) demonstrated that process stabilization could be achieved up to a 90% probability of sensor losses.⁹⁷ It was also observed that for larger constraints on the input (*i.e.*, a higher u_{\max}), the system became more sensitive for data loss (*e.g.*, the process destabilized already at a 75% probability of sensor losses when u_{\max} was doubled in their simulations). These simulation results suggest that u_{\max} can be reduced artificially to make the system more robust in the presence of significant data losses due to measurement failures. Finally, in general, the relatively high values for sensor loss probability indicate that the used model-based controllers are rather robust with respect to sensor failures.

4.7 Actuators

Basic crystallizer configurations may lack sufficient and flexible process actuators. Therefore, a great amount of research on the potential of novel process actuators has been conducted, which often follows the