

1. A temperature control loop to enable isothermal operation, which is often implemented as a cascade control loop with an inner pressure control loop and outer temperature control loop. The purpose of operating at low pressure is to minimize energy consumption and possibly to prevent product degradation.
2. A level control loop using the feed or product flow rate as manipulated variable. The objective is to obtain stable operation by rejecting disturbances of the system throughput and optimizing hydrodynamic conditions in the draft tube.
3. A production rate control loop of which the manipulated variable is the flow rate of a heating medium (*e.g.*, hot water, steam) and the controlled variable is the heat input to the system. The heat input may be split over different heat exchangers (*e.g.*, one heat exchanger in the fines dissolution loop and another one in the center of the draft tube or jacket) to decouple the fines destruction loop from the energy control loop. The objective is to obtain a certain slurry density (*i.e.*, third moment of the CSD) that matches a desired throughput and practical considerations related to slurry transport.
4. A fines destruction control loop of which the manipulated variable is the flow rate in the fines dissolution loop and the controlled variable is some characteristic of the CSD that depends on the amount of fines present in the system or supersaturation (*e.g.*, the number of crystals per unit volume of suspension). The objective is to obtain stable operation by avoiding oscillatory or unstable behaviour and obtaining a product with desired specification.

Similar control loops can be synthesized for different crystallization methods such as cooling crystallization or anti-solvent crystallization.

#### 4.4.2 Plug-flow Crystallizer

To improve flexibility to achieve control objectives, a tubular crystallizer with multiple cooling zones can be used (see Figure 4.3), which can also be achieved by creating a cascade of MSMPR crystallizers in series.<sup>71-73</sup> Typical physical realizations of tubular crystallizers are based on static mixers,<sup>74</sup> segmented flows,<sup>75-77</sup> or oscillatory flow around orifices<sup>78</sup> and are designed to create plug-flow conditions under overall low flow velocities, which would otherwise lead to laminar flow violating the desired plug-flow behaviour needed for uniform crystal quality. For an ideal plug-flow system, which can be obtained by promoting radial mixing and eliminating axial mixing in a tubular crystallizer or by placing a large number of MSMPR crystallizers in series, the length coordinate acts as a time coordinate when comparing to batch crystallization. Therefore, different temperature profiles can be implemented, which is comparable to implementing a dynamic temperature profile for a batch crystallization with fixed batch time. The latter is a well-studied topic in literature for several decades, which can be