1.3.4 Plug Flow Type Crystallization Process

There are several approaches available to provide all crystals with the same (or very similar) residence time which is the hallmark of a plug flow process. These include: (1) turbulent flow conditions, (2) oscillatory flow conditions, or (3) segmented/slug flow.

In order to achieve turbulent rather than laminar flow conditions in a simple long straight tube, the flow rate would need to be very large, resulting in small residence times. For crystals with a typical fast growth rate of 10^{-7} m s^{-1}, the residence time needed to make 100 μm crystals is 1000 seconds. For a 1 cm^2 section area of a 10 m long tube ($V = 0.001\ m^3 = 1l$) this indicates a flow rate of $\varphi = V_{cr}/\tau = 1$ mL s^{-1} which is much too low to induce turbulence in the tube. Therefore, either the PFC should be very long or the flow rate φ should be decoupled from the mixing in the tube.

This decoupling of flow rate and turbulence induction can be achieved by using an OBC (see Chapter 3). An OBC is a PFC equipped with periodically spaced orifice baffles creating well-mixed conditions in the individual cells between the baffles due to an oscillatory flow motion with specific frequency and amplitude superimposed on the net flow φ through the OBC (Figure. 3.5). The oscillatory flow in combination with the baffles give a good radial mixing to allow mass transfer between solution and crystals while the slow net flow φ gives a plug flow-like behavior in the OBC determining the average residence time of the crystals. Since the oscillation cannot achieve perfect plug flow some back-mixing of crystals will occur resulting in a narrow yet substantial residence time distribution of the crystals.

In the case of a PFC in the absence of seeding, primary nucleation is required to generate the initial distribution of crystals that grow out throughout their residence time while travelling through the length of the crystallizer. Details of primary and secondary nucleation, locality and also (non-ideal) backmixing are discussed in Chapter 3.

1.4 Continuous Seeding and Nucleators

1.4.1 Continuous Seeding

It is often taken for granted that primary nucleation processes cannot be well controlled. Therefore, seeding is commonly used in industry to get improved crystallization processes and product control. Perhaps one could see the wide application of seeding as a symptom of our inability to understand and control crystal nucleation.

The generation of seeding suspensions by dry or wet milling is nowadays routinely performed in industry. However, there are many challenges related to these seeding suspensions. Ultimately, to seed a continuous crystallization process a suspension of seed crystals of desired solid form, particle size and number density is needed. It should be able to grow well under suitable