Another approach of structure for PFCs is adopted from fluid (gas, liquid) reaction systems, which induces centrifugal forces through coiling the tubes (Figure 7.8b) leading to secondary flow profiles, so-called 'Dean vortices'.[44,112] Theoretically, these vortices intensify particle fluidization[113,114] and decrease wall scaling[115] through enhanced radial mixing, which leads also to narrower RTDs compared to straight tubes (Figure 7.8a).[116] The positive effect of coiling can be enhanced further by frequently bending the coils with an angle of 90° in a so-called 'coiled flow inverter' (CFI) crystallizer, demonstrated by Kockmann and co-workers (Figure 7.8c).[44,117,118] Due to the direction changes of the centrifugal forces, the Dean vortices reorganize sequentially, which breaks-up stagnant regions in the center of the vortices leading to RTDs close to ideal plug flow.[119] However, despite these promising studies of structures applied in tubular crystallizers, it needs to be emphasized that relatively high flow rates are still necessary to maintain particulate suspension.[28,44,117]

Similarly to the segmented flow mechanism, which provides mild and uniform mixing conditions that can help to reduce secondary nucleation, air-lift crystallizers apply also an inert fluid phase to induce mild mixing by sparging air bubbles in a column (*e.g.*, riser). Specifically, the air-lift mechanism creates a density difference with any column in an open connection to the riser that leads to liquid circulation without moving parts.[120,121] Although not realized in a continuous operation yet, this concept could be operated in a continuous flow setting simply by connecting a number of air-mixed compartments in series to approach plug-flow behaviour while maintaining the favourable properties leading to reduced secondary nucleation.[120]

Oscillatory baffled crystallizers (OBCs), a particular type of tubular crystallizer with plug flow capability, provide more sophisticated auxiliary structures compared to the aforementioned concepts, in order to intensify radial and axial mixing. OBCs are equipped with periodically spaced restrictions, generally spatial orifice baffles, with oscillatory motion of the fluid (Figure 7.9). The fluid motion can be generated either by periodic movement of the intrinsic baffles[122] or periodic motion of the fluid where

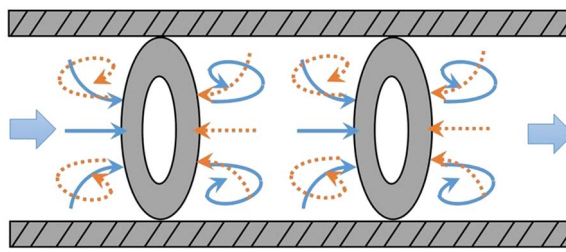

Figure 7.9 Schematic of oscillatory flow through periodically spaced spatial orifice baffles in oscillatory baffled crystallizers (OBCs). Reprinted from ref. 11, Copyright 2018, with permission from Elsevier.