INFLUENCE OF PULSATING FLOW ON DISPERSION IN HELICALLY COILED TUBES AND COILED FLOW INVERTERS

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Narrow Residence Time Distribution (RTD) is a desirable characteristic for many chemical engineering processes. However, when flow devices operate at low Reynolds number (characteristic for micro and millifluidic devices), significant fluid dispersion can occur. Narrowing RTD, while maintaining long space time, is currently a challenge. In this work, we addressed this by a combination of passive and active mixing techniques similar to those found in arterial flow. In the biomedical literature, plug flow is often assumed due to low axial dispersion in blood flow [1]. By reviewing this literature, we identified that the reduction in axial dispersion in arteries can be attributed to two factors, curvature of the blood vessels (Dean number in arteries reaches 260) [2] and pulsation of the flow [3]. Flow in curved geometries leads to formation of Dean vortices due to centrifugal force and is a well-established passive mixing technique [4]. At the same time, the introduction of a periodic variation in the flow rate (later on referred to as pulsation for simplicity) is an active technique which was first described in the fluid dynamics literature in the early 1960s [5]; however, it is yet to be utilized to its full potential within the millifluidic community. In process engineering, each of these techniques has been shown separately to have a positive effect and here we investigate the effect of utilizing both of these techniques simultaneously for narrowing RTD. The effect of two key dimensionless pulsation parameters, amplitude ratio (\(\alpha\), dimensionless amplitude of pulsation) and Strouhal Number (St, dimensionless frequency of pulsation), on RTDs was studied in Helically Coiled Tubes (HCTs) and Coiled Flow Inverters (CFIs). Additionally, the contribution of tube elasticity was also considered, since arteries are less rigid than the hard walled channels typically used in chemical engineering processes.

An experimental system was developed to conduct RTD experiments via step injection of tracer at the tube inlet and measurement of tracer concentration via UV-Vis spectroscopy at the tube outlet. Experiments without pulsation were also conducted for comparison. The results showed that in the presence of pulsation narrower RTDs are achievable. Furthermore, both increase in amplitude and frequency of pulsation have a positive effect on reducing dispersion. Separately, pulsation and curved geometries could achieve a maximum reduction of vessel dispersion number (dimensionless parameter that measures the extent of axial dispersion) from 190 to 110 and 125, respectively. When tube curvature and flow pulsation are combined, the vessel dispersion number was reduced by an order of magnitude (from 190 to 20). Numerical simulations supported the experimental results and showed that in the presence of pulsation there is a significant enhancement of radial mixing. Further consideration included the effect of tube elasticity on RTD. It was found that reduction in the RTD width in a harder material is more pronounced than that in a softer material. Overall, the results show a promising technique for reducing the RTD, which can benefit a variety of fields including process intensification, particle synthesis and continuous manufacturing.