Experimental Investigation of Fluid Mixing with Dean Vortices in Sinusoidal

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Enhancing fluid mixing is a common engineering challenge, especially in heat transfer applications. Mixing enhancement techniques often make use of structures to induce vortex formation, however these can be complex to manufacture and require significant additional pumping pressure. A possible alternative is the generation of Dean vortices by turning of the mean flow. Extensive research has been conducted in Dean vortex formation, and its mixing properties, at the macroscale (e.g., geophysical flows, such as sediment transport in rivers) and microscale (e.g., biological flows or mixing in microfluidics), but there is a research gap at intermediate Reynolds numbers, which is crucial for many engineering applications. This study aims to address that gap. The objective of this study is to investigate enhanced fluid mixing through Dean vortex formation in the context of solar collectors. This research will focus on optimizing a wavey-channel geometry to maximize mixing performance in rectangular cross-section channels.

Solar collectors require low-pressure drop designs with cheaply manufacturable geometries. They operate at low Reynolds numbers and hence cannot utilize multi-pass heat exchangers. Therefore, enhancing mixing through geometry-induced secondary flows is essential as it does not contribute much to pressure drop in the channel.

We will initially investigate sinusoidal-shaped rectangular cross-section channels, as these are easily manufacturable with flow dividers in a larger rectangular channel. The curved geometry induces Dean vortices, a specific type of secondary flow arising from centrifugal forces at channel bends. In particular, spanwise vorticity formed in the boundary layers undergoes vortex tilting into streamwise vorticity, when a wall-normal turn is applied.

This study will utilize state-of-the-art experimental facilities at the University of Alberta, utilizing a 3D printed channel with multiple planes of optical access, through which multi-camera flow diagnostics can be performed. In particular, 3D-PTV will be utilized here, due to its inherent advantages in computing the Cauchy-Green strain tensor.

The mixing efficiency of the sinusoidal channels will be quantified using Finite-Time Lyapunov Exponents (FTLE). While FTLE has been primarily applied to identify Lagrangian Coherent Structures (LCS), such as in ocean pollution tracking and weather prediction, it can also be applied to quantify mixing performance. FTLE ridges will be used to measure fluid stretching and folding, serving as a quantitative metric for mixing intensity within the channel. A repelling FTLE ridge, for example, identifies a point where adjacent fluid elements tend to end up in significantly different positions downstream, which is precisely the mixing problem.

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