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The use of dimensionless groups to analyse the mixing of streams with large density differences in sub- and supercritical water

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HIGHLIGHTS

- Dimensionless groups are used to characterise mixing.
- Colour matrices are used to visualise trends in mixing behaviour.
- Pseudo fluid mixing is compared to supercritical fluid mixing.
- The approach is applied to considerations for reactor scale-up.

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ABSTRACT

As water approaches supercritical conditions, it undergoes sharp changes in density, dielectrics, surface tension and viscosity. Thus, the mixing of supercritical and sub-critical water streams can be potentially impacted by the vast differences in the properties of each fluid.

The reactor configurations employed have been characterised using previously reported experimental techniques for assessing the mixing performance in systems with large density gradients. The results obtained have been used to construct a model framework characterised by the turbulence, relative stream momenta and relative buoyancy of the different streams. This has been applied to rationalise the observed reaction outcomes.

The results in this paper demonstrate the need for caution when comparing sets of data from supercritical water reactors, undertaken with differing reactor geometries.

1. Introduction

In 2005, Hessel reviewed mixing principles in micro mixers and noted that for turbulent flow to exist where viscous dissipation occurs, there must be sufficient energy to overcome the viscous forces [1]. This energy can be kinetic or potential in nature, and can be exploited through convective flow and buoyancy respectively. These effects can be characterised by dimensionless numbers. For example, turbulence is characterised by the Reynolds number, which is the ratio of convective to viscous forces. The ratio of buoyant to viscous forces is characterised by the Grashof number and the ratio of convective to buoyant forces by the Richardson number. Otherwise, for laminar flows where the energy is insufficient to overcome viscosity, mixing relies on maximising the interface area and on diffusion, which is aided by small length scales and by temperature. The Peclet number (the rate of advection to the rate of diffusion) or the mass Fourier number (residence time/diffusive mixing time) are dimensionless numbers used to characterise such convective/diffusive flow and mixing. For laminar, uniaxial flows, the mixing length L_m is proportional to the product of the Peclet number and the channel diameter. In such laminar flow systems mixing times can be reduced by maximising interfacial surface area and minimising the length scales for mixing. Thus, in a tee-piece mixer, it is important to achieve effective jet penetration of one stream into the other, and this requires that the jetting stream has sufficient momentum relative to the secondary stream.

The mixing efficiency of tee-piece mixer arrangements have been extensively studied, as in Chilton and Genereaux [2], Ger and Holley [3], Forney and Kwon [4], Reed And Narayan [5], Maruyama, Suzuki and Mizushina [6], Forney and Lee [7], O'Leary and Forney [8], Tosun [9], Cozewith, Busko [10] and Sroka [11].

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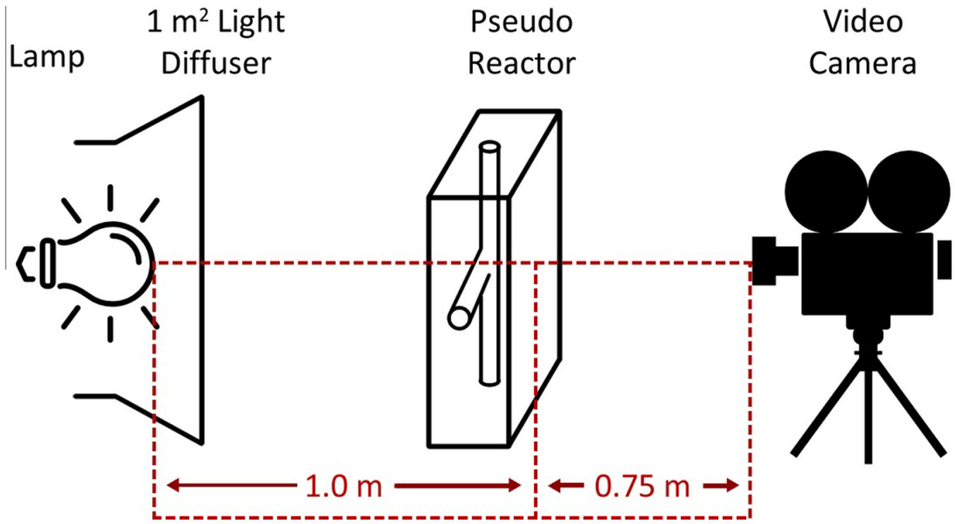

Fig. 1. Experimental configuration for capturing mixing video images for subsequent light absorption imaging.

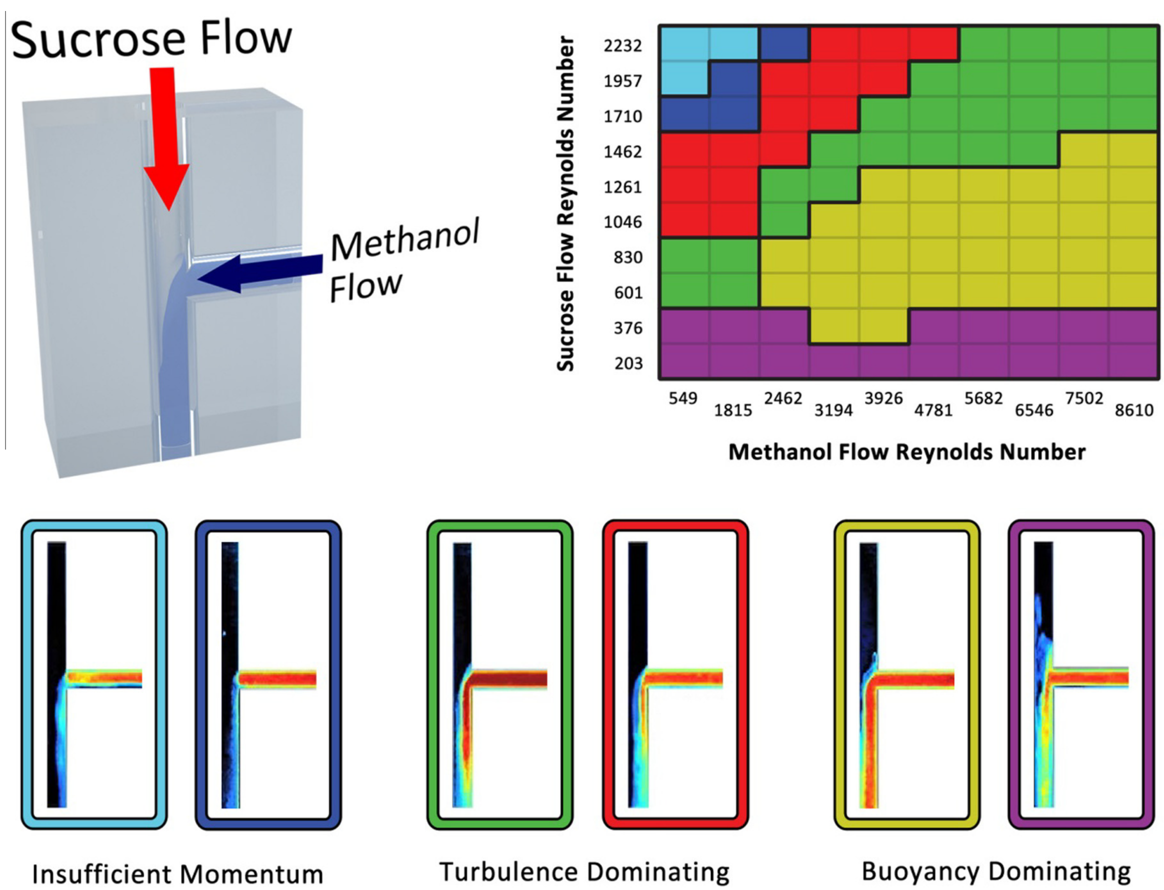

Fig. 2. Use of model fluids to characterise mixing regimes. Regimes are assessed and mapped onto an inlet Reynolds number matrix. Each mixing regime is illustrated with Light Absorption Imaging (see text).

Forney, Lee, Cozewith and Busko provide good summaries of the works prior to their publications.

In these studies, a variety of parameters were used to characterise the efficiency and extent of the mixing. These were generally expressed in dimensionless form and can be characterised as those describing the effect of turbulence such as jet and pipe Reynolds numbers, those related to the relative momenta of the streams such as velocity ratio, diameter ratio, flow rate ratio, density ratio and those describing the relative buoyancy of the streams such as densitometric Froude number and density ratio.

Work on the synthesis of metal oxide nanoparticles in supercritical water showed the importance of the reactor configuration