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Xuereb

► To cite this version:

Nur Azmina, Hadirah Binti Hamdan, Joelle Aubin, Martine Poux, Catherine Xuereb. Scale-up strategies for the blending of miscible liquids with large viscosity differences. 12th European Congress on Chemical Engineering, Sep 2019, Florence, Italy. hal-02373140

HAL Id: hal-02373140

<https://hal.science/hal-02373140>

Submitted on 20 Nov 2019

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Scale-up strategies for the blending of miscible liquids with large viscosity differences

Nur Azmina Hadirah Binti Hamdan¹, Joelle Aubin^{1*}, Martine Poux¹, Catherine Xuereb¹

¹ Laboratoire de Génie Chimique, Université de Toulouse, CNRS, Toulouse, France

*Corresponding author: joelle.aubin@ensiacet.fr

Highlights

- $N.t_m$ versus Re^* allows identification of stirrer or added liquid regimes
- Re^* does not allow $N.t_m$ to be replicated across scales
- Impeller tip speed or specific power replicate $N.t_m$ better across scales

1. Introduction

Blending of small quantities of additives that have higher viscosity and/or density than the bulk is a common operation in the process industries (personal care, food, water treatment), it is however a difficult task. A few studies have addressed the subject and it was found that a modified Reynolds number, $Re^* = \rho ND^2/\mu_a$ allows identification of whether the added liquid has an effect on mixing time compared with turbulent blending [1, 2]. [2] also looked the effect of scale on blend time in these systems and found that large viscosity differences may affect small scale more than in large scale vessels and that depending on the scale the operating regimes (stirrer controlled or added liquid controlled) may change. Whilst correlating dimensionless mixing time ($N.t_m$) with Re^* may be useful for determining if turbulent blending correlations can be used for these systems, it does not provide guidance for scaling-up or down. The objective of this work is to identify which stirred tank operating parameters should be kept constant to replicate blending miscible liquids with large viscosity ratios across equipment scales.

2. Methods

Experimental set-up. The tanks employed in this work are dish-bottomed cylindrical tanks with dimensions, $T_1 = H_1 = 0.19$ m and $T_2 = H_2 = 0.6$ m, which correspond to volumes of 5 L and 171 L, respectively. The tanks are equipped with four equally spaced Perspex baffles of width $w = T/10$ placed 90° to each other. An axial flow Mixel TT impeller ($D = T/2$) used to blend the liquids with an off-bottom clearance of $C = T/3$, where C is defined as the distance from the vessel bottom to the lowest horizontal plane swept by the impeller.

Fluids and operating conditions. The fluid in the bulk of the tank was tap water at 20°C. The impeller speed was in the range 130-400 rpm for the 5 L tank and 90-185 rpm for the 171 L tank, which correspond to fully developed turbulent flow. The viscous additive was a solution of carboxymethyl cellulose (CMC) at concentrations ranging from 1% w/w to 7% w/w. For CMC solutions with concentrations less than 2% w/w, the rheological behaviour was quasi-Newtonian and the viscosity ranged from 0.1 to 1.3 Pa.s. However, for higher concentrations, the additive had an increasingly shear-thinning behaviour. The apparent viscosity at 10 s⁻¹ (approximate shear

rate in injection zone) was taken as a reference, being 11 Pa.s, 35 Pa.s, 580 Pa.s and 820 Pa.s for 4-7% CMC solutions. Nevertheless, the amount of viscous fluid added to the bulk was relatively small, being 1 mL or 10 mL, and this was assumed to have no impact on the turbulent flow regime in the tank.

Mixing time measurements. Macro mixing time was determined using a coloration-decolouration method based on an oxido-reduction between sodium thiosulfate and iodine. The water in the tank is initially coloured brown with an iodine solution. CMC is dissolved in sodium thiosulfate and this solution is then injected into the bulk at the liquid surface using a large syringe, midway between the shaft and the tank wall and midway between two baffles. The sodium thiosulfate solution decolours the brown iodine solution. The macro mixing time is evaluated visually and is determined as the time taken for all of the iodine to have disappeared. For each operating condition, the experiment was repeated four times and an average value was used for analysis.

3. Results and discussion

Figure 1 (left) shows a constant dimensionless mixing time in the 5L tank for $Re^* \geq 10$ corresponding to the stirrer controlled regime, whilst for decreasing values of Re^* lower than this limit, $N.t_m$ increases, which corresponds to the added liquid controlled regime. Indeed, for viscosity ratios $\mu_a/\mu_b < 10^3-10^4$, mixing time may be predicted by conventional correlations for turbulent blending. It is noted however that this does not hold when working in the 171L tank, suggesting that Re^* may not be the appropriate scale-up invariant. On the other hand, for a given viscosity ratio, $N.t_m$ is better replicated at both scales when impeller tip speed (Figure 1, right) or power per unit volume are kept constant, at least for lower viscosity ratios.

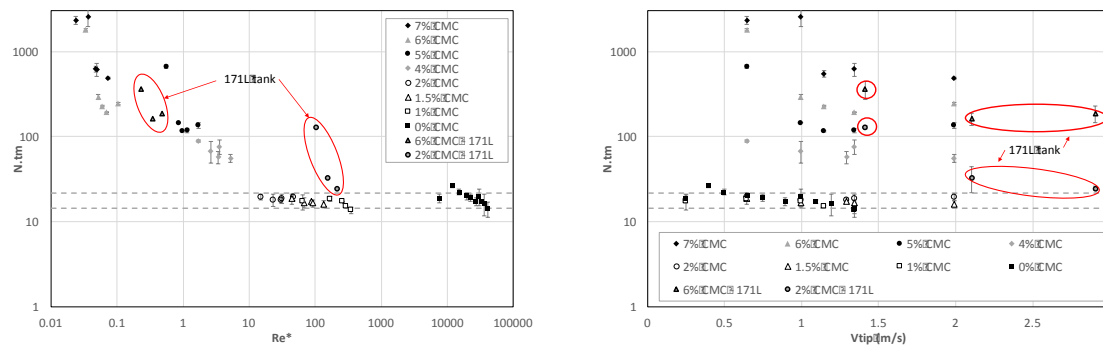


Figure 1. Dimensionless mixing time in the 5L and 171L tanks as a function of Re^* (left) and impeller tip speed (right).

4. Conclusions

Mixing time is unaffected by additive viscosity for $\mu_a/\mu_b < 10^3-10^4$, however it increases significantly for higher ratios. Also, $N.t_m$ is not constant over the entire turbulent flow regime as the viscosity ratio increases. $N.t_m$ correlates better with the modified Re^* based on the viscosity of the added liquid although Re^* does not seem to correctly replicate $N.t_m$ across scales when at large viscosity ratios. $N.t_m$ appears to better replicated at both scales at constant impeller tip speed or power per unit volume.

References]

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