Proceedings of the 8th World Congress on Momentum, Heat and Mass Transfer (MHMT'23)
Lisbon, Portugal – March 26 – 28, 2023
Paper No. ENFHT 147
DOI: 10.11159/enfht23.147

Power Consumption Analysis for Gas Dispersion in a Dual Coaxial Mixer Containing Yield-Pseudoplastic Fluids via Experimental and Numerical Approaches

Forough Sharifi, Ehsan Behzadfar, Farhad Ein-Mozaffari
Department of Chemical Engineering, Toronto Metropolitan University
350 Victoria Street, Toronto M5B 2K3, Canada
Forough.sharifi@ryerson.ca; Behzadfar@ryerson.ca; fmozaffa@ryerson.ca

Extended Abstract

Gas dispersion in non-Newtonian fluids is broadly used in the chemical, biochemical, and pharmaceutical sectors, and wastewater treatment facilities [1,2]. In this respect, the design of the aerated mixing tanks with a greater-than-one aspect ratio (i.e., the ratio of fluid height to tank diameter) is highly favored to improve the homogeneity of the final products [3]. When compared to single-impeller mixing systems, employing multiple impellers on the same shaft significantly contributes to uniformly distributing the shear within the mixing tank as well as enhancing gas residence time, gas-liquid contact, and mass transfer per power consumption [4,5]. However, in spite of the advantages of multiple impellers for an aerated mixing tank with an aspect ratio of more than one, recent studies have revealed that the use of multiple impellers on the same shaft failed to properly disperse gas throughout the mixing tank containing high-viscosity non-Newtonian fluids [6]. In previous studies, coaxial mixers comprised of double central impellers in combination with an anchor have been recommended as an efficient design for mixing highly viscous non-Newtonian fluids in which the high-speed central impellers generate intense shear and fluid motion while the low-speed anchor mostly rotates the bulk fluid and cleans the tank wall [3, 7]. Analysis of the power consumption of aerated mixing systems plays a significant role in finding energy-efficient operating conditions. Assessment of the power consumption for gas dispersion in pseudoplastic fluids has been conducted in previous studies [8]. However, according to our thorough literature review, no study has been carried out to evaluate the power consumption of aerated dual coaxial mixers containing pseudoplastic fluids possessing yield stress. The purpose of this study was to assess the power consumption of the aerated dual coaxial mixer under various operating conditions, including central impeller speed, anchor speed, aeration rate, rotational mode (i.e. co-rotating and counter-rotating), and pumping direction (i.e. downward and upward) of the central impeller. To achieve this objective, both un-gassed and gassed power consumptions were measured experimentally and the assessment of the complex flow hydrodynamics within the aerated coaxial mixer as a function of the operational conditions was conducted using a validated CFD model. It was observed that the contribution of the anchor power to overall power consumption was far less than that of the central impellers. The counter-rotating mode consumed greater power than the co-rotating mode, which was explained by the opposing flow produced by the central impeller rotation. Interestingly, it was discovered that in the counter-rotating mode, the anchor power rose with increasing the central impeller speeds, however, an opposite trend was observed for the co-rotating mode. According to our findings, the relative power demand (RPD) in the counter-rotating mode was higher than that in the co-rotating mode. In the co-rotating mode, the higher RPD values were acquired for the upward pumping coaxial mixer. The obtained results for RPD were in accordance with the size of gas cavities formed around the central impellers such that the lowest RPD was attained for the largest cavity size. Using the volume rendering contours obtained from the computational fluid dynamics (CFD) method, it was shown that larger cavities were created in downward pumping directions in both co-rotating and counter-rotating modes. Finally, the applicability of Jamshidzadeh et al.'s correlation was investigated under different operating conditions. It is noteworthy that the yield stress term was incorporated into this correlation to account for the Herschel-Bulkley fluids. This correlation was successful in predicting the impact of speed ratio and different configurations on the power consumption of the investigated dual coaxial mixer.

References

[1] Doran, P. M. (2009). Bioreactors, stirred tank for culture of plant cells. Encyclopedia of Industrial Biotechnology: Bioprocess, Bioseparation, and Cell Technology, 1-35.

[2] Zhou, T. C., Zhou, W. W., Hu, W., & Zhong, J. J. (2009). Bioreactors, cell culture, commercial production. Encyclopedia of industrial biotechnology: bioprocess, bioseparation, and cell technology, 1-18.

[3] Jamshidzadeh, M., Kazemzadeh, A., Ein-Mozaffari, F., & Lohi, A. (2020). Intensification of gas dispersion in pseudoplastic fluids with coaxial mixers. Chemical Engineering and Processing-Process Intensification, 155, 108058.

[4] Puthli, M. S., Rathod, V. K., & Pandit, A. B. (2005). Gas–liquid mass transfer studies with triple impeller system on a laboratory scale bioreactor. Biochemical engineering journal, 23(1), 25-30.

[5] Bao, Y., Yang, J., Wang, B., & Gao, Z. (2015). Influence of impeller diameter on local gas dispersion properties in a sparged multi-impeller stirred tank. Chinese Journal of Chemical Engineering, 23(4), 615-622.

[6] Liu, B., Xiao, Q., Gao, P., Sunden, B., & Fan, F. (2020). Investigation of gas–liquid dispersion and mass transfer performance of wide-viscosity-range impellers in water solutions of xanthan gum. Chemical Engineering Research and Design, 154, 60-69.

[7] Jamshidzadeh, M., Ein-Mozaffari, F., & Lohi, A. (2020). Local and overall gas hold-up in an aerated coaxial mixing system containing a non-Newtonian fluid. AIChE Journal, 66(11), e17016.

[8] Jamshidzadeh, M., Kazemzadeh, A., Ein-Mozaffari, F., & Lohi, A. (2020). Analysis of power consumption for gas dispersion in non-Newtonian fluids with a coaxial mixer: New correlations for Reynolds and power numbers. Chemical Engineering Journal, 401, 126002.