Contents lists available at SciVerse ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Scalar mixing in a turbulent stirred tank with pitched blade turbine: Role of impeller speed perturbation

*Somnath Roy, Sumanta Acharya**

Mechanical Engineering Department, Louisiana State University, Baton Rouge, LA 70803, United States

ABSTRACT

Mixing of a passive scalar inside a pitched blade turbine (PBT) impeller stirred tank (STR) is studied using large-eddy simulation (LES) coupled with the immersed boundary method (IBM) for resolving moving interfaces. Mixing time is calculated based on the 95% homogenization of the scalar over the entire tank volume. Growth rate of the unmixed tracer volume is observed in order to identify the effects of low frequency macroinstability (MI) oscillations. Mixing time is significantly reduced when the STR flow is perturbed using a step-change in the impeller speed with a specific MI frequency. The enhancement in turbulent kinetic energy and changes in mean flow field due to the perturbation is observed. The spatio-temporal behavior of the large-scale mixing structures for the fixed impeller-speed case and the perturbed case are compared. The mechanism of mixing enhancement is further explored by observing dynamic changes in the concentration distribution and the velocity field over a perturbation cycle. Penalty in power requirement due to perturbation is calculated.

Keywords: Stirred tank; Turbulence; Mixing; Perturbation

1. Introduction

Many commonly used plastics and polymers are derived from hydrocarbon processing techniques in the chemical industry. Some examples include: the non-metallic components in an automobile, tennis shoes, packaging materials for food and other products, electronic components including cases, CD disks, wire and cable coatings, fibers for super-absorbent baby diapers and foam products including acoustical and thermal insulating materials such as those found in residential and commercial building materials. Many of these polymer products are manufactured in stirred tank reactors (STR) where impellers are used to mix reactants to form products. Due to high viscosities, diffusion time scales are large compared with reaction and polymerization kinetics. Therefore, an efficient mechanical mixing process is extremely important for better production rate. Mixing technologies are estimated to produce several hundred billion dollars of polymer-based products annually. Improvements in existing technologies can therefore potentially translate to several billion dollars in annual cost savings. U.S. chemical industry yields nearly 350 billion dollar products via STR applications and suffers around $10 billion dollars of annual loss due to inefficient operation of these devices (Paul et al., 2004). Better design of STRs requires a detailed understanding of the associated flow behavior which involves identification of large-scale mixing structures and the dynamics of their growth and dispersion with the inherent instabilities of the STR flows.

In stirred tank bioreactors, the specific reactants such as the substrate and living cells are brought in close contact with the correct stoichiometry so that the necessary biological reactions can occur. Examples of such reactions include biomass production and synthesis of biological products from DNA molecules to biologically active proteins. The dispersal of the synthesized products including the toxic products, inhibitors and secondary products is also of interest in the mixing process. Industrial fermentation is another application where stirred tanks play a major role and where the mixing process is vital to the right product yield. For example, concentration gradients can induce overflow metabolism in the micro-organisms in the culture and lead to locally depleted oxygen concentrations and non-homogeneity resulting in unexpected chemistry. Starvation conditions, non-uniform concentrations and temporal oscillations have all been linked

* *Corresponding author.*
E-mail address: acharya@me.lsu.edu (S. Acharya).

Received 16 January 2011; Received in revised form 5 September 2011; Accepted 17 October 2011
0263-8762/$ – see front matter © 2011 The Institution of Chemical Engineers. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.cherd.2011.10.009