CFD Analysis of Two Phase Flow with a Prediction of Torque Demand of a Bi-Lobe Rotor of a Mixing Chamber

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Abstract: An attempt to study the fluid dynamic behavior of two phase flow comprising of solid and liquid with nearly equal density in a geometrical case that has an industrial significance in the areas like processing of polymers, food, pharmaceutical, paints. In this work, crystalline silica is considered as the dispersed medium in glycerin. In the CFD analysis carried out, the two phase components are considered to be premixed homogeneously at the initial state. The flow in a cylinder that has an axially driven bi-lobe rotor, a typical blender used in polymer industry for mixing or kneading to render the multi-component mixture to homogeneous condition is considered. A viscous, incompressible, isothermal flow is considered with an assumption that the components do not undergo any physical change and the solids are rigid and mix in fully wetting conditions. Silica with a particle diameter of 0.4 mm is considered and flow is analyzed for different mixing fractions. An industry standard CFD code is used for solving 3D-RANS equations. As the outcome of the study the torque demand by the bi-lobe rotor for different mixture fractions which are estimated show a behavioral consistency to the expected physical phenomena occurring in the domain considered.

Keywords: Multiphase Flow, Polymer Mixing, Viscous Flow, Viscous Torque

1. Introduction

Mixing is an essential process in many industrial applications and polymer industry is one such application. Dispersion and distribution of the components are the main criteria considered for mixing. The process is dominated by a strong solid liquid interaction in the mixing chamber. Mixing is performed by stirring by special purpose rotors. Bi-lobe, shown in Fig. 1 is one of the types of rotors widely used for mixing and is considered for the analysis in this study. Torque required to drive the rotor is one of the important the design parameter of this equipment and the torque largely used up in the mixing process of the fluids with high viscosity. The flow analysis is used get the derived parameter torque estimated by the viscous drag encountered by the rotor. In the present work, as a first step of the study, a set of non-transforming two phase components are considered for the modeling and behavior of the mixing device is predicted and analyzed.

2. Problem Statement

Most of the works reported on two phase flows particularly on solid-liquid systems in stirred vessels have led in capturing a range of empirical formulations of the observed behavior. The crucial drawbacks in empirical approaches are in their limitation of having narrow application band and are not generic to be used for design optimizations and to have a fairly dependable empirical model it calls for large information capture, time and cost [1]. A bi-lobe as the rotor in a cylindrical stator, as shown in the Fig. 1 is considered for the present work. Meshing has been done using blocking strategy involving structured and controllable grids of the sizes around 0.2 to 0.4 million nodes. Since the domain of computation involves a rotor over which the flow field is to be captured, moving mesh is adopted for the analysis. Crystalline silica used as the solid particles, premixed with glycerin is set to be filled completely in the cavity of the mixing chamber and varying silica fractions are used for the analysis. Standard continuity and momentum equations formulated for 3-D RANS approach is adopted and second order upwind scheme is used for the numerical solution. Turbulence model k-ω is considered in the analysis that has provided the nearest predictions as compared to the visualization experiments and with the flow fields observed to have large re-circulating flows and large velocity gradients.

3. Results and Discussion

The solutions have been obtained considering a four decade fall of the residuals as the criteria of convergence. Quasi-steady approach is used with solutions at every 0.5° of rotation of the bi-lobe rotor. The results of grid independence show that 0.2 million nodes are adequate for capturing the flow field and a doubling of the mesh nodes have produced the results within 3.5% of deviation, as can be seen in Fig. 2. The analysis is carried out with a varied silica volume fraction in the range of 0.2 to 0.97. For the present study the rotor is considered for a constant rotational speed of 50 rpm, driven counter clockwise. The flow patterns captured provide a good compliance to a typical cavity driven flow indicating that the moving meshes have captured the solutions properly. Flow pattern in one of the angular snap-shots with a silica fraction of 0.4 is shown with in stream lines plots in Fig. 3. The estimated

torque due to the viscous drag on the bi-lobe rotor is obtained from the flow field and is shown in Fig 4. One of the acceptable part of the torque predictions is that while the torque demand reduces indicating reduced viscous drag with the added solid component and at the nearing extreme condition of silica fraction of 0.97, the torque demand shows an increasing trend indicating that the solid friction factor is dominating the torque component – a physically acceptable argument indicating that the solution obtained is consistent.

4. Conclusion

Numerical Investigations have been carried out to understand the multi-phase behavior in an industry standard bi-lobe based mixing device. The results of the study has revealed good insight in to the mixing and the torque demand for the process and is considered as a significant step towards understanding and optimization of design studies of such industrial mixers.
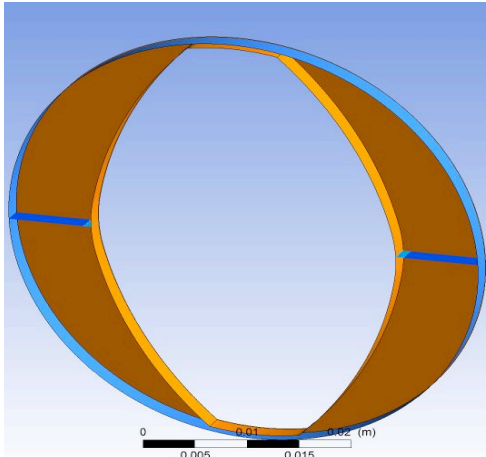

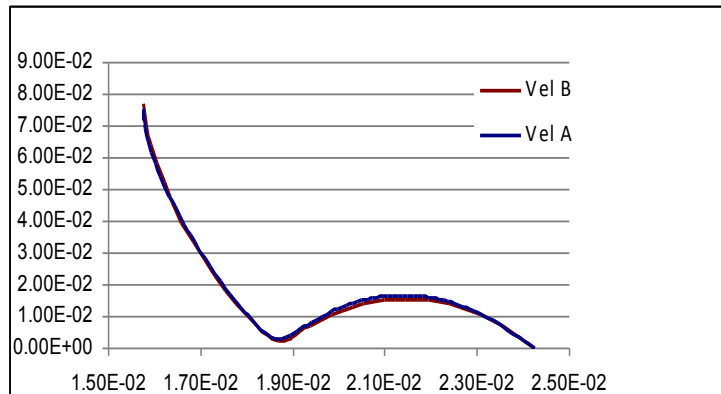Fig. 1. A Bi-lobe Rotor in a Cylindrical Stator

Fig. 2. Variation in velocities with 0.2 and 0.4 million nodes with distance on x axis and velocity on y axis
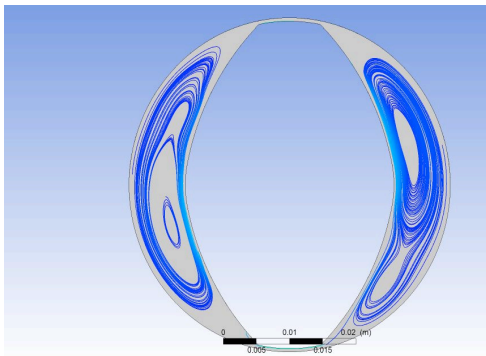

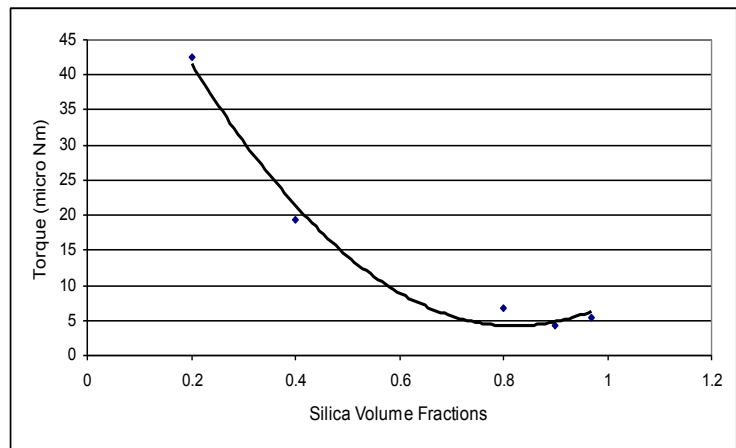Fig 3. Stream Line Plot with 0.4 fill fraction

Fig. 4. Estimated torque demand with varying solid fractions in the two phase flow

References:

[1] Feng Wang et.al 'CFD Simulation of Solid-Liquid Two-Phase Flow in Baffled Stirred Vessels with Rusthton Impellers', Third International Conference on CFD in the Minerals and Process Industries, CSIRO, Melbourne, Australia, 2003