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

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Abstract: The work is an effort to study the fluid dynamic behavior of two phase flow comprising of solid and liquid with nearly equal density in a specialized geometrical case that has an industrial significance in the area of processing of polymers in applications related to food processing, pharmaceuticals, paints etc. In this work, crystalline silica with a mean diameter of 50 microns is considered as the dispersed medium in liquids of high viscosity, honey and glycerin. In the study carried out, the two phase components are premixed homogeneously at the initial state. The study made uses flow in a cylinder that has an axially driven bi-lobe rotor, identical to a typical blender used in polymer industry for mixing or kneading used in rendering the multi-component mixture to a homogeneous condition. In the CFD analysis made, 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 are mixed in fully wetted conditions. The study is carried out for different mixing fractions and at different speeds. An industry standard CFD code that uses 3D-RANS approach is used for the study. As the outcome of the study the torque demand by the bi-lobe rotor for different mixture fractions are estimated that has shown a behavioral consistency to the expected physical phenomena occurring in the domain considered. The results of the computation are validated using experiments. The outcome of the study is expected to of significance for design of the industrial polymer mixers.

Keywords: Multiphase Flow, Viscous drag, Torque, Slurry.

1. Introduction

In a large fraction of the operations in the field of chemical industries, mixing and dispersion of solids in liquids is involved [1]. Mixing forms the initial stage in the processing and is carried-out in mechanically agitated equipments such as single or twin screw extruders. 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 is one of the types of rotors widely used for mixing and is considered for the analysis in this study. It is expected to perform the task of kneading comprising of wetting and mixing. Wetting is process of completely soaking of the suspended solid particle in the continuum fluid and mixing is allowed to achieve the homogeneity. 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 torque demand can also be an indicator to the degree of mixing. The CFD analysis is used for the torque estimation by the viscous drag and the pressure drag encountered by the rotor. In the work presented, a set of non-transforming two phase components are considered for the modeling and behavior of the flow and mixing in the device is predicted and analyzed. The result of computation is validated using experiments and found to have a general agreement.

2. Summary of the Analysis

Many reported work carried out on two phase flows particularly on solid-liquid systems in stirred vessels have led in capturing of a range of empirical formulations of the observed behavior. One of the crucial drawbacks in the empirical approaches is in their limitation of covering narrow application band and thereby not generic enough to be used for design optimizations and to have a fairly dependable model it calls for large set of trials, time and cost [2]. Mathematical modeling and simulating the flow would be cost effective to obtain the parameters of interest and adds to capabilities of efficient designs. CFD analysis is recognized to be much economical as compared to building of multiple prototypes and testing their performance [3]. A configuration with a bi-lobe as the rotor, as shown in the Fig.1, is set to operate in a cylindrical stator, is considered for the present work and the modeling is meshed using multi-block strategy involving structured and controllable mesh. Since the domain of computation involves a rotor over which the flow field is to be captured, moving mesh is deployed for the analysis. Crystalline silica with a mean size of 0.05mm is used as the solid particles, premixed with two selected liquids honey and glycerin and is set to be filled completely in the cavity of the mixing chamber. Varying fractions of silica are used for the study to obtain the behavior pattern. Bulk viscosities of slurries with glycerin and honey are found using a Brookfield viscometer. 3-D RANS approach is adopted with second order upwind scheme for the numerical solution. From the CFD results of the computation, the torque demand is obtained as applicable to the rotor in driving the slurry fill fraction used at a preset speed.

Fig 1: Bi-lobe Rotor

3. Geometry and Computational Details

3.1 Details of Geometry

Surface modeling of the geometry considered is made using Catia V5 tool. Details of geometry are shown in Fig. 2. Bi-lobe rotor is at the geometric center of the cylindrical chamber with equal clearances of 0.5mm as seen in Fig. 2. The free volume between the bilobe rotor and the chamber forms the fluid domain for CFD analysis. The thickness of the lobe considered is 10mm and tested to rotate in the chamber freely in the mechanical arrangement.

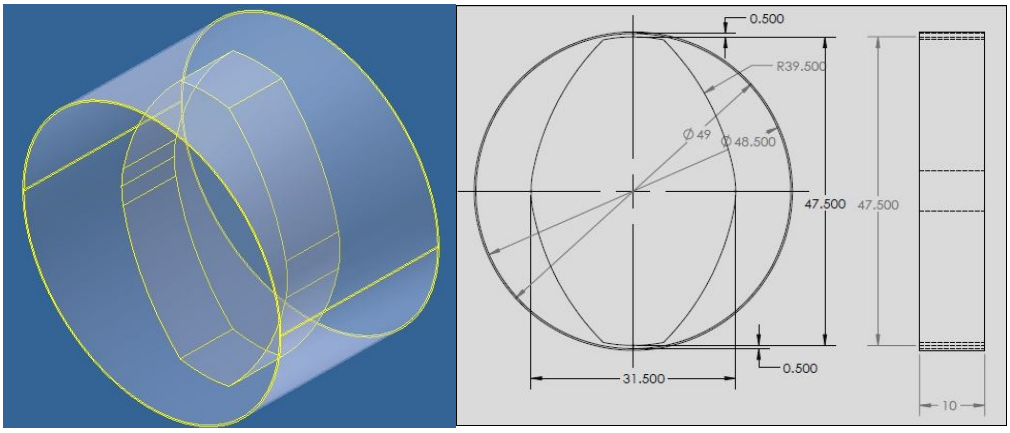

Fig. 2: Geometrical Details of Bilobe in the Chamber

3.2 Computational Details

Structured mesh is generated using ANSYS ICEM using multi-block strategy. Clustering of meshes was carried out with the smallest mesh size set at 0.04 mm next to the moving wall and to the bilobe rotor. Study of grid-independence to the solution was carried-out with three different mesh strengths of around 0.1, 0.2 and 0.3 million nodes. It was found that mesh with 0.2 million is adequate and optimal and this mesh, shown in Fig. 3 is used for all other cases for the parametric study of the CFD analysis. The geometrical components include the inlet, outlet, the bilobe rotor and the stationary chamber.

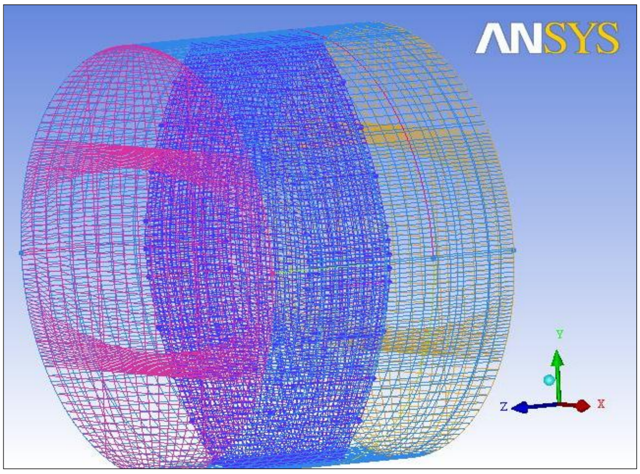

Fig. 3: Structured Mesh Bilobe Rotor in the Chamber

Ansys CFX-12.0 is used as the flow solver. Inlet and the outlet are situated at a distance of 10 mm on either side from the bilobe surface. Inlet, outlet and the chamber are imposed with stationary, no-slip wall condition. Bilobe rotor is imposed with no-slip moving wall condition. Bilobe rotor is set at different speeds for different fill fractions of silica in honey and glycerin.

3.3 Experimental Details

Silica crystals, honey and glycerin are having nearly same bulk density of around 1.3 g/cc. This choice is made to reduce the effect of density variation in the mixture and their influence in the flow. Silica is mixed in 5%, 10%, 15%, 20%, 25%, and 30% by volume in the honey and glycerin forming the slurry. The fraction of solid was limited to 30%, as there was no wetting beyond 30% and the computations and experiments were carried-out up to this fill fraction of silica. Bulk viscosities of the slurries are measured using a Brookfield viscometer. The photographs of experimental set-up of the mixing chamber with the bilobe rotor and the power supply are shown in Fig. 4.

Fig. 4: Experimental Set-up

The experimental set-up was found to require precision alignments in view of the small clearances between the bilobe and the casing of the cavity. The speed of the rotor, driven by the DC geared motor (gear ratio of 1:90) operating on 12volts, was controlled by varying the input voltage to the motor with a variable and regulated DC power supply. During the experiments the top of the chamber is closed with a metallic lid and fastened. Required speeds of the bilobe rotor were diligently set using a tachometer. Voltage and the current drawn by the motor at each speed of the rotor were noted.

Quiescent current of the motor and threshold voltage for the run under dry and no-load condition were noted and the equivalent quiescent torque obtained from this was used as the offset for the torques measured in loaded conditions. This experiment was carried-out for different fill fractions of the solid particles and for both the liquids mentioned.

4. Results and Discussion

In the first part of the investigation the bulk viscosity of the well mixed slurry was measured and it was found as is shown in plot at Fig.5. Expectably the viscosity increases with the solid fraction in the liquids. However the enhanced growth in the trend appears explainable on the basis of the inter-particle gaps reducing, the shear forces tend to increase. However, a closer investigation is required to qualify this behavior. One part of the consistency observed includes that both the liquid bases produce a trend with similarity indicating that the phenomenon is consistent and are reproducible.

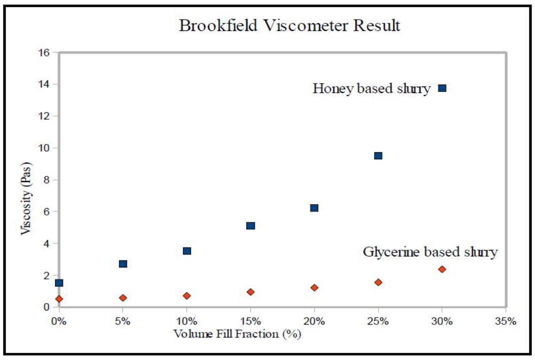

Fig. 5: Viscosities of Slurries

One can see from the plot (in Fig. 5) that increased silica content results in increased viscosity. It was observed that in the cases of both liquids beyond silica fraction of 30%, there was no wetting of silica particles and the study carried out is confined to this limit.

From the measurement of the torque demand made a fixed speed for different mix fractions, the trend in both the liquid bases as shown in Fig 6 and Fig.7 have a closer match to the viscosity trend and is expectable because the torque demand is directly accountable to energy dissipation to the mixture that is proportional to the viscosity. One observation that can be made from this is that with components of the phases exhibiting no changes and the similarity in the trends between two liquids indicate that the flow is largely Newtonian from the first look.

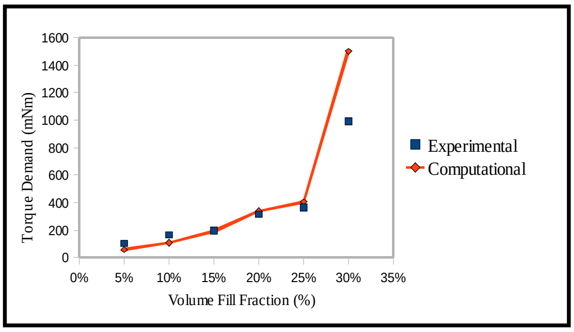

Fig. 6: Torque demand with Honey base

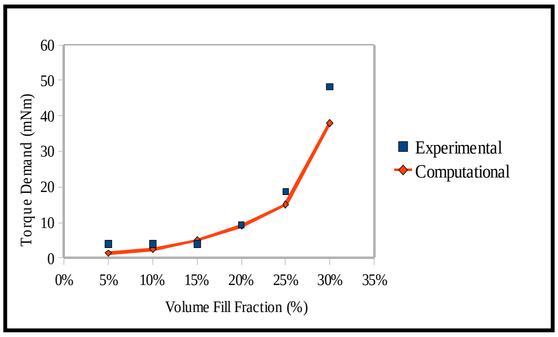

Fig. 7: Torque demand with Glycerin base

It is important to note that the CFD analysis made, the assumption that the bulk viscosity is constant for a mixture that provides a close match to the experimental data as can be seen in the Figs 6 and 7 suggest that the assumption of Newtonian flow is valid for this case.

In the continued set of experiments, the torque was measured at different speeds of the rotor to see if the trend has any universal behavior. The different mixture fractions were subjected to different speeds in the confined stator. The plots of the variations in the torque demands are shown in the plots in Fig.8 and Fig.9 for the two phase mixtures with honey and glycerin as liquid bases, respectively. In a trend that is much different from what is observed against a single speed, the torque does not have a clear increasing trend. In some fractions they have a falling trend towards higher solid fractions and at the limiting 30%, the behavior is very different indicating that the continuum of the liquid phase is disturbed and the interactions are quite non-linear. The CFD analysis is able to pick this trend at the lower solid fractions fairly well but a substantial change is observed in the limiting mixture fraction

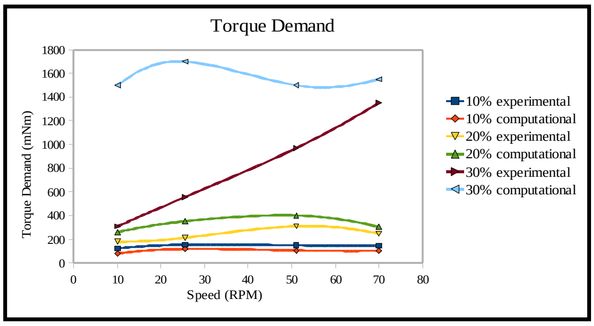

Fig. 8: Variation of torque demand at varied speeds with honey base

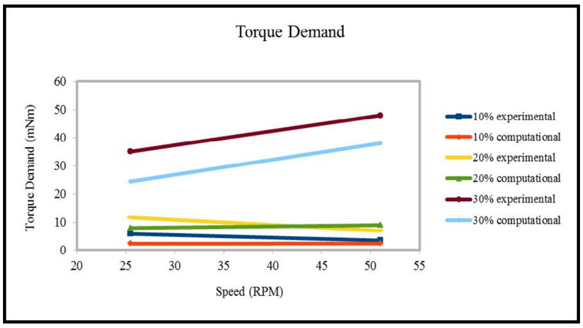

Fig. 9: Variation of torque demand at varied speeds with glycerin base

of 30% where the wetting of the solid particles is not adequate and liquid and solid surface interactions are not resulting to a drag driven solid particle motion. The decreasing trend of the torque demand at the higher speeds at lower fractions could be attributed to the rigidity of the solids that their inertia helps in enhanced momentum transport that dominate at higher velocities. Further investigations are essential for clear postulations on this behavior.

5. Concluding Remarks

A study of two phase flow with a solid-liquid mixture in an industrially applicable geometry is carried out. Crystalline Silica of 50 microns average size and two liquids of higher viscosity – honey and glycerin are used in different proportions to obtain the characteristics of the mixing flow. Both experiments and CFD analysis made indicate with complementarily agreeable results that lead to understand that the flow is different from the conventional single component flow and mixing is both influenced as well as influenced by the multi-phase behavior. The investigations in this aspect is considered of high relevance to the industries that have mixing as an important process that include polymer and food industries where the power demand at the design levels are still not predictable well at present. The CFD analysis and experiments conducted to validate them is considered to have provided a good step in this direction.

References

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