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Fluid Forces on Rotary Components: An Insight

A Simulation

Chinababu Anima
Cynergy Team
Cyient Limited
Hyderabad, India

Ravi Katukam
Cynergy Team
Cyient Limited
Hyderabad, India

***Abstract*—Single phase and multi phase fluid mixing has been a complex phenomenon that has been a challenge to engineers to design devices that enable fluid mixing. Typically rotors, blenders, are used for this purpose. The design of these components needs an accurate prediction of fluid force that will during all operation conditions of blender. The main aim of this work is to identify a proper Computational Fluid Dynamics (CFD) simulation strategy for the calculation of fluid blending and vertical suction force in stirred beakers for a hand blender mixer. The extensive analysis study has been carried out on existing hand blenders to explore scope for improvement. The shapes of the cups used for the study are: hemispherical cup with cut-outs and bell shape cup without cut-outs. The fluid dynamic behavior of two phase flow comprising of gas and liquid in the home applications related to ice crushing, juice mixture, etc. In this work, ambient air is considered as the dispersed medium in liquids of high viscosity water. In CFD analysis, a viscous incompressible, isothermal flow is considered with an assumption of the no cavitation effects. As the outcome of the study the vertical fluid suction force demand by the hand blender for two different cup geometries of the hand blender are estimated as shown a behavioral consistency of the expected physical phenomena. The computation results are validated with the experimental results and visual representation. The CFD-results provide a insight to interrelate the mixing performance, minimum vertical section force and shapes of blender.**

***Keywords*—Fluid, force, rotary.multiphase, single phase**

I. INTRODUCTION

Majority of the real world operating environment is made up of multiphase flows. The multiphase mixing and flow is complex phenomenon to understand. The design of equipment that operates under multiphase flows needs an accurate understanding of the forces that are imposed by multiphase fluid on the operating component. Towards establishing a methodology of fluid forces in multiphase environment. A generic case study is conducted on a hand bender. A hand blender, also referred to as an immersion blender or stick blender, is a kitchen tool used to blend items within their own jars, bowls, or pots. Unlike a traditional blender, where all the ingredients must be combined into the blender's own container, a hand blender can be used in virtually any container.

This hand blender possesses an elongated, tubular housing portion in which a working shaft spaced from the walls of the housing is rotatable guided. Received in the upper area of the housing is the electric motor which is adapted to be coupled to the working shaft in an either fixed or releasable manner. Arranged at the lower end of this shaft housing in the area of the shaft's output end is a bell / hemispherical shaped casing whose cross-sectional dimension normal to the axis of the working shaft is such as to enable a cutter blade to be received therein. The bell/ hemispherical shaped casing is closed relative to the tubular housing portion by means of a lid or a cover plate, and the working shaft is carried in this area in a bearing.

Conventionally, such a hand blender is utilized in combination with a container in which the food materials of the most diverse consistencies from solid and viscous to liquid are filled for comminuting or mixing. During the comminuting and mixing process, it can be observed that a vacuum builds up inside the bell because the bell is placed on the base of the container with its opening facing down, closing or narrowing the opening. As this occurs, the food materials are ejected through the slots in the bell, but it is not possible for a further supply of food to be drawn in through the opening. Accordingly, a pressure below atmospheric develops in the lower chamber of the bell. To obtain uniform blending and comminuting results, it is therefore necessary for the bell, that is, the appliance, to be moved up and down in a reciprocating motion to enable all food materials to be drawn in through the bell opening to subsequently reach the bite of the cutter blade. Lifting the hand blender requires considerable manual effort because of the vacuum formed between the base of the container and the bell, which necessarily results in handling discomfort. Also the initial breakaway torque occurring during lifting is apt to cause tipping of the container or an accelerated withdrawal of the bell from the materials being mixed. In addition, materials clinging to the operating end, that is, the mixing. The mixing is allowed to achieve the homogeneity. Minimum amount of torque/vertical suction force required to handling the shaft 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.

II. FLUID STRUCTURE INTERACTION

The CFD analysis is used for the torque/vertical suction force estimation by the viscous drag and the pressure drag encountered by the casing and blade. 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.

Fig.1: A typical blender shapes

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 [1]. 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 [2]. A configuration with a Hemispherical and Bell shaped as the casing, as shown in the Fig.1, The modeling is meshed using Boundary layer strategy involving unstructured and controllable mesh. Since the domain of computation involves a blade over which the flow field is to be captured, multiple rotating frame (MRF) mesh is deployed for the analysis. The water and air is set to be filled completely in the cavity of the mixing chamber. Varying fractions of water & air are used for the study to obtain the behavior pattern.3-D RANS approach is adopted with second order upwind scheme for the numerical solution. From the CFD results of the computation, the blending and vertical suction force/torque is obtained as applicable to the casing and blade in driving the water used at a preset speed.

III. Geometry and Computational Details

Surface modeling of the geometry considered is made using Commercial design tool. The components are Becker, shaft, outer jar, casing and blade. Details of geometry are shown in Fig. 2 & Fig.3. The gap considers between Becker and casing bottom is 5mm. Shaft and casing assembly are place at center of the Becker. The thickness of the casing considered is 4 mm.

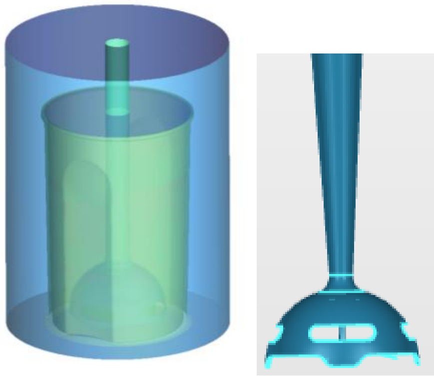

Fig.2: Domain Type -1 operation

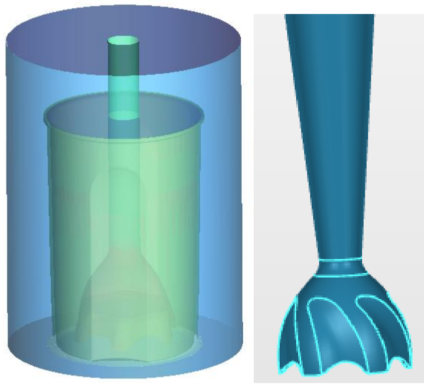

Fig.3: Domain Type -2 operation

A. Computational Details

Unstructured with appropriate Boundary layers mesh is generated using commercial meshing tool. Clustering of meshes was carried out with the smallest mesh size set at 0.04 mm next to the blade wall and to the casing and shaft. Study of grid-independence to the solution was carried-out with three different mesh strengths of around 0.2, 0.3 and 0.5 million nodes. It was found that mesh with 0.2 million is adequate and optimal and this mesh is used for both casing configuration study of the CFD analysis. The geometrical components include the open vent, blade wall and casing wall.

Commercial CFD tool is used as the flow solver. Open vent defined at top surface of outer jar and specified atmosphere pressure conditions. Shaft wall, casing wall, Becker wall and outer jar wall are imposed with stationary, no-slip wall condition. Blade wall is imposed with no-slip moving wall condition. Define the ram-up speed to rotating domain to achieve the maximum speed in half second. Blade wall is set at relative speed with respect to rotating fluid domain.

B. Experimental Details

The most challenging part in the executing experimental is fixture design. The major components of fixture are base plate, vertical column plate, force gauge holder, hangers and linear bearings. The fixture function is holding the hand blender assembly in certain height and allowing only in the translation motion.

Fig.4: Testing equipment

The experimental set-up with a typical equipment as shown in Fig.4 was found to require precision alignments in view of the gap between the Becker and the casing bottom and center position of blade unit. Force gauge calibration was conducted for the precession of the force measurement.

This experiment was carried-out for different fill fractions of the solid particles and for both the liquids mentioned.

IV. RESULTS AND DISCUSSION

In the first part of the investigation blending quality of the well mixed water was measured by in the form of shear strain rate (1/s) and it was found as is shown in plot at Fig.5. Expectably the viscosity increases with the air fraction in the liquids, the shear strain rate tend to increase. Plane was created 2.5mm above from the bottom surface of Becker. In this plan maximum & minimum shear strain rate are 1050 s-1 and 50s-1 respectively at instant time of 5seconds.Considering

In the bell shaped casing configuration, max & min shear strain rates are 2000s-1 and 50s-1.

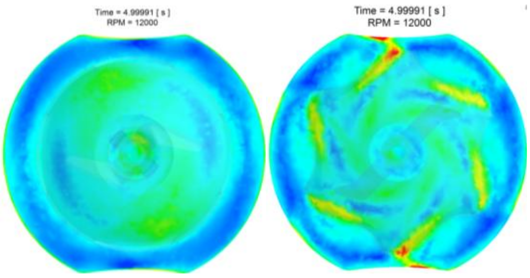

Fig.5: Shear Strain Contours

Observed from shear strain pattern in the both casing configuration, bell shaped casing is better uniform than hemispherical shaped casing. When compared both casing configuration for quality of blending, quantitatively measure area weighted average shear strain rate at require plan for entire time duration are shown inFig.6.

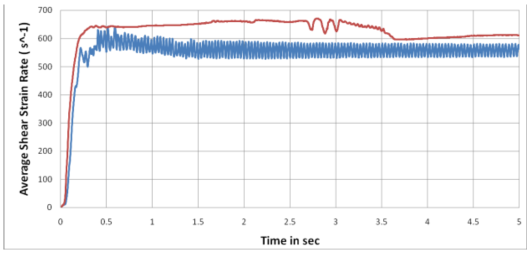

Fig.6: Shear Strain graph

At the end of the simulation, overall area weighted shear strain rate for bell shape casing and hemispherical casing are 630s-1 and 525s-1. The second part of the investigation vertical suction forces on the both casing configuration of hand blenders was measured by in the form of pressure acting on vertical project area of components like blade and casing.

From the CFD simulation, contribution of vertical force from blade geometry is very less compared to casing geometry. Plotted pressure distribution at required plan for both casing configuration are shown in Fig.7.In hemispherical casing minimum pressure is -30000Pa.With a pressure below atmospheric developing progressively in the Becker of the hemispherical -shaped casing a suction effect occurs on the blender assembly.

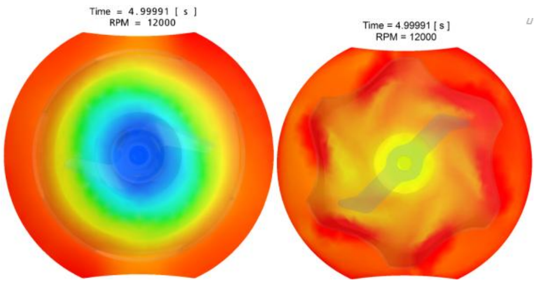

Fig.7: Pressure Contours

It is important to note that the CFD analysis made, the assumption that the cavitations was not consider.

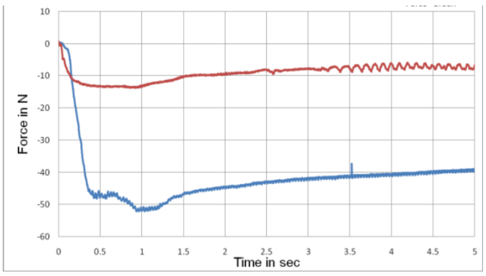

Fig.8: Force Variation graph

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The CFD result and the experimental data as can be seen in the table.

Product	CFD Force(N)	Experiment Force(N)
Type-1	-28	-38
Type-2	-7	-8

The percentage of variation CFD results with experimental for chosen product is 26%.For a variant product the variation is 12.5%. The force estimation from simulation in variant product is in close agreement with the experimental measurement whereas in chosen product, there is little gap between simulation and experiment. The reason for the gap in chosen product is shorter simulation time as seen Fig.8; chosen product force curve did not reach the stabilization stage while variant force curve almost reached the stabilization within the simulated time of 5 seconds.

V. CONCLUDING REMARKS

A study of two phase flow with an air-liquid mixture in a home applicable geometry is carried out. Both experiments and CFD analysis made indicate with complementarily agreeable results that lead to understand that the suction force is very high in the chosen product. From the CFD results the present invention to configure a hand blender or a container for a hand blender of the type initially described such as to accomplish improved blending quality in operation of the processing tool while at the same time any vacuum buildup that may occur in the area of the bell-shaped casing is controllable. 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.

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