J. Appl. Environ. Biol. Sci., 8(1)241-248, 2018

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Stresses and Power Consumption Analysis of Mixing Flow in Cylindrical Shaped Container

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Received: November 1, 2017
Accepted: January 3, 2018

ABSTRACT

The paper in hand is the part of our previous study of rotating mixing flow in cylindrical container. A pair of co–rotating stirrers has been considered for the computational analysis, the stirrers are rotating in same direction of the container and fixed eccentrically. The two-dimensional complex industrial mixing flow of Newtonian fluid is analyzed. A semi-implicit time-stepping Taylor-Galerkin/pressure-correction finite element multi stepping scheme adopted as numerical method, posed in a cylindrical coordinate system. Effects of inertia on hoop, radial differences and rate of work done are the core interest of the study. The numerical predicted results have shown a good behavior with the actual industrial mixing process.
KEY WORDS: Finite Element Method, Effects of inertia, Newtonian fluid, hoop and radial stresses

1. INTRODUCTION

Improvement of the design of mixers and process products are considered major application of this research. This research is concerned with mixing industry such as powder mixing process, chemical process application and mixing of paper pulp in paper industry and others too. This research will be instrumented in reducing power consumption through optimization of the mixer designs and enhancing the level of work- done in the mixers.

The outline of the rotational blending in a mixed vessel to foresee power utilization is of modern significance, by and large mechanical issues are trying to bargain, especially in the field of substance procedure applications, for example, powder blending forms[1] , blending of butter in a food tackling industry granular blending ,and paper mesh blending in paper industry and various other mechanical based techniques. In numerous blending forms the convoluting components are the utilization of instigators with stirrer in certainty that the fomenter might be worked in the transitional administration, the utilization of the liquids which shows exceptionally complex rheological conduct and the rotational bearing and speed of stirrers.

The principle target of this examination is to build up a two-dimensional numerical model for stream between an external pivoting round and hollow vessel divider and stationary and turning twofold tube shaped stirrers in co-turning. Stirrers are situated on the blending vessel top, and being set in whimsical position, as vessel under two dimensional suspicions, as vessel originally will be taken as interminable stature. Somewhere else, the limited vessel issue in three-measurements [2-6] will be viewed as furthermore diverse numbers and sorts of stirrers [7, 8] will dissect.

As far as recent exploration is concerned, is almost within 20 years, great advances has been made , especially it encompass semi Taylor–Galerkin Pressure–Correction plan that has developed and refined . This plan, at first imagined in successive structure [9] and in this manner in parallel style [10-12], is suitable for the recreation of incompressible Newtonian and non-Newtonian.

The re-enactment strategy addresses the numerical arrangement of the two-dimensional force conditions for incompressible streams. A galerkin spatial discretization immediate ensured by fleeting discretization in a taylor

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arrangement and finally it entails a supposed time walking Taylor-Galerkin limited component plan. A semi verifiable treatment for dissemination is utilized to address direct dependability requirements. The stream is demonstrated as incompressible by means of a weight revision plane

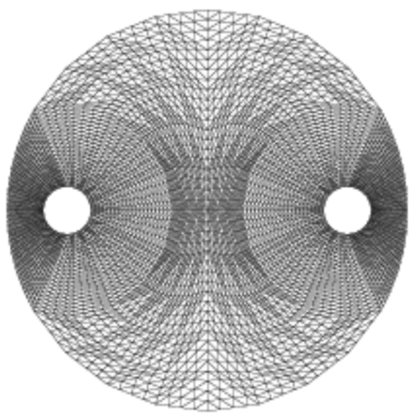
The present work is focused on the investigations for effects of variation in inertia and stirrer's speed on the overall flow patterns, work-done rate and consumption of power .The dough kneading applications are primarily focus of this research and could be achieved through development of new material structure and maximizing the rate of work-done per unit power. Newtonian fluids have used in the computations.

2. PROBLEM SPECIFICATION

Mostly the food industry comprises the non-Newtonian fluids. In present work, investigations are made for 2D mixing flows of Newtonian fluids. practically the fluid in industrial processes, rotation of lid of vessels drives the fluid causing mixing and the stirrers are attached with the vessel lid. Eccentrically configured double stirrers have used with fixed and rotating movements. Initially, analysis of problem was made for rotating flow between rotating cylindrical vessel and stationary stirrers to validate the predictions of finite element calculations for this cylindrical polar co-ordinate system by comparing the results against findings of previous research [13, 14]. Subsequently, co-rotational direction of stirrers is also investigated against stationary stirrers in a rotating cylindrical vessel.

This research study includes various parameters shear stress, shear rate, contour plots of velocity gradients, hoop and radial stress difference and power are submitted and perceived as solution fields of interest the spatial integral of the rate of work may be defined power, where as invariant of rate of deformation tensor is I_2 ,and work-done per total time as w, v_θ, t_n and v_r are components in radial 'r' and azimuthal 'θ'direction respectively and ω is domain of interest in two dimensional polar coordinate.

Effects of increasing inertia on stresses and power consumption for co-rotating stirrers will be analyzed. Numerical simulations of all fields of interest, difference of stresses(hoop and radial) and rate of work-done will be presented through contour plots of velocity gradient with increasing Reynolds numbers for generalized Newtonian fluids. Speed of rotating stirrers will be considered at half, same and double against the speed of outer container. Finally the differences of all the addressed variables will be discussed in terms of comparative study between results available in literature and predicted results of generalized Newtonian fluids.



FIGURE–1: Finite Element Meshed Geometry of Double stirred-Eccentric Rotating Cylinder flow.

Figure–1 shows the computational domain along with finite element mesh to solve the selected problem. The mesh contains 8960 total number of elements, 18223 nodes and 40057 degrees-of-freedom. Further details about the convergence of mesh along with initial and boundary conditions are available in our previous investigations [15–17]. In present work, contour plots of velocity and other variables of interest are presented as solution fields.

3. GOVERNING EQUATIONS AND PROPOSED NUMERICAL SCHEME

A system consisting of conservation of mass, generalization of momentum transport and Newtonian constitutive equations can be modelled of two dimensional isothermal flow of incompressible Newtonian fluid. Domain Ω is taken over by coordinate system from of two dimensional cylindrical components.

$$\nabla \cdot \mathbf{u} = 0, \tag{1}$$

The conservation of momentum transport equation, as

$$\frac{\partial u}{\partial t} = \frac{1}{\mathrm{Re}}\nabla^2 u - u.\nabla u - \nabla p \tag{2}$$

Whereas ∇ is considered as the spatial differential operator, p denote isotropic fluid pressure and μ is taken as fluid velocity vector.

Relevant non dimensional Reynolds number is defined as

$$\mathrm{Re} = \frac{\rho VR}{\mu} \tag{3}$$

Since V is considered to be rotational speed of the vessel, ρ is denoted by fluid density and μ is characterized by zero shear- rate viscosity and R is characteristic length scale is the radius.

In this research solutions through contour plots of stream function and pressure will be investigated. Other area of interest considered for solution is power and rate of work done and shear stress. The spatial component of the amount of work done is called perceived as power.

These quantities are defined in Table -1.

Table 1: Definitions of various parameters.

Sr. No.	Parameter	Mathematical definitions
1	Shear-rate	$\dot{\gamma} = \sqrt{2I_2}$
2	Local rate-of-work done	$\dot{w} = T : \nabla \boldsymbol{u}$
3	Power	$\dot{P}(t) = \int_{\Omega} \dot{w}(\boldsymbol{x},t)\, d\Omega$
4	Total work done	$W = \int_{T} \dot{P}(t)\, dt$

W and p are represented by local rate of work done and pressure respectively. I_2 is the second invariant of rate of deformation tensor.

Relevant non-dimensional Reynolds number is defined as:

$$R_e = v^{-1} V_c R,$$

Where kinematic viscosity $v = \mu_c \rho^{-1}$;

V_c is the characteristic velocity, considered as speed of the vessel .R, is radius the characteristic scale. μ_c denotes zero shear- rate viscosity. Suitable scaling takes the form in each variable $p = p^* \frac{V_c \mu_c}{R}$, $\dot{\gamma} = \dot{\gamma}^* \frac{V_c}{R}$ and $\dot{W} = \dot{W}^* \frac{\mu_c V_c^2}{R^2}$.

At a 50 rpm of characteristic rotational speed and zero shear viscosity of 105 Pa s, scaling yields dimensional variables $p = 2444\, p^*$, $\dot{\gamma} = 23.28\, \dot{\gamma}^*$ and $\dot{W} = 56894\, \dot{W}^*$, with shear-rates O(102)s^{-1}.

4. RESULTS AND DISCUSSION

The predicted solutions are analyzed in co-rotating rotational direction for various speed of the stirrers. The minimum values to maximum values of a variable in a range are plotted as contours. The solutions of equations are analyzed numerically through plots of work-done with respect to time interval and consumption of power. The comparative study is also carried out.

Different levels of zero-shear viscosities μ_o in increasing order are considered and then Reynolds number calculations are made as discussed above. At zero shear viscosities are μ_o = 1.05 Pa s, μ_o = 10.5 Pa s and μ_o= 105.0 Pa s the corresponding calculated Reynolds Numbers are Re=8.0, Re=0.8 and Re=0.08 respectively. These levels are actually simulating the material properties in the form of model fluid to model dough to actual dough respectively.

4.1 C**ontours of hoop and radial stress difference** (N_1)

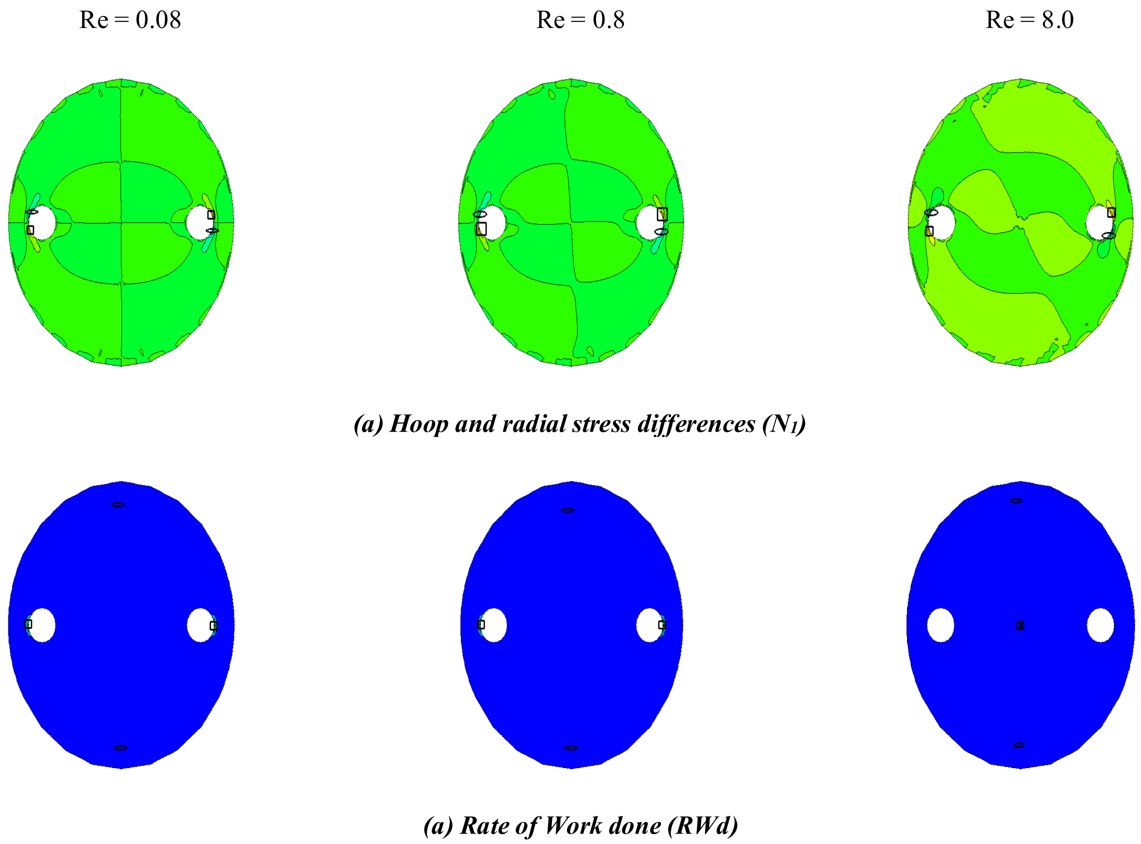
The figure–2 shows the symmetric behavior on both stirrers with equal magnitude but when we reaches upto inertial level 8.0 the symmetry in isobars change to asymmetry at half velocity (v_θ) =0.5. and extrema remaining at same position as upper and lower of stirrers between narrow gap and in fig(3) at same velocity v_θ =1.0 and same Reynolds Numbers no any change seemed in symmetry as shown in previous case but extrema shifted from narrow to wide gap and also extrema shifted their position from up to down. and at inertial level 0.8 same thing is happened and also circular region is observed and at Reynolds number 8.0, extrema twisted from narrow to wide gap. In fig(4), at double speed and Re=0.08, there is no change in symmetry as shown in previous case but once again extrema shifted from wide to narrow gap and circular region is also observed at narrow gap and on stirrers , at Re=0.8 also same symmetry is seemed as in figure–3 but only difference is that extrema shows also in narrow gap and no change at inertial level 8.0.

Now we define the RWd contour figures at different Reynolds Numbers and velocities i.e., (0.08, 0.8 and 8.0) at half velocity in figure–2 the symmetry is seemed out in contours from inertial level 0.08 to 0.8 maxima is shown on stirrers between narrow gap and wall of vessel and minima is shown near the outer wall of vessel between stirrers in wide range and asymmetry is seemed at Re=8.0 just only maxima moved towards center of wide range. In figure–2 symmetric structure is viewed but only maxima twisted from narrow gap to wide gap range at inertial level 0.08 and 0.8 at same speed i.e (v_θ =1.0) finally in figure–4 also same symmetry observed just only maxima shifted from narrow gap to wide gap range at inertial levels 0.08 and 0.8 at double speed i.e(v_θ =2.0).

Contours with asymmetric nature are observed with increase of inertia from Re=0.08 to Re=8.0. At Re=0.08 with double rotational speed of stirrers, influence of comparable equilibrium have been observed through the variants of geometry from minima to maxima on N_1 and RWd. Similar magnitude in non-dimensional negative and positive extrema on both sides (lower and upper) was observed along with symmetrical contours at narrow gap of both sides as shown in Fig. 4.The increase of stirrers' speed (from half to double) against the vessel speed affected the all

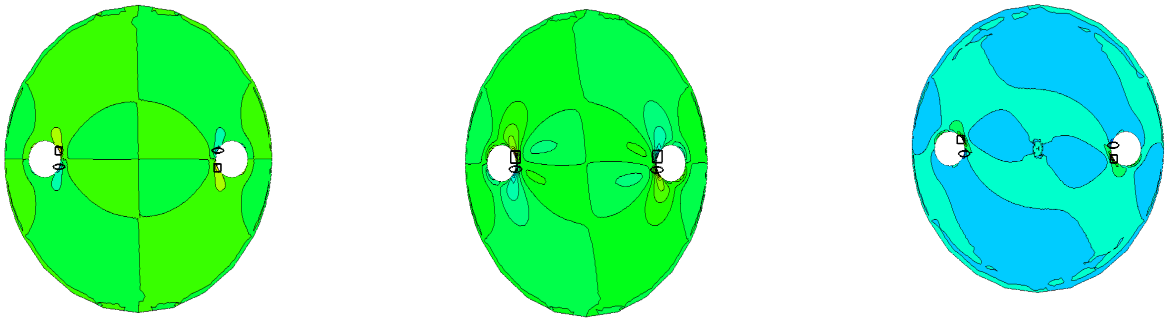
depended variables which are listed in Table 2.For all the cases of both inertial values, an increase in the maxima and minima have observed with the increase in speed of stirrers.
The symmetrical velocity gradients were observed with respect to geometry from minimum(half) to maximum(double)the speed of stirrers for the inertial values of Re=0.08 and Re=0.8. Whereas the asymmetrical trends were in velocity gradients with increase in minima and maxima with increase of Reynolds Number i.e. Re=8.0.Doubling the speed of stirrers shows no effect on consumption of power at minima however at maxima it increase upto 25%.

At first, the vessel flow is driven with very high work-done. Later, a rapid decrease in work-done was observed and reaches at some uniformity for getting steady-state solution for half speed with co-rotating stirrers but this solution is changed further of doubling the speed with a gradual decrease in work-done.

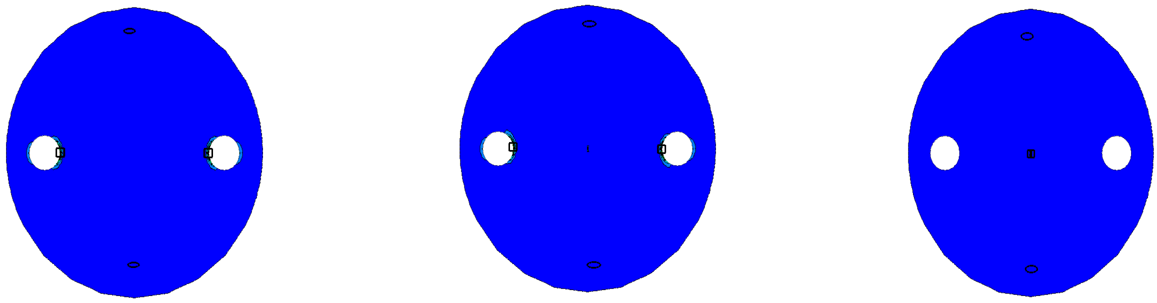


Figure–2: Effects of inertia on hoop and radial differences (N_1) and Rate of Work done (RWd) when velocity is fixed at V_0= 0.5

Re = 0.08 Re = 0.8 Re = 8.0



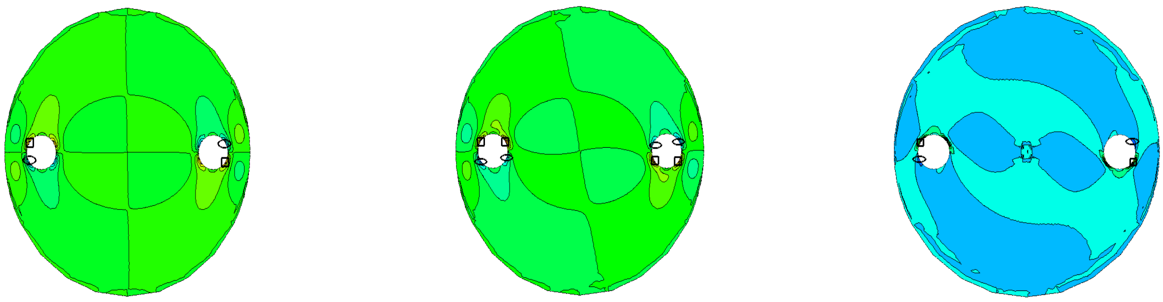
(a) Hoop and radial stresses differences (N_1)



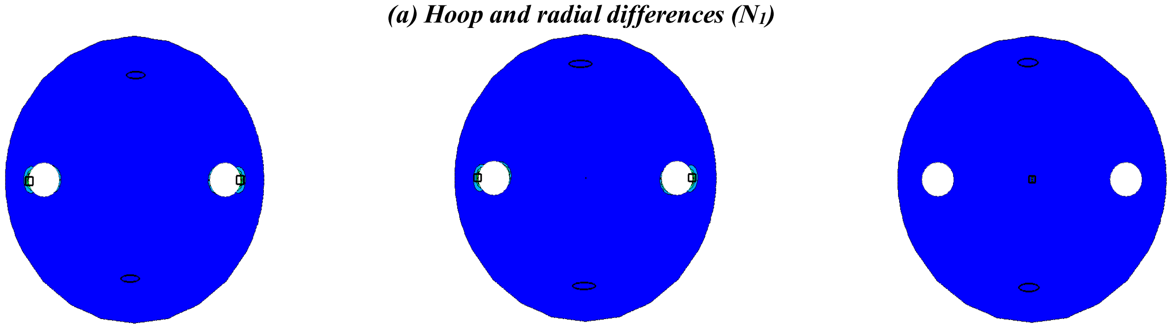
(a) Rate of Work done (RWd)

Figure–3: Effects of inertia on hoop and radial differences (N_1) and Rate of Work done (RWd) when velocity is fixed at V_0= 1.0

Re = 0.08 Re = 0.8 Re = 8.0



(a) Hoop and radial differences (N_1)



(a) Rate of Work done (RWd)

Figure–4: Effects of inertia on hoop and radial differences (N_1) and Rate of Work done (RWd) when velocity is fixed at V_0= 2.0

5. CONCLUSIONS

The performance of industrial problem associated with mixing was successfully predicted with the help of numerical flow simulator. Realistic simulations were successfully developed for complex mixing process for Newtonian fluids.

The co-rotating twin stirrer case was investigated with increasing inertia (Reynolds no.) from 0.08 to 8.0. Increase in the speed of stirrers for co-rotating stirrers case, an increase in all medium values of inertia. The symmetrical velocity gradients were observed with respect to geometry from minimum (half) to maximum (double) the speed of stirrers for small and medium inertial values (Re=0.08 and 8.0). Whereas the asymmetrical trends were in velocity gradients with increases in minima and maxima with increase of Reynolds Number i.e. Re=8.0. Power consumption has no effect at minima on doubling the speed of the stirrers. The optimized mixer designs could be developed for completing dough mixing processes with robust predictive capability of numerical solutions.

The future work may be directed for the in-depth investigations of rotation of concentric configured two co-rotating stirrers with Newtonian fluids and agitators.

6. ACKNOWLEDGEMENT

The authors are greatly acknowledged to the Mehran University of Engineering and Technology, Jamshoro and Shaheed Z. A. Bhutto campus for supporting and providing computational facility.

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