Sindh Univ. Res. Jour. (Sci. Ser.) Vol.47 (1):15-18 (2015)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Computational Analysis of Rotating Mixing of Bird Carreau Model Fluid

R. A. MEMON[++], M. A. SOLANGI*, R. B. KHOKHAR*, A. BALOCH**, K. S. SAYED***

Department of Basic Sciences and Related Studies, Mehran UET, Shaheed Z. A. Bhutto Campus Khairpur

Received 18th July 2014 and Revised 24th December 2014

Abstract: Bird Carreau model is employed under the presented study of two–dimensional rotating flow. Numerical solutions for a rotating container are carried out in terms of complex mixing flows for the case of contra rotating stirrers. The problem is relevant to the food industry. The mobility of the fluid is considered as driven by the outer rotating wall and movement of stirrers is considered in the contra rotating direction at various speeds. The solutions are obtained through a finite element semi–implicit Taylor–Galerkin/pressure–correction scheme. The method is based on second order multi–stage time–stepping algorithm posed in a cylindrical polar coordinate system. The predicted results are validated against previously simulated results and are observed identical with one and another.

Keywords*:* Rotational Mixing, Contra Rotating Stirrer, Bird Carreau Model

1 INTRODUCTION

The objective of the study is to be proficient to improve the efficiency of mixer, in terms of improving energy efficiency and the amount of work done on the dough kneading, through a more informed understanding of the process (Biniding *et al.,* 2002). However, the meditatived geometry in this study is consists a cylindrical tub, fitted with a set of two rotating stirrers eccentrically fitted with lid. Both stirrers are rotating in opposite (contra rotating) direction of the outer tub (Memon, *et al.,* 2013).

The geometry and fluids are analysed in this investigation which represents the intermediate step in the improvement of methods of numerical simulation of the flow that are encountered in dough kneading in industrial mixers (Baloch *et. al*, 2003). In the industrial mixers, the container partially filled with the dough, which is driven by stirring rods in the fixed tub (Biniding *et al.,* 2002). Due to the importance of such mixing flows the simulations are carried out for Bird–Carreau model fluid at various inertial grades and speeds. The work is presented in this paper has adopted a semi implicit TGPC scheme, The incompressible flow is modelled by the use of such scheme in a two dimensional cylindrical polar coordinate system (Sujatha *et al.,* 2002).

In this study, the investigation of solutions is depending upon the various levels of viscosity, different rotational speeds and fixed dimensionless parameter. The effects of the above parameters on streamline contours and pressure isobars for Bird–Carreau model fluid is express throughout the study. This numerical flow solver is used as predictive tool for mixing of dough at industrial level (Baloch and Webster, 2003).

2 MATERIAL AND METHODS

Problem Specification

A cylindrical tub with a set of two rotating cylindrical stirrers is considered. The fluid is driven by the outer wall of the tub and two rotating cylindrical stirrers are eccentrically fitted at the top of the tub by a lid. Contra rotating stirrers with half, same and double rotational speeds of stirrers against the speed of cylindrical tub has considered. For the numerical study of the computational domain, triangular elements are adopted in finite element mesh. For the initial and boundary conditions reader are referred to (Memon, *et. al*, 2011).

3 GOVERNING SYSTEM OF EQUATIONS AND THE NUMERICAL SCHEME

Two-dimensional system of cylindrical coordinate is employed over the domain Ω. In the absence of the body forces, the system of equations is adopted through the conservation of mass and the conservation of momentum transport equations as $\nabla \cdot \mathbf{u} = 0$ and $\rho \frac{\partial \boldsymbol{u}}{\partial t} = \nabla . \boldsymbol{\sigma} - \rho \boldsymbol{u} . \nabla \boldsymbol{u}$ respectively (Solangi, *et. al,* 2011). Applying the finite element approximation, the multi stages fully discrete system for details of terms and matrices of the following scheme, readers are referred (Memon, 2013) is defined as,

Stage 1a:

[++]Corresponding Author: email: ra_memon1@yahoo.com

* Department of Basic Sciences and Related Studies, Mehran University of Engineering and Technology, Jamshoro

**Department of Computer Science, ISRA University Hyderabad, Sindh, Pakistan.

*** Centre of Advance Studies in Applied and Pure Mathematics, Bahuddin Zakirya University, Multan

$$\left[\frac{2\mathrm{M}}{\Delta \mathrm{t}}+\frac{S}{2\,\mathrm{Re}}\right](\mathrm{V}^{\mathrm{n}+\frac{1}{2}}-\mathrm{V}^{\mathrm{n}})=-\left\{\mathrm{SV}+\mathrm{L}^{\dagger}\mathrm{P}+\mathrm{ReN}(\mathrm{V})\mathrm{V}\right\}^{\mathrm{n}}$$

Stage 1b:

$$\left[\frac{\mathrm{M}}{\Delta \mathrm{t}}+\frac{S}{2\,\mathrm{Re}}\right](\mathrm{V}^{*}-\mathrm{V}^{\mathrm{n}})=\left\{\mathrm{L}^{\dagger}\mathrm{P}-\frac{S}{\mathrm{Re}}\mathrm{V}\right\}^{\mathrm{n}}-N(V)V^{n+\frac{1}{2}}$$

Stage 2:

$$\theta K\left(P^{n+1}-P^{n}\right)=\frac{1}{\Delta \mathrm{t}}\mathrm{LV}^{*}$$

Stage 3:

$$\frac{\mathrm{M}}{\Delta \mathrm{t}}(\mathrm{V}^{n+1}-\mathrm{V}^{*})=-\theta\mathrm{L}^{\dagger}\left(P^{n+1}-P^{n}\right)$$

The time-step (Δt), is taken as 10^{-2}, so as to satisfy a local Courant condition constraint (Memon, 2013).

4. NUMERICAL RESULTS AND DISCUSSIONS

The numerical results are demonstrated and evaluated with the results published previously. To make the assessment directly for recirculation of fluid and pressure of Bird–Carreau model fluid is investigated across the computational domain. The parameters are considered with increasing inertial level (i.e., from 0.08 to 8.0) and speeds of stirrers (i.e., half speed and double).

In **(Fig.1)** computational results of fluid replicate the behaviour of the original problem. Six re-circulation regions are formed in whole computational domain at inertial level 0.08 and 0.8. Fluid twist in the rotational direction of outer wall as velocity increases from half to double. At all speeds and inertial level 0.08, minimum value of re-circulation noted at outer wall. Whilst, at inertial level 0.8 and 8.0, minimum value seemed in the centre near the stirrers and maximum value remains at same place, that is, upper and lower regions. The noticeable feature appeared, that is, the maximum value of re-circulation is moved to narrow gap between outer wall and stirrers.

The pressure isobars in **(Fig.2)** are shown, the pressure differential at Re = 0.08, shows the symmetric behaviour on both stirrers with equal magnitude. At half speed of stirrers and all inertial levels, the non–dimensional positive and negative extrema appeared on both the sides of stirrers at inlet and outlet respectively when fluid drive in the narrow gap. The symmetry in isobars change to asymmetry as velocity increases and reaches up to double. The noticeable feature emerges at double speed and inertial level at 8.0, the maximum value of pressure appeared at outer wall before entry in narrow gap between boundaries of stirrers and outer container. At the entry and exit, the fluid pressed expands respectively when the flow passes through the narrow gap. Here the material stretches and showing high extension rates.

The numerical solutions have excellent concurrence with the available experimental data. Through the results of this study of contra rotating flows, it is clear that this algorithm has convergence, accuracy and stability for the full incompressible Navier–Stokes equations.

5 CONCLUSION

The flow is investigated within the cylindrical domain with contra rotating stirrers. The effects of inertia, velocity and non-dimensional parameter on flow re-circulation and pressure are analysed. The attractive features emerges into view are; more shearing and stretching of the Bird–Carreau model fluid occurs in the region, that is around the both stirrers and the rate of work done approach at a maximum value at same place. This is fully replicating the nature of the physical industrial problem. In continuation of this, the maximum pressure arises at entry between the gap, whilst, minimum at exit.

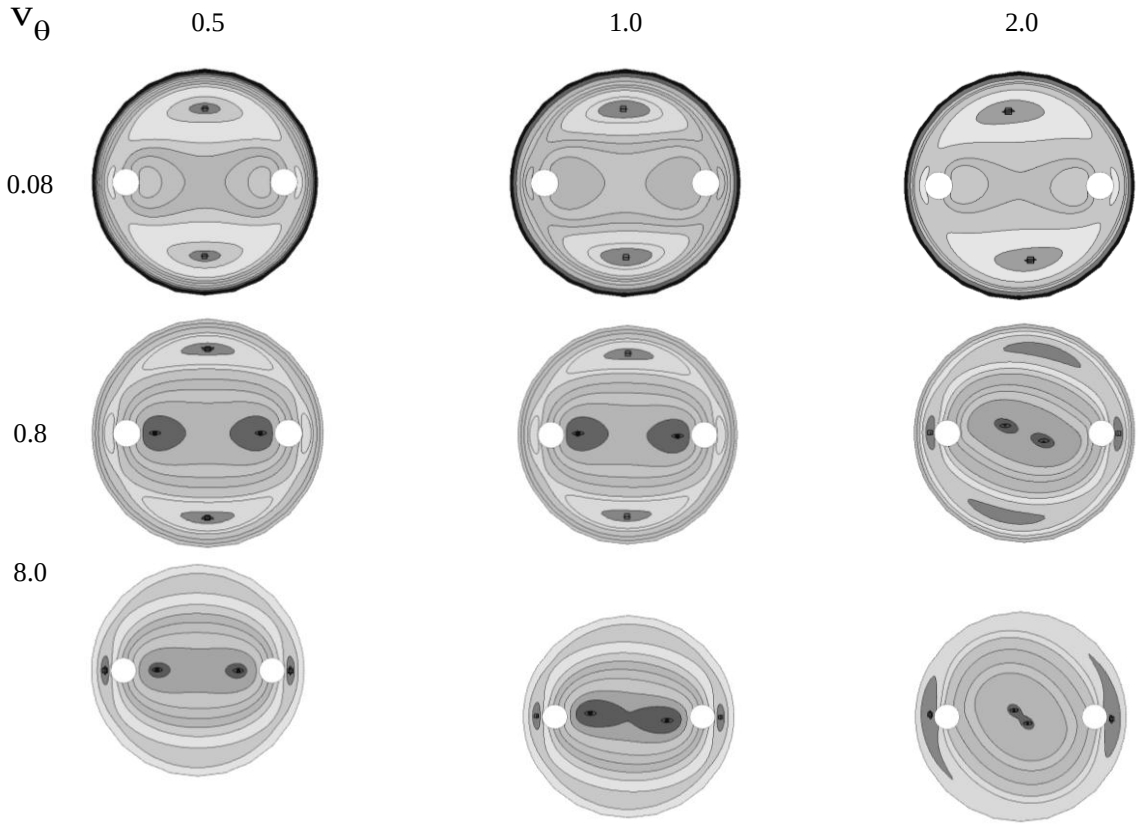


Fig. 1: Impact of rational velocity of stirrers on flow patterns of Bird–Carreau model fluid for various inertial levels and dimensionless parameter is 0.6.

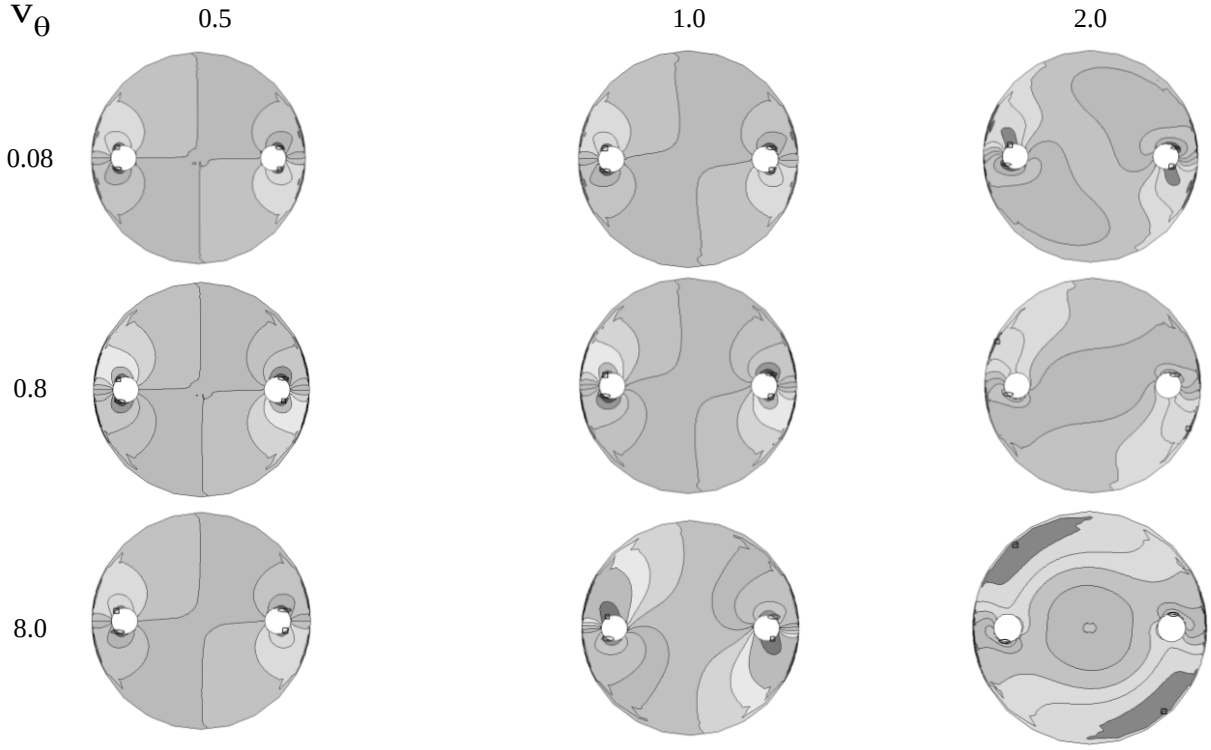


Fig. 2: Impact of rational velocity of stirrers on pressure isobars of Bird–Carreau model fluid for various inertial levels and dimensionless parameter is 0.6.

REFERENCES:

Binding D. M., M. A. Couch, K. S. Sujatha, M. F. Webster, (2002) 'Experimental and numerical simulation of dough kneading in filled geometries', J. Foods Eng., 57, 1–13.

Baloch, A. and M. F. Webster, (2003) 'Distributed Parallel Computation for Complex Rotating Flows of Non-Newtonian Fluids', Int. J. Num. Meth. Fluids, 43, 1301-1328.

Memon, R. A., A. Baloch, and M. A. Solangi, (2011). 'Simulation of Rotational Flows in Cylindrical Vessel with Double Rotating Stirrers (PART-A: Analysis of Flow Structure and Pressure Differentials)', Punjab U. J. of Mathematics, 43, 29–45.

Memon. R. A., (2013) 'Finite Element Modelling of Complex Rotational Flows', PhD thesis, Centre for Advanced Studies in Pure and Applied Mathematics, Bahauddin Zakariya University Multan, Pakistan.

Solangi, M. A., A. Baloch and R. A. Memon, (2011). 'Influence of Blood Inertia on Vortex Enhancement in the Wake of Plaque Deposited Arties', Mehran University Research. Journal of Engineering and Technology, 30(2), 213–224.

Sujatha K. S., M. F. Webster, D. M. Binding, M. A. Couch (2002) 'Modelling and experimental studies of rotating flows in part-filled containers: wetting and peeling', J. Foods Eng., 57, 67–79.