ISSN: 1999-6691, e-ISSN: 2782-3709 **DOI:** http://doi.org/10.7242/1999-6691/2024.17.4.39

Research article

Flow of a Newtonian fluid in agitators of different configurations

E.I. Borzenko, D.N. Garbuzov

Tomsk State University, Tomsk, Russian Federation

The flow of a viscous incompressible fluid in agitators with solid and anchor blades is analyzed. Mathematical formulation for the problem involves Navier-Stokes and continuity equations in the plane approximation. A solution algorithm is developed based on the control volume method and a SIMPLE correction procedure. The differential equations are discretized with unstructured triangular meshes that take into account the geometric features of the flow region. Tests were performed to verify the approximation convergence and to estimate the order of accuracy of the numerical scheme, as well as to verify the original calculation program. Parametric studies were carried out for Reynolds numbers in range of $0.1 \div 100$, which is characteristic of the technology of fluid materials processing in industrial mixers. Distributions of the kinematic and dynamic characteristics of the flow were obtained, and the flow patterns, whose specific feature is the presence of circulation zones in paddle agitators of different configurations, were demonstrated. Calculations are done to determine the position of marker particles and the evolution of reference lines, which give a visual representation of the process and demonstrate the presence of areas of uniform and non-uniform mixing. A quantitative mixing quality parameter is introduced to compare agitators of different configurations with each other and to consider the process of mixing over time. The process is evaluated quantitatively by the values of the integral of the dissipative function, which shows the energy consumption, and by the value of the quantitative parameter of the inhomogeneity of the marker particle distribution. The latter allows a more detailed study of the mixing process over the volume over time.

Keywords: viscous liquid, agitator, blade, control volume method, unstructured mesh, circulation zone, mixing quality

Received: 22.02.2024 / *Published online*: 30.12.2024

References

1. *Nagata S.* Mixing. Principles and applications. Kodasha LTD., 1975. 458 p.
2. *Glushkov I.A.*, *Milekhin Y.M.*, *Merkulov V.M.*, *Banzula Y.B.* Modelirovaniye formovaniya izdeliy iz svobodno-lit'yevykh kompozitsiy. Moscow: Arkhitektura-S, 2007. 362 p.
3. *Benmoussa A.*, *Rahmani L.*, *Draoui B.* Simulation of viscoplastic flows in a rotating vessel using a regularized model. The International Journal of Multiphysics. 2017. Vol. 11. P. 349–358. DOI: 10.21152/1750-9548.11.4.349
4. *Et J.B.*, *Couderc J.P.* Agitation de fluides pseudoplastiques par un agitateur bipale. The Canadian Journal of Chemical Engineering. 1982. Vol. 60. P. 738–747. DOI: 10.1002/cjce.5450600604
5. *Komoda Y.*, *Date T.* Enhancement of laminar mixing by an anchor impeller with rotationally reciprocating motion. AIP Advances. 2022. Vol. 12, no. 1. P. 14. DOI: 10.1063/5.0075750
6. *Laidoudi H.* Hydrodynamic analyses of the flow patterns in stirred vessel of two-bladed impeller. Journal of the Serbian Society for Computational Mechanics. 2020. Vol. 14, no. 2. P. 117–132. DOI: 10.24874/jsscm.2020.14.02.08
7. *Mokhefi A.*, *Bouanini M.*, *Elmir M.* Numerical Simulation of Laminar Flow and Heat Transfer of a Non-Newtonian Nanofluid in an Agitated Tank. International Journal of Heat and Technology. 2021. Vol. 39, no. 1. P. 251–261. DOI: 10.18280/ijht.390128
8. *Stręk F.* Mieszanie i mieszalniki. Warszawa: Wydawnictwa Naukowo-Techniczne, 1971. 426 p.
9. *Bubenchikov A.M.*, *Firsov O.K.*, *Kotovshchikova M.A.* Numerical solution of 2D viscous fluid dynamics problems using finite volume method (FVM) on triangular grid. Mathematical Models and Computer Simulations. 2007. Vol. 19, no. 6. P. 71–85.
10. *Kim D.*, *Choi H.* A Second-Order Time-Accurate Finite Volume Method for Unsteady Incompressible Flow on Hybrid Unstructured Grids. Journal of Computational Physics. 2000. Vol. 162, no. 2. P. 411–428. DOI: 10.1006/jcph.2000.6546
11. *Patankar S.V.* Numerical Heat Transfer and Fluid Flow. Hemisphere Publishing Corporation, 1980. 197 p.
12. *Lashkin S.V.*, *Kozelkov A.S.*, *Yalozo A.V.*, *Gerasimov V.Y.*, *Zelensky D.K.* Efficiency analysis of parallel implementation of SIMPLE algorithm on multi-processor computers. Computational Continuum Mechanics. 2016. Vol. 9, no. 3. P. 298–315. DOI: 10.7242/1999-6691/2016.9.3.25
13. *Bouche D.*, *Ghidaglia J.-M.*, *Pascal F.* Error Estimate and the Geometric Corrector for the Upwind Finite Volume Method Applied to the Linear Advection Equation. SIAM Journal on Numerical Analysis. 2005. Vol. 43, no. 2. P. 578–603. DOI: 10.1137/040605941
14. *Bakhvalov P.A.* Numerical estimation of accuracy order for transport equation on meshes of special structure. Keldysh Institute Preprints. 2016. No. 105. P. 1–32. DOI: 10.20948/prepr-2016-105

15. *Abalakin I.*, *Bakhvalov P.*, *Kozubskaya T.* Edge-based reconstruction schemes for unstructured tetrahedral meshes. International Journal for Numerical Methods in Fluids. 2016. Vol. 81, no. 6. P. 331–356. DOI: 10.1002/fld.4187

16. *Loitsyanskii L.G.* Mechanics of liquids and gases. Pergamon Press, 1966. 804 p.

17. *Shankar P.N.*, *Deshpande M.D.* Fluid Mechanics in the Driven Cavity. Annual Review of Fluid Mechanics. 2000. Vol. 32. P. 93–136. DOI: 10.1146/annurev.fluid.32.1.93

18. *Fomin A.A.*, *Fomina L.N.* Numerical simulation of viscous 2D lid-driven cavity flow at high Reynolds numbers. Computational Continuum Mechanics. 2014. Vol. 7, no. 4. P. 363–377. DOI: 10.7242/1999-6691/2014.7.4.35

19. *Erturk E.*, *Corke T.C.*, *Gökçöl C.* Numerical solutions of 2-D steady incompressible driven cavity flow at high Reynolds numbers. International Journal for Numerical Methods in Fluids. 2005. Vol. 48, no. 7. P. 747–774. DOI: 10.1002/fld.953

20. *Ghia U.*, *Ghia K.N.*, *Shin C.T.* High-Re solutions for incompressible flow using the Navier-Stokes equations and a multigrid method. Journal of Computational Physics. 1982. Vol. 48. P. 387–411. DOI: 10.1016/0021-9991(82)90058-4

21. *Margareta M.*, *Beu Z.*, *Chen J.-H.* Numerical Investigation of Fluid in 2D and 3D Lid-Driven Cavity at Different Reynolds Numbers. Jurnal IPTEK. 2023. Vol. 27. P. 13–22. DOI: 10.31284/j.iptek.2023.v27i1.3427

22. *Hami O.*, *Draoui B.*, *Mebarki B.*, *Rahmani L.*, *Bouanini M.* Numerical model for laminar flow and heat transfer in an agitated vessel by inclined blades anchor. Proceedings of CHT-08 ICHMT International Symposium on Advances in Computational Heat Transfer. Begell House, 2008. P. 1–19. DOI: 10.1615/ICHMT.2008.CHT.1270