References

Agarwal, A. (2020), “Modification of On-Site Velocity Boundary Condition in LBM for D3Q27 Lattice Structure”, *Transactions of the Indian National Academy of Engineering*, pp. 1–11 2020

Agarwal, A. and Prakash, A. (2018), “Comparative study of boundary conditions in lbm for incompressible laminar flow”, *in International conference on mathematical modelling and scientific computation*, pp. 241–251, Springer 2018

Agarwal, A., Singh, G., and Prakash, A. (2021), “Numerical investigation of flow behavior in double-rushton turbine stirred tank bioreactor”, *Materials Today: Proceedings* 2021

Agrawal, A., Djenidi, L., and Antonia, R. (2006), “Investigation of flow around a pair of side-by-side square cylinders using the lattice Boltzmann method”, *Computers & fluids*, Vol. 35, No. 10, pp. 1093–1107 2006

Aidun, C. K. and Clausen, J. R. (2010a), “Lattice-Boltzmann method for complex flows”, *Annual review of fluid mechanics*, Vol. 42, pp. 439–472 2010a

Aidun, C. K. and Clausen, J. R. (2010b), “Lattice-Boltzmann method for complex flows”, *Annual Review of Fluid Mechanics*, Vol. 42, pp. 439–472 2010b

An, B., Bergadà, J., Mellibovsky, F., and Sang, W. (2020), “New applications of numerical simulation based on lattice Boltzmann method at high Reynolds numbers”, *Computers & Mathematics with Applications*, Vol. 79, No. 6, pp. 1718–1741 2020

Ayranci, I., Machado, M. B., Madej, A. M., Derksen, J. J., Nobes, D. S., and Kresta, S. M. (2012), “Effect of geometry on the mechanisms for off-bottom solids suspension in a stirred tank”, *Chemical Engineering Science*, Vol. 79, pp. 163–176 2012

Bakker, R. (1995), “Laser-Doppler measurements in a baffled stirred tank reactor with a disc turbine. Experimental data to appear in his Ph. D”, Ph.D. thesis, thesis, Delft University of Technology, the Netherlands 1995

Bartels, C., Breuer, M., Wechsler, K., and Durst, F. (2002), “Computational fluid dynamics applications on parallel-vector computers: computations of stirred vessel flows”, *Computers & fluids*, Vol. 31, No. 1, pp. 69–97 2002

Behrend, O. (1995), “Solid-fluid boundaries in particle suspension simulations via the lattice Boltzmann method”, *Physical Review E*, Vol. 52, No. 1, p. 1164 1995

Benzi, R. and Succi, S. (1990), “Two-dimensional turbulence with the lattice Boltzmann equation”, *Journal of Physics A: Mathematical and General*, Vol. 23, No. 1, p. L1 1990

Benzi, R., Succi, S., and Vergassola, M. (1992), “The lattice Boltzmann equation: theory and applications”, *Physics Reports*, Vol. 222, No. 3, pp. 145–197 1992

Bespalko, D. J. (2011), “Validation of the lattice Boltzmann method for direct numerical simulation of wall-bounded turbulent flows”, Ph.D. thesis, Queen’s University 2011

Bhatnagar, P. L., Gross, E. P., and Krook, M. (1954), “A model for collision processes in gases. I. Small amplitude processes in charged and neutral one-component systems”, *Physical Review*, Vol. 94, No. 3, p. 511 1954

Bonvillani, P., Ferrari, M., Ducrós, E., and Orejas, J. (2006), “Theoretical and experimental study of the effects of scale-up on mixing time for a stirred-tank bioreactor”, *Brazilian Journal of Chemical Engineering*, Vol. 23, No. 1, pp. 1–7 2006

Broadwell, J. E. (1964), “Study of rarefied shear flow by the discrete velocity method”, *Journal of Fluid Mechanics*, Vol. 19, No. 3, pp. 401–414 1964

Chen, S. and Doolen, G. D. (1998), “Lattice Boltzmann method for fluid flows”, *Annual Review of Fluid Mechanics*, Vol. 30, No. 1, pp. 329–364 1998

Chen, S., Chen, H., Martnez, D., and Matthaeus, W. (1991), "Lattice Boltzmann model for simulation of magnetohydrodynamics", *Physical Review Letters*, Vol. 67, No. 27, p. 3776 1991

Chen, S., Martinez, D., and Mei, R. (1996), "On boundary conditions in lattice Boltzmann methods", *Physics of fluids*, Vol. 8, No. 9, pp. 2527–2536 1996

Cheng, J., Grossman, M., and McKercher, T., *Professional CUDA c programming*, John Wiley & Sons 2014

Chikatamarla, S., Frouzakis, C., Karlin, I., Tomboulides, A., and Boulouchos, K. (2010), "Lattice Boltzmann method for direct numerical simulation of turbulent flows", *Journal of fluid mechanics*, Vol. 656, pp. 298–308 2010

Chunmei, P., Jian, M., Xinhong, L., and Zhengming, G. (2008), "Investigation of fluid flow in a dual Rushton impeller stirred tank using particle image velocimetry", *Chinese Journal of Chemical Engineering*, Vol. 16, No. 5, pp. 693–699 2008

Cornubert, R., d'Humières, D., and Levermore, D. (1991), "A Knudsen layer theory for lattice gases", *Physica D: Nonlinear Phenomena*, Vol. 47, No. 1-2, pp. 241–259 1991

Deen, N. G., van Sint Annaland, M., and Kuipers, J. (2004), "Multi-scale modeling of dispersed gas–liquid two-phase flow", *Chemical engineering science*, Vol. 59, No. 8-9, pp. 1853–1861 2004

Derksen, J. (2001), "Assessment of large eddy simulations for agitated flows", *Chemical Engineering Research and Design*, Vol. 79, No. 8, pp. 824–830 2001

Derksen, J. and Van den Akker, H. (1998), "Parallel simulation of turbulent fluid flow in a mixing tank", *in International Conference on High-Performance Computing and Networking*, pp. 96–104, Springer 1998

Derksen, J. and Van den Akker, H. E. (1999), "Large eddy simulations on the flow driven by a Rushton turbine", *AIChE Journal*, Vol. 45, No. 2, pp. 209–221 1999

Derksen, J., Kooman, J., and Van den Akker, H. (1997), "Parallel fluid flow simulations by means of a lattice-Boltzmann scheme", *in International Conference on High-Performance Computing and Networking*, pp. 524–530, Springer 1997

Derksen, J., Doelman, M., and Van den Akker, H. (1998), "Three-dimensional phase-resolved LDA experiments in the impeller region of turbulently stirred tank", *in Int. Symp. on Applications of Laser Techniques to Fluid Mechanics*, pp. 233–250 1998

d'Humieres, D. (1994), "Generalized lattice-Boltzmann equations", *Progress in Astronautics and Aeronautics*, Vol. 159, pp. 450–450 1994

d'Humières, D. (2002), "Multiple–relaxation–time lattice Boltzmann models in three dimensions", *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, Vol. 360, No. 1792, pp. 437–451 2002

d'Humieres, D., Lallemand, P., and Frisch, U. (1986), "Lattice gas models for 3D hydrodynamics", *EPL (Europhysics Letters)*, Vol. 2, No. 4, p. 291 1986

d'Humières, D., Bouzidi, M., and Lallemand, P. (2001), "Thirteen-velocity three-dimensional lattice Boltzmann model", *Physical Review E*, Vol. 63, No. 6, p. 066702 2001

Eggels, J. and Somers, J. (1995), "Numerical simulation of free convective flow using the lattice-Boltzmann scheme", *International Journal of Heat and Fluid Flow*, Vol. 16, No. 5, pp. 357–364 1995

Eggels, J. G. (1996), "Direct and large-eddy simulation of turbulent fluid flow using the lattice-Boltzmann scheme", *International Journal of Heat and Fluid Flow*, Vol. 17, No. 3, pp. 307–323 1996

Escamilla-Ruíz, I., Sierra-Espinosa, F., García, J., Valera-Medina, A., and Carrillo, F. (2017), "Experimental data and numerical predictions of a single-phase flow in a batch square stirred tank reactor with a rotating cylinder agitator", *Heat and Mass Transfer*, Vol. 53, No. 9, pp. 2933–2949 2017

Fernandino, M., Beronov, K., and Ytrehus, T. (2009), "Large eddy simulation of turbulent open duct flow using a lattice Boltzmann approach", *Mathematics and Computers in Simulation*, Vol. 79, No. 5, pp. 1520–1526 2009

Feuchter, C., Wagner, O., Stief, A., and Beisswenger, T. (2019), "Turbulent flow simulations around a surface-mounted finite cylinder using an entropic multi-relaxation lattice Boltzmann method", *Fluid Dynamics Research*, Vol. 51, No. 5, p. 055509 2019

Frisch, U., Hasslacher, B., and Pomeau, Y. (1986), "Lattice-gas automata for the Navier-Stokes equation", *Physical Review Letters*, Vol. 56, No. 14, p. 1505 1986

Gillissen, J. and Van den Akker, H. (2012), "Direct numerical simulation of the turbulent flow in a baffled tank driven by a Rushton turbine", *AIChE Journal*, Vol. 58, No. 12, pp. 3878–3890 2012

Ginzbourg, I. and Adler, P. (1994), "Boundary flow condition analysis for the three-dimensional lattice Boltzmann model", *Journal de Physique II*, Vol. 4, No. 2, pp. 191–214 1994

Ginzburg, I. and d'Humieres, D. (2003), "Multireflection boundary conditions for lattice Boltzmann models", *Physical Review E*, Vol. 68, No. 6, p. 066614 2003

Ginzburg, I., Verhaeghe, F., and d'Humieres, D. (2008a), "Study of simple hydrodynamic solutions with the two-relaxation-times lattice Boltzmann scheme", *Communications in Computational Physics*, Vol. 3, No. 3, pp. 519–581 2008a

Ginzburg, I., Verhaeghe, F., and d'Humieres, D. (2008b), "Two-relaxation-time lattice Boltzmann scheme: About parametrization, velocity, pressure and mixed boundary conditions", *Communications in Computational Physics*, Vol. 3, No. 2, pp. 427–478 2008b

Grunau, D., Chen, S., and Eggert, K. (1993), "A lattice Boltzmann model for multiphase fluid flows", *Physics of Fluids A: Fluid Dynamics*, Vol. 5, No. 10, pp. 2557–2562 1993

Guide, D. (2013), "Cuda c programming guide", *NVIDIA, July*, Vol. 29, p. 31 2013

Gunstensen, A. K., Rothman, D. H., Zaleski, S., and Zanetti, G. (1991), "Lattice Boltzmann model of immiscible fluids", *Physical Review A*, Vol. 43, No. 8, p. 4320 1991

Guo, Z. and Shu, C., *Lattice Boltzmann method and its applications in engineering*, Vol. 3, World Scientific 2013

Guo, Z., Zheng, C., and Shi, B. (2002), "Discrete lattice effects on the forcing term in the lattice Boltzmann method", *Physical review E*, Vol. 65, No. 4, p. 046308 2002

Hamane, D., Guerri, O., and Larbi, S. (2015), "Investigation of flow around a circular cylinder in laminar and turbulent flow using the Lattice Boltzmann method", *in AIP Conference Proceedings*, Vol. 1648, p. 850094, AIP Publishing LLC 2015

Han-Taw, C. and Jae-Yuh, L. (1993), "Numerical analysis for hyperbolic heat conduction", *International Journal of Heat and Mass Transfer*, Vol. 36, No. 11, pp. 2891–2898 1993

Hardy, J., Pomeau, Y., and De Pazzis, O. (1973), "Time evolution of a two-dimensional classical lattice system", *Physical Review Letters*, Vol. 31, No. 5, p. 276 1973

Hardy, J., De Pazzis, O., and Pomeau, Y. (1976), "Molecular dynamics of a classical lattice gas: Transport properties and time correlation functions", *Physical Review A*, Vol. 13, No. 5, p. 1949 1976

Hartmann, H., Derksen, J., Montavon, C., Pearson, J., Hamill, I., and Van den Akker, H. (2004), "Assessment of large eddy and RANS stirred tank simulations by means of LDA", *Chemical Engineering Science*, Vol. 59, No. 12, pp. 2419–2432 2004

He, X. and Luo, L.-S. (1997), "Theory of the lattice Boltzmann method: From the Boltzmann equation to the lattice Boltzmann equation", *Physical Review E*, Vol. 56, No. 6, p. 6811 1997

Hecht, M. and Harting, J. (2010), "Implementation of on-site velocity boundary conditions for D3Q19 lattice Boltzmann simulations", *Journal of Statistical Mechanics: Theory and Experiment*, Vol. 2010, No. 01, p. P01018 2010

Higuera, F. and Jimenez, J. (1989), "Boltzmann approach to lattice gas simulations", *EPL (Europhysics Letters)*, Vol. 9, No. 7, p. 663 1989

Ho, J.-R., Kuo, C.-P., Jiaung, W.-S., and Twu, C.-J. (2002), "Lattice Boltzmann scheme for hyperbolic heat conduction equation", *Numerical Heat Transfer: Part B: Fundamentals*, Vol. 41, No. 6, pp. 591–607 2002

Hou, S., Sterling, J., Chen, S., and Doolen, G. (1994), "A lattice Boltzmann subgrid model for high Reynolds number flows", *arXiv preprint comp-gas/9401004* 1994

Hou, Y., Angland, D., Sengissen, A., and Scotto, A. (2019), "Lattice-Boltzmann and Navier-Stokes simulations of the partially dressed, cavity-closed nose landing gear benchmark case", *in 25th AIAA/CEAS Aeroacoustics Conference*, p. 2555 2019

Jahanshaloo, L., Pouryazdanpanah, E., and Che Sidik, N. A. (2013), "A review on the application of the lattice Boltzmann method for turbulent flow simulation", *Numerical Heat Transfer, Part A: Applications*, Vol. 64, No. 11, pp. 938–953 2013

Kajzer, A. and Pozorski, J. (2017), "Application of the Lattice Boltzmann Method to the flow past a sphere", *Journal of Theoretical and Applied Mechanics*, Vol. 55, No. 3, pp. 1091–1099 2017

Kang, S. K. and Hassan, Y. A. (2011), "A comparative study of direct-forcing immersed boundary-lattice Boltzmann methods for stationary complex boundaries", *International Journal for Numerical Methods in Fluids*, Vol. 66, No. 9, pp. 1132–1158 2011

Kao, P.-H. and Yang, R.-J. (2008), "An investigation into curved and moving boundary treatments in the lattice Boltzmann method", *Journal of Computational Physics*, Vol. 227, No. 11, pp. 5671–5690 2008

Kellay, H., Wu, X., and Goldburg, W. (1998), "Vorticity measurements in turbulent soap films", *Physical review letters*, Vol. 80, No. 2, p. 277 1998

Kerdouss, F., Bannari, A., and Proulx, P. (2006), "CFD modeling of gas dispersion and bubble size in a double turbine stirred tank", *Chemical Engineering Science*, Vol. 61, No. 10, pp. 3313–3322 2006

Kim, D.-H., Yang, K.-S., and Senda, M. (2004), "Large eddy simulation of turbulent flow past a square cylinder confined in a channel", *Computers & fluids*, Vol. 33, No. 1, pp. 81–96 2004

Kobayashi, H. (2005), "LES of MHD turbulent channel flows with a local SGS model based on coherent structures", *CTR Annual Research Briefs*, p. 235 2005

Koda, Y. and Lien, F.-S. (2015), "The lattice Boltzmann method implemented on the GPU to simulate the turbulent flow over a square cylinder confined in a channel", *Flow, Turbulence and Combustion*, Vol. 94, No. 3, pp. 495–512 2015

Koelman, J. (1991), "A simple lattice Boltzmann scheme for Navier-Stokes fluid flow", *EPL (Europhysics Letters)*, Vol. 15, No. 6, p. 603 1991

Kutay, M. E., Aydilek, A. H., and Masad, E. (2006), "Laboratory validation of lattice Boltzmann method for modeling pore-scale flow in granular materials", *Computers and Geotechnics*, Vol. 33, No. 8, pp. 381–395 2006

Lallemand, P. and Luo, L.-S. (2000), "Theory of the lattice Boltzmann method: Dispersion, dissipation, isotropy, Galilean invariance, and stability", *Physical Review E*, Vol. 61, No. 6, p. 6546 2000

Lallemand, P., d'Humieres, D., Luo, L.-S., and Rubinstein, R. (2003), "Theory of the lattice Boltzmann method: three-dimensional model for linear viscoelastic fluids", *Physical Review E*, Vol. 67, No. 2, p. 021203 2003

Lammers, P., Beronov, K., Volkert, R., Brenner, G., and Durst, F. (2006), "Lattice BGK direct numerical simulation of fully developed turbulence in incompressible plane channel flow", *Computers & fluids*, Vol. 35, No. 10, pp. 1137–1153 2006

Lavallee, P., Boon, J. P., and Noullez, A. (1991), "Boundaries in lattice gas flows", *Physica D: Nonlinear Phenomena*, Vol. 47, No. 1-2, pp. 233–240 1991

Li, Z., Hu, M., Bao, Y., and Gao, Z. (2012), "Particle image velocimetry experiments and large eddy simulations of merging flow characteristics in dual Rushton turbine stirred tanks", *Industrial & engineering chemistry research*, Vol. 51, No. 5, pp. 2438–2450 2012

Lu, Z., Liao, Y., Qian, D., McLaughlin, J., Derksen, J., and Kontomaris, K. (2002), "Large eddy simulations of a stirred tank using the lattice Boltzmann method on a nonuniform grid", *Journal of Computational Physics*, Vol. 181, No. 2, pp. 675–704 2002

Luo, L.-S., Liao, W., Chen, X., Peng, Y., Zhang, W. *et al.* (2011), "Numerics of the lattice Boltzmann method: Effects of collision models on the lattice Boltzmann simulations", *Physical Review E*, Vol. 83, No. 5, p. 056710 2011

Lyn, D. A., Einav, S., Rodi, W., and Park, J.-H. (1995), "A laser-Doppler velocimetry study of ensemble-averaged characteristics of the turbulent near wake of a square cylinder", *Journal of Fluid Mechanics*, Vol. 304, pp. 285–319 1995

Mayer, G. and Házi, G. (2006), "Direct numerical and large eddy simulation of longitudinal flow along triangular array of rods using the lattice Boltzmann method", *Mathematics and Computers in Simulation*, Vol. 72, No. 2-6, pp. 173–178 2006

McNamara, G. R. and Zanetti, G. (1988), "Use of the Boltzmann equation to simulate lattice-gas automata", *Physical Review Letters*, Vol. 61, No. 20, p. 2332 1988

Mei, R., Shyy, W., Yu, D., and Luo, L.-S. (2000), "Lattice Boltzmann method for 3-D flows with curved boundary", *Journal of Computational Physics*, Vol. 161, No. 2, pp. 680–699 2000

Menter, F. R. (1994), "Two-equation eddy-viscosity turbulence models for engineering applications", *AIAA journal*, Vol. 32, No. 8, pp. 1598–1605 1994

Micale, G., Brucato, A., Grisafi, F., and Ciofalo, M. (1999), "Prediction of flow fields in a dual-impeller stirred vessel", *AIChE journal*, Vol. 45, No. 3, pp. 445–464 1999

Mussa, A., Asinari, P., and Luo, L.-S. (2009), "Lattice Boltzmann simulations of 2D laminar flows past two tandem cylinders", *Journal of computational physics*, Vol. 228, No. 4, pp. 983–999 2009

Nakagawa, S., Nitta, K., and Senda, M. (1999), "An experimental study on unsteady turbulent near wake of a rectangular cylinder in channel flow", *Experiments in fluids*, Vol. 27, No. 3, pp. 284–294 1999

Noble, D. R., Chen, S., Georgiadis, J. G., and Buckius, R. O. (1995), "A consistent hydrodynamic boundary condition for the lattice Boltzmann method", *Physics of Fluids*, Vol. 7, No. 1, pp. 203–209 1995

NVIDIA, T. (2016), "P100 white paper", *NVIDIA Corporation* 2016

Pattison, M. J., Premnath, K. N., and Banerjee, S. (2009), "Computation of turbulent flow and secondary motions in a square duct using a forced generalized Lattice Boltzmann equation", *Physical Review E*, Vol. 79, No. 2, p. 026704 2009

Peng, C., Geneva, N., Guo, Z., and Wang, L.-P. (2018), "Direct numerical simulation of turbulent pipe flow using the lattice Boltzmann method", *Journal of Computational Physics*, Vol. 357, pp. 16–42 2018

Peng, Y. and Luo, L.-S. (2008), "A comparative study of immersed-boundary and interpolated bounce-back methods in LBE", *Progress in Computational Fluid Dynamics, an International Journal*, Vol. 8, No. 1-4, pp. 156–167 2008

Perumal, D. A. and Dass, A. K. (2015), "A Review on the development of lattice Boltzmann computation of macro fluid flows and heat transfer", *Alexandria Engineering Journal*, Vol. 54, No. 4, pp. 955–971 2015

Qian, Y. H. (1990), "Lattice gas and lattice kinetic theory applied to the Navier-Stokes equations", Ph.D. thesis 1990

Qian, Y.-H., d'Humières, D., and Lallemand, P. (1992), "Lattice BGK models for Navier-Stokes equation", *EPL (Europhysics Letters)*, Vol. 17, No. 6, p. 479 1992

Raabe, D. (2004), "Overview of the lattice Boltzmann method for nano-and microscale fluid dynamics in materials science and engineering", *Modelling and Simulation in Materials Science and Engineering*, Vol. 12, No. 6, p. R13 2004

Rushton, J. H., Costich, E. W., and Everett, H. J. (1950), "Power characteristics of mixing impellers", *Chemical Engineering Progress*, Vol. 46, No. 8, pp. 395–476 1950

Rutherford, K., Lee, K., Mahmoudi, S., and Yianneskis, M. (1996), "Hydrodynamic characteristics of dual Rushton impeller stirred vessels", *AIChE Journal*, Vol. 42, No. 2, pp. 332–346 1996

Sharma, K. V., Straka, R., and Tavares, F. W. (2019), "Lattice Boltzmann Methods for Industrial Applications", *Industrial & Engineering Chemistry Research*, Vol. 58, No. 36, pp. 16205–16234 2019

Shu, S. and Yang, N. (2018), "GPU-accelerated large eddy simulation of stirred tanks", *Chemical Engineering Science*, Vol. 181, pp. 132–145 2018

Skordos, P. (1993), "Initial and boundary conditions for the lattice Boltzmann method", *Physical*

Review E, Vol. 48, No. 6, p. 4823 1993
Smagorinsky, J. (1963), "General circulation experiments with the primitive equations: I. The basic experiment", *Monthly weather review*, Vol. 91, No. 3, pp. 99–164 1963
Srinivas, Y., Biswas, G., Parihar, A., and Ranjan, R. (2006), "Large-eddy simulation of high Reynolds number turbulent flow past a square cylinder", *Journal of engineering mechanics*, Vol. 132, No. 3, pp. 327–335 2006
Stephen B., P., *Turbulent Flows*, Cambridge University Press 2000
Succi, S., Benzi, R., and Higuera, F. (1991), "The lattice Boltzmann equation: A new tool for computational fluid-dynamics", *Physica D: Nonlinear Phenomena*, Vol. 47, No. 1-2, pp. 219–230 1991
Wang, X., Shangguan, Y., Onodera, N., Kobayashi, H., and Aoki, T. (2014), "Direct numerical simulation and large eddy simulation on a turbulent wall-bounded flow using lattice Boltzmann method and multiple GPUs", *Mathematical Problems in Engineering*, Vol. 2014 2014
Wei, Y.-K. and Hu, X.-Q. (2017), "Two-dimensional simulations of turbulent flow past a row of cylinders using lattice Boltzmann method", *International Journal of Computational Methods*, Vol. 14, No. 01, p. 1750002 2017
Wolfram, S. (1986), "Cellular automaton fluids 1: Basic theory", *Journal of statistical physics*, Vol. 45, No. 3, pp. 471–526 1986
Wu, H. and Patterson, G. (1989), "Laser-Doppler measurements of turbulent-flow parameters in a stirred mixer", *Chemical Engineering Science*, Vol. 44, No. 10, pp. 2207–2221 1989
Xinhong, L., Yuyun, B., Zhipeng, L., Zhengming, G., and Smith, J. M. (2008), "Particle image velocimetry study of turbulence characteristics in a vessel agitated by a dual Rushton impeller", *Chinese Journal of Chemical Engineering*, Vol. 16, No. 5, pp. 700–708 2008
Yasuda, T., Hashimoto, T., Tanno, I., Tanaka, Y., Minagawa, H., Morinishi, K., and Satofuka, N. (2014), "Efficient simulation for incompressible 3-dimensional turbulence flow using lattice Boltzmann model", *in Proceeding of the 8th international conference on computational fluid dynamics (ICCFD8)*, pp. 1661–1668 2014
Yasuda, T., Hashimoto, T., Tanno, I., Tanaka, Y., Minagawa, H., Morinishi, K., and Satofuka, N. (2017), "Effect of collision and velocity model of lattice Boltzmann model on three-dimensional turbulent flow simulation", *International Journal of Computational Fluid Dynamics*, Vol. 31, No. 4-5, pp. 258–268 2017
Zadghaffari, R., Moghaddas, J., and Revstedt, J. (2009), "A mixing study in a double-Rushton stirred tank", *Computers & chemical engineering*, Vol. 33, No. 7, pp. 1240–1246 2009
Ziegler, D. P. (1993), "Boundary conditions for lattice Boltzmann simulations", *Journal of statistical physics*, Vol. 71, No. 5, pp. 1171–1177 1993
Zou, Q. and He, X. (1997), "On pressure and velocity boundary conditions for the lattice Boltzmann BGK model", *Physics of fluids*, Vol. 9, No. 6, pp. 1591–1598 1997

Appendix A: Knowledge Dissemination

The following journals/book chapters/conference proceedings had been published from this thesis so far:

A1 INTERNATIONAL JOURNAL

1. Agarwal, A., Singh, G., and Prakash, A. (2021). Effect of baffles on the flow hydrodynamics of dual-Rushton turbine stirred tank bioreactor—a CFD study. *Brazilian Journal of Chemical Engineering*, 38(4), 849-863.

2. Agarwal, A., Gupta, S., and Prakash, A. (2021). A comparative study of three-dimensional discrete velocity set in LBM for turbulent flow over bluff body. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 43(1), 1-11.

3. Agarwal, A. (2020). Modification of On-Site Velocity Boundary Condition in LBM for D_3Q_{27} Lattice Structure. *Transactions of the Indian National Academy of Engineering*, 1-11.

4. Agarwal, A., Gupta, S., and Prakash, A. (2020). A comparative study of bounce-back and immersed boundary method in LBM for turbulent flow simulation.*Materials Today: Proceedings*, 28, 2387-2392.

5. Agarwal, A., Singh, G., and Prakash, A. (2021). Numerical investigation of flow behavior in double-rushton turbine stirred tank bioreactor. *Materials Today: Proceedings*, 43, 51-57.

A2 BOOK CHAPTER

1. Agarwal, A., and Prakash, A. (2018). Comparative study of boundary conditions in LBM for incompressible laminar flow. In *Mathematical Modelling and Scientific Computing with Applications* (pp. 241-251). Springer, Singapore.

A3 CONFERENCE PROCEEDINGS

1. Agarwal, A., and Prakash , A. (2018). LBM-LES Simulation of Flow Past a Square Cylinder Confined in a Duct using GPU Parallel Computing. In *FMFP-2018, IIT Bombay conference proceeding*

2. Agarwal, A., and Prakash, A. (2016). Validation of LBM based on BGK on Poiseuille's Flow and Vortex Street in a Channel Flow. In *ACSM-2016, Bangkok conference proceeding*

A4 SOLVER DEVELOPMENT

1. Agarwal, A., B. Ravindra, and Prakash, A. "**CuLB-LES**: A GPU Parallelized Lattice Boltzmann Solver for Turbulent Flow Simulation (Documents Submitted to R&D IIT Jodhpur for Copyright-Approved in IIPMG Meeting)

Appendix B: Grid Independence Study

B1 TURBULENT FLOW OVER BLUFF BODY

To demonstrate the effect of different grid sizes on the benchmark case of turbulent flow over a bluff body. The simulations are carried out using the D_3Q_{19} discrete velocity model of LBM on two different grid sizes: $800 \times 200 \times 120$ and $1000 \times 200 \times 200$. The results for mean streamwise velocity, RMS streamwise velocity fluctuations, and Reynolds shear stress are presented.

As shown in Figures B1 and B2, the results obtained from a fine mesh of $1000 \times 200 \times 200$ for the mean streamwise velocity near the downstream face of the cylinder agree with the experimental results of Nakagawa *et al.* [1999] and the simulation results of Kim *et al.* [2004] better than the results obtained from a grid size of $800 \times 200 \times 120$. The same is discussed in the explanation of Figure 4.3, that finer mesh is expected to produce more accurate results near the downstream face of the cylinder.

Other results also show a similar pattern. The profiles of RMS streamwise velocity fluctuations and Reynolds shear stress (see Figure B3 and B4) show that near the downstream face of the cylinder, results obtained from fine mesh are in better agreement, but far from the downstream face of the cylinder, grid size has a negligible impact.

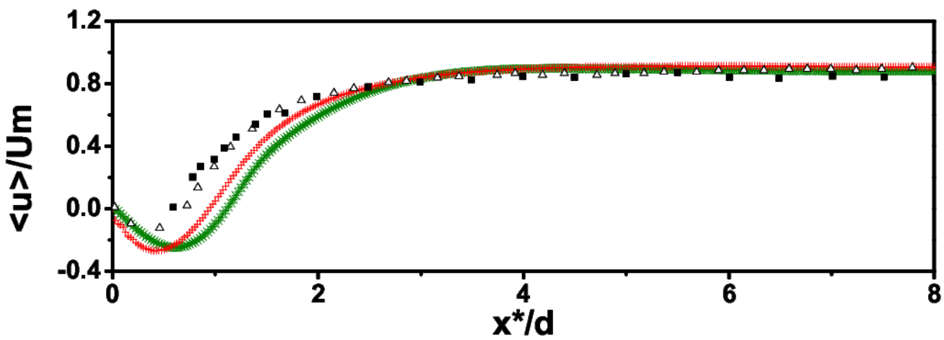


Figure B1 : Centerline distribution of mean streamwise velocity at different grid size (red plus : $1000 \times 200 \times 200$, green asterisk : $800 \times 200 \times 120$, open triangle : Kim *et al.* [2004], filled square: Nakagawa *et al.* [1999]).

B2 FLUID FLOW SIMULATION IN STIRRED TANK REACTOR

The preliminary results for axial profiles of phase-averaged radial velocity at different radial locations for Case 1 (i.e. parallel flow) for both baffles and without baffles are shown in Figure B5. The results depicted approximately similar results for 150^3 and 200^3 grid size and are in good agreement with the experimental data. However, the coarser grid size 100^3 under-predicted the results.

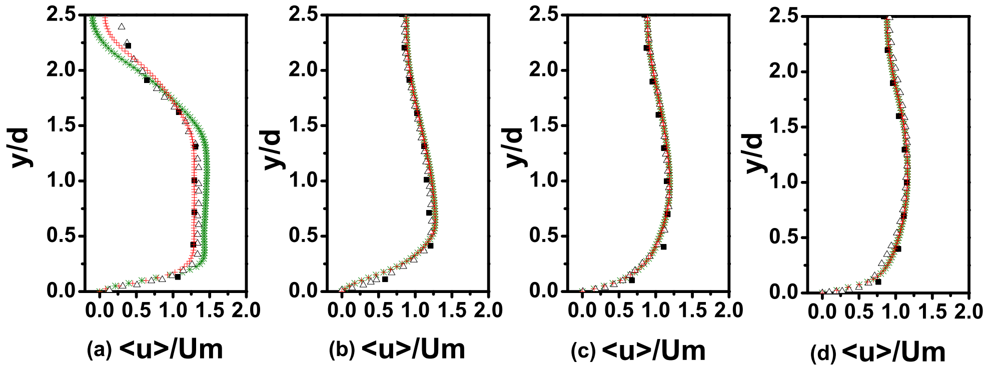


Figure B2 : Profiles of mean streamwise velocity at different grid size (red plus : $1000 \times 200 \times 200$, green asterisk : $800 \times 200 \times 120$, open triangle : Kim *et al.* [2004], filled square: Nakagawa *et al.* [1999]) : (a) x^*/d = 1.0, (b) x^*/d = 3.5, (c) x^*/d = 6.0, (d) x^*/d = 8.5.

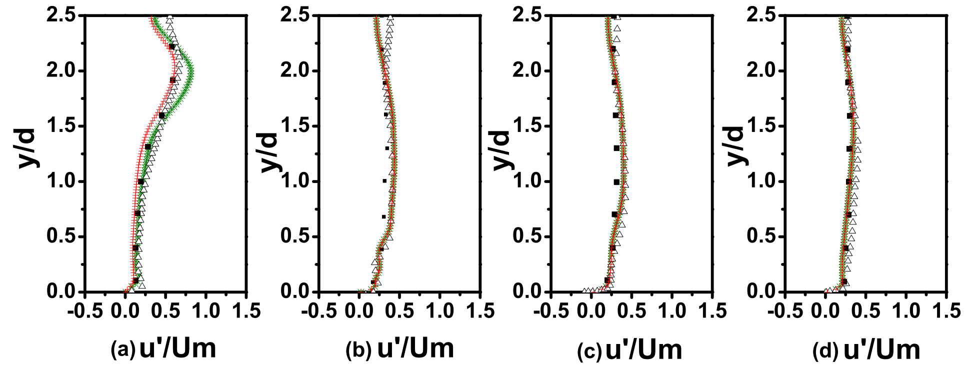


Figure B3 : Profiles of RMS streamwise velocity fluctuations at different grid size (red plus : $1000 \times 200 \times 200$, green asterisk : $800 \times 200 \times 120$, open triangle : Kim *et al.* [2004], filled square: Nakagawa *et al.* [1999]) : (a) x^*/d = 1.0, (b) x^*/d = 3.5, (c) x^*/d = 6.0, (d) x^*/d = 8.5.

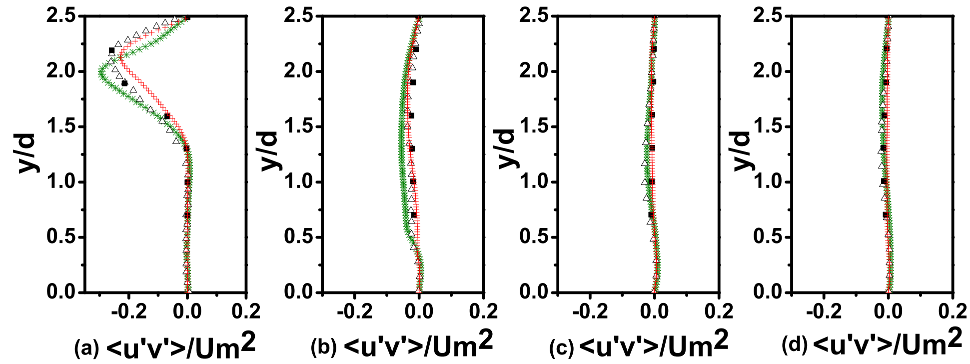
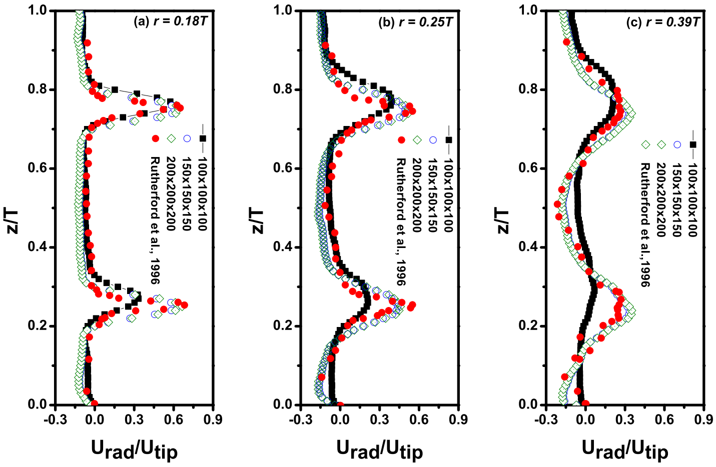
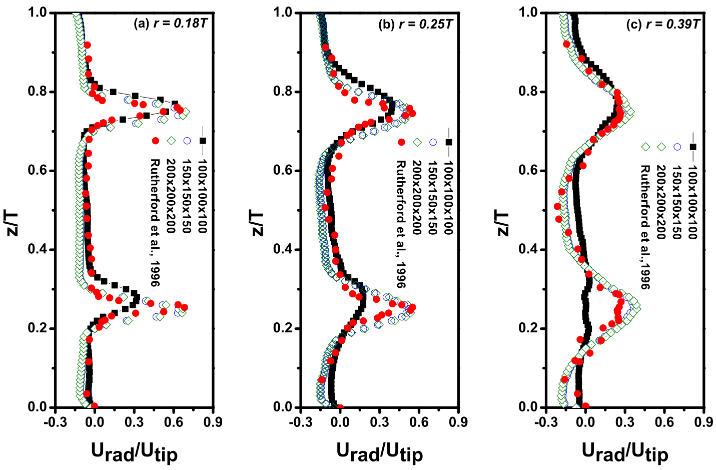


Figure B4 : Profiles of Reynolds shear stress at different grid size (red plus : $1000 \times 200 \times 200$, green asterisk : $800 \times 200 \times 120$, open triangle : Kim *et al.* [2004], filled square: Nakagawa *et al.* [1999]) : (a) x^*/d = 1.0, (b) x^*/d = 3.5, (c) x^*/d = 6.0, (d) x^*/d = 8.5.



(a)



(b)

Figure B5 : Comparison of axial profiles of phase-averaged radial velocity at different radial locations for Case 1 at different grid sizes a) with baffles, and b) without baffles.