Kim, Junseok

A continuous surface tension force formulation for diffuse-interface models. (English)

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Summary: We present a new surface tension force formulation for a diffuse-interface model, which is derived for incompressible, immiscible Navier-Stokes equations separated by free interfaces. The classical infinitely thin boundary of separation between the two immiscible fluids is replaced by a transition region of small but finite width, across which the composition of the one of two fluids changes continuously. Various versions of diffuse-interface methods have been used successfully for the numerical simulations of two phase fluid flows. These methods are robust, efficient, and capable of computing interface singularities such as merging and pinching off. But prior studies used modified surface tension force formulations, therefore it is not straightforward to calculate pressure field because pressure includes the gradient terms resulting from the modified surface tension term. The new formulation allows us to calculate the pressure field directly from the governing equations. Computational results showing the accuracy and effectiveness of the method are given for a drop deformation and Rayleigh capillary instability.

MSC:

76D45	Capillarity (surface tension) for incompressible viscous fluids
76T99	Multiphase and multicomponent flows
76E17	Interfacial stability and instability in hydrodynamic stability
76M25	Other numerical methods (fluid mechanics) (MSC2010)

Keywords:

continuum surface tension; diffuse-interface; phase field

Software:

PROST

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References:

[1] Almgren, A.S.; Bell, J.B.; Colella, P.; Howell, L.H.; Welcome, M.L., A conservative adaptive projection method for the variable density incompressible Navier-Stokes equations, J. comput. phys., 142, 1-46, (1998) · Zbl 0933.76055

[2] Anderson, D.M.; McFadden, G.B.; Wheeler, A.A., Diffuse-interface methods in fluid mechanics, Ann. rev. fluid mech., 30, 139-165, (1998) · Zbl 1398.76051

[3] Boyer, F., A theoretical and numerical model for the study of incompressible mixture flows, Comput. fluids, 31, 41-68, (2002) · Zbl 1057.76060

[4] Badalassi, V.E.; Ceniceros, H.D.; Banerjee, S., Computation of multiphase systems with phase field models, J. comput. phys., 190, 371-397, (2003) · Zbl 1076.76517

[5] Bell, J.; Collela, P.; Glaz, H., A second-order projection method for the incompressible Navier-Stokes equations, J. comput. phys., 85, 2, 257-283, (1989) · Zbl 0681.76030

[6] Brackbill, J.U.; Kothe, D.B.; Zemach, C., A continuum method for modeling surface tension, J. comput. phys., 100, 335-354, (1992) · Zbl 0775.76110

[7] Chang, Y.C.; Hou, T.Y.; Merriman, B.; Osher, S., A level set formulation of Eulerian interface capturing methods for incompressible fluid flows, J. comput. phys., 124, 449-464, (1996) · Zbl 0847.76048

[8] Cahn, J.W.; Taylor, J.E., Surface motion by surface diffusion, Acta metall., 42, 1045-1063, (1994)

[9] Chella, R.; Viñals, J., Mixing of a two-phase fluid by cavity flow, Phys. rev. E, 53, 3832-3840, (1996)

[10] Gueyffier, D.; Li, Jie; Nadim, Ali; Scardovelli, R.; Zaleski, S., Volume-of-fluid interface tracking with smoothed surface stress methods for three-dimensional flows, J. comput. phys., 152, 423-456, (1999) · Zbl 0954.76063

[11] Gao, D.; Morley, N.B.; Dhir, V., Numerical simulation of wavy falling film flow using VOF method, J. comput. phys., 192, 624-642, (2003) · Zbl 1047.76569

[12] Gurtin, M.E.; Polignone, D.; Viñals, J., Two-phase binary fluids and immiscible fluids described by an order parameter, Math. models meth. appl. sci., 6, 6, 815-831, (1996) · Zbl 0857.76008

[13] Jacqmin, D., Calculation of two-phase Navier-Stokes flows using phase-field modeling, J. comput. phys., 155, 96-127, (1999) · Zbl 0966.76060

[14] Jacqmin, D., Contact-line dynamics of a diffuse fluid interface, J. fluid mech., 402, 57-88, (2000) · Zbl 0984.76084

[15] Kim, Junseok, A diffuse-interface model for axisymmetric immiscible two-phase flow, Appl. math. comput., 160, 589-606, (2005) · Zbl 1299.76043

[16] Kodama, H.; Doi, M., Shear-induced instability of the lamellar phase of a block copolymer, Macromolecules, 29, 2652-2658, (1996)

[17] Kim, Junseok; Kang, Kyungkeun; Lowengrub, J., Conservative multigrid methods for Cahn-Hilliard fluids, J. comput. phys., 193, 511-543, (2004) · Zbl 1109.76348

[18] Junseok Kim and John Lowengrub, Ternary Cahn-Hilliard fluids, submitted for publication · Zbl 1109.76348

[19] Lee, H.Y.; Lowengrub, J.S.; Goodman, J., Modeling pinchoff and reconnection in a Hele-Shaw cell. I. the models and their calibration, Phys. fluids, 14, 2, 492-513, (2002) · Zbl 1184.76316

[20] Lee, H.Y.; Lowengrub, J.S.; Goodman, J., Modeling pinchoff and reconnection in a Hele-Shaw cell. II. analysis and simulation in the nonlinear regime, Phys. fluids, 14, 2, 514-545, (2002) · Zbl 1184.76317

[21] Liu, Chun; Shen, Jie, A phase field model for the mixture of two incompressible fluids and its approximation by a Fourier-spectral method, Physica D, 179, 211-228, (2003) · Zbl 1092.76069

[22] Lowengrub, J.S.; Truskinovsky, L., Quasi-incompressible Cahn-Hilliard fluids and topological transitions, Proc. R. soc. lond. A, 454, 2617-2654, (1998) · Zbl 0927.76007

[23] Prosperetti, A., Motion of two superposed viscous fluids, Phys. fluids, 24, 1217-1223, (1981) · Zbl 0469.76035

[24] Rayleigh, W.S., On the instability of jets, Proc. London math. soc., 10, 4-13, (1878) · Zbl 11.0685.01

[25] Renardy, Y.Y.; Renardy, M., PROST: a parabolic reconstruction of surface tension for the volume-of-fluid method, J. comput. phys., 183, 400-421, (2002) · Zbl 1057.76569

[26] Renardy, Y.Y.; Renardy, M.; Cristini, V., A new volume-of-fluid formation for surfactants and simulations of drop deformation under shear at a low viscosity ratio, Eur. J. mech. B/fluids, 21, 49-59, (2002) · Zbl 1063.76077

[27] Starovoitov, V.N., Model of the motion of a two-component liquid with allowance of capillary forces, J. appl. mech. techn. phys., 35, 891-897, (1994) · Zbl 0999.76595

[28] Shu, C.W.; Osher, S., Efficient implementation of essentially non-oscillatory shock capturing schemes II, J. comput. phys., 83, 32-78, (1989) · Zbl 0674.65061

[29] Sussman, M.; Smereka, P.; Osher, S., A level set approach for computing solutions to incompressible two-phase flow, J. comput. phys., 114, 146-159, (1994) · Zbl 0808.76077

[30] Scardovelli, R.; Zaleski, S., Direct numerical simulation of free surface and interfacial flow, Annu. rev. fluid mech., 31, 567-603, (1999)

[31] Taylor, G.I., The deformation of emulsions in definable fields of flows, Proc. R. soc. lond. A, 146, 501-523, (1934)

[32] Tang, Hao; Wrobel, L.C.; Fan, Z., Tracking of immiscible interfaces in multiple-material mixing processes, Comp. mater. sci., 29, 103-118, (2004)

[33] Trottenberg, U.; Oosterlee, C.; Schüller, A., Multigrid, (2001), Academic Press New York

[34] Verschueren, M.; Van De Vosse, F.N.; Heijer, H.E.H., Diffuse-interface modelling of thermocapillary flow instabilities in a Hele-Shaw cell, J. fluid mech., 434, 153-166, (2001) · Zbl 0971.76030

[35] Yokoi, K.; Xiao, Feng, Mechanism of structure formation in circular hydraulic jumps: numerical studies of strongly deformed free-surface shallow flows, Physica D, 161, 202-219, (2002) · Zbl 1044.76020

[36] X. Zheng, S.M. Wise, V. Cristini, Nonlinear simulation of tumor nectrosis, neo-vascularization and tissue invasion via an adaptive finite-element/level-set method, Bull. Math. Biol., in press · Zbl 1334.92214