Euler/Lagrange method for dispersed multiphase flows with technical applications

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The Euler/Lagrange approach is a method for numerical calculations of dispersed multiphase flows on a macroscopic level. As such, this approach is limited to dispersed particle-laden flows and may be combined with any type of fluid flow modelling, i.e. laminar flow, DNS, LES and RANS, which determines the level of flow and turbulence resolution and turbulence modelling requirements.
An essential feature of the Euler/Lagrange approach is the consideration of individual particles or numerical particle groups (so-called parcels) as point-masses which are moved through the before-hand simulated flow field. In contrary to continuum formulations (or multi-fluid methods), where the particles are represented by cell-based averaged properties, this method features the discrete nature of the particles. Nevertheless, both methods are complementary.
A fundamental assumption of the Euler/Lagrange method is the treatment of the particles as point-masses which should be also much smaller than the dimension of the numerical grid. Note, there are also approaches, which relax this quite restrictive demand by using for example spatially distributed coupling (see e.g. Reichardt and Sommerfeld 2007). Consequently, particles are moved through the flow field based on all relevant forces acting on them (Sommerfeld et al. 2008) by using appropriate resistance coefficients also valid for larger particle Reynolds numbers. The major advantages of the Euler/Lagrange approach compared to multi-fluid formulations are the simple consideration of particle size distributions and the descriptive way of incorporating elementary processes occurring on the particle scale, such as, wall collisions, inter-particle collisions and coalescence or agglomeration. It should be emphasized that there exists no limitation on the volume fraction of the dispersed phase in applying this method as long as all physical effects are modelled properly, consider for example the vast literature on the hybrid CFD-DEM method.
Very important for this hybrid approach is the way of coupling continuum fluid flow simulations on a fixed Eulerian grid with Lagrangian discrete particle simulations. In any case when considering two-way coupling (i.e. considering the influence of particles on fluid flow and turbulence) fluid and particle phase have to be simulated sequentially until a convergent solution is obtained. Depending on the problem of consideration, the flow may be simulated for a steady-state condition or it is necessary to run a fully unsteady simulation. For steady-state simulations particles may be tracked sequentially or simultaneously and the source terms have to be evaluated for each computational cell from tracking a huge number of particles. When considering unsteady flows different time steps may be used for flow simulations and particle tracking. Normally the time steps for particle tracking are much smaller than those for the fluid flow simulations being determined by the temporal resolution of the flow field (Sommerfeld 2017). In any case, a dynamic Lagrangian particle time step is suggested for

efficiency, which is determined by the local relevant time scales, such as, particle response time, integral time scale of turbulence and inter-particle collision time scale.
The lecture will summarise the main features of the Euler/Lagrange approach and introduce some applications to particle dispersion in stirred vessel, unsteady swirling flows as well as pneumatic conveying. For the latter also different effects on bend erosion will be highlighted. Other applications are particle separation in cyclones, particle dispersion in an oscillating mixer and hydrodynamics of bubble columns accounting for bubble dynamics behaviour.

References

Crowe, C.T., Schwarzkopf, J.D., Sommerfeld, M. and Tsuji, Y.: Multiphase Flows with Droplets and Particles. 2nd Edition, CRC Press, Boca Raton, U.S.A. (2012), ISBN 978-1-4398-4050-4.

Sommerfeld, M., van Wachem, B. and Oliemans, R.: Best Practice Guidelines for Computational Fluid Dynamics of Dispersed Multiphase Flows. ERCOFTAC (European Research Community on Flow, Turbulence and Combustion, ISBN 978-91-633-3564-8 (2008)

Sommerfeld, M., Kohnen, G. and Rüger, M.: Some open questions and inconsistencies of Lagrangian Particle dispersion models. Ninth Symposium on Turbulent Shear Flows, Kyoto, Aug. 1993, Paper 15.1.

Sommerfeld, M., Kohnen, G. and Qiu, H.-H.: Spray evaporation in turbulent flow: Numerical calculations and detailed experiments by phase-Doppler anemometry. Revue de L`Institut Francais du Petrole, Vol. 48, No. 6, 677-695 (1993)

Kohnen, G., Rüger, M. and Sommerfeld, M.: Convergence behaviour for numerical calculations by the Euler/Lagrange method for strongly coupled phases. Numerical Methods in Multiphase Flows 1994, (Eds. C.T. Crowe, R. Johnson, A. Prosperetti, M. Sommerfeld, and Y. Tsuji), ASME Fluids Engineering Division Summer Meeting, Lake Tahoe, U.S.A., FED-Vol. 185, 191-202 (1994)

Reichardt, Th. and Sommerfeld, M.: Euler-Lagrange Approach with spatially distributed coupling. Proceedings of the 6th International Conference on Multiphase Flow, ICMF2007, Leipzig Germany, Paper No. S3_Mon_C_7 (2007)

Rüger, M., Hohmann, S., Sommerfeld, M. and Kohnen, G.: Euler/Lagrange calculations of turbulent sprays: The effect of droplet collisions and coalescence. Atomization and Sprays, Vol. 10, 47-81 (2000)

Böttner, C.-U. and Sommerfeld, M.: Numerical calculation of electrostatic powder painting using the Euler/Lagrange approach. Powder Technology, Vol. 125, 206-216 (2002)

Sommerfeld, M. and Decker, S.: State of the art and future trends in CFD simulation of stirred vessel hydrodynamics. Chemical Engineering Technology, Vol. 27, 215-224 (2004)

Lipowsky, J. and Sommerfeld, M.: LES-simulation of the formation of particle strands in swirling flows using an unsteady Euler-Lagrange approach. Proceedings of the 6th International Conference on Multiphase Flow, ICMF2007, Leipzig Germany, Paper No. S3_Thu_C_54 (2007)

Sommerfeld, M., Lipowsky, J. and Laín, S. (keynote lecture): Transient Euler/Lagrange modelling for predicting unsteady rope behaviour in gas-particle flows. Proceedings of FEDSM2010 ASME Joint U.S. - European Fluids Engineering Summer Meeting, August 1 – 5, 2010, Montreal, Canada, Paper No. FEDSM-ICNMM2010-31335.

Sommerfeld, M.: Numerical methods for dispersed multiphase flows. In: Particles in Flows (Eds. T. Bodnár, G.P. Galdi, Š. Necčasová), Series Advances in Mathematical Fluid Mechanics, Springer International Publishing, 327 – 396 (2017), ISBN 978-3-319-60281-3

Sommerfeld, M., Muniz, M. and Reichardt, Th.: On the importance of modelling bubble dynamics for point-mass numerical calculations of bubble columns. Journal of Chemical Engineering of Japan, Vol. 51, 1 – 17 (2018)