Development of *solidParticle* Library for the Particle Transfer in EM Induced Turbulent Flows

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The present work deals with the transportation of solid particles in an electromagnetically (EM) induced turbulent recirculated flow of metal melt in industrial electroheat equipment (e.g. induction crucible furnace - ICF). Such simulation corresponds to the dynamics of the impurities like dirty secondary metals that leads to the deposition as well as the erosion of the walls of the crucible. These processes can significantly reduce the efficiency of the equipment up to breakdown. In addition there is a problem of the homogenization of alloying particles, which are mixed in a steel melt to improve properties. It is important to achieve homogeneous admixtures distribution to ensure a high quality of the alloy. Furthermore, it is desirable to reduce the time of mixing to decrease the energy consumptions and prevent the melt from overheating. The industrial problems described above state the interest to the simulation of the particle transfer inside such equipment.

The flow of the metal melt inside industrial and laboratory electroheat equipment is described with Reynolds number (e.g. for laboratory ICF it is about 10^5). Therefore Large Eddy Simulation (LES) method and *pisoFoam* solver are used to resolve the intensive low frequency pulsations of the liquid metal between the vortices of the averaged flow close to the wall of the crucible [1].

solidParticle library conducts a simulation of particles using Euler-Lagrange approach in the limit of dilute conditions (one-way coupling). The used Lagrange equation in non-modified *solidParticle* library includes drag and buoyancy forces. However, as far as the flow is non-stationary and turbulent and the particle size is enough to calculate them as inertia particles, the Lagrange equation should be supplemented with additional EM, lift, acceleration and added mass forces. The significance of these forces is statistically proved in the paper [2]. Therefore the modified Lagrange equation in *solidParticle* library becomes as follows:

$$\underbrace{\left(1+\frac{C_\mathrm{A}}{2}\frac{\rho_\mathrm{f}}{\rho_\mathrm{p}}\right)\cdot\frac{\mathrm{d}\boldsymbol{u}_\mathrm{p}}{\mathrm{d}t}}_{\mathrm{d}\boldsymbol{u}_\mathrm{p}/\mathrm{d}t+\text{added mass force}} = \underbrace{C_\mathrm{D}\cdot\boldsymbol{U}}_{\text{drag force}} + \underbrace{\left(1-\frac{\rho_\mathrm{f}}{\rho_\mathrm{p}}\right)\cdot\boldsymbol{g}}_{\text{buoyancy force}} - \underbrace{\frac{3}{4}\frac{1}{\rho_\mathrm{p}}\boldsymbol{f}_\mathrm{em}}_{\text{EM force}} + \underbrace{\frac{\rho_\mathrm{f}}{\rho_\mathrm{p}}C_\mathrm{L}\boldsymbol{\xi}}_{\text{lift force}} + \underbrace{\left(1+\frac{C_\mathrm{A}}{2}\frac{\rho_\mathrm{f}}{\rho_\mathrm{p}}\right)\cdot\frac{\mathrm{D}\boldsymbol{u}_\mathrm{f}}{\mathrm{D}t}}_{\text{acceleration+added mass}},$$

where $\boldsymbol{U}=\boldsymbol{u}_\mathrm{f}-\boldsymbol{u}_\mathrm{p}$, $\boldsymbol{u}_\mathrm{f}$ and $\boldsymbol{u}_\mathrm{p}$ are liquid and particle velocities respectively, ρ_f and ρ_p are liquid and particle density respectively, $\boldsymbol{g}$ is the free fall acceleration; $\boldsymbol{f}_\mathrm{em}=0.5\cdot(\boldsymbol{j}\times\boldsymbol{B}^*)$ is the averaged Lorenz force density (which is calculated with ANSYS commercial software), $\boldsymbol{j}$ is the current density, $\boldsymbol{B}^*$ is the complex conjugated magnetic field induction, $\boldsymbol{\xi}=\boldsymbol{U}\times(\nabla\times\boldsymbol{U})$; $C_\mathrm{A}(\mathrm{d}U/\mathrm{d}t, U)$, $C_\mathrm{D}(U)$ and $C_\mathrm{L}(U)$ are acceleration, drag and lift force coefficients respectively. As far as the Lagrange equation is non-linear, Pikar's iteration method is used to solve this equation.

The homogenization of alloying particles in the melt of ICF is analyzed by the authors using the present algorithm [3].

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