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IMPROVING THE PERFORMANCE OF HERSCHEL-BULKLEY RHEOLOGICAL MODEL IN LIQUID-SOLID PHASE CHANGE PROBLEMS

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Abstract. Computational rheology plays a pivotal role in mechanical engineering, with widespread applications: blood flow dynamics, latent heat energy storage, and casting of polymers and metal/alloys, among others. Generally, conventional rheological models depend on several parameters such as restrictive yield stress, power index, deformation rate, time, and temperature, inducing non-linearities that increase the computation time in CFD approaches. For this reason, this work introduces a robust three-dimensional CFD model that simulates the complex unsteady liquid-solid phase change of a ternary aluminum alloy (Al-7%Si-0.3%Mn) using the non-Newtonian Herschel-Bulkley (H-B) rheology. The coupling of fluid flow, heat transfer, and phase change is assessed by the Finite Volume Method (FVM) and the pressure-correction algorithm SIMPLERnP. The 3D-FVM/SIMPLERnP scheme is validated with 2D solutions and numerical data in the scientific literature, showing negligible variations of velocity components and in the liquidus-solidus moving front during the convective solidification. The classical generalized H-B model is improved with three discontinuity regularizations: (i) Bercovier and Engelman, (ii) Papanastasiou, and (iii) Bi-viscosity. The results are focused on analyzing three key aspects: First, the variations in inner cycles of the pressure correction in the SIMPLERnP scheme; second, the accuracy and convergence of the H-B models; and, finally, exploring the performance of SIMPLERnP compared to three reliable P-V-T algorithms (SIMPLER, PISO, and IDEAL). The main findings established that the Bercovier and Engelman regularization leads to a reduction in the convergence time by 13%; for its part, Papanastasiou and Bi-viscosity models reduce the computational time by 17% and 8%, compared to the classical H-B model, maintain the same accuracy in the primitive variables. Finally, we concluded that SIMPLERnP with ten optimized inner cycles considerably reduces the time of computation compared to SIMPLER, PISO, and IDEAL algorithms during the liquid-solid phase change.

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