Rheological Behaviour of Biphasic Material

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Abstract: The rheological behaviour of a biphasic material is quite complex to model because of the difficulties of representing the evolution of the space position of each solid particle in the solid matrix. The first part of this study considers an equivalent material by homogenisation method. The main point of this first part was the representation of the rotation of the rheometer stirrer. The second part focuses on the biphasic aspect of the problem. The aim of our study is to develop a model that is able to show the convection phenomena in the liquid part, the influence of temperature, stirrer geometry, rotation speed and so on; all parameters responsible for the quality of such mixing.

Keywords: rheology, ALE, dynamic viscosity

1. Introduction

One of the industrial processes used by Nexter Munitions to manufacture energetic materials consists in preparing a mixture of molten fusible explosive and solid particles of other products (energetic or not). The homogeneity of the mixture depends on its viscosity which is a function of different parameters such as temperature, solid fraction and rotation speed of the stirrer. The aim of this study is to develop a simulation that represents the behaviour of a huge quantity of particles suspended in a viscous liquid. This paper presents the first part of our work: the simulation of a homogeneous equivalent material. The ability to understand rheological effects of various parameters like temperature, rotation speed is of great interest for the optimisation of mixing process.

2. Experiments to be simulated

In order to study experimentally the viscosity variation of a two phase flow, a rheometer is used with specific measuring systems. As we study concentrated suspensions, a six-blade stirrer is used.

Figure 1 : rheometer used

Figure 1 shows the apparatus used. This makes it possible to study the effects of rotation speed, temperature and solid fraction. Because of the relatively long time necessary for the performance of experiments (especially for thermal stabilisation) and the impossibility of seeing what happens in the mixture at a microscopic scale, we decided to develop a two phase flow approach by the use of Comsol Multiphysics®.

3. Methods

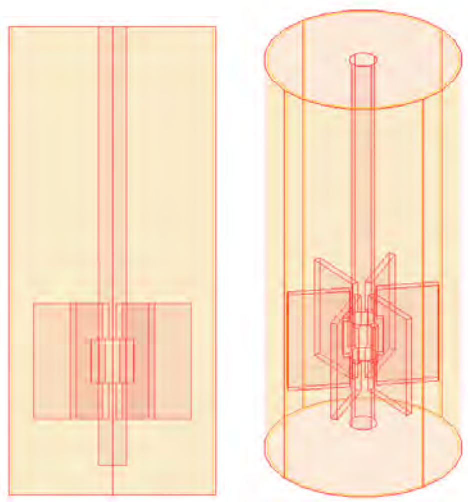


Figure 2 : Geometrical representation of the rheometer

Figure 2 shows the geometrical model considered.

We are studying a two phase flow problem where the liquid phase is made of molten explosive and the solid phase of small particles. The stirrer rotates at a given speed in the mixture. The problem relates to fluid dynamics so the Navier-Stokes equations are used.

$$\begin{cases} \rho\dfrac{\partial u}{\partial t} + \rho u.\nabla u = \nabla.\left[-pId + \eta(\nabla u + (\nabla u)^T)\right] + \rho g + \sigma\kappa\delta n \\ \nabla u = 0 \end{cases}$$

ρ is the density, η the dynamic viscosity, Id the identity tensor, g the field of gravity, σ the surface tension coefficient, n the unit normal to the interface, κ=-∇n the curvature of the fluid interface, δ a delta function concentrated at the interface between the fluids, u the field of velocity (m/s) and p the pressure (Pa).

The dynamic viscosity is firstly considered for a Newtonian fluid (this is the case of the liquid phase studied). So, the dynamic viscosity follows the usual law:

$$\eta = A\exp\left(\frac{B}{T}\right)$$

In order to represent the thermal conduction and convection, a heat equation is coupled.

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u\nabla T - \nabla.(k\nabla T) = 0$$

And to take into account the influence of the phase change on the viscosity, a Heavyside evolution of the heat capacity is added to the heat equation.

$$C_p = C_{p\,solide} + \frac{\Delta H_f}{T_f}(flc2hs(T - T_f,1)) + \Delta H_f \exp\left(-\frac{(T-T_f)^2}{\sqrt{\pi}}\right)$$

C_p is the heat capacity, ΔH_f is the melting specific heat and T_f the melting point of the liquid phase.

A moving mesh model is used to simulate the rotation of the stirrer. The following equations are used (rotation matrix for a rotation around z):

$$dx = \cos(-2\pi\omega t).X - \sin(-2\pi\omega t).Y - X$$
$$dy = \sin(-2\pi\omega t).X + \cos(-2\pi\omega t).Y - Y$$
$$dz = 0$$

The boundary conditions are defined by “no slip wall” for the external ones and by “moving/leaking wall” for the internal ones with the following conditions:

$u_w = x.t$
$v_w = y.t$
$w_w = 0$

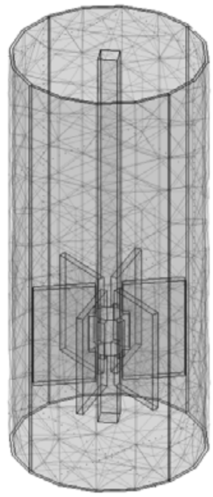


Figure 3 : mesh

The domain is meshed by 1637 nodes and 6265 tetrahedral elements, corresponding to about 34000 DOF. Computations have been performed with the direct solver UMFPACK, COMSOL Multiphysics® version 3.5a.

4. Results

The visualisation of the field of velocity in the viscous material is of great interest for the understanding of the influence of the stirrer’s geometry on the homogeneity of the mixture. The behaviour of the liquid phase is different for a Couette type stirrer.

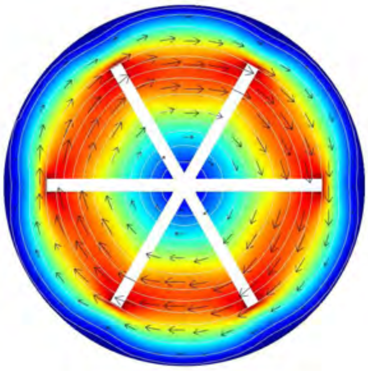
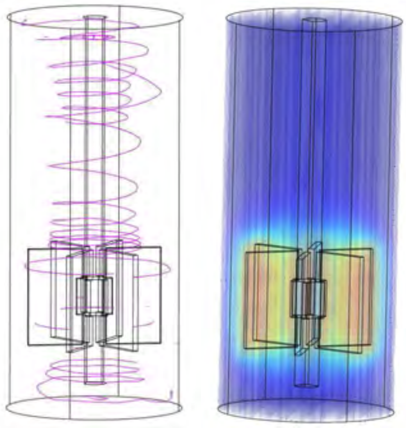


Figure 4 : speed field visualisation



5. Conclusion

This study was the first step in representing the rheological behaviour of a two phase flow. The next step will be the addition of solid granular species in the liquid phase.

6. References

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