Theoretical Investigations of Flow Phenomena in a Liquid Composite Molding Process using SPH Methodology

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ABSTRACT: The composites industry employs novel fabrication techniques to combine high-performance reinforcements and resins in making composite structures. Resin Transfer molding (RTM) is one of the liquid composite molding (LCM) manufacturing processes in which resin is injected into a mould cavity pre-filled with a fibrous preform. This process involves a viscous thermosetting resin flowing through a bundle of fibers, completed within a limited duration of time, before the resin gels. The flow also should be in such a way that no air is entrapped during the resin fill. Complete saturation of the preform during RTM is necessary for successful manufacturing and performance of the composite product [1]. This process is quite intricate and complicated. Comprehensive studies are necessary and attention should be focused on this problem, involving following areas associated in the resin-flow through the mould.

- Resin flow idealized as flow through porous media.
- Resin viscosity changes during the flow.
- The porosity of the reinforcements as a material property.
- Effect of imposed pressure on the porosity and other mould conditions (For example, the nature of venting and their location)

Resin flow idealized as flow through porous media

The subject of flow through porous media is not new, in the sense that this problem is common with most of the Engineering problems. For example consider **a.** Seepage flow through soils (Civil Engineering), **b**. Filtration of water in water treatment plants (Civil Engineering), **c.** Chemical reactors involving the heat and mass flow rates (Chemical Engineering) and **d.** Flow of exhaust gases through the automobile silencers, molten metal flow in a pressure die casting mould (Mechanical Engineering).

To analyse flow through porous media, there are a few important and useful mathematical models based on a) Darcy's law and b) Finite Element/Volume Method c) Smoothed Particle Hydrodynamics (SPH) theory supported by experimental results.

Models based on Smoothed Particle Hydrodynamics

Smoothed particle hydrodynamics (SPH) is a *meshless Lagrangian method* applied for modeling mass flow and heat transfer problems. Material properties are approximated by their values at a discrete set of disordered points, or *SPH particles*. SPH is directly based on the resolution of the macroscopic governing equations, such as the Navier-Stokes equations. These equations are written as a set of ordinary differential equations for the mass and heat flux of the SPH particles. The SPH method has its origin over the past two decades, primarily applied to the problems of the astrophysical phenomena [2]. More recently, this method has been extended to incompressible enclosed flows [3-4] and applied to industrial problems such as high velocity impact damage and high-pressure die casting [5].

The application of the SPH method to numerical flow simulations of industrial interest is relatively new. A mesh less Lagrangian technique has been shown to be particularly well adapted to applications involving complex geometries and free surfaces. The advantages of this method are illustrated by its application to two industrial processes: high-pressure die-casting and resin transfer molding. Recently, a number of researchers have analysed 2D, 3D mesoscopic-scale modeling of flow in porous media using lattice gas [6-7] and lattice Boltzmann methods [8-9].

The SPH method is briefly explained below. An interpolated value of any field *A* at position **r** is approximated by

$$A(r) = \sum_b m_b \frac{A_b}{\rho_b} W(r - r_b, h) \quad (1)$$

Where A_b = the value of *A* associated with particle *b* at $\mathbf{r}_b$

m_b and $\boldsymbol{\rho}_b$ = the mass and density of particle *b* respectively.

$W(\mathbf{r},h)$ = a spline-based interpolation kernel (of radius twice the interpolation length *h)*.

The kernel is a C^2 function that approximates the shape of a truncated Gaussian function with support radius 2*h*. The sum in Eq. (1) is thus restricted to all particles *b* within a radius 2*h* of $\mathbf{r}_b$.

Sawley et al. [10], developed a novel numerical method for the simulation of flow in porous media, based on a mesoscopic-scale modeling using SPH. They considered flows through saturated and unsaturated porous media. They used this method for mould filling dynamics and demonstrated its ability to predict the edge effects associated with RTM. They have also observed that Darcy's law is applicable for low drift velocities in a saturated medium.

Hence the present paper investigates the flow phenomena (resin) in a resin transfer molding process using Darcy and smoothed particle hydrodynamics technique to study viscosity variations, effect of closed and open vents etc.

KEYWORDS: Resin transfer molding, Flow through porous media, Darcy law, Smoothed particle hydrodynamics

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