Hot Melt Ink-Jet Printing: Droplet Impact

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Introduction
Droplet impact is one of the basic sub-processes of many existing and emerging technologies such as ink-jet printing, spray coating, solder-jet technology, DNA sequencing etc. An understanding of fluid dynamics and heat transfer accompanied, with or without phase change, is crucial in the selection of proper materials and in optimizing operating conditions. But, the analysis is complicated by the presence of various interfaces as shown in Figure 1.

![Various interfaces involved during spreading of a drop on a solid surface.](image)

Figure 1 Various interfaces involved during spreading of a drop on a solid surface.

Objectives
- To model non-isothermal impact of a micron-sized droplet on a chemically inactive solid surface.
- Investigate the effect of fluid rheology on its impact behaviour.

Method
The Diffuse Interface Method (DIM) [1] is applied to capture the effects of surface tension ($\gamma$) and contact angle ($\theta$) and, moreover, to resolve the singularity at the moving three phase contact line.

The DIM equations read (upon non-dimensionalizing):
- Cahn-Hilliard Equation for concentration ($c$)
  \[
  \frac{\partial c}{\partial t} + \nabla \cdot (v \cdot \nabla c) = \frac{1}{Pe} \nabla^2 c
  \]  
  (1)
- Landau-Ginzburg free energy ($f$) gives chemical potential ($\mu$)
  \[
  \mu = \frac{\partial f}{\partial c} - c_h \nabla^2 c = c^3 - c - c_h \nabla^2 c
  \]  
  (2)
- Unsteady modified Navier-Stokes equation
  \[
  \frac{We}{Ca} \frac{\partial v}{\partial t} + \nabla \cdot (v \cdot \nabla v) = \nabla \cdot (\tau) + \frac{Bo}{Ca} \rho^* (\mu v \cdot \nabla c - \nabla f)
  \]  
  (3)
- Equation of continuity
  \[
  (\nabla \cdot \rho^* v) = 0
  \]  
  (4)

where:
\[
\tau = -p I + \rho^* (\nabla v + \nabla v^T)
\]

Boundary conditions:
\[
v = 0; \quad \nabla c \cdot n = 0; \quad \nabla \mu \cdot n = 0.
\]

Results
Non-linear set of equations (1)-(4) is solved using finite element method as described in [1].

![Non-isothermal impact of a 67 $\mu$m diameter Pedot drop with 4 m/s velocity on a solid surface. The contact angle equals 90°, $\gamma$ = 70 mN/m and $\lambda$ = 1000 is used.](image)

As shown in Figure 2, when the entire impact energy of the droplet is dissipated via viscous resistance and storage as surface energy, the droplet attains maximum diameter of about 130 $\mu$m. This happens at $t \approx 12$ $\mu$s. After this the droplet recoils. This prediction is in qualitative agreement with the experiments of [2] although in our simulation the density of the droplet material is only 10 times that of ambient gas ($\rho = 10$) and Cartesian co-ordinates are used.

Summary
Our current model gives qualitative agreement. For a quantitative comparison we are going to use:
- more realistic value of $p$.
- axisymmetric co-ordinates.

After attaining this, we can incorporate non-isothermal effects and also, study the effects of fluid rheology to achieve our goals.

References:

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