A Pragmatic Multiphysics Numerical Model for Melt Hydrodynamics in Selective Laser Melting

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Introduction: This study explores the significance of the recoil pressure, Marangoni convection and surface tension effects in selective laser melting of Ti-6Al-4V. A pragmatic two dimensional model with appropriate powder distribution over a substrate of finite thickness has been developed in Comsol Multiphysics®.

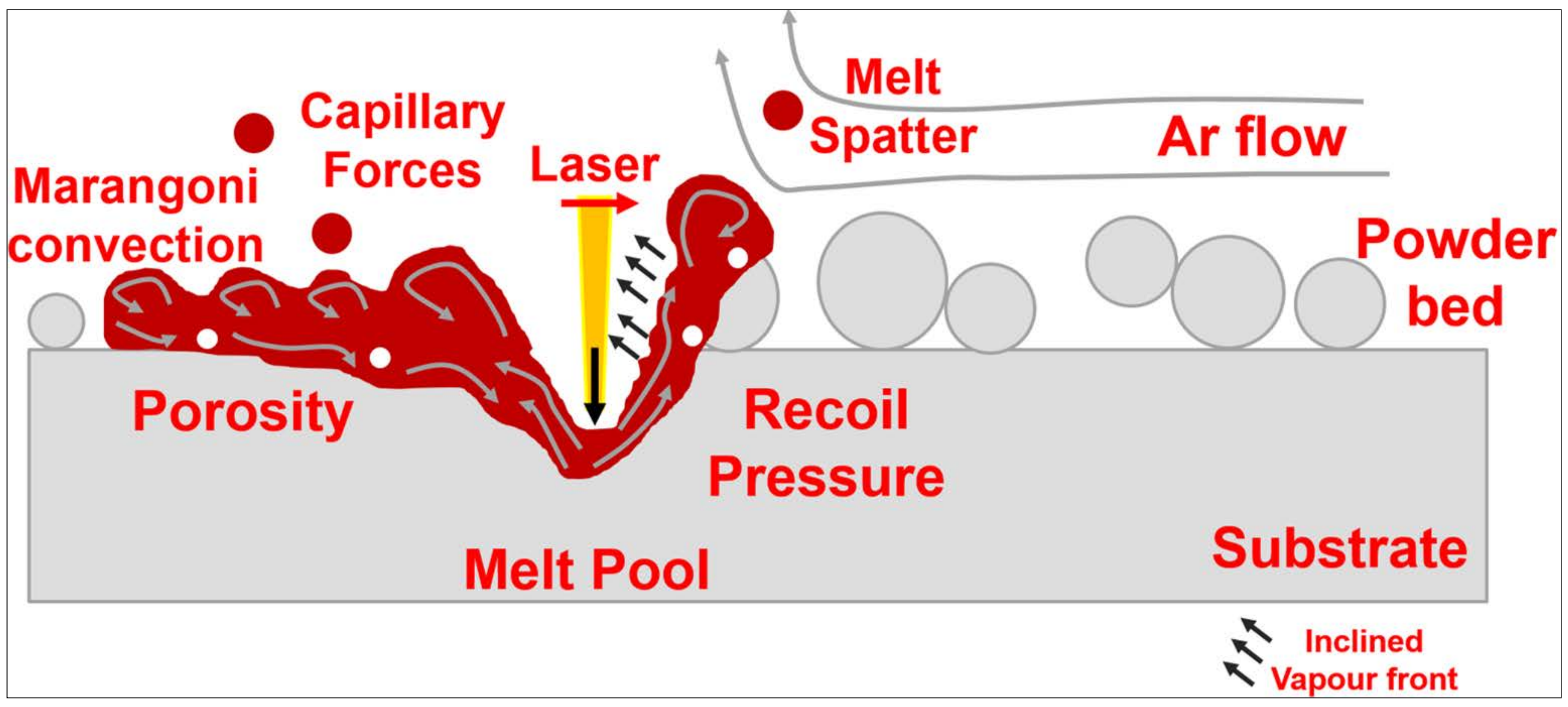


Figure 1. Schematic of Thermo-physical process in laser powder bed fusion.

Computational Methods: A 2D model with appropriate powder distribution over substrate is built to describe multiphase Multiphysics problem using heat transfer and two phase laminar flow phase field modules. The primary governing equations are-

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p (\vec{u} \cdot \nabla T) = \nabla \cdot (k \nabla T) + Q$$

$$\rho \nabla \cdot (\vec{u}) = 0$$

$$\rho \frac{\partial \vec{u}}{\partial t} + \rho (\vec{u} \cdot \nabla) \vec{u} = -\nabla p + \mu \nabla^2 \vec{u} + \rho g + \vec{F}$$

$$\frac{\partial \phi}{\partial t} + u \cdot \nabla \phi = \nabla \cdot \frac{\gamma \lambda}{\varepsilon^2} \Psi$$

$$\Psi = -\nabla \cdot \varepsilon^2 \nabla \phi + (\phi^2 - 1)\phi$$

Volumetric Heat Source[1] with evaporative heat loss[2] :-

$$Q = (I(x,y) - qevap)^{*}\delta(\phi)$$

Interfacial boundary condition[2] :-

$$n_i \cdot \left(\mu(\nabla u - (\nabla u)^T)\right) = -P_{recoil}\, n_i + \sigma(\nabla_s \cdot n_i) n_i - \nabla_s \sigma$$

Results: The different regimes of melt hydrodynamics in SLM are studied.

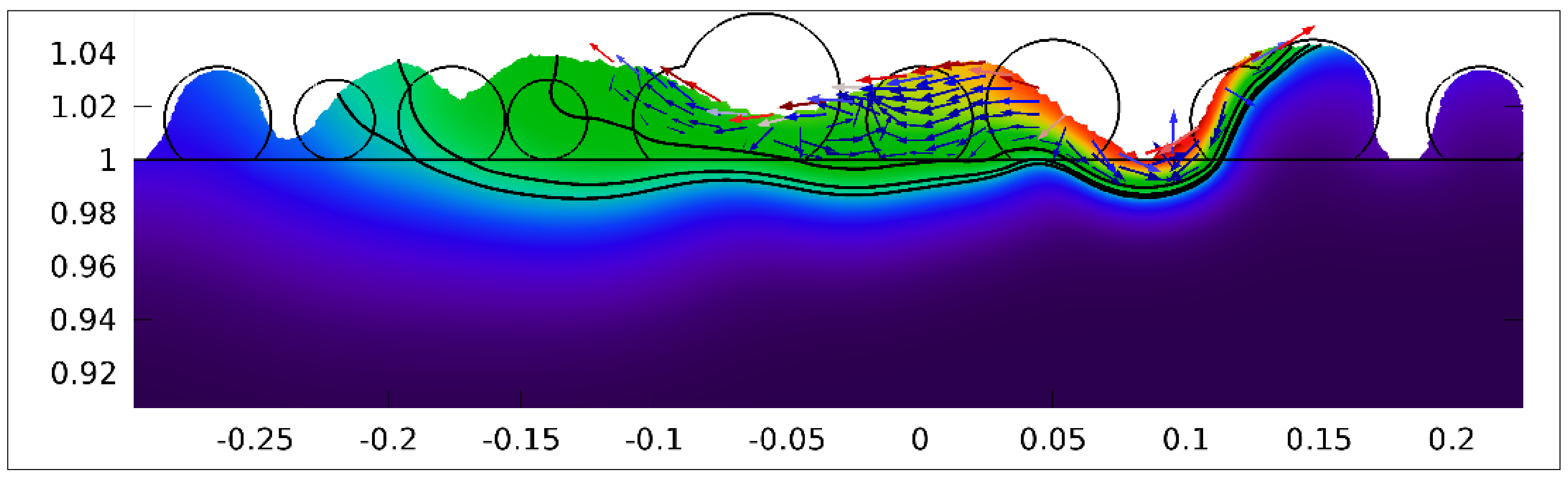


Figure 2. P= 400 W, v=4 m/s, stable melt flow.

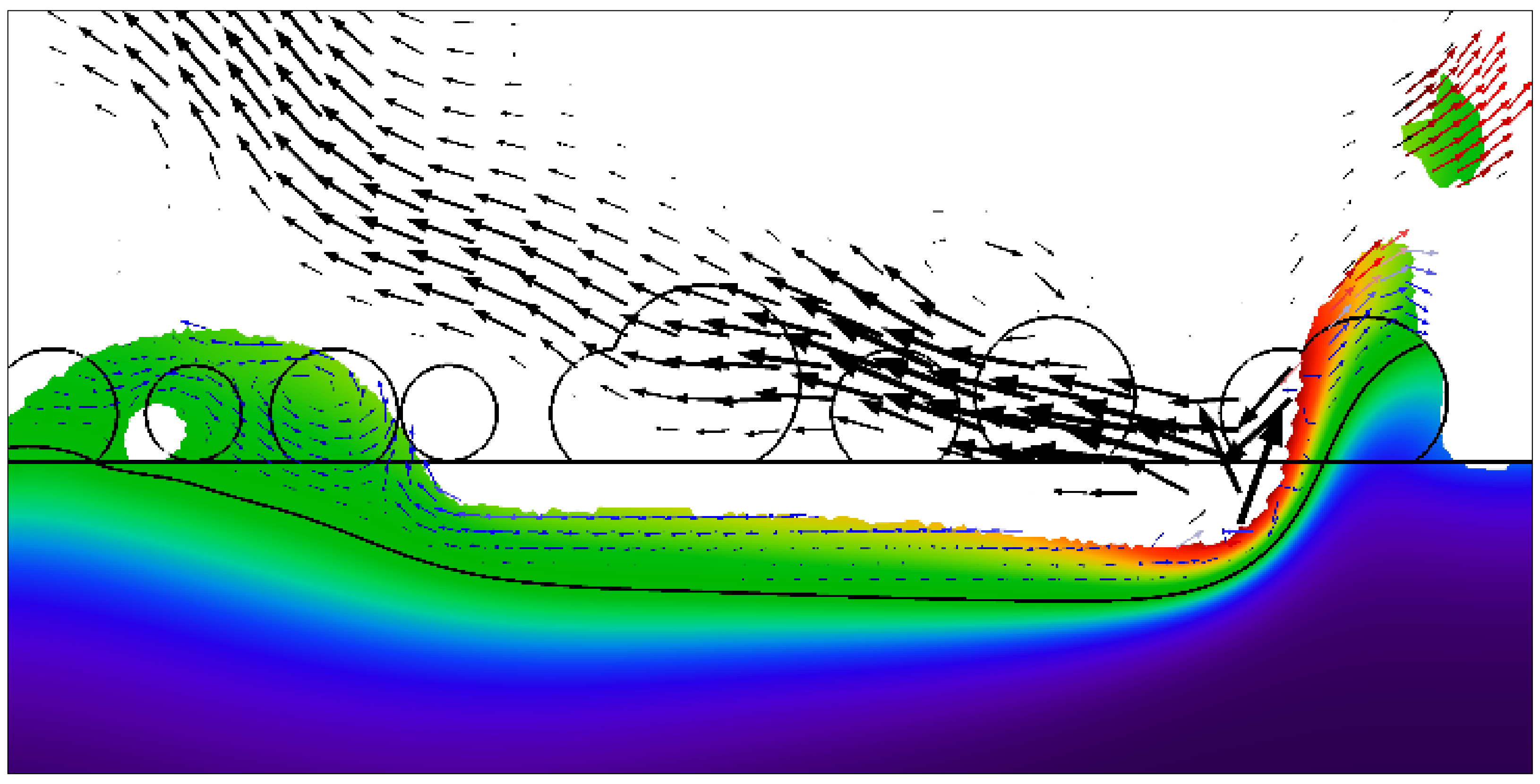


Figure 3. P= 400 W, v=2 m/s, vaporization dominant flow, formation of spatter and porosity.

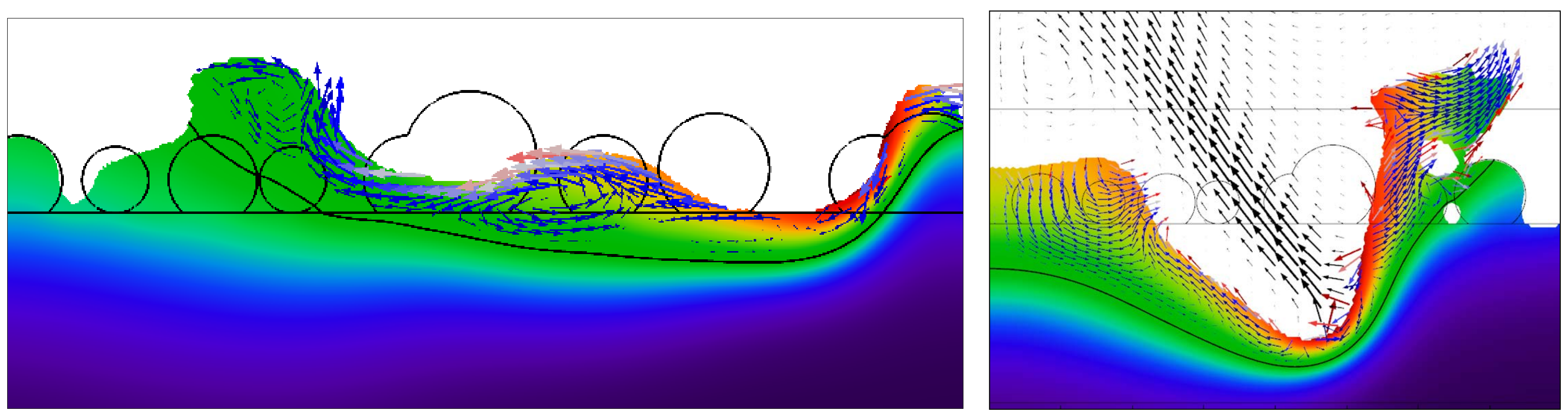
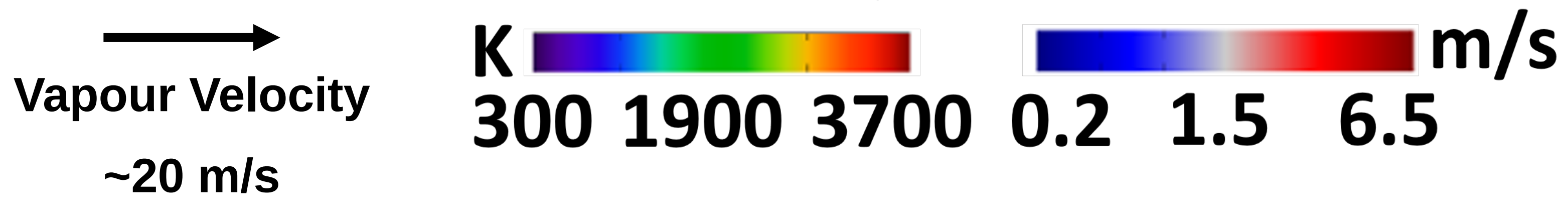


Figure 4. (a) Formation of melt humps (400W, 4m/s) (b) Formation of vaporization induced keyhole (200W, 0.5 m/s).



Conclusions: The model reveals complex time-varying flow patterns having strong susceptibility towards process parameter selection. The mechanisms associated with SLM, such as balling effect, the formation of humps, entrainment of pores, the transition from conduction to keyhole regime and formation of spatters have been elucidated.

References:

1. Leitz et al., Thermo-Fluid dynamical Modeling of Laser Beam-Matter Interaction in selective laser melting, Comsol Conference, Munich, (2016)
2. Sharma et al., Numerical simulation of melt hydrodynamics induced hole blockage in Quasi-CW fiber laser micro-drilling of TiAl6V4, Journal of Material Processing Technology, 262, 131-148, (2018)