A numerical study of a liquid flow solidification in a microchannel

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1. INTRODUCTION & OBJECTIVE

Solidification of a liquid has been an active area of research because of its relevance in many natural processes and industrial applications. Being a highly complex phenomena and involving the interplay of multiple physics, it remains an area of continuous research. In past, researchers have presented a number of analytical [1] and approximate mathematical models [2] to study solidification in stationary systems. Some recent experimental [4] and numerical studies [3] have also been performed to study the solidification in microchannels and pipes, respectively. However, the analytical studies, because of obvious reasons, have been limited to simplified problems whereas the experimental studies have involved restrictive models, such as neglecting temperature varyiation in flowing liquid because of difficulties associated with temperature measurement at microscale. Solidification process of a a flowing liquid is of prime importance in the development modern lab-on-chip devices such as phase-change valves [5]. This necessitates an in-depth study of flow solidification in a microchannel for the effective design and development of systems and devices based on solid-liquid phase change.

In this study, a numerical model has been developed to investigate the solification of water in a pressure driven flow through a microchannel. As shown in the schematic of the problem Fig.1., water enters in a microchannel with a temperature T_o greater than its freezing point temperature T_f. The channel walls are subejected to constant wall temperature T_w lower than T_f. A thin layer of ice near the wall is considered to start with the analysis to avoiding the singularities arising at the very start of the solidification near walls. The appropriate equations govering the problem such as, equation of continuity, Navier-stokes and energy equations for the flow domain and heat equation in solid domain alongwith the Stefan condition at the phase-change boundary have been established and solved using a finite element based software COMSOL Multiphysics 4.4.

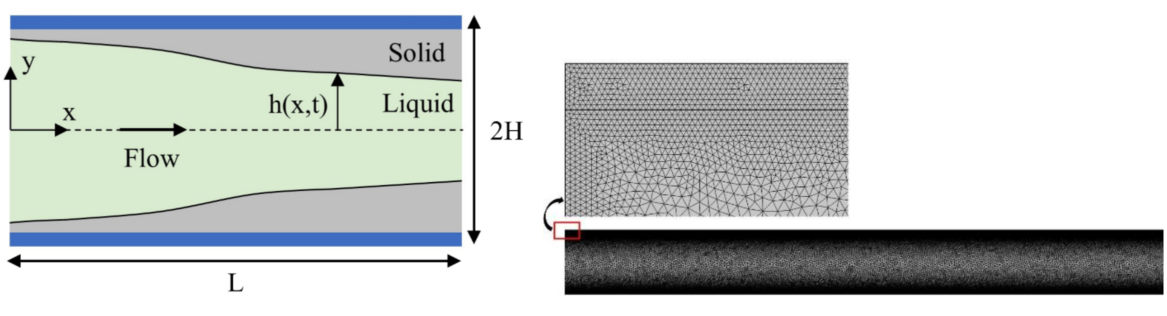

Fig.1. Schematic of the physical problem and meshed computation model

2. RESULTS & HIGHLIGHTS OF IMPOINTANT POINTS

Some of the key results discusses the effect of fluid flow on the dynamics of solidification and evolution of phase-change interface in great detail by fully considering the effects on convection of fluid and trasnsient nature of the problem.

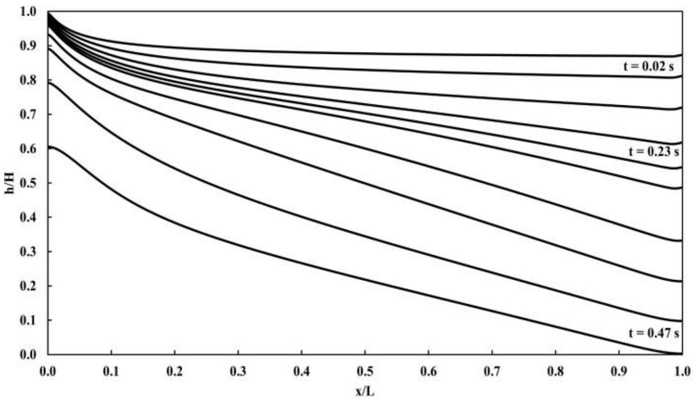

Fig.2. Evolution of phase-change interface with time

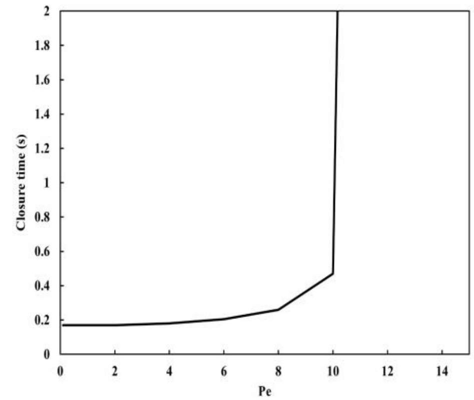

Fig.3. Channel closure time with Pe

The channel closure is studied for a wide range of Peclet numbers Pe and results show that with the increase of Pe number the channel closure time increases, Fig.2. It also reveals that beyond a critical flow rate (for Pe greater than 10) the channel will never close which attributes to the balance of heat addition and heat removal rate from the system. In addition, the channel closure time is also observed to significantly depend on the channel wall temeperature and fluid inlet temperature. The variations of temperature profiles and other detailed results will be discussed and shown in full length paper.

In conclusion, the study provides with the limiting values of performance parameters to better design of thermal systems where a precise control of solidification rate is essential.

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