Numerical Simulation of Boiling in a Porous Medium by Using Two-Phase Approach

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ABSTRACT

The paper presents the results of a numerical study of heat and mass exchanges inside a porous matrix. The porous medium is in contact with a solid surface heated over boiling point and steeped in a liquid (water). The behaviours of liquid and vapour phases being considered independent, the mass, momentum and energy equations used by the CFD solver (FLUENT ® V.4) are completed by specific terms describing the interactions between the phases.

Phase velocities, concentration and temperature distributions obtained for a given porous medium element emphasize non-stationary and asymmetric character of the studied phenomena.

Keywords: boiling, porous matrix, numerical modelling, two phase flow.

1. INTRODUCTION

Since one century, the need to increase the heat flux dissipated in industrial systems originated a substantial amount of research on how to intensify the heat exchanges between a solid surface and a fluid.

Among different techniques used to improve heat transfer, the coating of exchange surface with a thin porous layer gives very encouraging results, some experiences show that the quantity of dissipated heat can reach 100 W/cm². The complexity of involved phenomena makes that the study of heat transfer mechanisms inside a porous laye remains an attractive domain for experimental investigation, but also for numerical modelling.

The most of models treat this problem at macroscopic scale or study the evolution of an isolated bubble (microscopic approach). The aim of the present study is to make a compromise between two approach and to quantify heat exchange at few pores scale b representing vapour bubble action trough local values of vapour concentration, flow and vapour velocities and temperatures.

The numerical code used for those calculations is FLUENT® V.4 , adapted to this specific use.

2. MODELLING

In general, a two-phase flow is characterised by an interface between the phases that creates discontinuity of mass and energy transfer.

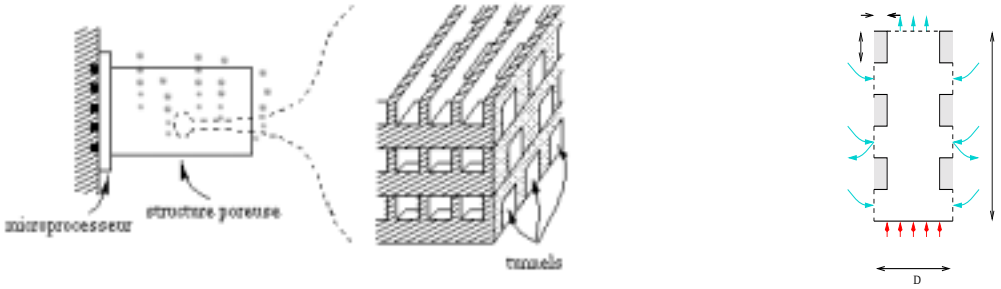
When the continuum mechanics is applied to two-phase flows, the two phases are considered to form single phase regions separated by a mobile and deformable border. The continuity equations are applied on each phase by considering adequate jump and limit conditions. The problem is so defined in term of local and instantaneous variables that are subsequently averaged in space and time.

The simulation of flow and heat transfer inside a porous structure is carried out by means of FLUENT® V4 solver that uses finite volume based technique to solve the conservation equations for mass, momentum, energy and concentration.

Since the data on local vapour concentration and temperature values inside a porous media do not exist, the mathematical and numerical model applied here were calibrated and validated by using the results of measurements obtained in more simple two phase flow and heat transfer configurations: cavity-flow, T-junction-flow, bubble reactor and pipe-flow.

3. GEOMETRY

In the frame of this study, the objective was to simulate fluid dynamics and heat exchange inside a porous medium in contact with a heated surface. The porous medium may have any structure and the pores could be of different forms. The article presents a case with rectangular pores as on the Figure 1.a.



a. b.

Fig. Geometry of the porous element

The calculations shown here are carried out in 2D on the basis of a periodic element as on the Figure 1.b.

The matrix is made of stainless steel with following thermic characteristics:

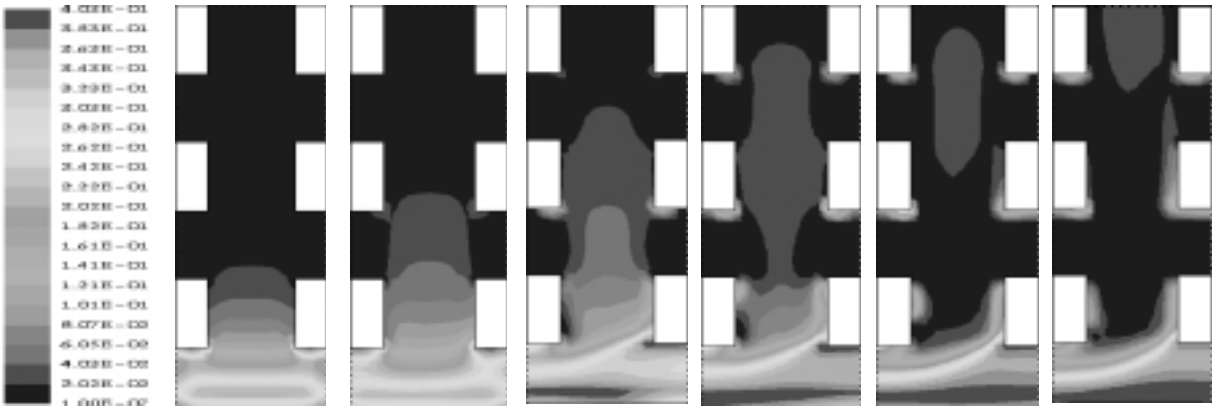
Conductivity [W/(m.K)]	16.6
Calorific capacity [J/(kg.K)]	515
Mass volume [kg/m^3]	7900

The grid used for calculation consisted of 1281 cells and the iteration time step was 0.001 s. The porous element was "filled" with water at a temperature nea $T_{saturation}$. At instant t = 0, the temperature of the base of the porous element, i.e. the surface of a microprocessor, rises at 573°K and remain constant over calculation time. The temperature distribution at the heated surface can be uniform, but since in practice this situation is rare, a gradient was imposed with total difference of 3°K from left to the right side of the element.

The boundary conditions were following: free lateral inlets/outlets and adiabatic steel made solid surfaces.

4. RESULTS

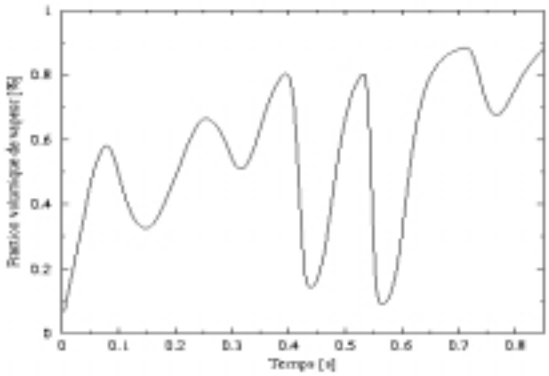
The figure shows the time evolution of steam concentrations:



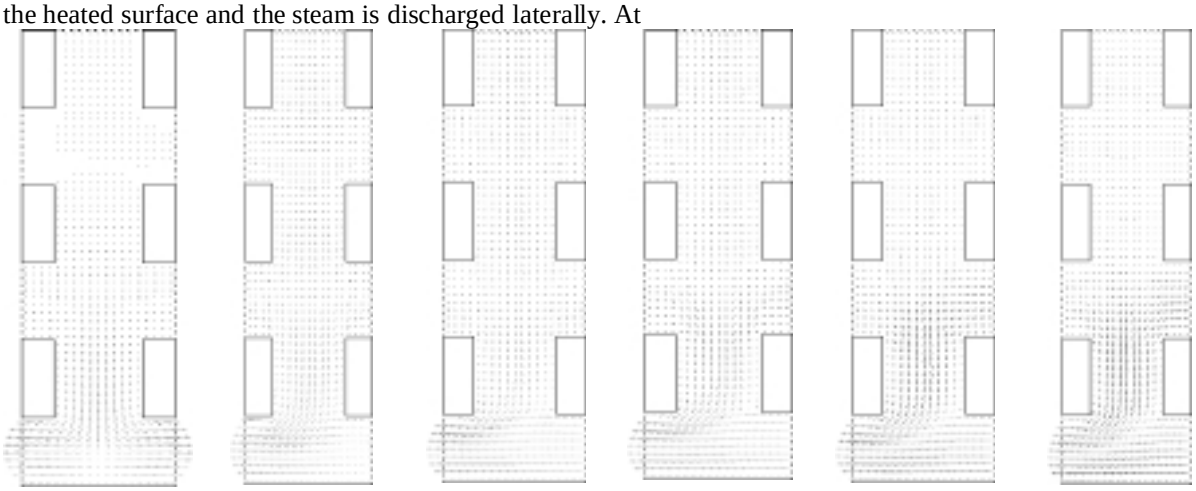
t = 0.02 s t = 0.04 s t = 0.06 s t = 0.08 s t = 0.1 s t = 0.12

Fig. 2: Time variation of vapour concentration

As in the case of symmetric heating, the vapour is created at the heated surface by nucleation and evacuated periodically under the effect of buoyancy. The figure 3 gives the variation of the steam concentration at the heated surface.



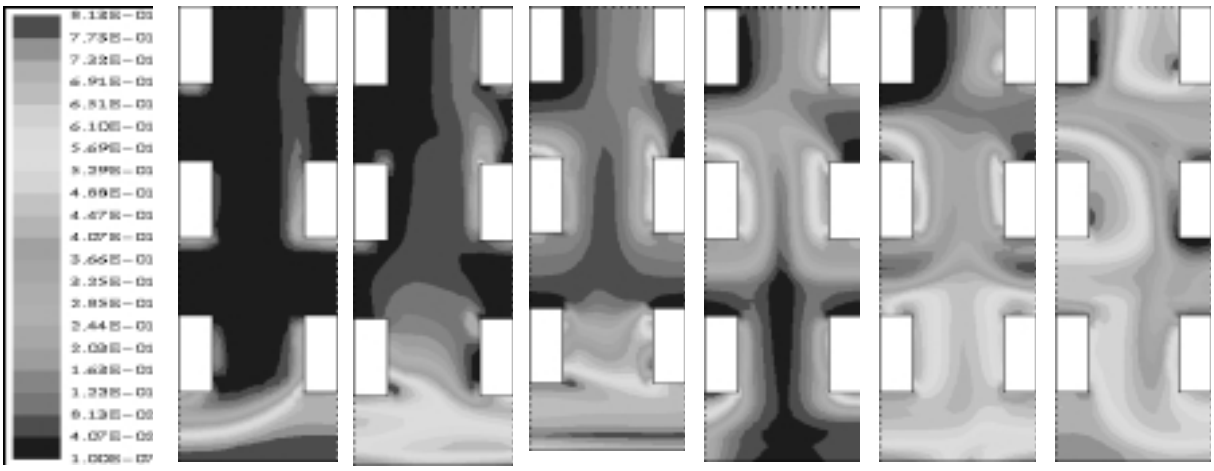
The liquid phase velocity vectors represented on the figure 4 indicate that at the very first moments the water at under saturation temperature is sucked towards the heated surface and the steam is discharged laterally. At the same time, the temperature field (not presented here) expands through both, upper region of liquid phase and matrix.).



t = 0.02 s t = 0.04 s t = 0.06 s t = 0.08 s t = 0.1 s t = 0.12 s

Fig. 4: Liquid phase velocity vectors coloured by steam concentration

In consequence, vapour evacuation by the upper region, non-existent at the beginning, becomes stronger (figure 5 The asymmetric pattern of the heat and mass transfer originated by the temperature gradient and the pulsating regime of vapour evacuation are clearly shown.



t = 0.15 s t = 0.25 s t = 0.3 s t = 35 s t = 40 s t = 50 s

Fig. 5: Time variations of vapour concentrations - asymmetric and unstable behaviou

5. CONCLUSION

The calculations carried out in the frame of this study established clearly the joint interaction of pore geometry and porous matrix conductivity to the heat transfer and the dynamic behaviour of the fluids (liquid and vapour).

The vapour generation, i.e. nucleation, seams to be very well simulated. The circulation through the matrix is manly non-stationary, in form of steam puffs or pockets that sometimes may stagnate into the pores.

The liquid phase behaviour is closely linked to that of the steam. The flow patter can be very complicated and time variable.

Temperature variations depend in the beginning on liquid characteristics, but later, the heat transfe through porous matrix becomes more important.

The case presented here, as all others carried out in this study, demonstrates a significant lack of stability of heat exchange and flow inside the porous matrix/water/vapour system, that could come partly from the calculation code itself. The measurements made in similar conditions are only able to estimate the reliabilit of the numerical model.

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