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Hydrodynamic Characterisitics of Two-phase Fluid Flow Affecting Calcite Deposition Rate in a Geothermal Wellbore

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ABSTRACT

The work presents Computational Fluid Dynamic (CFD) analysis of two-phase flow in a geothermal wellbore with calcite scaling. The analysis uses Eulerian six-equation model for modeling two-phase flow. The model calculates velocities of each phase separately, thus taking into consideration the effect of slip velocity on heat transfer between the two phases. Effect of various hydrodynamic forces including lift and drag is taken into consideration to understand the bubble phase motion in the flow, which is mainly assumed to be the major cause of calcite deposition in the near wall region. Results from the model simulation for a case study shows bubble motion and heat transfer in the calcite region as a major cause contributing to higher deposition rate in the same region.

1. INTRODUCTION

One of the most common problem occurring in geothermal wellbore systems is that of calcite scaling. Geothermal resources with high calcium and carbonate concentration in the fluid tend to show mineral precipitation due to change in fluid flow thermodynamic state along the flow (Amannsson, 1989). Mineral precipitation along the wellbore causes reduced cross-section of the flow area, thus causing decrease in mass flow output and hence reduced productivity. Additional losses in terms of exergy destruction occurs due to pressure drop in the throttle section of the wellbore formed by scaling.

Observation shows occurrence of calcite scaling causes blockage of wellbore components such as slotted liner and throttling valve (Figure 1), leading to operational and economic risk to the geothermal power plant (Thomas and Gudmundsson, 1989).

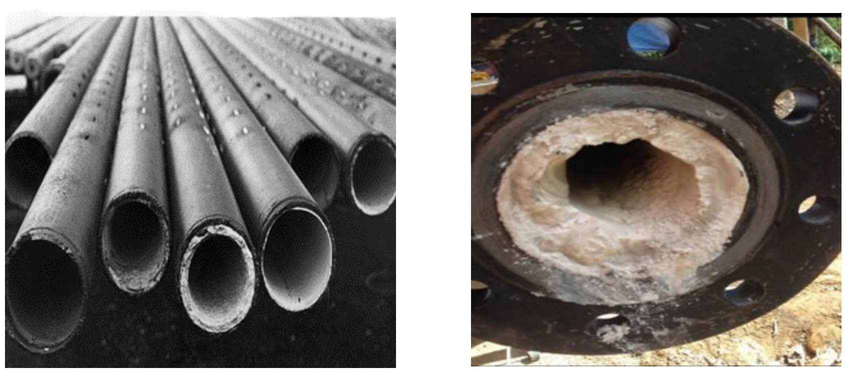

Figure 1: Calcite scaling inside a slotted liner (left) and in a throttling valve (right) (Thorhallsson, 2019).

Conventional way of mitigating calcite scaling in geothermal wellbore is achieved by either of the two ways: pretreatment and post treatment. The pretreatment method involves controlling the mineral precipitation process by changing chemical characteristics of the fluid flow. The methods includes chemical treatment using inhibitors such as methylene phosphonic acid and polycarboxylic acid into the wellbore (Siega et al., 2005). The post-treatment method involves reaming using a drill rig or changing the wellhead pressure to change the flashpoint zone inside the wellbore (Gunnlaugsson et al., 2014).

Application of any of the above discussed methods for mitigating calcite scaling requires considerable investment. Occurrence of calcite scaling in geothermal wellbore can therefore become a question of economic viability of the overall project for some resources. An insight into the process of calcite scaling is thus of high interest for developing an economic way of mitigating the problem.

Calcite scaling occurring on the walls of a wellbore involves three different processes: mineral precipitation, mineral transport and mineral deposition. Extensive studies with regard to the chemistry of mineral precipitation and its kinetics is available in the literature (Arnorsson, 1989, Moller et al., 1998, Xu et al., 2004). The studies suggest primary cause of mineral precipitation due to CO_2 stripping caused by decreased solubility in the liquid phase during phase transition due to flashing in the wellbore. This causes pH to increase and thus the concentration of the carbonate to increase, leading to mineral precipitation. The explanation in the literature regarding the cause of scaling is limited to mineral precipitation and its kinetics as a preliminary cause. Literature study (Gunnlaugsson et al., 2014) shows increased scaling propensity in the area around the point of flashing occurring due to CO_2 degasification during the phase change process. The proportion of mass fraction converting from liquid to gas during phase transition in a given volume therefore should control the degree of mineral precipitation in the volume. The parameters affecting heat and mass transfer processes therefore must play an important role in governing the degree of precipitation. In addition, as discussed earlier, the scaling involves process of precipitated mineral transport and then its deposition. The hydrodynamic forces controlling the fluid motion therefore must control the rate of mineral transport and its deposition. Flash boiling in the fluid flow through a geothermal wellbore pipe with calcite scaling on the surface is more or less represented as flash boiling occurring in a convergent-divergent section. The fluid flow through the section can be assumed bubbly upto a high vapour fraction, as suggested by Blinkov et al. (1993). The liquid-bubble interface in the two-phase flow thus act as a site for mineral precipitation occurring due to phase transition caused by heat transfer due to thermal non-equilibrium. A study on vapour mass flux and hydrodynamic forces causing bubble motion can provide an understanding of the fluid flow parameters affecting causing mineral transport and its deposition.

2. CONSERVATION EQUATIONS

In order to under two-phase flow with flash boiling inside a geothermal wellbore with calcite scaling, study using Computational Fluid Dynamic (CFD) is followed. A literature review of simulation case studies for different two-phase flow processes can be found in the literature (Liao and Lucas, 2017). The CFD analysis helps in detailed understanding of different aspects of heat and mass transfer during the flashing process which is not possible to achieve using traditional wellbore modeling tools used in geothermal industry such as WELLSIM (Gunn and Freeston, 1991), HOLA (Bjornsson,1987), WFSA and WFSB (Hadgu and Freeston, 1990) and GEOWELL (Garcia et al., 2006).

Two-phase flow simulation using CFD can be obtained using two approaches: Lagrangian-Eulerian approach and Eulerian-Eulerian approach. The former assumes one phase continuous and another phase dispersed which is tracked separately. The later approach assumes both phases as continuous. The Eulerian-Eulerian approach is further distinguished based on the number of conservation equation, the model considers for simulation for phase mass, momentum and energy. Details of the various approaches can be found in the literature (Laurien and Giese, 2003). The present work uses six-equation Eulerian-Eulerian model available in Ansys Fluent (2013) for modelling fluid flow. The conservation equations for mass, momentum and energy respectively for each phase are expressed as follows (Liao et al. 2013):

$$\frac{\partial}{\partial t}(\varepsilon_i \rho_i) + \nabla \cdot (\varepsilon_i \rho_i \boldsymbol{U}_i) = M_i \tag{1}$$

$$\frac{\partial}{\partial t}(\varepsilon_i \rho_i \boldsymbol{U}_i) + \nabla \cdot (\varepsilon_i \rho_i \boldsymbol{U}_i \boldsymbol{U}_i) = -\varepsilon_i \nabla p + \nabla \cdot \left[\varepsilon_i \mu_{eff,i}(\nabla \boldsymbol{U}_i + (\nabla \boldsymbol{U}_i)^T)\right] + \varepsilon_i \rho_i g + M_i \boldsymbol{U_i} + F_i \tag{2}$$

$$\frac{\partial}{\partial t}\left(\varepsilon_i \rho_i \left(H_i - \frac{p}{\rho_i}\right)\right) + \nabla \cdot (\varepsilon_i \rho_i \boldsymbol{U}_i H_{tot,i}) = \nabla \cdot [\varepsilon_i \lambda_i \nabla T_i] + M_i H_{tot,i} + E_i \tag{3}$$

where ε_i, U_i, T_i, λ_i, $H_{tot,i}$ are the volume fraction, velocity, temperature, heat conductivity and total specific heat for phase *i*. Detailed discussion of these terms can be found in the literature (Liao et al. 2013).

3. SIMULATION CASE STUDY

To understand the effect of various hydrodynamic parameters on two-phase flashing flow characteristics and factors effecting calcite scaling, a case study for a geothermal wellbore in Svartsengi, Iceland (Stefansson and Steingrimsson, 1980) is done. The geometry of the wellbore with calcite scaling, as measured using 3-arm caliper tool is shown in Figure 2.

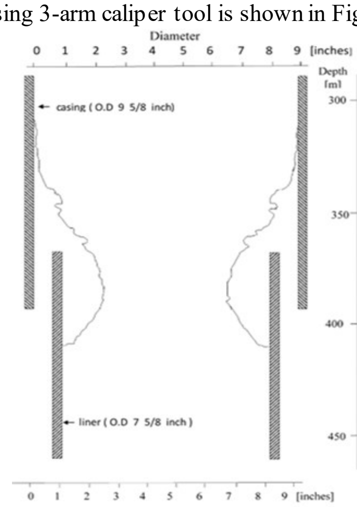

Figure 2: Wellbore with calcite scaling from Svartsengi, Iceland (Stefansson and Steingrimsson, 1980).

The initial and boundary conditions for the CFD simulation were based on the wellbore data log and the flow measurements done during that period. The mass flow rate at the inlet is 24.6 kgs^{-1} with a temperature of 514 K. The pressure at the outlet is 21 bar absolute. The wall surface is assumed to have a roughness constant of 0.6 with adiabatic conditions. The simulation considers the effect of lift, drag, wall lubrication and turbulent dispersion force into the simulation. To estimate the disperse phase eddy viscosity, a so-called dispersed phase turbulence model is used. The eddy viscosity of the water is calculated using the Standard k-ω turbulence model and influence of the bubble phase on the turbulence is taken into account by selecting the Sato model. Details of the various selected models are described in Ansys Fluent theory guide (Ansys, 2013).

4. RESULTS

To understand the effect of hydrodynamic parameters affecting calcite scaling, various parameters of two-phase flow as obtained from CFD simulation are analyzed. Figure 3 shows the variation of liquid phase velocity along the flow direction. As seen the figure, the fluid velocity increases in the throttling section of the wellbore where scaling exists.

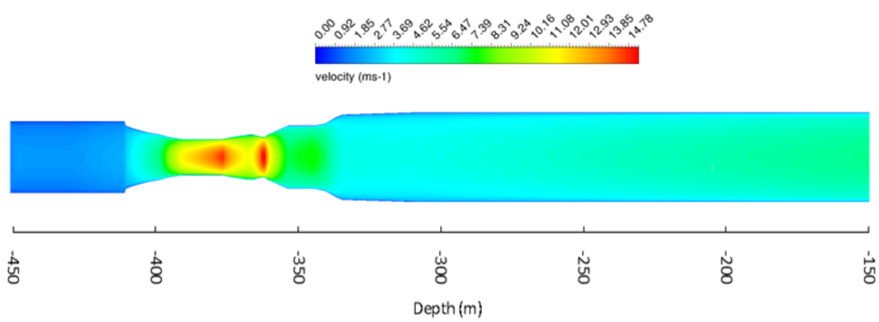

Figure 3: Variation of liquid phase velocity along the flow.

Figure 4 shows the rate of interphase mass transfer during phase change along the fluid flow. As seen from the figure, the rate of phase change per unit volume is high in the convergent zone of scaling. The explanation can be made with respect to figure 5, showing axial and radial slip velocity between the two phases. Since the phase transition occurs due to heat transfer, increase in heat transfer coefficient due to increased slip velocity caused increased phase transition, shown by figure 4.

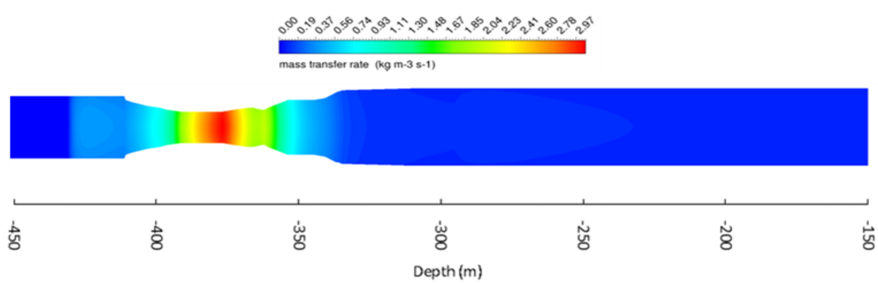

Figure 4: Rate of interphase mass transfer rate during phase transition along the wellbore depth.

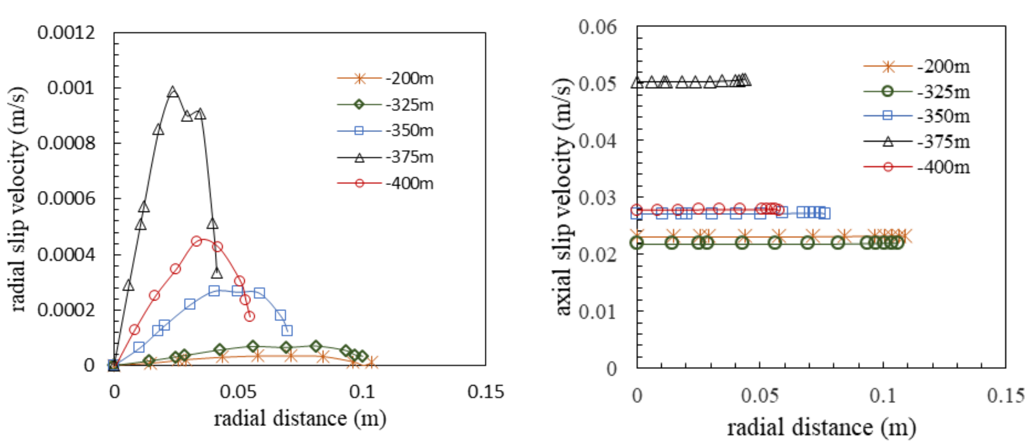

Figure 5: Radial and axial slip velocity at different cross-sections along the wellbore length at different depths of the wellbore.

The effect of hydrodynamic forces on the rate of mineral scaling can be observed by the degree of bubble flux normal to the wall as shown in figure 6. The lift force acting on the vapour bubbles causes smaller bubble to have a tendency to move towards the wall boundary. The vapour bubble flux towards the wall is found to be high in the convergent zone due to high lift force in the section. This clearly explains the occurrence of calcite scaling in a limited region, where the scaling already exists.

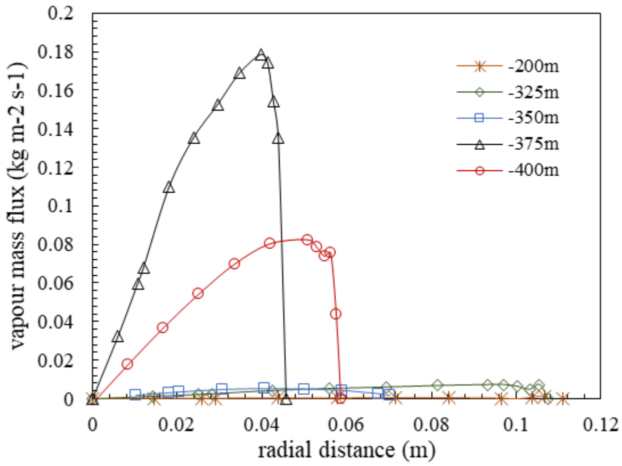

Figure 6: Radial mass flux of vapour at different cross-sections of the wellbore.

5. CONCLUSION

Two-phase flashing flow occurring a geothermal wellbore with calcite scaling inside was analyzed using CFD approach. The results show the effect of hydrodynamic parameters on the processes contributing to calcite scaling, such as increase in slip velocity causing increased phase change leading to increased mineral precipitation and increase in normal bubble flux causing increase mineral transport and deposition. The work therefore shows importance of studying hydrodynamic parameters in a two-phase flow for developing new techniques for minimizing calcite scaling occurring in geothermal wellbores.

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