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Pore-scale level-set simulation of drainage-imbibition cycles of trapped gas during decline and incline of reservoir pressure

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New uses of subsurface reservoirs such as temporary storage of natural gas and hydrogen, involve seasonal gas injection and production schedules accompanied by seasonal inclines and declines in reservoir pressure, respectively. In the gas withdrawal stage, rising water will trap gas in the gas/water transition zone below the producing gas cap. The injection and production of gas leads to drainage and imbibition processes in the reservoir which traditionally have been studied by two-phase displacement of continuous flow of gas and water at the pore scale. Here, we will instead focus on the drainage and imbibition characteristics that occur due to the expansion and compression of the trapped gas when the reservoir pressure changes.

To this end, we use a level set model for capillary-controlled displacement with local volume conservation as a basis for the investigations [1]. The model enforces volume conservation of disconnected ganglia by modifying their pressure (that is, the normal level-set velocity) to prevent volume changes, and it also conserves volume during ganglion splitting and merging. Thus, simulations predict the pressures of trapped ganglia, which is a prerequisite for describing pressure-volume behaviour of ganglia under various processes, such as Ostwald ripening of trapped gas [2]. Here, we extend the model to handle local mass conservation of a compressible gas when the (uniform) reservoir pressure changes stepwise. The strategy is to first calculate the equilibrium gas pressures for trapped ganglia from which we calculate the number of moles of gas from an equation of state (EOS). Then, for each stepwise change in reservoir pressure, we combine the EOS with the volume conservation equation to find the gas pressure in each level set iteration that corresponds to the volume for the current reservoir pressure. In case of Peng-Robinson EOS the resulting pressure equation is a fourth order polynomial which we solve either numerically or analytically in each level set iteration. The reservoir pressure is changed once a static fluid configuration is achieved.
Using the developed model, we perform quasi-static simulation of pressure incline followed by pressure decline on trapped gas configurations after imbibition on a 3D segmented micro-CT image of sandstone. We monitor changes in average ganglion pressure as a function of trapped gas saturation and show the hysteresis behaviour. The simulations also show that pressure incline results in snap-off of large ganglia as they get compressed. Further, both coalescence and snap-off are observed during pressure decline when ganglia grow and extend into nearby pores.

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References

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