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# Hydrogeologic controls on saturation profiles in heat-pipe-like hydrothermal systems: numerical study

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Most geothermal reservoirs are of the liquid-dominated type, and their unexploited-state pressure profile approximately follows the hydrostatic gradient. In very hot liquid-dominated systems, temperature typically follows a boiling-point-for-depth (BPD) relationship. By contrast, vapor-dominated systems exhibit (in their unexploited state) surprisingly small vertical gradients of temperature and pressure, such that a constantly high temperature is encountered over a large vertical thickness, while their pressure approximately follows vapour pressure, pvap(T°).
This implies that (Pruess 1985, Truesdell and White 1973):
(i) for a vapor-dominated reservoir to exist, it must be sealed laterally – otherwise it would be flooded by neighboring groundwaters with hydrostatic p profile, and
(ii) liquid water should somehow be present in the whole system – otherwise p values would not be constrained by the pvap(T°) relationship for water.
Historically, one of the most puzzling aspects of vapor-dominated systems was the large amount of heat flowing upwards, while vertical T° gradients remained negligible. This mechanism was deemed as 'heat pipe'(HP) (Eastman 1968): In the central zone of a vapor-dominated system, both vapor and liquid are mobile; vapor flows upwards, condenses at shallower depth, and the liquid condensate flows downwards. Due to the large amount of latent enthalpy released in vapor condensation, the vapor-liquid counter-flow can generate large rates of heat flow with negligible net mass transport (Pruess 1985).
In order to be able to exploit two-phase (including vapor-dominated) reservoirs in a sustainable manner, one first needs to understand the conditions under which a two-phase (or a vapor-dominated) system has evolved naturally, and which have led to its present (quasi-) steady undisturbed state. Past studies have found that HP can exist in two distinct states, corresponding to liquid-dominated and vapor-dominated p profiles, respectively.
Within this work, we explore some mechanisms and geologic controls that can lead to the formation of extensive vapor-dominated zones within a two-phase system. In particular, we investigate the effect of vertical heterogeneity of permeability (stratified reservoir, containing a permeability barrier) on the liquid water saturation profile within a modified HP model.
Though in field observations liquid water has been directly encountered only within the condensation zone at reservoir top, it was speculated that large amounts of liquid water might also exist below the condensation zone. This is of great practical significance to the exploitation of vapor-dominated reservoirs, as their longevity depends on the fluid reserves in place.
Within this work, we demonstrate by numerical simulations of a modified HP model that high values of liquid water saturation (>0.8) can prevail even far below the condensation zone. Such findings are useful as a baseline for future calculations regarding the economic exploitation of vapor-dominated systems, where premature productivity drop (or dry-out) is the main issue of concern.
References:
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