ON THE EXISTENCE OF TWO-PHASE FLUID IN GOOD COMMUNICATION WITH LIQUID WATER

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ABSTRACT

It has been argued that wells of high discharge enthalpy (two-phase wells) at Baca must be isolated from communication with an extensive liquid reservoir. It is shown that such communication has existed, and been maintained, during the history of Wairakei and Broadlands fields.

Interpretation of downhole measurements in two-phase fields, and the nature of the two-phase reservoir fluid, is also treated.

INTRODUCTION

This paper stems from conflicting interpretations of downhole data from Baca field, New Mexico. Figure 1 shows the crux of the most important conflict (4,5). Shown are the stable pressure profiles in three wells (1-3). Wells B-6 & B-13 show very similar profiles, each well containing a column of water with a water level within the casing, and the pressures in the two wells are very similar. B-15 shows a markedly different profile. The pressure gradient is intermediate between steam static and hydrostatic. Beneath 5850' (above sea level) B-15 has a lower measured pressure, and from 5850' to 6610' (casing shoe in B-15 (2,3)) the pressure in B-15 exceeds that in the other two wells. The profile in B-15 was interpreted by Union Oil (1,4,6) as reflecting a zone of different reservoir pressure, and because of this pressure difference, a zone not in communication with the rest of the reservoir - an "underpressured steam zone" (1).

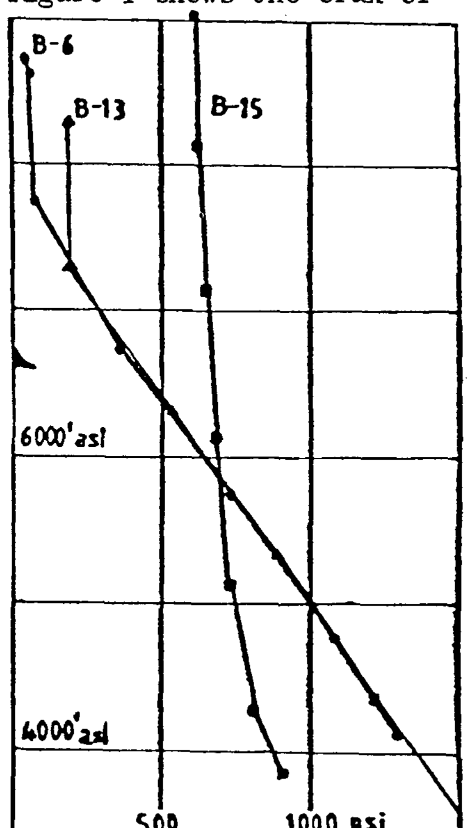


FIG. 1 BACA PRESSURES

The author has presented a different interpretation (5,7), which interpretation is the same as has been presented in other published and unpublished discussions of similar wells: that a strong upflow of steam and water is present in the wellbore, disguising the reservoir profile.

The pressure profile in B-15 immediately leads to the question - what fluid is in the wellbore? The profile is that of a flowing well, discharging not to surface pipework but to a shallow feed zone of the well. Steam and water enter B-15 near bottomhole, flow up and are injected between 5850' and 6610'. This was termed an "internal discharge" (5,7). The pressure profile does not reflect static reservoir pressures, no more than in any flowing well, and so there is no inference that B-15 differs in pressure from the other Baca wells, which have pressures similar to B-6 and B-13.

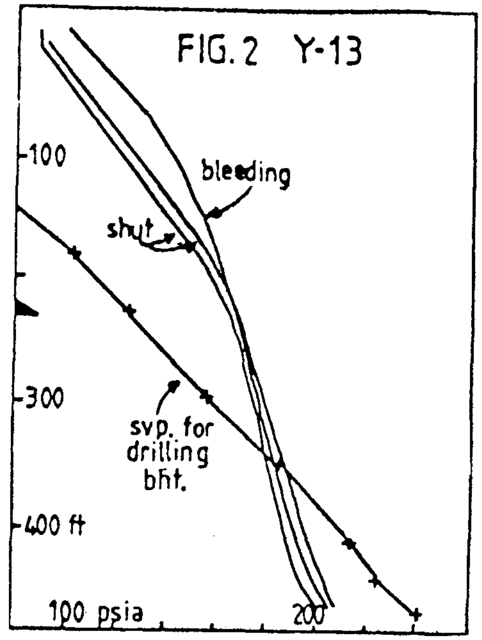
The two interpretations can be tested against field and well data in other places where the same phenomenon has occurred.

OTHER FIELDS

Yellowstone

Internal discharges were found in wells drilled at Yellowstone National Park (8). Figure 2 shows measurements in Y-13. Bottomhole temperatures were measured during drilling, and these show that the stable pressure profile in the well does not correspond to the pressures present in the reservoir before drilling. It was concluded "Boiling water and steam from a zone near the bottom of the hole apparently flow up and out...near..227 ft". To infer, on the basis of the stable downhole pressures, that Y-13 was isolated from other wells (eg the adjacent Y-4) would be quite incorrect.

FIG. 2 Y-13



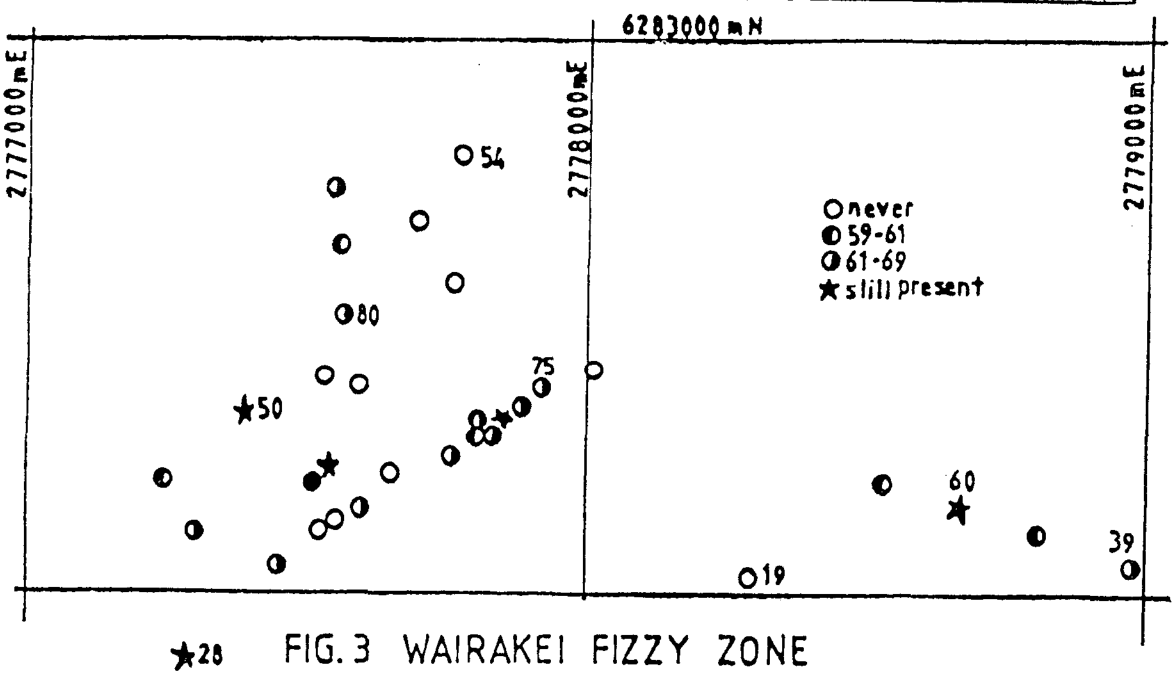


FIG. 3 WAIRAKEI FIZZY ZONE

Wairakei

Before large-scale discharge began at Wairakei, the stable profile in a shut well was a column of water, with pressure on the wellhead. Now it is a column of water in the lower part of the well, above which is a column of steam ("steam cap" profile, reflecting the artificially-created vapor zone in the reservoir). Between these two states, some wells showed internal discharges for a period of time, most commonly during 1959-64. This was referred to as the "fizzy zone". Figure 3 shows the borefield.

Only wells open below 2000', and drilled before 1962 are shown. A few are numbered for orientation. The map indicates the period of time when the wells exhibited the internal discharge profile: divided into those that never did, those that did within 1959-61, those that did within 1961-69 (usually within 61-64), and the five that still do. No systematic pattern is apparent. Wairakei is so well known for its high horizontal uniformity and rapid pressure transmission that all modelling attempts concentrate on a single field pressure. The disparate nature of the well behaviour indicates that the variations in pressure profile from well to well reflect only peculiarties of each well, and that the pressure profile in each well cannot be interpreted as reflecting reservoir profiles.

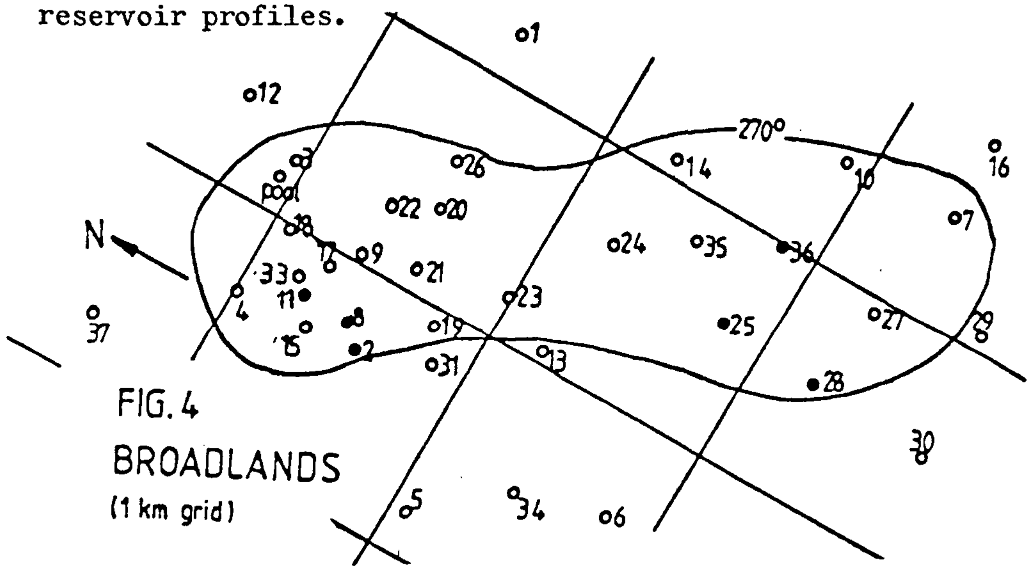


FIG. 4
BROADLANDS
(1 km grid)

Broadlands

Internal discharges have been a feature of wells at Broadlands since the drilling of BR2: "Many of the wells after their initial discharge are found to contain a column of low-density water-steam -gas mixture existing over a considerable depth and in an apparently stable condition. Pressures in such a column are unlikely to represent the pressures in the surrounding aquifers.." (9). Persistent and severe internal discharges appeared in BR2 (8/66-5/70), BR8 (12/67-2/70), BR11 (7/68-8/73), BR25 (1/71 on), BR28 (12/74 on) and BR36 (3/79 on). Figure 4 above shows well locations. In each case the internal discharge began soon after completion of the well, after a heating period during which the well contained a water column.

BR2,8 & 11 are closely spaced, interfere with each other and with the shallow BR33. There is also a questionable observation of interference with Ohaki Pool, which responds well to BR3. All these wells and the Pool lie near the Ohaki Fault. Interference between BR2 & 8 gives kh = 15 darcy-m (9), using fracture relative permeabilities (15). BR2 & 11 show a poorly-observed response of similar magnitude. At their feed depth (500m) BR2,8 & 11 are so strongly coupled that the author has tended to regard them as one well. From 5/70 to 8/73 there is a marked contrast between the pressure profiles in BR11 on the one hand and BR2&8 on the other. From this disparity it would be incorrect to conclude that there is no communication.

Changes in the vertical pressure and fluid distribution at Broadlands have been estimated and reported elsewhere (11).

RESPONSE TO COMMENTS

Atkinson (4) has made specific criticisms of the author's interpretation of Baca data. Most of these are answered by the preceeding discussion. However it should be noted that "large lateral pressure gradients" are Union's interpretation, and no such gradients in reservoir pressure exist in the author's interpretation. Carbon dioxide partial pressures needed to contain a given amount of gas in solution are readily calculated. If downhole data is interpreted to deny the presence of such partial pressures, this contradicts either the discharge sampling or the assertion that the reservoir fluid is wholly liquid. Partial pressures in flowing wells are irrelevant - whatever the steam fraction of the reservoir fluid, additional steam flashes with falling pressure as fluid flows to the well, reducing partial pressure far below the undisturbed reservoir value.

NATURE OF TWO-PHASE FLUID

Behind the disagreement about the interpretation of the B-15 measurements are apparently different concepts of the nature of two-phase fluid in the reservoir. The interpretation of B-15 as a "two-phase gradient" apparently corresponds to the concept of two-phase fluid as a low-density steam-water mixture - a froth - with static pressure gradient corresponding to low mixture density. This concept has been used by others.

The author's concept is different, and is now outlined. A reservoir containing two-phase fluid has in its permeable passages - pores or fractures - a steam-water mixture. Thus the average density of the fluid in place lies between that of water and that of steam. This density appears frequently in computer codes for two-phase flow. But the vertical pressure gradient does <u>not</u> correspond to a static column of this density; nor indeed is the reservoir fluid ever static.

Darcy's Law for the volume flux density of each phase is:

$$V_i = -\frac{k}{\mu_i} k_{ri}(S_i)\left(\frac{dP}{dZ} - \rho_i g\right) \qquad i = s,w$$

The net pressure gradient driving each phase upward is the vertical pressure gradient, less the weight of a static column of that phase alone. This contrasts with the flow up a well, where water flows upwards despite a subhydrostatic pressure gradient. A static froth is not permiited. There are only two possible static two-phase reservoir states: a reservoir containing immobile water, mobile steam and with a steam-static gradient (ie a vapor reservoir); and a reservoir containing immobile steam, mobile water and a hydrostatic gradient (apparently never realised).

The observation of discharge enthalpies well above liquid, but not dry steam, in reservoirs such as Baca or Broadlands, reflects the presence in the reservoir of both steam and water, both mobile. Such a reservoir fluid cannot be static. The presence of two-phase fluid requires a vertical flux of fluid, and so two-phase fluid in an undisturbed reservoir depends upon the natural upflow.

In a liquid-dominated reservoir, the upflow is primarily liquid. Water, or a mixture of steam and water, flow upward. To do this, the pressure gradient must exceed static for both phases, and in particular exceed hydrostatic. If the steam flux is smaller (as is often the case) the steam saturation must be near residual. It can be calculated from the enthalpy of the upflow and the pressure gradient (12,13). The profiles so calculated show a pressure gradient somewhat above hydrostatic, and a steam saturation somewhat above residual. Figure 5 shows a calcuated profile for a simple upflow model of Wairakei, assuming a base temperature of 250°C and no gas. Rather than the unobservable saturation, the (horizontally) flowing enthalpy is shown, along with the enthalpy of liquid at local temperature. The reservoir fluid profile is very similar to a column of liquid water, which coincidentally happens to be at boiling point. The pressure gradient is no different in character from a reservoir containing only liquid. The two-phase column could well be adjacent to a column of liquid (such a column could be found toward the field margin) and there is little in the pressure distribution to cause an lateral flow of fluid. The two-phase liquid-dominated reservoir contains in its natural state fluid with a pressure profile similar or identical to that of liquid water, but distinguished by the presence of some free (mobile) steam.

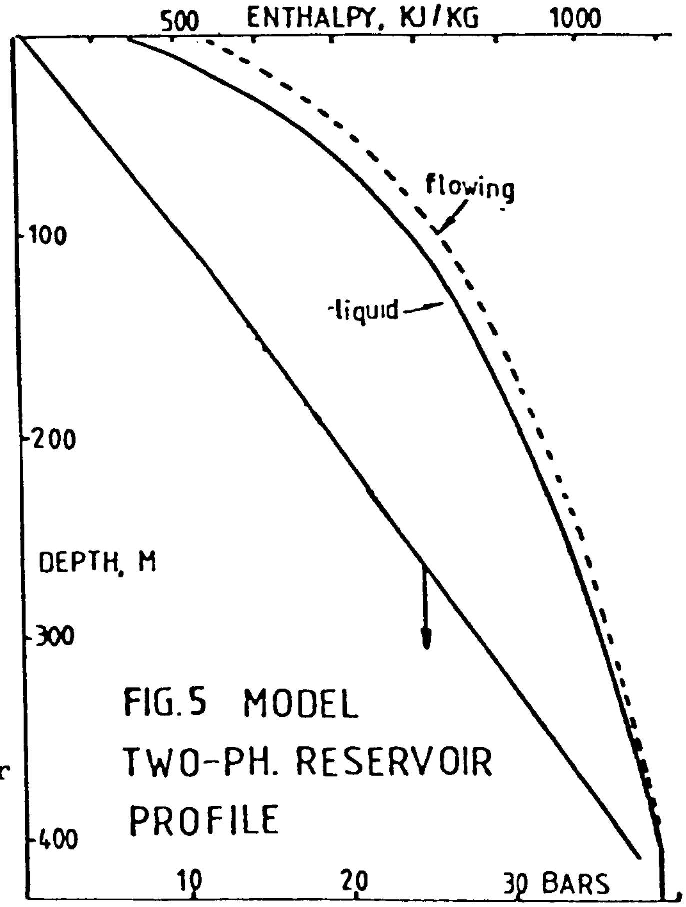


FIG.5 MODEL TWO-PH. RESERVOIR PROFILE

This steam is recognised by the presence of saturation pressure/temperatures (for the actual reservoir fluid) and by discharge enthalpies above liquid (at temperature of the well feed or entry). Figure 5 shows that this discharge enthalpy can be little above liquid, so despite the importance of identifying two-phase conditions in a new reservoir (4,14), this may be difficult. A well penetrating a column of fluid such as that in Figure 5 will look little different from a well penetrating liquid. Only the temperature profile is definitive - and that is easily disguised by convective effects in the well.

The model of Figure 5 applies to situations of uniform upflow. If there is also lateral flow in the natural state, considerably higher steam fractions will occur towards the top of the upflow zone, as the local upflow enthalpy is increased by the loss of water to lateral outflow. Hence the higher steam fraction in wells such as B-15.

ACKNOWLEDGEMENT

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