FIELD CASE STUDIES OF PRESSURE BUILDUP BEHAVIOR IN GEYSERS STEAM WELLS

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The purpose of this paper is to illustrate and discuss practical application of pressure buildup test theory in The Geysers steam reservoir. This field, located in Sonoma County in Northern California, has installed generating capacity of 522 MW. Total withdrawal rate is approximately 8.5 million pounds per hour from 93 wells.

The reservoir is naturally fractured greywacke, a very competent rock with low interstitial porosity and permeability. It is underpressured, initial pressure being approximately 520 psia at sea level datum. Static pressure gradient is that of saturated steam to total depths reached to date.

Application

Practical application of pressure buildup analysis at The Geysers has been used to make qualitative interpretations about such things as fracture geometry and boundary conditions.

Quantitative estimates of reservoir permeability are made on a routine basis. Quantitative estimation of porosity using pressure buildup analysis requires a very accurate knowledge of reservoir geometry, so this application must be approached with caution, since the reservoir is still being delineated by exploratory drilling.

The pressure buildup can conveniently be divided up into three general periods for purposes of discussion: (1) short-time, (2) radial flow, and (3) late-time. During short-time, pressure buildup is dominated by either wellbore storage and skin effect, linear flow along a fracture plane, or a combination of these. After these short-time effects die out, pressure becomes a linear function of the logarithm of time. This semi-log straight period will be called radial flow for purposes of discussion in this paper. At late-time, pressure departs from semi-log straight in various ways depending upon boundary conditions.

Any or all of the above three periods typical of pressure buildup behavior at wells in The Geysers reservoir may be masked by such unpredictable things as condensation in the wellbore.

Short-Time Behavior

The short-time behavior designated by straight lines on Figs. 1 and 2 commonly lasts for no more than a few minutes. This data, recorded by hand using a test gauge and a stop watch, is valuable in characterizing fracture geometry and in doing type curve matching to identify the proper semi-log straight line. The wellhead data is converted to datum (usually midpoint of steam entries) using the Cullender-Smith Method of calculating bottomhole pressure [1].

Short-time buildup behavior at The Geysers generally falls into one of the two types: (1) half-slope as in Fig. 1, and (2) unit slope, as in Fig. 2. Ramey [2] identified the significance of these two types, showing that unit slope behavior is characteristic of a well with storage and skin, and that half-slope behavior is characteristic of flow along a linear fracture plane. Unit slope behavior is most common at The Geysers; however, fractured wells commonly exhibit storage effects with early behavior showing anything from 1/2 to unit slope. Certain methods of analysis discussed in Reference 3 are used to avoid labeling a particular buildup a storage case when it is actually a fracture case with storage.

For pressure buildup analysis in wells exhibiting fracture flow, Wattenbarger's "double delta p" rule, discussed in Reference 3, has been used successfully to find the start of the proper semi-log straight line. As noticed by Wattenbarger [4], dimensionless pressure at the start of the semi-log straight line is approximately twice the dimensionless pressure at the top of the one-half slope line. This rule also helps to differentiate between fracture cases with wellbore storage, and cases that are only storage and skin effect because in the latter case, application of the "double delta p" rule will lead to a pressure difference for greater than possible for the start of a semi-log straight line. Applying the "double delta p" rule to Fig. 2 shows that this buildup might be a fracture case, even though it has a unit slope. Comparison of this buildup to type curves for a vertically fractured well having wellbore storage effects verified that this was a fracture case.

Log-log graphs such as Figs. 1 and 2 require an accurate knowledge of flowing pressure prior to shut-in. Flowing pressure measured at the wellhead is generally not directly usable for constructing a log-log graph. This is because wellhead flowing pressure reflects friction pressure losses, and small inaccuracies in estimating friction pressure drop lead to very substantial changes in the log-log graph. The most useful procedure for identifying the proper value to use for graphing has been to record short-time data at 5-second intervals for the first minute of the buildup, then visually inspect the data to determine incremental rise in pressure per 5-second interval. Best estimate of this can usually be made using data beyond 10 seconds. Pressure at time zero is then corrected to make it consistent with the observed incremental pressure rise beyond 10 seconds.

Radial Flow Behavior

Pressure buildup beyond the short-time period is a linear function of the logarithm of time. Fig. 3, showing this behavior for a steam well at The Geysers, describes a semi-log straight line for five log cycles. Quantitative estimates of permeability-thickness, kh, made from graphs such as this, give remarkably consistent values from test to test on a given well.

The most prevalent problem with testing the dry steam wells at The Geysers has been condensation, which causes erratic pressure behavior. In serious cases, wellhead pressure may even drop as the wellbore loads with water condensation. The data scatter on Fig. 3 is probably due to condensation and revaporization effects. Fig. 4 is a more dramatic case, showing that a part of the semi-log straight line has been masked by these two-phase wellbore effects. In very serious cases, a long vaporizing period may be mistaken for a semi-log straight line. This mistake can be avoided by comparing the buildup to the appropriate log-log type curve.

The two-phase effects illustrated in Fig. 4 have been most common in wells shut-in on small vents, i.e., 1/2" or less. This problem is eliminated by doing two-rate buildup tests. The two-rate tests require that the well be choked back to a second rate high enough to avoid condensation. The pressure buildup analysis method, developed from Chapter 6 of Reference 5, for use at The Geysers, accounts for this second rate, resulting in the analytic method shown on Fig. 5. The two-rate method gives results that compare well with conventional buildup tests. For example, kh obtained from Fig. 5 was within 13% of the kh value obtained on the same well using conventional buildup test procedures.

Late-Time Behavior

When drainage boundaries or other reservoir heterogeneities begin to affect pressure buildup at a well, the data will no longer be a semi-log straight function of time. Boundary conditions at The Geysers are not well understood, so that our analysis of boundary effects on pressure buildup must be confined to qualitative comparisons with type curves. For example, the theoretical behavior for the case of a vertically fractured well in a closed square (Fig. 6) was published by Gringarten, et al [6]. Theoretical behavior for the system shown on Fig. 6, with uniform flux along the fracture, is illustrated on Fig. 7. The field data shown on Fig. 7, from a non-commercial well at The Geysers, matches a type curve from the first data point, recorded at 10 seconds shut-in time, up until a shut-in time of 147 hours. Fig. 7 shows the importance of recording accurate short-time data. Field cases of this type are extremely rare.

The most common type of late-time behavior observed at The Geysers conforms to the theoretical behavior for the drainage system illustrated in Fig. 8. This system, and the corresponding type curves shown on Fig. 9, are from work published by Ramey, et al [7]. Field data graphed on Fig. 9 follow the general shape and timing of events characteristic of the type curves; deviation of the field data from the type curves during late-time is probably due to the condensation effects discussed earlier. The type curves shift upward and to the right correspondingly as producing time prior to shut-in is increased. This behavior, peculiar to systems with strong pressure support, is exhibited by most wells in The Geysers reservoir.

Type curve matches, such as Fig. 9, can be used to make reliable, quantitative estimates of reservoir pore volume and porosity, provided the system is at initial conditions and location and nature of drainage boundaries can be reasonably identified. Practical application of this has been demonstrated in a naturally fractured gas field [8]. Obviously, geologic and engineering investigations must be a joint cooperative effort.

Concluding Remarks

Pressure buildup behavior recorded at wells in The Geysers dry steam field has been valuable in gaining insight into reservoir mechanics. Modern well test analysis methods have been applied successfully to describe field data and extract practical information. Buildup testing, however, is not an end in itself, but must be harmonized with other engineering and geological methods. Analysis of pressure buildup behavior along with geologic information, is a logical first stage of analysis leading to more sophisticated methods such as reservoir simulation using digital computers.

Nomenclature

L = Fracture length, wellbore to tip
P = Pressure
T = Flowing Time
ΔT = Shut-in Time
W = Flow Rate, lbs/hr
X_E = Linear Distance, boundary to boundary
X_F = Linear Distance, fracture tip to tip

Subscripts

D = Dimensionless
TF = Wellhead flowing
TS = Wellhead shut-in
WF = Bottomhole flowing
WS = Bottomhole shut-in

References

(1) Theory and Practice of the Testing of Gas Wells, Oil and Gas Conservation Board, Calgary, Alberta, Second Edition (1965), pg. 161.

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(3) Ramey, H.J., Jr.: "Practical Use of Modern Well Test Analysis," SPE 5878, 46th Annual California Regional Meeting, SPE of AIME, Long Beach (April 8-9, 1976).

(4) Wattenbarger, R.A., and Ramey, H.J., Jr.: "Well Test Interpretation of Vertically Fractured Gas Wells," J. Pet. Tech. (May, 1969) pgs. 625-632.

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(6) Gringarten, C.A., Ramey, H.J., Jr., and Raghavan, R.: "Unsteady-State Pressure Distributions Created by a Well with a Single Infinite--Conductivity Vertical Fracture," Soc. Pet. Eng. J. (August, 1974) pgs. 347-360; AIME Trans., Volume 257.

(7) Ramey, H.J., Jr., Kumar, A., and Gulati, M.S.: Gas Well Test Analysis Under Water-Drive Conditions, American Gas Association Monograph, 1973.

(8) Strobel, C.J., Gulati, M.S., and Ramey, H.J., Jr.: "Reservoir Limit Tests in a Naturally Fractured Reservoir--A Field Case Study Using Type Curves," J. Pet. Tech. (September, 1976) pg. 1097.

FIGURE 1

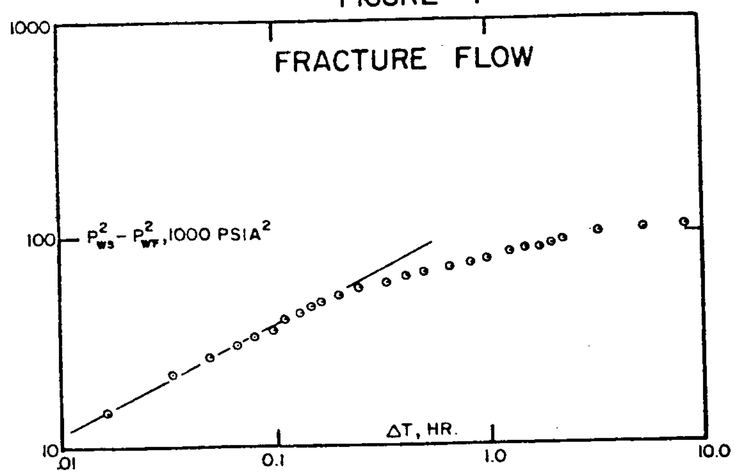


FIGURE 2

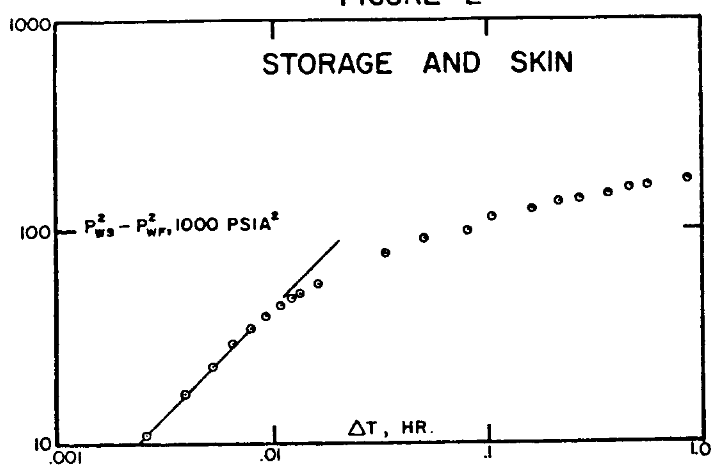
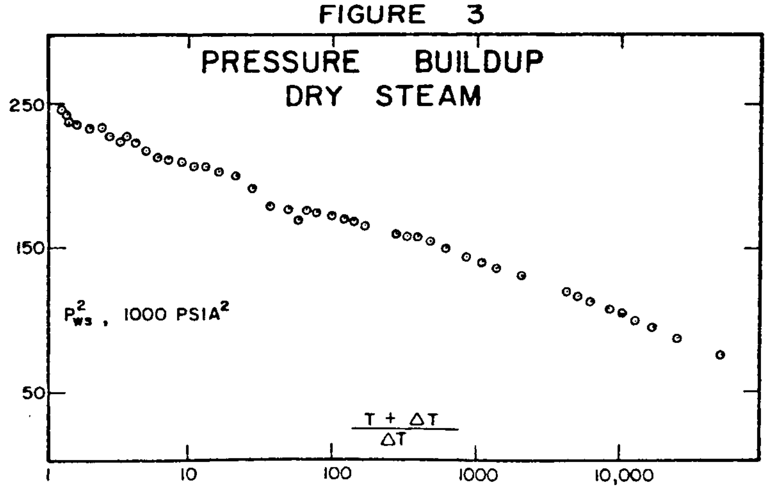


FIGURE 3



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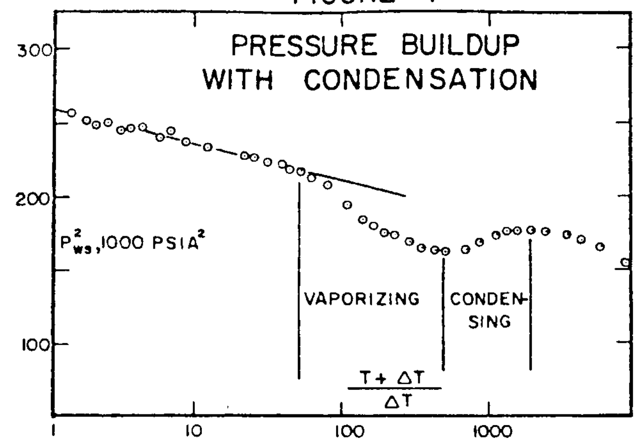


FIGURE 5

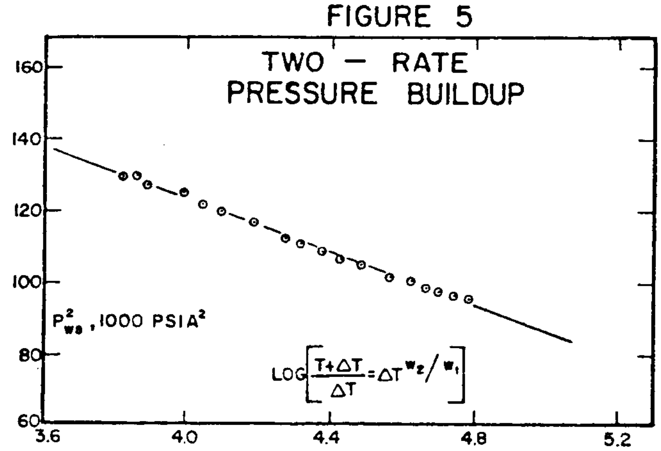
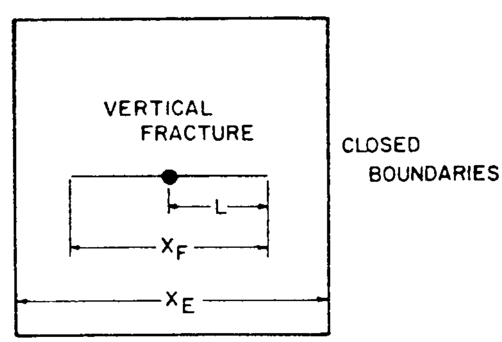


FIGURE 6

DRAINAGE AREA



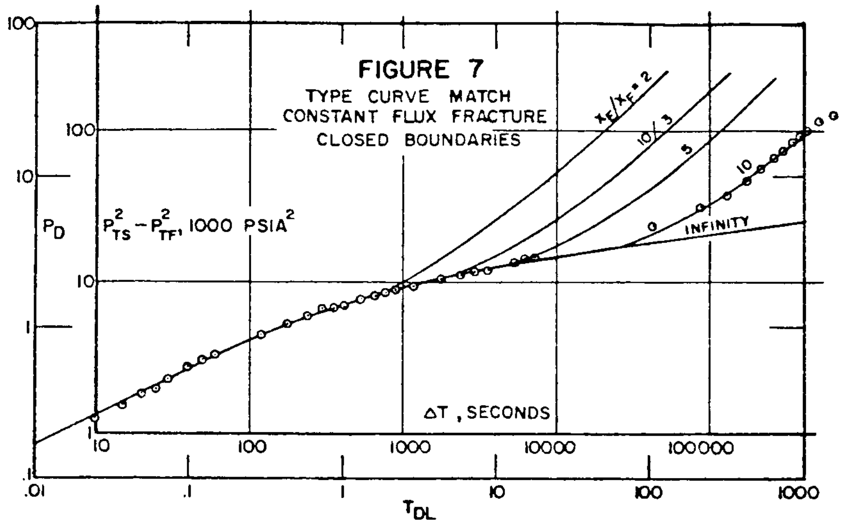


FIGURE 8
DRAINAGE AREA
CONSTANT PRESSURE BOUNDARIES

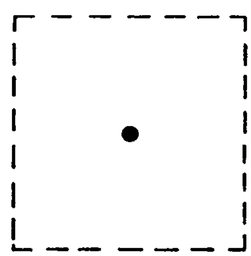


FIGURE 9