The Effect of Restricted Fluid Entry on Well Productivity

Journal of Petroleum Technology, Vol. 13, No. 2, pp. 172-174

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INTRODUCTION

In the past, other authors[1, 2] have studied the influence of a skin effect on the productivity of a well. This skin effect, expressed by the skin factor S, is considered to be caused by a thin layer of impaired permeability immediately around the wellbore and extending vertically over the whole productive interval penetrated by the well. The skin factor S is defined as follows.

The pressure drop Δp in a well without skin is given by

$$\Delta p = \left(\frac{q\mu}{2\pi kh}\right) p_T \quad \ldots \ldots \ldots \ldots (1)$$

(For the meaning of the pressure function p_T see Ref. 3.)

The skin effect causes an increase in pressure drop described by

$$\Delta p = \frac{q\mu}{2\pi kh}(p_T + S) \quad \ldots \ldots \ldots \ldots (2)$$

where S is the skin factor, and $\left(\frac{q\mu}{2\pi kh}\right) S$ is the pressure drop in the skin.

Based on this, the impairment in productivity caused by a skin can be expressed by the fractional loss in productivity I, which is the loss in productivity divided by the total unimpaired productivity. For compressible flow in a stabilized well which drains a circular area of radius r_e, I is given by

$$I = \frac{S}{\ln r_e/r_w - 0.75 + S} \quad \ldots \ldots \ldots (3)$$

STATEMENT OF PROBLEM

The present paper deals with a different kind of productivity impairment. Consider a well in which part of the productive formation is blocked off completely, either by incomplete penetration or by exclusion of parts of the productive zone by blank casing.

In Fig. 1 (A, B and C), three examples are shown. Fig. 1(A) shows the situation where a well only partially penetrates the formation. This often is done to combat the actual or imagined danger of bottom-water coning. Fig. 1(B) shows a well producing from only the central portion of a productive interval. This type of completion is sometimes used where both water and gas coning are a problem. Although the case of a well producing through perforated casing cannot be treated in a manner similar to the previous two cases (where radial flow in the horizontal plane is assumed), Fig. 1(C) shows several intervals open to production and qualitatively describes this case (as will be discussed later).

To study the loss in productivity in all these cases, two parameters are introduced which fully determine the impairment. The first is the penetration ratio "b," i.e., the total interval open to fluid entry divided by the total thickness of the productive zone. The second is the ratio h/r_w. In this ratio, r_w is the wellbore radius. The definition of h is more cumbersome. In Fig. 1(A), h is the thickness of the total productive interval. The streamline configuration for this case of partial penetration is basic to the other two cases considered (Views B and C of Fig. 1). It will be obvious from Fig. 1(A) that the flow lines in the uppermost portion of the formation will be essentially horizontal, while those in the lower portion will curve upward toward the well. In Fig. 1(B), with only the middle portion of the zone open to production, the streamline configuration of the upper half will be an exact mirror image of that in the lower half of the zone. Hence, for the case illustrated in Fig. 1(B), h is defined as one-half the total sand thickness. It follows, then, that in Fig. 1(C) h is one-half the distance between corresponding points in adjacent intervals. (In gun-perforated casing, h would be one-half the distance between perforations.)

DISCUSSION OF RESULTS

In a paper by Nisle[4] and a paper given by the present authors[5], the mathematical theory was developed for the cases under consideration. In the present publication, the emphasis is put on the results of these studies; consequently, the equations derived in Refs. 4 and 5 will be omitted, for the most part.

The pressure drop Δp in a well producing from only a portion of the total formation thickness can, in analogy with Eq. 1, be expressed by

$$\Delta P = \frac{q\mu}{2\pi kh} p_T(b) \quad \ldots \ldots \ldots \ldots (4)$$

where

$$p_T(b) = \frac{1}{2b}\int_0^t F(\tau)\, d\tau \quad \ldots \ldots \ldots \ldots (5)$$

and $F(\tau)$ is a function given in Refs. 4 and 5.

Numerical solution of Eq. 5 by use of the IBM 650 leads to the following important conclusions. First, during a short period after starting production (usually on the order of a few minutes), the function $p_T(b)$ is given by

Original manuscript received in Society of Petroleum Engineers office July 14, 1959. Revised manuscript received Dec. 1, 1960. Paper presented at 34th Annual Fall Meeting of SPE, Oct. 4-7, 1959, in Dallas.

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[1]References given at end of paper.

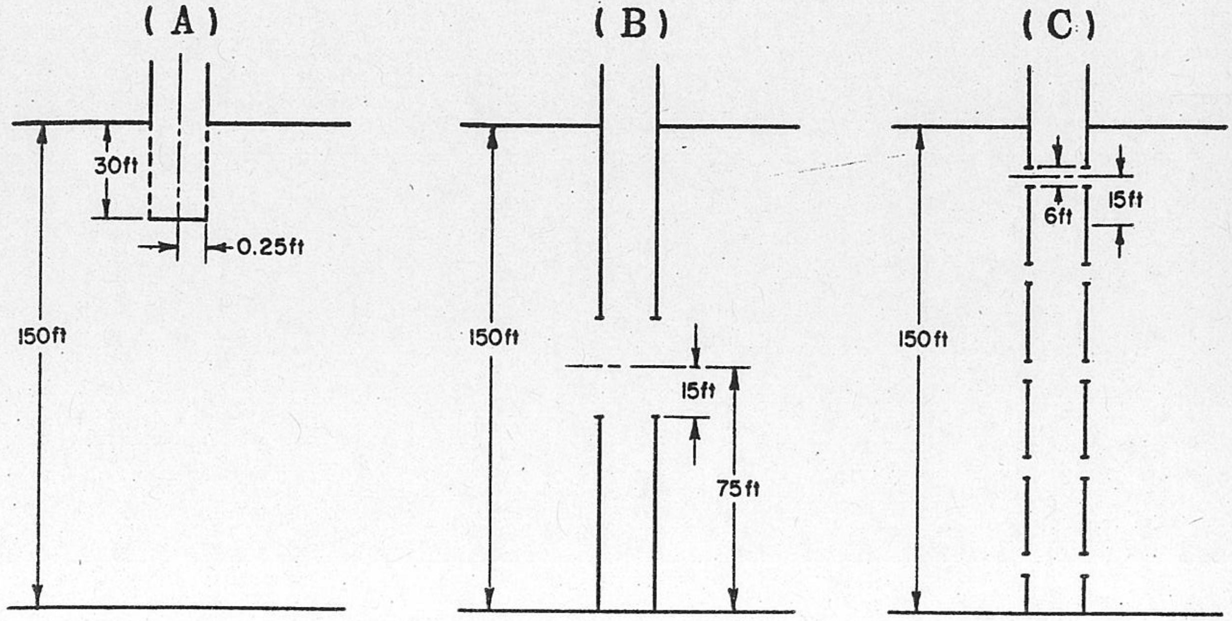

FIG. 1—EXAMPLES SHOW (A) WELL ONLY PARTIALLY PENETRATING FORMATION, (B) WELL PRODUCING FROM ONLY THE CENTRAL PORTION OF PRODUCTIVE INTERVAL, AND (C) WELL WITH SEVERAL INTERVALS OPEN TO PRODUCTION.

$$p_T(b) = \left(\frac{1}{b}\right) p_T \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

This means that the pressure drop during this very short initial period is expressed by

$$\Delta P = \frac{q\mu}{2\pi kbh} p_T \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

Compared to Eq. 1, this shows that during this time the well behaves as if the total sand thickness were equal to bh, i.e., the interval open to flow.

Secondly, after a short transition period, the pressure function is given by

$$\Delta P = \frac{q\mu}{2\pi kh}\left[p_T + \frac{1-b}{b}\left(\ln\frac{h}{r_w} - G(b)\right)\right] \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

The second term in the bracketed expression is time independent, being a function only of b and h/r_w. This means that the restriction to fluid entry by virtue of only partial well penetration results in an additional pressure drop, independent of time, similar to that caused by a skin. In analogy with Eq. 2, a "pseudo" skin factor S_b is introduced and is defined by

$$S_b = \frac{1-b}{b}\left(\ln\frac{h}{r_w} - G(b)\right) \quad . \; . \; . \; . \quad (9)$$

where $G(b)$ is a function of b. Since this function cannot be expressed analytically, it has been calculated numerically. In Table 1, $G(b)$ is given for a range of b values.

Based on Eq. 9 and Table 1, pseudo skin factors S_b were calculated for a range of values of h/r_w and b, as shown in Table 2 and Fig. 2. Note that Eq. 9 loses its validity for low values of h/r_w. This limitation can be explained by the fact that, for low values of h/r_w, r_w becomes of the same order of magnitude as h; consequently, the "point-source" solution on which the equations are based no longer applies. In such cases the exact solution, rather than the point-source solution, should be used.[5] The exact S_b values for low values of h/r_w are included in Table 2 and Fig. 2.

The fractional loss in productivity I is related to the skin factor S_b by Eq. 3. Based on this relation, I is given in Fig. 3 as a function of S_b, for $r_e = 660$ ft and $r_w = 3$ in. By comparison, Muskat[6] gives a solution for the case of incompressible flow. In Fig. 4, values of I based on Muskat's equations are compared with those calculated for depletion-type flow, for $h/r_w = 100$ and $h/r_w = 1{,}000$ and using the same values for r_e and r_w as shown in Fig. 3. This plot shows that the values for incompressible and depletion-type flow are quite close. However, Muskat's method is not applicable to low h/r_w values.

Considering again the conditions sketched in Fig. 1 (A, B and C), it is seen that in all cases the penetration ratio b is 0.2. However, h/r_w is 600, 300 and 60, respectively, in Views A, B and C of Fig. 1. It follows from Fig. 3 that, for $r_e = 660$ ft and $r_w = 3$ in., the loss in productivity I is 68, 56 and 11 per cent, respectively. From these results, we conclude that better productivity is obtained from an interval open in the

TABLE 1—$G(b)$ FOR RANGE OF b VALUES

b	$G(b)$
0.1	2.337
0.2	1.862
0.4	1.569
0.6	1.621
0.8	1.995

TABLE 2—PSEUDO SKIN FACTORS S_b FOR RANGE OF h/r_w AND b

	b				
h/r_w	0.1	0.2	0.4	0.6	0.8
1	S_b = 0.6359	0.4474	0.2214	0.0938	0.0246
2	1.2384	0.8587	0.4197	0.1782	0.0474
5	2.8750	1.9210	0.9120	0.3893	0.1073
10	5.1589	3.2949	1.5146	0.6502	0.1867
20	8.6406	5.2130	2.3101	0.9982	0.3002
50	15.0060	8.3839	3.5562	1.548	0.4932
100	20.7013	11.0340	4.5669	1.9962	0.6571
200	26.7437	13.7617	5.5968	2.4535	0.8272
300	30.2995	15.3695	6.2011	2.7219	0.9272
500	34.9150	17.4159	6.9679	3.0628	1.0551
700	37.9347	18.7602	7.4723	3.2869	1.1391
1000	41.1398	20.1860	8.0071	3.5246	1.2282
10,000	61.8577	29.3953	11.4607	5.0596	1.8038

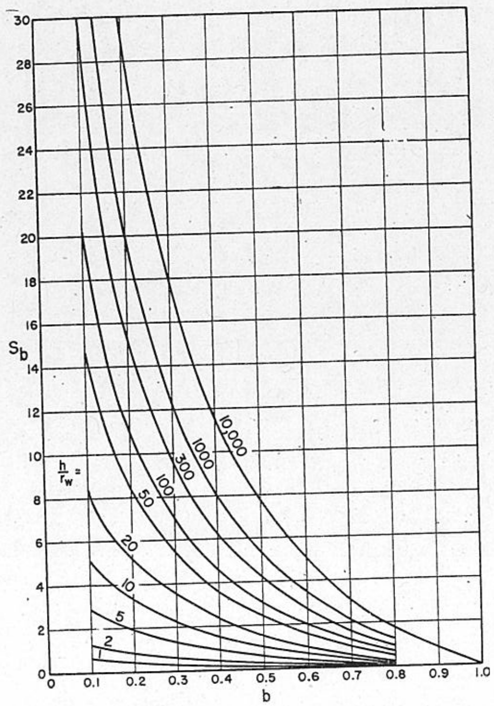

FIG. 2—PSEUDO SKIN FACTOR S_b AS A FUNCTION OF b AND h/r_w.

middle of a productive zone than from the same open interval located at either the top or bottom of the zone.

Additionally, we conclude that the larger the number of intervals for a given total-penetration ratio, the higher the productivity will be.

Although the case of a well producing through perforated casing is not covered by the present theory, which assumes radially symmetric flow in the horizontal plane, qualitatively speaking the foregoing may still be applied to this case. It supports the experience that, above a certain perforation density, the productivity is almost unimpaired although the fraction of the formation actually open to the wellbore may be small and, further, that above a certain density increasing the number of perforations per foot will add little to the productivity. To put these statements on a quantitative basis, the present theory must be modified to include this type of completion.

Finally, all previous statements are valid only for isotropic permeability distribution; any degree of horizontal stratification will lower the productivity until, for zero vertical permeability, I becomes equal to $1 - b$ (see Fig. 2).

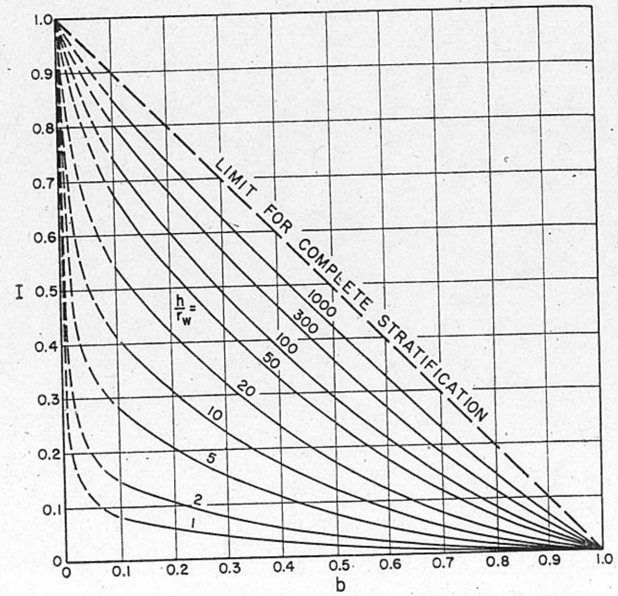

FIG. 3—FRACTIONAL LOSS OF PRODUCTIVITY I AS A FUNCTION OF b AND h/r_w FOR r_e = 660 FT AND r_w = 3 IN.

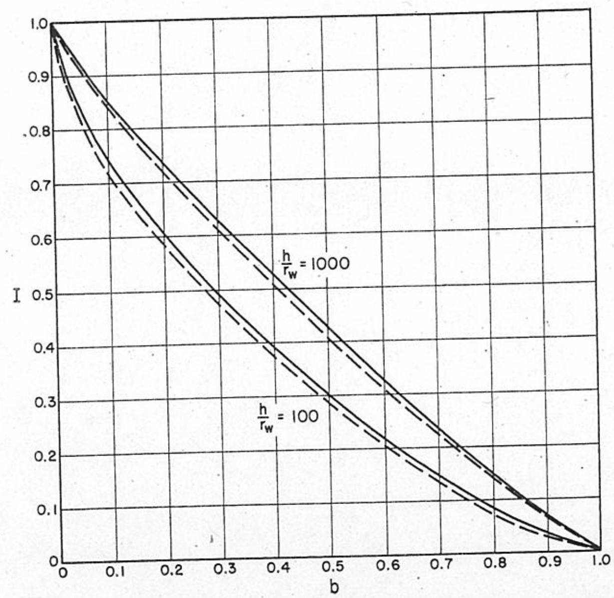

FIG. 4—COMPARISON BETWEEN FRACTIONAL LOSS OF PRODUCTIVITY I. (SOLID LINE REPRESENTS CALCULATIONS MADE BY THIS PAPER; DASHED LINE REPRESENTS COMPARISON MADE BY MUSKAT.[6])

REFERENCES

1. Van Everdingen, A. F.: "The Skin Effect and Its Influence on the Productive Capacity of a Well", *Trans.*, AIME (1953) **198**, 171.
2. Hurst, William: "Establishment of the Skin Effect and Its Impediment to Fluid Flow Into a Well Bore", *Pet. Engr.* (Oct., 1953).
3. Van Everdingen, A. F. and Hurst, W.: "The Application of the Laplace Transformation to Flow Problems in Reservoirs", *Trans.*, AIME (1949) **186**, 305.
4. Nisle, R. G.: "The Effect of Partial Penetration on Pressure Build-up in Oil Wells", *Trans.*, AIME (1958) **213**, 85.
5. Brons, F. and Marting, V. E.: "The Effect of Restricted Fluid Entry on Well Productivity", Preprint of paper 1322-G presented at 34th Annual Fall Meeting at SPE (Oct. 4-7, 1959) in Dallas.
6. Muskat, M.: *Physical Principles of Oil Production*, McGraw-Hill Book Co., Inc., N. Y. (1949) 211.

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