01 May 1994

Skin Effects Due to Perforations – A Study of Analysis Techniques

Jon Michael Gibbs

Recommended Citation

Gibbs, Jon Michael, "Skin Effects Due to Perforations -- A Study of Analysis Techniques" (1994). *Opportunities for Undergraduate Research Experience Program*. 31.
https://scholarsmine.mst.edu/oure/31

SKIN EFFECTS DUE TO PERFORATIONS- A STUDY OF ANALYSIS TECHNIQUES

Jon Michael Gibbs
Petroleum Engineering

ABSTRACT

Until 1991, two methods could be used to evaluate the skin effect due to perforations, the Brons and Marting Method and the Harris Method. Due to the simplicity of the technique, the Brons and Marting Method has been the preferred method of use in the petroleum industry. However, with the recent development of a third technique to evaluate the skin effect due to perforations, the need has arisen to evaluate each of these techniques to determine which method is the most accurate under given conditions. This paper reviews and compares each of the three methods for evaluating the perforations skin. Recommendations concerning the use of these methods have also been made by the author.

INTRODUCTION

In petroleum engineering, engineers are not able to see the environment which they study, the reservoir. Subsequently, they must be able to obtain sufficient information about the reservoir to analyze its performance and to predict its future production under various modes of operation [1]. Much of this information can be determined from a pressure transient test.

Transient pressure testing techniques, or well testing, include pressure buildup, drawdown, injectivity, falloff, and interference. These techniques all consist of generating and measuring pressure verses time at reservoir depth. The most useful information obtained from a transient pressure test includes the permeability, average reservoir pressure, and the relative amount of skin damage or skin improvement [2].

DEFINING THE SKIN EFFECT

At or near the wellbore, the ability of the reservoir fluids to flow into and through the wellbore may be altered due to a change in the near wellbore permeability or by any flow restrictions below the pressure measuring device. This phenomena is called the skin effect. The change in permeability near the wellbore may be reduced due to mud caking, cement problems, clay dispersion, partial completion, paraffin buildup, or plugged perforations. It also may be increased resulting by acidizing or fracturing a well. Flow restrictions which may contribute to the skin effect include downhole chokes or downhole pumps, to name a couple. The sign convention for the skin factor is as follows: a positive indicates wellbore damage and a negative skin indicates wellbore improvement. Since the change in permeability is close to the wellbore, its effect may be accounted for as an additional pressure drop caused by the presence of the 'skin'. A schematic of the skin effect is shown in Figure 1: Skin Effect. Following along the pressure profile curve, note the additional pressure drop encountered within the skin, or zone of damage. To overcome the additional pressure loss, the wellbore pressure must be drawn down an additional amount equal to the Δp_{skin} in order to receive the same amount of fluids from the reservoir as if the skin were not present.

The skin factor is determined from a transient pressure analysis. The transient pressure analysis will yield the total skin factor. As equation (1) shows, the total skin factor is a combination of several individual skins. Some of these individual skins are the skin due to perforations, skin due to partial penetration, skin due to slant hole, skin due to turbulence, skin due to fractures, and the skin due to equipment.

$$S_{total} = S_{actual} + S_{perfs} + S_{pen} + S_{slant} + S_{turb} + S_{frac} + S_{equip} \quad \text{...}(1)$$

The individual skin effects must be determined to evaluate the actual skin factor (as shown in equation (1)) from the total skin factor, as wellbore remedial treatments should be designed based on the actual skin factor.

Little research has been conducted concerning the skin due to perforations, s_{perfs}. This effect is created when a well is completed with casing and perforated. The perforations are small holes in the casing which limit the flow into the wellbore (as compared to an open hole completion). Until recently, only two techniques existed to evaluate the skin due to perforations.

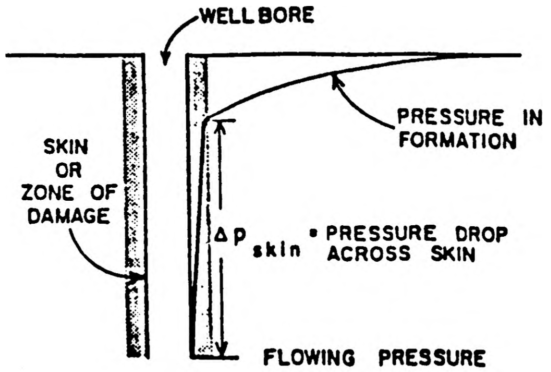


Figure 1: Skin Effect

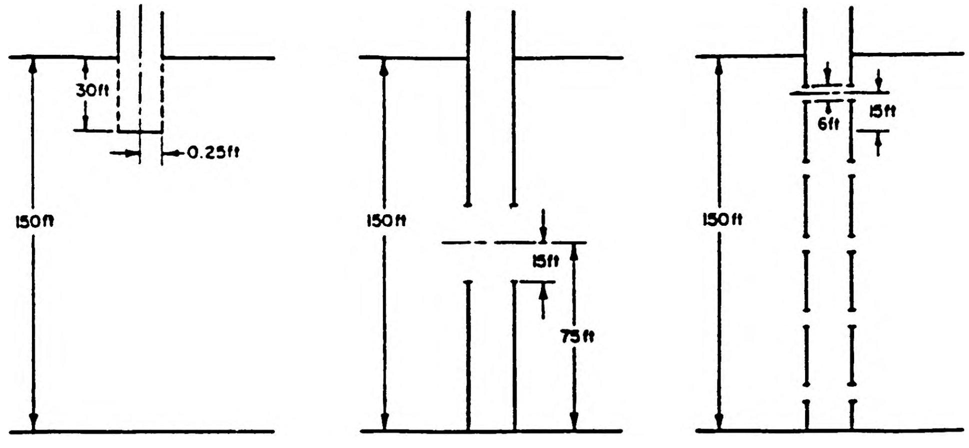
EVALUATION TECHNIQUES

Currently, there are three techniques to evaluate the skin due to perforations, Brons and Marting Method, Harris Method, and Karakas and Tariq Method. The following section addresses each of the three method for evaluating the skin due to perforations. A detailed evaluation of the Karakas and Tariq method is included since little research has been conducted on this technique.

Brons and Marting Method:

The first technique to determine the skin due to perforations was developed by F. Brons and V.E. Marting in 1960 [3]. However, their technique was not originally developed to evaluate the skin due to perforations, but rather is an extension of the skin due to partial completion and partial penetration. Figure 2: Brons and Marting Technique, represents the development of their skin due to perforations.

Figure 2A shows the situation where a well only partially penetrates the formation. Skin effects would be present in this situation since the reservoir fluids in the lower portion of the reservoir will not flow as readily into the wellbore as the reservoir fluids horizontal to the perforated penetrated portions of the reservoir. Figure 2B shows a well producing from only the central portion of a productive reservoir. A skin effect will also be present in this situation since reservoir fluids from the upper and lower portions of the producing interval must flow vertically to enter the wellbore as opposed to the horizontal flow in the portions adjacent to the completed interval. Figure 2C is Brons and Marting's 'model' for the skin due to perforations. It is a combination of the situations presented in 2A and 2B. In Figure 2C, the entire reservoir has been penetrated and completed. However, a skin effect due to perforations will still be present since all portions of the reservoir do not have equal access to the wellbore (i.e. the flow is not entirely horizontal in all areas). Also note that their model assumes an open disk, or 360° of perforations as opposed to individual shots for perforations.



(A) (B) (C)

Figure 2: Brons and Marting Technique

Figure 3: Brons and Marting Skin Factor for Perforations, is the graph which is used in their technique to evaluate the skin due to perforations (it can also be used to evaluate partial penetration and partial completion skins).

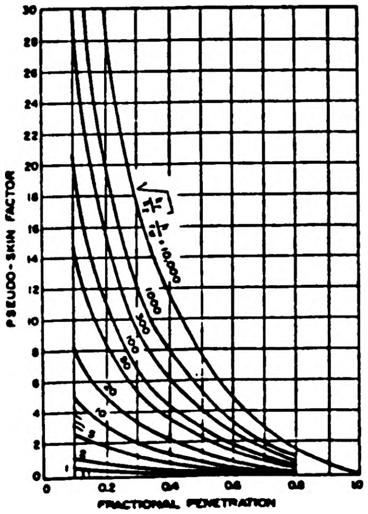


Figure 3: Brons and Marting Skin Factor for Perforations

The plot indicates a pseudoskin factor as a function of the fractional penetration, which for all possible cases is defined as the ratio of the open interval(s) to the total interval.

$$f_p = \frac{h'}{h} \quad \text{...(2)}$$

where:
f_p = fractional penetration
h' = interval open to flow (ft)
h = total net pay (ft)

The plot is also a function of the term

$$\sqrt{k_r/k_z}\left(\frac{h}{r_w}\right) \quad \text{...(3)}$$

where:
k_r = radial permeability (md)
k_z = vertical permeability (md)
r_w = wellbore radius (ft)
h = for perforated intervals use one-half of the distance between perforations (ft)

Therefore, to evaluate the skin due to perforations by Brons and Marting's technique, calculate the fractional penetration (equation 2) and the term in equation (3), enter the plot shown in Figure 3 and read the pseudoskin, which in this case is the skin due to perforations.

The Harris Method:
The second technique to determine the skin due to perforations was introduced in 1966 by M.H. Harris [4]. Unlike the Brons and Marting technique, Harris' technique was specifically designed to evaluate the skin due to perforations. Figure 4: Harris Model is an illustration of the model for the Harris technique. Harris' model assumes an asymmetrical perforation design, or multiple perforation shots within a given plane. Once again, this type of perforating does not depict current perforation techniques.

Harris defines three dimensionless variables and 'm', the number of perforations per plane, which are used to evaluate his skin due to perforations.

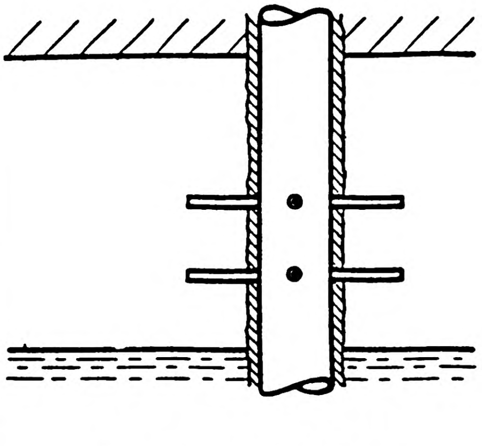


Figure 4: Harris Model

$$d_D = \frac{d}{r_w}\sqrt{k_r/k_z} \quad \text{...(4)}$$

$$a_D = \frac{a}{r_w} \quad \text{...(5)}$$

$$h_D = \frac{h}{r_w}\sqrt{k_z/k_r} \quad \text{...(6)}$$

$$m = \frac{360}{\theta_z} \text{..} (7)$$

where

d = perforation diameter (inches) r_w = wellbore radius (inches)
k_r = radial permeability (md) k_z = vertical permeability (md)
h = vertical perforation spacing (inches) m = no. of perforations per plane
θ_z = angular dimension (phasing, degrees)
a = perforation on notch penetration beyond cement sheath (inches)

To determine the skin effect, several plots, similar to that shown in Figure 5: Example Harris s_{perf} Plot, have been generated which apply to various values of 'm' and the three dimensionless variables. For example, the graph in Figure 5 would apply to a well with an h_D between 4 and 100 (the actual h_D is interpolated), four shots per plane (m), an a_D between zero and 9, and a d_D of 0.1666. To determine the skin due to perforations the dimensionless skin from the coordinate axis must be adjusted by the term in parenthesis. Thus, if a dimensionless skin effect of 10 was read from the plot, the skin due to perforations would be 10 - 4, or 6.

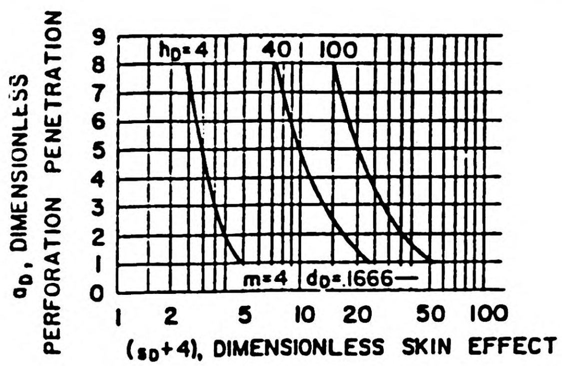


Figure 5: Example Harris S_{perfs} Plot

Karakas and Tariq Method:

In 1991, Metin Karakas and S.M. Tariq developed a technique through the use of a finite element method to evaluate the skin due to perforations [5]. A diagram of the model for their technique is presented in Figure 6: Karakas & Tariq Model. Several downhole parameters, phase angle, perforation diameter, perforation spacing, perforation diameter, crushed zone diameter, damaged zone diameter, and open hole diameter comprise their model.

In Karakas and Tariq's technique, the skin due to perforations is the sum of several 'mini-skins', consisting of wellbore, vertical, and horizontal skin values. In equation form:

$$s_{perfs} = s_{wellbore} + s_v + s_h \text{............................} (8)$$

The parameters shown in Figure 6 contribute to the above mini-skins. Three dimensionless terms have been introduced to evaluate each mini-skin: dimensionless perforation spacing,

$$h_D = (h / L_p)\sqrt{k_h / k_v} \text{..................................} (9)$$

dimensionless perforation radius,

$$r_{pD} = (r_p / 2h)(1 + \sqrt{k_v / k_h}) \text{.....................} (10)$$

and dimensionless well radius,

$$r_{wD} = r_w/(L_p + r_w) \qquad (11)$$

where.

h = spacing between perforations (inches)

L_p = length of perforations (in.)

k_h = horizontal permeability (md)

k_v = vertical permeability (md)

r_p = perforation radius (inches)

r_w = wellbore radius (inches)

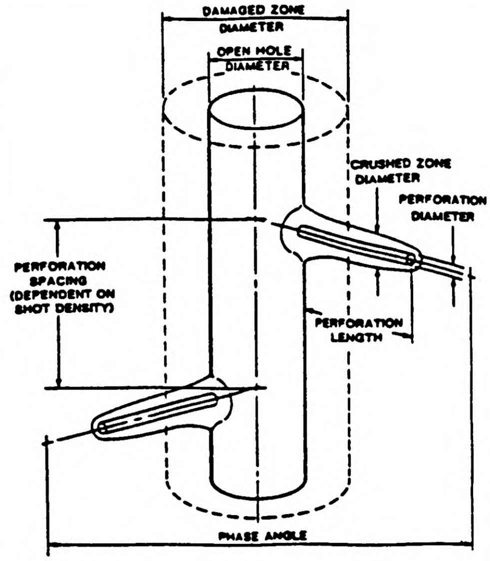


Figure 6: Karakas & Tariq Model

The mini-skins are defined individually as the wellbore mini-skin, s_{wb}:

$$s_{wb} = c_1(\theta)\exp[c_2(\theta)r_{wD}] \qquad (12)$$

for $0.30 \leq r_{wD} \leq 0.90$, where c1 and c2 are given in Table I: Variable c1 & c2 in Eq. (12).

Table I: Variable c_1 &c_2 in Eqn. 12

Phasing (degrees)	c_1	c_2
0(360)	1.6×10^{-1}	2.675
180	2.6×10^{-2}	4.532
120	6.6×10^{-3}	5.320
90	1.9×10^{-3}	6.155
60	3.0×10^{-4}	7.509
45	4.6×10^{-5}	8.791

The last term in equation (8) is the horizontal mini-skin, s_h:

$$s_h = \ln(r_w/r_{we}) \qquad (13)$$

where r_{we} is the effective well radius and is given by:

$$r_{we}(\theta) = \begin{cases} 1/4Lp & \text{if } \theta = 0 \\ \alpha\theta(r_w + L_p) & \text{otherwise} \end{cases} \qquad \text{.................(14)}$$

and the variable alpha can be determined form Table II: α_θ Determination. The vertical mini-skin, s_V is

$$s_V = 10^a h_D^{b-1} r_{pD}^{b} \text{.......................(15)}$$

where

$$a = a_1 \log_{10}(r_{pD}) + a_2 \text{.....................(16)}$$

$$\text{and } b = b_1 r_{pD} + b_2 \text{.........................(17)}$$

Table II: α_θ Determination

Phasing (degrees)	$r_{we}/(r_w+L_p)$
0(360)	0.250
180	0.500
120	0.648
90	0.726
60	0.813
45	0.860

The coefficients in equations (16) and (17) are listed in Table III: Vertical Skin Correlation Coefficients.

Karakas and Tariq also provide an equation for a crushed zone mini-skin. However, since the permeability in the crushed zone must be known, and since it is difficult to obtain this data without extensive laboratory testing, the crushed zone mini-skin has not been included in this paper.

The equations which Karakas and Tariq have developed were verified by comparing their outcomes with those obtained through actual, finite-element simulations. (For further discussion concerning these results, see reference 5).

Table III: Vertical Skin Correlation Coefficients

Phasing (degrees)	a_1	a_2	b_1	b_2
0(360)	-2.091	.0453	5.1313	1.8672
180	-2.025	.0943	3.0373	1.8115
120	-2.018	.0634	1.6136	1.7770
90	-1.905	.1038	1.5674	1.6935
60	-1.898	.1023	1.3654	1.6490
45	-1.788	.2398	1.1915	1.6392

NOTE: Values good for $h_D \leq 10$ and $r_{pD} \geq 0.01$

ANALYZING THE KARAKAS AND TARIQ METHOD

To evaluate Karakas and Tariq's technique for determining the skin due to perforations, a FORTRAN computer program was developed. The program is a direct application of equations (8) through (17).

Several values for each of the five parameters in the model where chosen to evaluate the skin due to perforations by the Karakas and Tariq Technique. Table IV: FORTRAN Program Variables contains the values of each parameter evaluated in the program. The skin due to perforations was determined for every combination of the variables shown in Table IV, resulting in 540 runs with the program.

Table IV: FORTRAN Program Variables

r_w: 2", 3", 4"
L_p: 1", 3", 6", 9"
Phasing: 0^o, 45^o, 90^o, 120^o, 180^o
k_v/k_h: 0.01, .1, 1.0
h: 12", 4", 2" (1 spf, 3 spf, 6 spf)

Since constants for several phasing values were calculated (see Tables I, II, III) by Karakas and Tariq, the effect of phasing on the skin due to perforations was studied.

The two cases shown in Table V: Phasing and Wellbore Effects on Perforation Skin, show the relationship between the perforation skin and phasing. First consider the 2" wellbore radius in Case I. Throughout the range of phasing, the skin due to perforations only changes from a minimum of 1.61 at 90^o, to a maximum of 1.86 at 45^o. The difference in the skin due to perforations over the phasing range is 0.25, a very small change. Similar trends are shown for the 3" and 4" wellbore radius in Case I. Examining Case II, the same trends are present. For example, the skin due to perforations only changes from 5.47 to 6.37 for the 2" wellbore: a change in skin of only 0.9. For Case II, as in Case I, the skin due to perforations varies very little over practical phasing values.

Table V not only shows the relationship between phasing and the perforations skin, but also the effect of wellbore radius on perforations skin. Consider Case I with a phasing of 45^o. The perforation skin changes from 1.86 at an r_w = 2" to 2.22 at an r_w = 4", a difference of less then 0.50. The trend is also present for each phasing angle in both Case I and Case II.

Table V: Phasing and Wellbore Radius Effects on Perforation Skin

Case I:

k_v/k_h = 1.0
Perf. Length (L_p) = 3 inches
3 shots per foot (h=4")

	Phasing			
	45^o	**90^o**	**120^o**	**180^o**
rw = 2"	1.86	1.61	1.77	1.71
rw = 3"	2.08	1.85	2.03	2.02
rw = 4"	2.22	2.01	2.21	2.25

Case II:

k_v/k_h = 0.01
Perf. Length (L_p) = 3"
3 Shots per foot (h = 4")

	Phasing			
	45^o	**90^o**	**120^o**	**180^o**
r_w = 2"	5.67	5.47	6.37	6.28
r_w = 3"	5.89	5.71	6.63	6.59
r_w = 4"	6.03	5.87	6.81	6.82

There are several relationships which can now be developed for the skin due to perforations. First, as the k_v/k_h ratio decreases, the reservoir becomes more stratified, and the skin due to perforations increases (Case I average s_{perfs} of 2.0, Case II average s_{perfs} of 5.4). As the reservoir becomes more stratified, vertical flow in the reservoir is reduced which results in more damage in the near wellbore area, or a higher perforation skin. Secondly, for practical wellbore radii (2" to 4"), the perforation skin for a given phasing will change very little. Finally, the skin due to perforations will not significantly change over practical values of phasing, as shown in Table V. The phasing effect is important because we may not know the phasing of the well, and, as these results suggest, a best estimate for the phasing can be made which will still result in a reasonable estimation of the skin due to perforations.

REVIEW OF TECHNIQUES

Before a comparison is conducted between the three techniques for evaluating the skin due to perforations, a brief review of each technique will be discussed to highlight the important information from each method. The first technique was developed in 1960 by Brons and Marting. Their technique was not originally designed to determine the skin due to perforations, but rather is an extension of partial penetration and partial completion of a well. Brons and Marting's model also assumes an open plane, or disk, for perforations (see Figure 2).

The second technique was presented in 1966 by Harris. Although his technique was developed specifically to determine the skin due to perforations, the technique had limited computer and mathematical technology at the time of its development. Harris' model used multiple shots in a plane for perforations (see Figure 4), a technique which is no longer employed in well completions.

The final technique to evaluate the skin due to perforations was developed in 1991 by Karakas and Tariq. Their technique is the most recent since 1966 and it considers several downhole parameters. It is based on current computer and mathematical technology and it reflects current perforations methods, individual shots spiraling down the casing (see Figure 6).

COMPARISON OF TECHNIQUES

The three techniques to determine the skin due to perforations have been compared to determine the relevancy and similarities between the methods. The techniques have been compared in Table VI Comparison of Techniques. Several important conclusions can be drawn from Table VI. First, the skin due to perforations by Brons and Marting are significantly lower, indicating less damage, than those by Harris and Karakas and Tariq. Brons and Marting assume an open disk for perforations thereby allowing more fluid into the wellbore, or less flow restriction. This assumption will result in a lower skin due to perforations. The perforation skin values by Harris's technique are somewhat in-between those of Brons and Marting and Karakas and Tariq. This

Table VI: Comparison of Techniques

Wellbore Conditions:
$k_v/k_h = 1.0$
3 spf ($h = 4"$)
Perf. Length (L_p) = 3"

	Brons & Marting	Harris	Karakas & Tariq
r_w	s_{perfs}	s_{perfs}	s_{perfs}
2"	0.1	0.7	1.77
3"	0.1	2.0	2.03
4"	0.1	2.0	2.21

somewhat in-between those of Brons and Marting and Karakas and Tariq. This trend occurs because Harris' model assumes multiple perforation shots within a plane. The multiple shots will allow more fluid into the wellbore than Karakas and Tariq's method, but less than Brons and Marting's method thus resulting in skin due to perforations values between Brons and Marting's and Karakas and Tariq's. Table VI also shows that the skin due to perforations by Brons and Marting is constant for the given wellbore conditions. Under these conditions, the skin due to perforations must be determined from the lower left hand side of Figure 3. In this area, the curves are close together and therefore it is difficult to differentiate between the curves. Another trend present in Table VI is that the wellbore radius greatly affects the skin due to perforations by Harris' technique, as the perforation skin more than doubles when changing from a 2" to 3" wellbore radius. Finally, the values for perforation skin by Karakas and Tariq's method are most representative of the actual skin due to perforations because their model reflects current perforation techniques.

CONCLUSIONS

This paper presents and discusses the three techniques presently available to evaluate the skin due to perforations. The first technique by Brons and Marting will yield optimistic values for the perforation skin due to their perforations model. The model assumes an open disk for perforations which consequently allows significantly more fluid into the wellbore than by conventional perforating methods. The second technique evaluated is by Harris. Values for his skin due to perforations will be less optimistic than Brons and Marting, but his definition of phasing is not practical today. Harris' model assumes multiple perforation shots within a plane which, as noted previously, does not reflect current perforating techniques. The method developed by Karakas and Tariq will yield the most representative values for the skin due to perforations for several reasons: the model considers several downhole criteria (see Figure 4), uses modern mathematical and computer technology, and the model reflects current perforation methods. It should also be noted that although Karakas and Tariq's method considers the perforation diameter, the perforation diameter within the range of 0.5" to 0.75" has little or no effect on the skin due to perforations. This observation is noted by Karakas and Tariq and, therefore, the perforation diameter in their model has been fixed at 0.5" for all calculations presented in this paper.

The significance of wellbore radius and phasing is small with respect to the skin due to perforations for practical wellbores (r_w = 2"-4", L_p >3"). The effect of the phasing is extremely important since the phasing of a well may not be known. These results suggest that a 'best guess' estimation of the phasing will result in reasonable estimations of the skin due to perforations.

RECOMMENDATIONS

Based on the research of this paper, the author would like to make the following recommendations. The method by Karakas and Tariq should be used to determine the skin due to perforations for the following reasons:

- the method considers many downhole criteria
- the method uses modern mathematical and computer technology
- the method is the most accurate representation of current perforating practices

During the 540 runs made with the FORTRAN program, the technique by Karakas and Tariq failed under the following conditions:

(1) low perforation length
(2) low wellbore radius
(3) low k_v/k_h (highly stratified reservoir)

The technique fails because one or more of the dimensionless parameters (equations (9), (10) or (11)) do not fall within the range specified by Karakas and Tariq (see Table III and equation (12)). The specific reason for the dimensionless term ranges, whether limits of the model or the limit of their calculations, is not given in their paper.

However, when Karakas and Tariq's technique does fail, Brons and Marting's technique should be used to evaluate the skin due to perforations. As a reservoir becomes more stratified, vertical flow is reduced and the downhole conditions approach the model presented by Brons and Marting, several individual reservoirs each producing through one set of perforations. It is not suggested that Harris' method be used due to the difficulty of converting conventional perforation definitions to those presented by his technique. The conversion must be performed to determine the dimensionless terms (see equations (4), (5), and (6)).

Results from the FORTRAN program also indicate that for a homogeneous reservoirs, $k_v/k_h = 1$, and reasonable perforation parameters, $L_p > 3"$, $r_w = 2"$ to 4", the skin due to perforations will be less than or equal to 2. The significance of this observation is that if a situation arises where a quick estimation of the actual skin factor must be made, a value of 2 can be used for the perforation skin. The estimation of the actual skin will therefore be a worst case scenario value.

Eliminating the skin due to perforations would obviously result in increased production, flow into the wellbore is increased. However, the only way to significantly decrease the skin due to perforations is to increase the perforation length. Perforation length is analogous to fracture length: the longer the fracture, the more fluid that will flow into the wellbore.

Although Karakas and Tariq's technique appears to be the best method to determine the skin due to perforations, it would be nice to prove their technique with a physical laboratory method or an actual well. However, while reviewing the literature for this paper, no references could be found either attempting to prove or disprove the techniques by Brons and Marting and Harris, and these techniques have been in existence for over thirty years.

ACKNOWLEDGMENTS

I would like to thank Dr. L.F. Koederitz, Head and Professor of Petroleum Engineering at the University of Missouri-Rolla, for supporting me and providing insight throughout the development of this paper. I would also like to thank Dr. Larry Vonalt for reviewing the paper.

REFERENCES

1. Earlougher, Jr.. "Advances in Well Test Analysis", Monograph Vol. 5 of the Henry L. Doherty Series, pages 1-19, 1977.
2. Koederitz, L.F.. "Notes on Well Test Analysis," pages 25-45, 1991.
3. Brons, F. and V.E. Marting: "The Effect of Restricted Fluid Entry on Well Productivity," *Trans.*, AIME 222, pages 172-174, 1961.
4. Harris, M.H.: "The Effect of Perforating on Well Productivity," *Trans.*, AIME 237, pages 518-528, 1966.
5. Karakas, Metin and S.M. Tariq: "Semianalytical Productivity Models for Perforated Completions," *Trans.*, AIME, 291, Section II pages 73-82, 1991.