J. Univ. Kuwait (Sci.) **5,** 1978

A statistical correlation for predicting oil and gas flow rates through chokes

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ABSTRACT

Oil flow rate through chokes, assuming critical flow conditions, can be predicted. The present method defines, statistically, empirical equations for wellhead choke performance in terms of a physical parameter (γ) which is a function of gas–oil ratio and fluid properties. From a minimum number of production tests, a statistical mean value for the physical parameter (γ) can be found for a reservoir in a particular field. Using this mean value of (γ), an equation for oil flow rate through chokes can be developed for a reservoir to account for pressure–volume–temperature (PVT) characteristics of oil and gas. This method has been tested for actual oilfields using the equation presented by Nind (1964). There is a close agreement between the actual and calculated values of flow rate when this method is used.

INTRODUCTION

It is essential in oilfield operations to know the oil and gas production rate of flowing wells, but it is not economical to test every well in the same field. It is often necessary to be able to predict a well's flow rate of oil and gas from knowledge of only its flowing wellhead pressure, downstream pressure (line pressure) and choke (bean) size.

Many technical papers have been written on this subject with differing approaches but with the same initial assumptions, and many investigators have developed empirical formulas (Gilbert 1954; Nind 1964; Pottmann 1963). The purpose of this paper is to show how an equation can be developed statistically and be used to predict the oil flow rate of wells in a field for a specific reservoir from a minimum number of actual production tests. Utilizing this information, charts can be constructed for field use. The method corrects empirical equations for choke performance under critical flow conditions, to take into account a statistical mean value for pressure–volume–temperature characteristics of the oil and gas.

THEORY

It is standard practice in oilfield operations to select a choke for a flowing well in such a way that the fluctuations in downstream pressure (line pressure) do not affect the wellhead pressure and thus the well flow rate. To satisfy this condition, the flow of fluid through the choke must be at critical flow conditions. This implies that the speed of the fluid through the choke should be equal to that of sound. For this to occur under the range of conditions found in oilfield operations, it has been shown by Fortunati (1972) that sub-critical flow in a two-phase mixture can occur at ratios of upstream to downstream pressure as high as 3·5 to 4.

Based on this finding, and by making several simplifying assumptions with regard to PVT characteristics of oil and gas, several investigators (Gilbert 1954, Nind 1964) have found empirical equations that define a relationship among variables of oil flow rate, gas–oil ratio, wellhead pressure and choke (bean) size.

$$Q=f(P_f, S, R) \tag{1}$$

where Q = gross oil flow rate-stock tank barrel/day, P_f = wellhead pressure (Psia), R = gas–oil ratio–MSCF/barrel, S = choke size in 1/64ths of an inch.

Nind (1964) states that under the range of conditions found in oilfield operations, an equation for choke performance under critical flow conditions is

$$Q=P_f S^2/CR^{0.5} \tag{2}$$

where C is a constant that is about 600 in the system of units defined above. Gilbert (1954) correlated data obtained from some California oilfield operations and gave an equation for predicting oil and gas flow rate through wellhead chokes,

$$Q=P_f S^{1.89}/435\ R^{0.546}. \tag{3}$$

Eqns (2) and (3) are in the form of eqn (1), which do not account for fluid properties in their development. To better define a relationship for fluid flow through chokes, it can be stated that

$$Q=f(P_f, S, \gamma) \tag{4}$$

where (γ) is a physical parameter which is a function of gas–oil ratio and fluid properties. Writing a relationship for wellhead choke performance in the form of eqn (4) eliminates the gas–oil ratio variable which is not available in most cases.

Eqn (2) can be written in the form of eqn (4), and P_f can be in Psig, rather than Psia,

$$Q=\gamma\ P_f S^2 \tag{5}$$

where $\gamma=f(1/CR^{0.5}$, fluid properties).

Eqn (5) can be solved for the physical property (γ)

$$\gamma=Q/P_f S^2. \tag{6}$$

Assuming that the producing gas–oil ratios for all wells in a reservoir do not vary widely as in the case where a reservoir is above bubble point pressure, then an average value for (γ) can be found from a minimum number of production test data measured in the field using statistical analysis technique (Volk 1961).

By obtaining an average value for the physical parameter (γ), it actually means that an average value for gas–oil ratio and PVT characteristics of oil and gas has been found in terms of this parameter.

In the case where there is a great variation in the producing gas–oil ratio for all wells in a given reservoir, then eqn (4) can be written as

$$Q=f(P_f, S, R, \gamma) \tag{7}$$

where (γ) is only a function of the fluid properties. The procedure presented here can be used to find a statistical mean value for (γ).

DISCUSSION

Finding an average value for the physical property (γ) actually means obtaining an average value for gas–oil ratio and PVT characteristics of oil and gas for that specific reservoir in that particular field. Consequently, it might be suggested that an average value for the gas–oil ratio be obtained from a minimum number of production tests, and then the flow equation at critical flow conditions used to find the flow rate rather than obtaining the average value for the physical parameter (γ). However, it must be remembered that eqns (2) and (3) do not take into account the PVT characteristics of oil and gas. By presenting eqns (2) and (3) in the form of eqn (4), the significance of the values of the fluid properties is considered indirectly in the averaging method.

A. Application to oil-bearing formation—oilfield A.

Table 1 shows the field data obtained from production tests together with the calculated value of the physical parameter (γ) for a reservoir above bubble point pressure for each test using eqn (6). Using the statistical analysis method, the arithmetic mean value for (γ) for oilfield A was found to be $4{\cdot}5495 \times 10^{-3}$, and the corresponding weighted arithmetic mean equal to $4{\cdot}4939 \times 10^{-3}$. Since, by definition, the weighted mean gives the mean value with due allowance for 'frequency of occurrence' of the individual variates, it was considered to be the more acceptable value. Substituting this weighted

Table 1. Data from production tests and the calculated physical parameter for oilfield A

Well No.	Choke 1/64″	Flowing wellhead pressure—Psig	Oil flow rate STB/day	$\gamma \times 10^3$
3	28	580	2158	4·745
4	24	620	1526	4·273
6	32	506	2143	4·136
8	40	611	4808	4·918
8	64	470	7200	3·740
10	32	464	2052	4·319
10	64	255	4528	4·335
13	28	430	1499	4·446
13	64	195	3372	4·221
17	32	280	1040	3·627
17	16	510	584	4·475
19	48	340	4093	5·224
19	20	690	1134	4·108
20	48	320	3281	4·450
21	24	680	1637	4·179
22	48	390	4400	4·896
24	32	540	2693	4·869
25	48	240	2981	5·391

Table 2. Comparison between actual and calculated values for oil flow rate (Q) for oilfield A

Well No.	Actual (Q) STB/day	Calculated (Q) STB/day		
		Nind (1964)	Gilbert (1954)	Nind Corrected
3	2156	1604	1643	2044
4	1526	1260	1313	1648
6	2143	1829	1846	2328
8	4808	3444	3393	4393
8	7200	6794	6355	8650
10	2052	1677	1693	2135
10	4528	3686	3448	4694
13	1499	1259	1289	1515
13	3372	2818	2637	3589
17	1040	0958	0967	1288
17	0584	0461	0502	0586
19	4093	2765	2669	3520
19	1134	0975	1036	1240
20	3281	2602	2512	3313
21	1637	1697	1442	1760
22	4400	3171	3062	4038
24	2693	1951	1970	2485
25	2981	1951	1884	2485

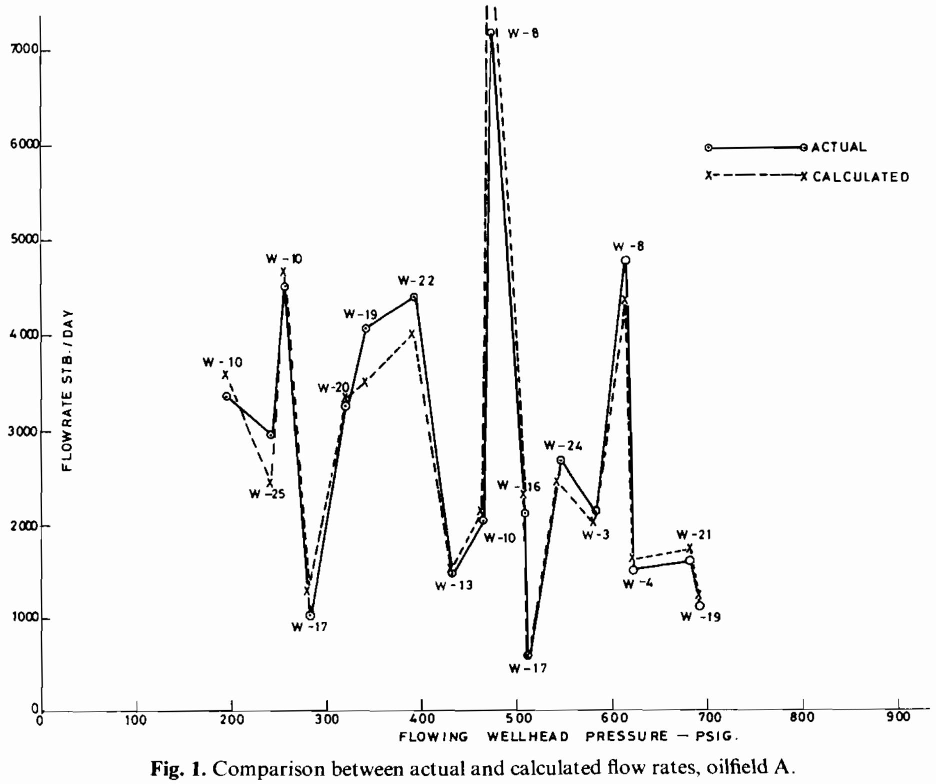

Fig. 1. Comparison between actual and calculated flow rates, oilfield A.

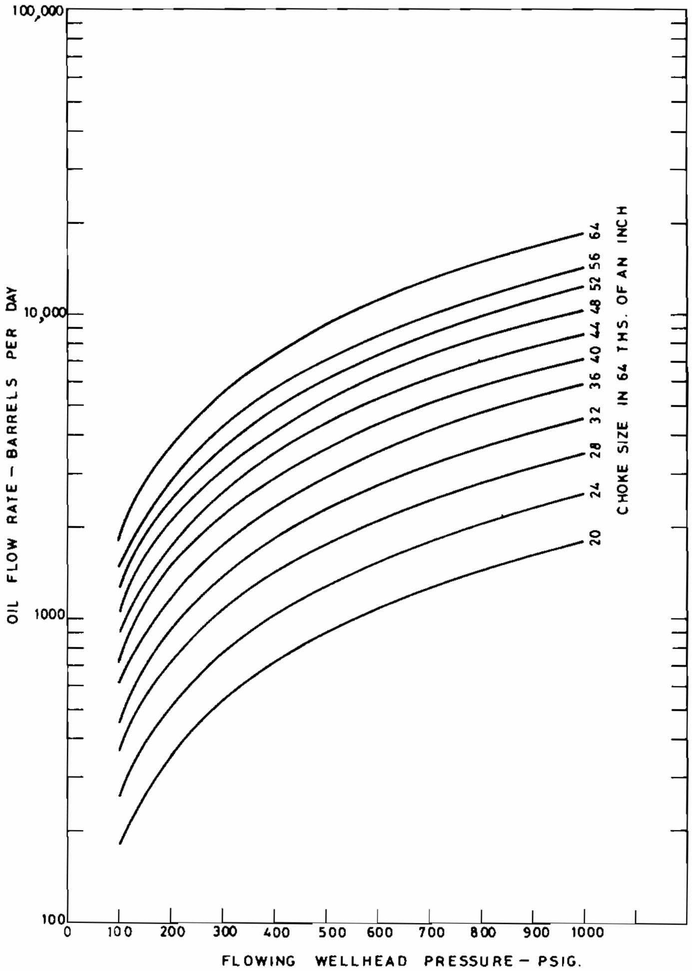

Fig. 2. Oil flow rate through chokes, oilfield A.

mean value of (γ) in eqn (5), the equation for flow rate of a well in oilfield A becomes

$$Q = 4{\cdot}4939 \times 10^{-3} P_f S^2 \tag{8}$$

The standard deviation was found to be $\pm 0{\cdot}53645$ and the arithmetic mean deviation was found to be 0·470588. As has been mentioned in the theory, the arithmetic mean deviation is less important than the standard deviation and this is the deviation to consider. For a normal distribution, the standard deviation (γ) indicates that 68·27% of all the points calculated for (γ) fall within $\pm 1\sigma$, 95·45% fall with $\pm 2\sigma$ and 99·73% fall within $\pm 3\sigma$. This means that 68·27% of all the points calculated for (γ) fall within $\pm 0{\cdot}53645$. Table 2 shows the comparison between the actual and the calculated values for oil flow rates through wellhead chokes. It can be noted that the present method (Nind 1964 corrected) gives far better results than the equations

Table 3. Data from production tests and the calculated physical parameter for oilfield B

Well No.	Choke 1/64″	Flowing wellhead pressure—Psig	Oil flow rate STB/day	$\gamma \times 10^3$
11	64	645	9054	3·426
16	48	470	4000	3·696
18	32	730	2649	3·543
23	32	800	3050	3·723

presented by Nind (1964) and Gilbert (1954), while Nind (1964) and Gilbert (1954) methods give almost identical results. These values were plotted on Fig. 1 for comparison. On the basis of eqn (8), Fig. 2 was constructed for predicting the flow rate for the oil-bearing formation in oilfield A.

B. Application to oil-bearing formation—oilfield B

The same procedure as outlined above was followed. Table 3 depicts the field data obtained from production tests, together with the calculated values of (γ). The arithmetic mean and the weighted arithmetic mean values for (γ) for oilfield B were both found

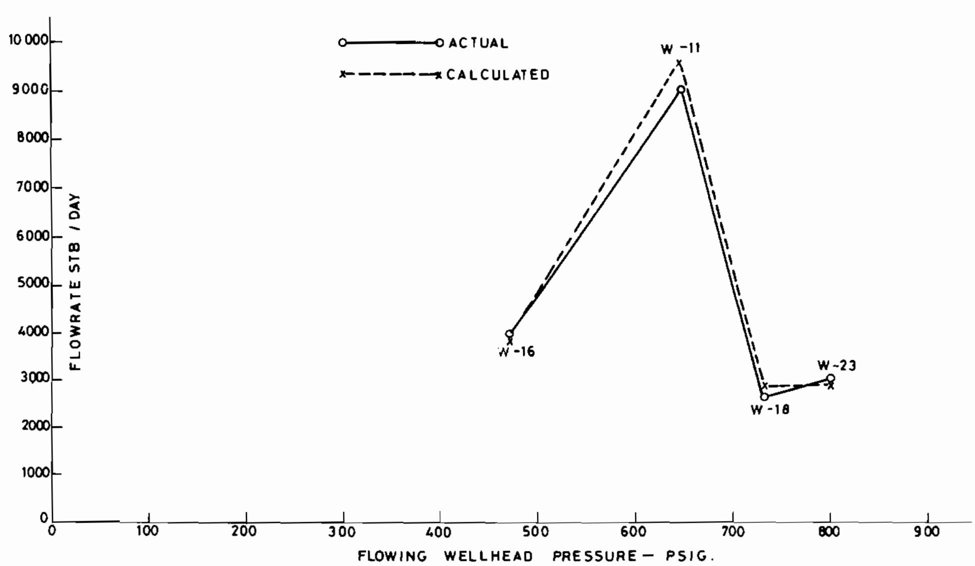

Fig. 3. Comparison between actual and calculated flow rates, oilfield B.

Table 4. Comparison between actual and calculated values for oil flow rate (Q) of oilfield B

Well No.	Actual (Q) STB/day	Calculated (Q) STB/day	% Deviation from actual
11	9054	9640	+4·72
16	4000	3951	−1·22
18	2649	2727	+2·94
23	3050	2989	−2·00

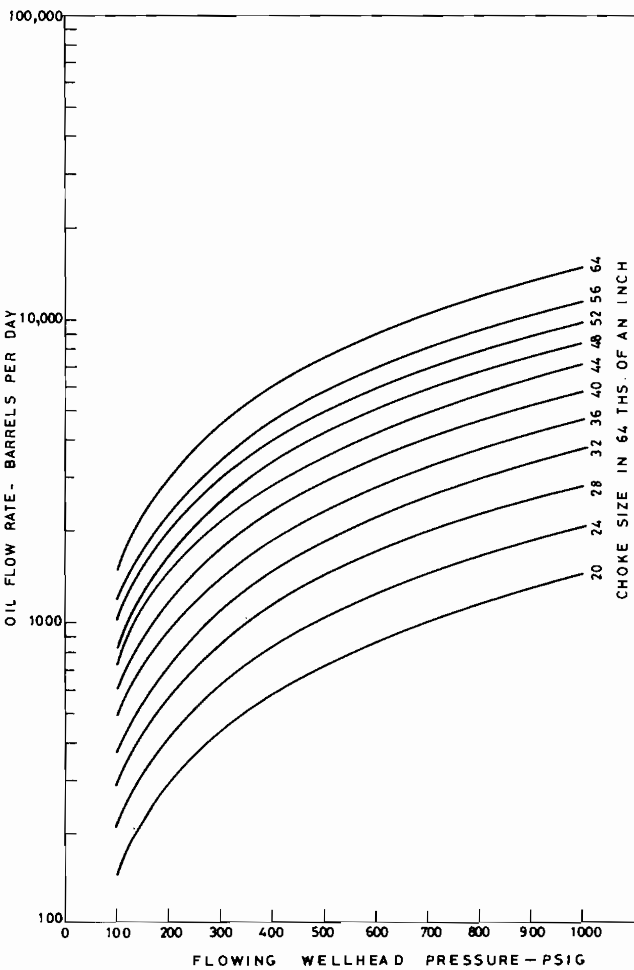

Fig. 4. Oil flow rate through chokes, oilfield B.

to be $3{\cdot}6495 \times 10^{-3}$. Substituting this value for (γ) in eqn (3), the equation to obtain the oil flow rate for a well in oilfield B becomes

$$Q = 3{\cdot}6495 \times 10^{-3}\, P_f S^2 \tag{9}$$

The standard and arithmetic mean deviations were found to be $\pm 0{\cdot}1118$. Consequently, 68·27% of all the points calculated for (γ) fall within $\pm 0{\cdot}1118$. Table 4 shows the percent deviations between the actual measured flow rates and the calculated flow rates from eqn (9). These values were plotted on Fig. 3, for comparison. On the basis of eqn (6), Fig. 4 was constructed for predicting the flow rate for oil bearing formation in oilfield B.

CONCLUSIONS

1. It is apparent that it is not necessary to run a production test on each and every well in the same reservoir for the same field to find flow rates.

2. Accurate data from production testing is required to find a reliable mean value for the physical parameter (γ).

3. It should be noted that the method does take into account indirectly PVT characteristics of the oil and gas.

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(Received 1 February 1978)

طريقة احصائية لتقدير معدلات سريان النفط والغاز خلال الصمامات الخانقة

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خلاصة

تم من خلال هذا البحث ايجاد معادلات تجريبية بالطرق الاحصائية لتقدير معدل سريان النفط والغاز خلال الصمامات الخانقة على فوهات آبار النفط .

وتعتمد هذه العلاقة على افتراض ان هذه المعدلات تقاس عند السريان الحرج حيث تعتمد على متغير فيزيائي وهذا المتغير يعتمد بالتالي على نسبة الغاز إلى الزيت والخواص الطبيعية لهمـــا .

ومن خلال اختبارات قليلة لآبار أحد الحقول يمكن ايجاد هذا المتغير الذي يستخدم بدوره لايجاد معدلات السريان . وقد تمت مقارنة هذه المعدلات المستنبطة من المعدلات التجريبية في هذا البحث بمعدلات الانتاج الواقعية وتم ايضا مقارنتها بمعادلة نند (Nind) المستعملة عالميا لقياس معدلات السريان ، وقد وجد ان الطريقة الحالية تتفوق على الأخيرة في حساب هذه المعدلات .