Prediction of Current Production Rates, Cumulative Production and Recoverable Reserves of Hydrocarbon Fields

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ABSTRACT- Modeling in the process of oil production has been used almost since the beginning of hydrocarbon field development, when there were ideas about the conditions of formation occurrence and oil flow to wells. An empirical model is proposed to calculate the current production rate of wells in the hydrocarbon field by year. Based on this model, an equation for calculating cumulative production was constructed. The proposed model is compared with known models and actual development history data. The resulting models of current production rates, cumulative production and recoverable reserves most accurately describe the actual results and have a high correlation parameter compared to other models..

Keywords; Current production rate, Cumulative production, Reservoir reserve, Empirical model, Correlation parameters.

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Introduction

For more than 50 years, domestic and foreign researchers have been dealing with the problem of creating models for calculating the total production rate of a field, the cumulative production and the recoverable reserves [1-3]. However, there is still no theoretical (physical) justification for these or other models. Basically, they are semi-empirical models based on statistical data, and then attempts are made to understand them theoretically. A systematization and analysis of more than 35 models of water - cut and flow rate drop curves were performed in many of the recent papers [4-6].

Figure 1 shows the curve of changes in current production over 50 years for Surakhani hydrocarbon field, given in the works [7-9] .

Fig. 1. Current production curve

Methodology

To describe such curves of current flow by year, we have proposed an empirical model of the form

$$q = a.t.e^{-bt} \quad (1)$$

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Here, a and b are empirical coefficients determined by the least squares (OLS) method [10-12].

To linearize this model, it is sufficient to divide both sides of (Eq.1) by t and logarithmize. Then use OLS for the equation

$$\ln\left(\frac{q}{t}\right) = \ln a - bt \quad (2)$$

The advantage of this model (Eq.1) is that for small values of t, the value of q $\approx$ at, and for t tending to large values, the exponent "works".

Furthermore, if we take the derivative for Eq.1 with respect to t and equate it to zero, we obtain

$$\frac{dq}{dt} = q\left(\frac{1}{t^*} - b\right) = 0 \quad (3)$$

It follows that at $t^* = 1/b$ the function 1 reaches its maximum:

$$q_{max} = \frac{0.368 a}{b} \quad (4)$$

By integrating expression 1 in the range from 0 to t, we obtain the cumulative production (Q) :

$$Q = \frac{a}{b^2}(1 - e^{-bt}) - \frac{a}{b}t \cdot e^{-bt} \quad (5)$$

Obviously, for

1. $t = 0$, then $Q = 0$, and
2. for $t \rightarrow \infty$, then $Q = a/b^2$.

These are the recoverable reserves.

Processing the above data presented in papers [7] and [13-16] gave the values $a = 51.2$ and $b = 0.129$ in the figure. Thus, our models of current production rates and cumulative production are as follows:

$$q = 51.2 t e^{-0.129t} \quad (6)$$

$$Q = 3076.7(1 - e^{-0.129t}) - 396.9 t e^{-0.129t} \quad (7)$$

Table 1
Models of cumulative and annual oil production

Author	Model type	
	accumulative production	annual production
Sipachev-Posevich	$Q = a + bt$	$q = \frac{a}{(a+bt)^2}$
Pirverdyan [4]	$Q = a - b \cdot \sqrt{t}$	$q = \frac{b}{2} t^{-3/2}$
Kambarov [7]	$Q = a - bt^{-1}$	$q = bt^2$
Sazonov	$Q = a + b \ln t$	$q = b/t$
Constant oil flow rate method	$Q = a + bt$	$q = \text{const}$
Aips	$Q = 1/b \ln(1 + b e^a t)$	—

Here Q - cumulative oil production, q - current annual production, a and b - empirical coefficients.

Consequently, recoverable reserves are predicted to be within $Q_i = 3076.7$ thousand tons, and maximum production will be at $t^* = 1/b = 7.5$ years. In this case, $q_{max} = 145.9$ thousand tons. The initial recoverable reserves determined by model (6) are $Q_i = 309.12$ thousand tons. The difference in the values of the reserves according to the model (7) and the work [7] is only 0.08.

In order to compare model (6) with the first four models from Table 1, we determined the coefficients of models a and b, we gave estimates of the correlation coefficients between the observed production rates and those calculated by the models. For clarity, Table 2 shows some calculated production rates and development history data.

Table 2
Comparison of current production rates of the field

Years of development	Models					Initial data
	1	2	3	4	(3)	
2	267	1366,2	754,8	543,05	19,1	90
5	164,4	345,6	120,8	217,2	134,3	199
7	125,7	262,9	61,6	155,2	145,3	136
10	88	122,2	30,2	108,6	140,9	88
20	95	43,2	7,5	57,2	77,6	68
25	27	30,9	4,8	43,2	50,9	50
30	25	23,5	3,4	36,2	32,0	25
40	13,7	15,3	2	27,1	11,7	13
45	11	12,8	1,5	24,1	6,9	5,9
50	4,6	10,93	1,2	21,7	4,1	4,6
Correlation coefficient	0,714	0,387	0,277	0,508	0,884	—
Standard deviation	73,2	301,6	167,3	122,5	54,3	—

It can be seen that our proposed model (6) best describes the current production rates for the field. We calculated the cumulative production using model (7) for the lifetime t_1 of 45 to 50 years. Calculated production Q_c and the actual production Q_a are given in the table. 3.

Table 3
Comparison of cumulative production rates

Calculated production	Number of years					
	45	46	47	48	49	50
Development history	2974,4	2974,4	2974,4	2974,4	2974,4	2974,4
By model (4)	2967,9	2967,9	2967,9	2967,9	2967,9	2967,9

Correlation coefficient - 0.99; Standard deviation - 24.22.

We could not evaluate the models of the paper [4], which are based on probabilistic concepts, because the extension of the initial assumptions to the whole field is associated with the transformation of the distribution laws of the current well rates.

Conclusion

In conclusion, we find that our models of current production rates (6), cumulative production (7), and recoverable reserves ($Q = a / b^2$) describe the actual results quite accurately and exhibit high correlation compared to other models;

1. Where the correlation coefficient and standard deviation for model (6) are 0.884 and 54.3, which is the best compared with the output of the other models.

2. The correlation coefficient and standard deviation for model (7) are 0.99 and 24.2 which are also the best when compared with the other models.

This makes that the proposed models can be used with more confidence in the development of hydrocarbon fields.

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