Practice lesson N5

Lesson topic: ENHANCED GAS RECOVERY FROM GAS FIELD AT GAS DRIVE

Current gas recovery factor of the field (deposits, reservoir) *β(t)* - characterizes the degree of gas production from the field, that is the ratio of cumulative gas production Q_{cum} to initial reserves Q_{init}.

$$\beta(t) = \frac{Q_{cum}(t)}{Q_{init}} , \qquad (1)$$

β (t)- current gas recovery factor;
Q_{cum}(t)- cumulative gas production;
Q_{init}- initial gas reserves;

$$\beta(t) = \frac{Q_{init} - Q_{resid}}{Q_{init}} = 1 - \frac{Q_{resid}}{Q_{init}} \qquad (2)$$

Q_{res}- residual gas reserves;

$$\beta(t) == 1 - \frac{P(t) z_{init}}{P_{init} z(P(T))} \qquad (3)$$

P(t)- current average reservoir pressures, MPa;

Task N1. Determine current gas recovery factor of gas deposit on gas drive for the data: gas productive area - $8 \cdot 10^7$ m^2, efficient gas-saturated reservoir thickness - 22 m, initial gas saturation - 0.77, open porosity coefficient - 0.15, initial reservoir pressure - 42 MPa, reservoir temperature - 75 ° C, gas gravity - 0.64, gas cumulative production from the field - $60 \cdot 10^9$ m^3.

Data:
$F = 8 \cdot 10^7 m^2$
$m_o = 0.15$
h=22 m
$\alpha_{init} = 0.77$
$P_{init.} = 42$ MPa
$T_{res.} = 75 + 273 = 348K$
$\bar{\rho}_g = 0.64$
$Q_{cum}(t) = 3 \cdot 10^{10} m^3$

$$Q_{init} = \frac{\alpha_{init} \cdot \Omega_{init} \cdot P_{init} \cdot T_{st}}{Z_{init} \cdot P_{at} \cdot T_{res}}$$

$p_{cr} = 4{,}892 - 0{,}4048 \cdot \bar{\rho}_g = 4{,}892 - 0{,}4048 \cdot 0{,}64 = 4{,}63$ MPa,

$T_{cr} = 94{,}717 + 170{,}8 \cdot \bar{\rho}_g = 94{,}717 + 170{,}8 \cdot 0{,}64 = 204$ K.

$$p_{red} = \frac{p_{init}}{p_{cr}} = \frac{42}{4{,}63} = 9{,}07,$$

$$T_{red} = \frac{T_{init}}{T_{cr}} = \frac{348}{204} = 1{,}71,$$

$$z_{init} = (0{,}4\lg(T_{red}) + 0{,}73)^{p_{red}} + 0{,}1 \cdot p_{red} =$$
$$= (0{,}4\lg(1{,}71) + 0{,}73)^{9{,}07} + 0{,}1 \cdot 9{,}07 = 1{,}08$$

$$Q_{init.} = \frac{0{,}77 \cdot 8 \cdot 10^7 \cdot 22 \cdot 0.15 \cdot 42 \cdot 293}{1{,}08 \cdot 0{,}1013 \cdot 348} = 6{,}57 \cdot 10^{10}\,\mathrm{m}^3$$

$$\beta(t) = \frac{Q_{cum}(t)}{Q_{init}} = \frac{3 \cdot 10^{10}}{6{,}57 \cdot 10^{10}} = 0{,}46.$$

Task N2.

Determine current gas recovery factor for the gas field, which is developing in the gas drive for the following data: initial reservoir pressure is 37 MPa, the current reservoir pressure - 14MPa, inition gas compressibility factor is 0,97, gas compressibility factor of current reservoir pressure is 0,9.

Data:

P_{init}=37MPa

P_{cur}=14MPa

Z_{init}=0,97

Z(P(t))=0,9

$$\beta(t) == 1 - \frac{P(t) z_{init}}{P_{init} z(P(T))}$$

$$\beta(t) == 1 - \frac{14 \cdot 0{,}97}{37 \cdot 0{,}9} = 0{,}592.$$

Task N3. Determine the initial gas reserves in the field according to the data of its development and current gas recovery factor, if cumulative gas production $40 \cdot 10^9$ m^3, and the dependence of the reduced reservoir pressure on cumulative gas production is described by the equation: $32-0,68 \cdot Q_{cum}$; P, MPa; Q_{cum}, 10^9 m^3.

Data:

$$\frac{p_{res}}{z(p_{res})} = 32 - 0,68 Q_{cum}$$

$Q_{cum} = 40 \cdot 10^9$ m^3

$$\frac{p_{res}}{z(p_{res})} = 0, \qquad Q_{init} = \frac{32}{0,68} = 47,01 \cdot 10^9 \text{ m}^3$$

$$\beta(t) = \frac{Q_{cum}(t)}{Q_{init}} \qquad \beta(t) = \frac{40 \cdot 10^9}{47,01 \cdot 10^9} = 0,021.$$

Final gas recovery factor of the field:

$$\beta_{final} = \frac{Q_{cum}}{Q_{init}}$$

$$\beta_{final} == 1 - \frac{P_{final} z_{init}}{P_{init} z(P_{final})} \quad (4)$$

For the approximate estimation of the final reservoir pressure, the following dependencies can be used at the stage of desighn of gas field development:

P_{final}= 0,345+ 0,00113·H, (5)

where H - average depth of deposit, m;

P_{final}=0,05· P_{init} + 0,8274, (6)

P_{final} = 0,12· P_{init} + 0,5309, (7)

P_{final}=0,1· P_{init}. (8)

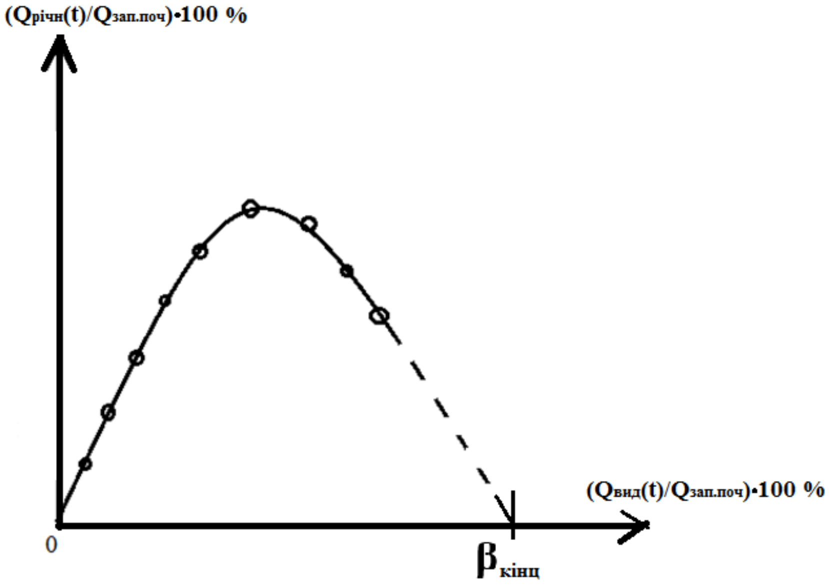
Task N4. Determine final gas recovery factor of gas deposit on gas drive for the data: average depth of deposit 2162 m, initial reservoir pressure 22,5 MPa, reservoir temperature 75 ^{0}C, and gas gravity 0.65.

The coefficient of the final gas output, found by using dependencies (5) - (8), characterizes the field gas output at the moment of gas supply interruption to the main gas pipeline.

Final reservoir pressure can be calculated based on the gas dynamic, technical and economical analysis, or using approximate analytical dependences. That is why it is necessary to determine ultimate gas recovery factor using field data of field development. There are two methods of ultimate gas recovery factor prediction:

average production curve (production decline curve and

- ***curve of gas annual production changes in time (method of straight line).***



The method of straight line is based on the dependence of the change in time of the annual gas production in the period of decline whih is described by exponential function in such form

$$Q_g(t) = Q_g(t_o)e^{-b(t-t_o)},$$

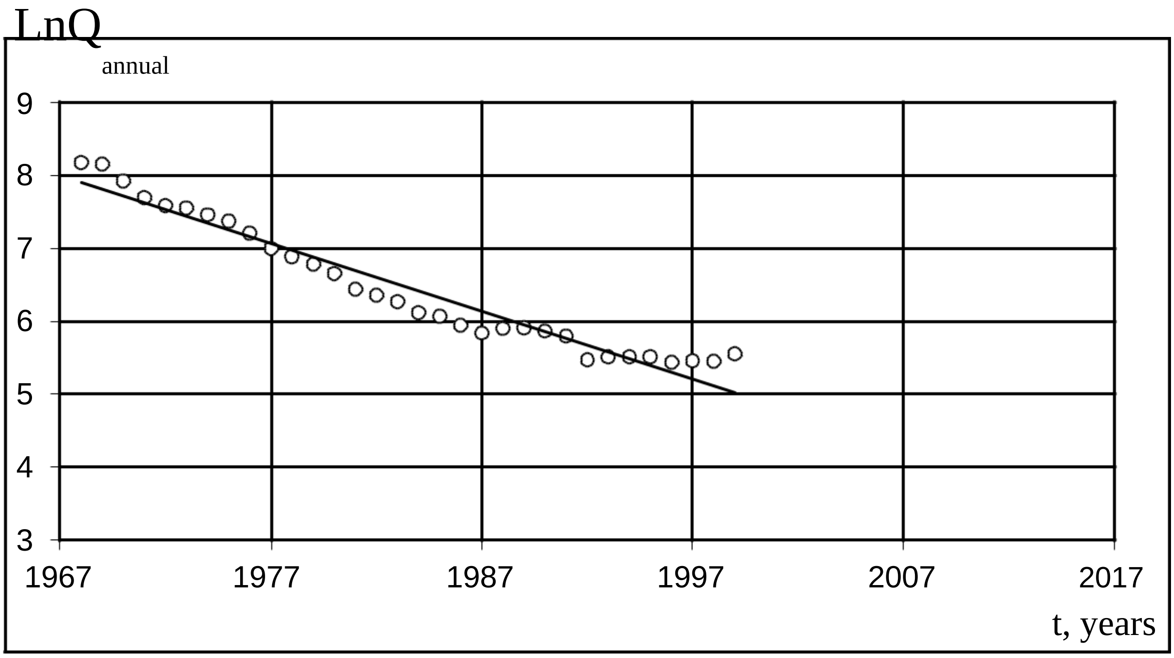
where – $Q_g(t)$, $Q_g(t_o)$- gas annual production at time t *and* t_o; b – decline coefficient (has specific values for the conditions of certain gas field). For t_o any moment of time can be chosen since the beginning of field development, which corresponds to the period of decreasing gas production.

The plot Ln (Qannual)=f(t) has linear character in semi-log coordinates . Extrapolating this line to economically profitable annual gas production (0.1% of initial reserves), predicted value of gas annual production for next year can be determined $Q_г(t_j)$. Gas cumulative production can be calculated as a sum of gas annual production until economical limit plus cumulative production for previous period of time.

$$Q_{cum}(t) = Q_{cum}(t_o) + \sum^{t} Q_g(t_j),$$

$j = t_o$

де $Q(t_o)$ – the amount of gas produced at time t_o.


LnQ
annual
9
8
7
6
5
4
3
1967
1977
1987
1997
2007
2017
t, years

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Task N5. Determine current gas recovery factor and final gas recovery factor deposit on gas drive the method of average production for the data:

Years	$Q_{years}(t)$, 10^6 m^3/years	$Q_{cum\ prod}(t)$, 10^6 m^3
1	1	1
2	2	3
3	3	6
4	4	10
5	5	15
6	6	21
7	7	28
8	8	36
9	9	45
10	10	55
11	9	64
12	8	72
13	7	79
14	6	85
15	5	90
16	4	94
17	3	97

Initial gas reserves in gas field - $140 \cdot 10^6 m^3$.

$Q(t)/Q_{init.}$ 10^{-3}	$Q_{cum.prod.}(t)/Q_{init.}$ 10^{-3}	Years
7	7	1
14	20	2
20	43	3
29	71	4
36	107	5
43	150	6
50	200	7
57	257	8
64	321	9
71	392	10
64	457	11
57	514	12
50	564	13
43	607	14
36	643	15
29	671	16
20	693	17

Draw a graph 1: $B_{cur.}$= 0,71; $B_{final.}$=0,79.

Task N6. Determine final gas recovery factor and gas cumulative production if the relationship between annual and total gas production has the form

$\frac{Q_{year}}{Q_{init}} = 3{,}85 - 0{,}04\frac{Q_{cum}}{Q_{init}}$, % Initial gas reserves equal $40 \cdot 10^6$ m^3.

Data:

$$\frac{Q_{year}}{Q_{init}} = 3{,}85 - 0{,}04\frac{Q_{cum}}{Q_{init}}$$

$Q_{init} = 40 \cdot 10^6$ m^3

$$\frac{Q_{year}}{Q_{init}} = 0, \qquad \frac{Q_{cum}}{Q_{init}} = \frac{3{,}85}{0{,}04} = 96\ \%$$

$$\beta_{final} = \frac{Q_{cum}}{Q_{init}} = 96\%$$

$Q_{cum} = Q_{init} \cdot \beta_{final} = 40 \cdot 10^6 \cdot 0{,}96 = 38{,}4 \cdot 10^6$ m^3

Task N7. Determine final gas recovery factor deposit on gas drive the method of straight line for the data:

Years	$Q_{years}(t)$, 10^6 m^3/years	$Q_{cum\ prod}(t)$, 10^6 m^3	
1	1	1	
2	2	3	
3	3	6	
4	4	10	
5	5	15	
6	6	21	
7	7	28	
8	8	36	
9	9	45	
10	10	55	
11	9	64	
12	8	72	
13	7	79	
14	6	85	
15	5	90	
16	4	94	
17	3	97	

Initial gas reserves in gas field - $140 \cdot 10^6 m^3$.

lnQ(t)	Years
13.8	1
14.5	2
14.9	3
15.2	4
15.4	5
15.6	6
15.8	7
15.9	8
16	9
16.1	10
16	11
15.9	12
15.8	13
15.6	14
15.4	15
15.2	16
14.9	17

$\ln Q_{\text{profitable annual gas production}} = \ln(0.1/100 \cdot Q_{init.}) = \ln(0.1/100 \cdot 140 \cdot 10^6) = 11.8$
Draw a graph 2.

$Q_{prod.}(17) = 97$ млн.м^3

$Ln(Q(18)) = 14.7$ $Q(18) = e^{14.7} = 2.3 * 10^6$ m^3/years
$Q(19) = e^{14.5} = 1.9 * 10^6$m^3/years
$(20) = e^{14.4} = 1.8 * 10^6$m^3/years
$Q(21) = e^{14.2} = 1.5 * 10^6$m^3/years
$Q(22) = e^{14} = 1.2 * 10^6$m^3/years
$Q(23) = e^{13.8} = 0.9 * 10^6$m^3/years
$Q(24) = e^{13.6} = 0.8 * 10^6$m^3/years
$Q(25) = e^{13.5} = 0.7 * 10^6$m^3/years
$Q(26) = e^{13.3} = 0.6 * 10^6$m^3/years
$Q(27) = e^{13.1} = 0.5 * 10^6$m^3/years
$Q(28) = e^{12.9} = 0.4 * 10^6$m^3/years
$Q(29) = e^{12.7} = 0.3 * 10^6$m^3/years
$Q(30) = e^{12.5} = 0.26 * 10^6$m^3/years
$Q(31) = e^{12.4} = 0.24 * 10^6$m^3/years
$Q(32) = e^{12.2} = 0.2 * 10^6$m^3/years
$Q(33) = e^{12} = 0.16 * 10^6$m^3/years
$Q(34) = e^{11.8} = 0.13 * 10^6$m^3/years

$B_{final.} = (Q(17) + Q(18) + \ldots + Q(34)) / Q_{init.} =$
$= (97+2.3+1.9+1.8+1.5+1.2+0.9+0.8+0.7+0.6+0.5+0.4+0.3+0.26+0.24+0.2+0.16+$
$+0.13)/140 = 112.83/140 = 0.81$