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Research on Oil Recovery by Steam Injection into the Reservoir

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Abstract

The enhanced oil recovery methods based on hot fluid injection into the reservoir have been applied during the last 50 years especially in shallow reservoirs containing heavy and very viscous oils. Both cyclic steam injection and steam-flood proved to be technically and economically efficient when they were implemented in reservoirs having appropriate characteristics for thermal oil recovery. This work deals with the presentation of an algorithm for estimating the performance of a steam-flood process in an oil reservoir, illustrated by a case study.

Key words: *cyclic steam injection, thermal productivity stimulation, steam-flood, thermal flux*

General Aspects

Experimental research showed that all oils having, in the conditions specific to shallow reservoirs, dynamic viscosities ranging between 10 mPa·s and 1,000,000 mPa·s present, at the temperature of 93 °C, viscosities less than 10 mPa·s. This fact allows, by increasing the reservoir temperature until the mentioned value, the mobilization and recovery of important amounts of oil.

Oil recovery by cyclic steam injection, also known as “huff and puff”, is basically a well productivity stimulation process in a reservoir containing viscous oil and having appreciable amounts of various energy forms. This process involves the successive use of the same well for both injecting a specified amount of steam and extracting the oil after the steam gave up the latent condensation heat to the oil bearing rock, thus increasing oil fluidity.

Cyclic steam injection does not impose the previous existence of a communication between the wells in the pattern, but, by continuing the mentioned procedure, such a communication can be reached, thus creating the conditions for passing to an oil recovery process by continuous steam injection.

The huff and puff process is a cyclic procedure, each cycle consisting in three stages as follows: a) steam injection, at a relatively high flow rate, for 2 to 4 weeks; b) steam condensation, by keeping the well closed during several days, with the view to condensing the whole amount of steam injected in the producing layer; c) production, which begins by putting the well into production and ends by passing to the next cycle, when the production flow rate decreased until a specified value.

The most important applications of the cyclic steam injection have been performed in the oil fields Cat Canyon, Coalinga, Huntington Beach, Kern River, Midway Sunset and Yorba Linda from California, as well as in the reservoirs Bachaquera, Lagunillos and Tia Juana from the Bolivar Coast in Venezuela [3]. Moreover, the huff and puff injection and the continuous steam injection (also known as steam-flood) have large-scale applications in oil fields from eastern and western China [4].

Steam-flood is frequently applied after the cyclic steam injection, when the region near the steam-stimulated well was depleted and the reservoir pressure substantially decreased.

Successful steam-flood tests were also realized in the oil fields Schoonebeck from Holland, Georgdorf from Germany and Lacq Supérior from France [5, 2].

It was established that the main operational parameters determining the performance of a steam-flood process are: the flow rate and the amount of steam injected, steam properties (pressure and quality), as well as the geometry of the injection and production well pattern.

The amount of heat dissipated into the rocks that constitute the top and the bottom of the oil bearing layer depends on reservoir thickness and steam tendency to invade a decreasing fraction of layer's thickness when this last increases. The research performed on a numerical simulator, based on the conditions existing into the Kern River reservoir from California, indicated that the optimum injected steam specific flow rate is almost independent of layer's thickness, at least when this thickness ranges between 9 and 27 m [5].

Procedure for Estimating the Performance of a Steam-Flood Process in an Oil Reservoir

The analytical methods for calculating the volume of the steam invaded region are based on taking into consideration the heat losses from the steam-containing zone to the layers bounding downwards and upwards the reservoir. For this purpose, the heat balance equation and the fluid (water, oil, and steam) flow equations were decoupled. Marx and Langenheim [6] performed this decoupling by completely neglecting fluid movement, while admitting that the injected thermal energy is retained by the formation in the steam-invaded region (at constant temperature) and yielded to the rocks that bound upwards and downwards the reservoir, with no heat transfer through the steam front.

Taking into account that the Marx–Langenheim procedure continues to be applied, either as a starting basis for certain algorithms as the Boberg–Lantz method, or for specified conditions afferent to relatively thick oil layers, low pressures and high injection rates, we will center our procedure upon this method.

Denoting by C_{cr}, C_{cp} and C_{ds} the amounts of heat injected into the reservoir, retained into the producing layer and dissipated into the strata bounding upwards and downwards the reservoir respectively, and neglecting the heat transfer through the steam front in radial plane movement, the following thermal balance equation can be written

$$C_{cr} = C_{cp} + C_{ds} \,, \tag{1}$$

where

$$C_{cr} = \int_0^t q_r \,\mathrm{d}t \,, \tag{2}$$

$$C_{cp} = C_r\, h(T_s - T_r)\, A(t) \,, \tag{3}$$

$$C_r = m(c_o\, \rho_o\, s_o + c_w\, \rho_w\, s_w) + (1 - m) c_r\, \rho_r \,, \tag{4}$$

$$Q_{cd} = 2\int_0^t \frac{\lambda_s \, \Delta T}{\sqrt{\pi \, a_s (t-\tau)}} \frac{\mathrm{d}A}{\mathrm{d}\tau} \mathrm{d}\tau \ , \tag{5}$$

$$q_r = q_g - (q_{ld} + q_d) \ , \tag{6}$$

$$q_{ld} = q_{sd} \, l \ , \tag{7}$$

$$q_d = \frac{2\pi \lambda_s \, r_{it} \, U}{\lambda_s + r_{it} \, U \, f(\bar{t})} \left[(T_s - T_0) H - \frac{g_t \, H^2}{2} \right] . \tag{8}$$

In these relationships, the following notations were used: q_r – heat flux injected into the reservoir; t, τ – current injection time; h – producing layer thickness; T_s — steam-invaded region temperature; T_r – unaffected region temperature; $A(t)$ – steam-invaded region area; m – rock porosity, c_o, c_w, c_r – oil, water, and rock specific mass heat values respectively; ρ_o, ρ_w, ρ_r – oil, water and rock densities; s_o, s_w – oil and water saturations; λ_s, a_s – thermal conductivity and thermal diffusivity of the strata adjacent to the reservoir; H – average depth of the perforated interval; r_{it} – tubing inner radius; U – global coefficient of the heat transfer from the steam flowing down through the tubing to the outer wall of the casing; g_t – geothermal gradient,

$$f(\bar{t}) = \frac{1}{2} \ln \frac{4\bar{t}}{\gamma} \ , \tag{9}$$

for $\bar{t} \geq 2.5$, where

$$\bar{t} = \frac{a_s t}{r_{ec}^2} \ , \tag{10}$$

$\gamma = 1.781$ and r_{ec} is the outer radius of the casing in the perforated interval.

By replacing expressions (2)…(5) into equation (1) and deriving, a differential equation is obtained, whose solution has the form

$$A(t) = \frac{q_r \, C_r \, h \, a_s}{4\lambda_s^2 \, \Delta T} \left[\mathrm{e}^{u^2} \mathrm{erfc}(u) + \frac{2u}{\sqrt{\pi}} - 1 \right] , \tag{11}$$

where

$$\mathrm{erfc}(u) = 1 - \mathrm{erf}(u) \ , \tag{12}$$

$$\mathrm{erf}(u) = \frac{2u}{\sqrt{\pi}} \int_0^u \mathrm{e}^{-y^2} \, \mathrm{d}y \ , \tag{13}$$

$$u = \frac{2\lambda_s}{C_r \, h} \sqrt{\frac{t}{a_s}} \ , \tag{14}$$

The cumulative oil production corresponding to the injection time t has the expression

$$\Delta N_p = m \, h (s_{oi} - s_{or}) \frac{A}{b_o} \ , \tag{15}$$

or

$$\Delta N_p = V_o \, A \ , \tag{16}$$

where

$$V_o = m \, h (s_{oi} - s_{or}) \frac{1}{b_o} \ , \tag{17}$$

and b_o is the oil volume factor.

Based on the relationships (11) and (16), the oil flow rate yields as

$$Q_o = \frac{\mathrm{d}\Delta N_p}{\mathrm{d}t} = V_o \frac{\mathrm{d}A}{\mathrm{d}t} = \frac{q_r V_o}{C_r\, h\, \Delta T} \mathrm{e}^{u^2} \mathrm{erfc}(u)\,. \tag{18}$$

Table 1. Values of e^{u^2} erfc u function and its derivative for values of the argument ranging between 0 and 10

u	e^{u^2} erfc u	$F(u)$	u	e^{u^2} erfc u	$F(u)$	u	e^{u^2} erfc u	$F(u)$
0.00	1.00000	0.00000	0.90	0.45653	0.47207	3.50	0.15529	3.10462
0.02	1.977.83	0.00039	0.92	0.45047	0.48858	3.60	0.15127	3.21343
0.04	1.95642	0.00155	0.94	0.44455	0.50523	3.70	0.14743	3.32244
0.06	1.93574	0.00344	0.96	0.43876	0.52201	3.80	0.14379	3.43163
0.08	1.91576	0.00603	0.98	0.43311	0.53892	3.90	0.14031	3.54099
0.10	0.89646	0.00929	1.00	0.42758	0.55596	4.00	0.13700	3.65052
0.12	0.87779	0.01320	1.05	0.41430	0.59910	4.10	0.13383	3.76019
0.14	0.85974	0.01771	1.10	0.40173	0.64295	4.20	0.13081	3.87000
0.16	0.84228	0.02282	1.15	0.38983	0.68746	4.30	0.12791	3.97994
0.18	0.82538	0.02849	1.20	0.37854	0.73259	4.40	0.12514	4.09001
0.20	0.80902	0.03470	1.25	0.36782	0.77830	4.50	0.12248	4.20019
0.22	0.79318	0.04142	1.30	0.35764	0.82454	4.60	0.11994	4.31048
0.24	0.77784	0.04865	1.35	0.34796	0.87127	4.70	0.11749	4.42087
0.26	0.76297	0.05635	1.40	0.33874	0.91847	4.80	0.11514	4.53136
0.28	0.74857	0.06451	1.45	0.32996	0.96611	4.90	0.11288	4.64194
0.30	0.73460	0.07311	1.50	0.32159	1.01415	5.00	0.11070	4.75260
0.32	0.72106	0.08214	1.55	0.31359	1.06258	5.20	0.10659	4.97417
0.34	0.70792	0.09157	1.60	0.30595	1.11136	5.40	0.10277	5.19602
0.36	0.69517	0.10139	1.65	0.29865	1.16048	5.60	0.09921	5.41814
0.38	0.68280	0.11158	1.70	0.29166	1.20991	5.80	0.09589	5.64059
0.40	0.67079	0.12214	1.75	0.28497	1.25964	6.00	0.09278	5.86305
0.42	0.65912	0.13304	1.80	0.27856	1.30964	6.20	0.08986	6.08581
0.44	0.64779	0.14428	1.85	0.27241	1.35991	6.40	0.08712	6.30874
0.46	0.63679	0.15584	1.90	0.26651	1.41043	6.60	0.08453	6.53184
0.48	0.62609	0.16771	1.95	0.26084	1.46118	6.80	0.08210	6.75508
0.50	0.61569	0.17988	2.00	0.25540	1.51215	7.00	0.07980	6.97845
0.52	0.60588	0.19234	2.05	0.25016	1.56334	7.20	0.07762	7.20195
0.54	0.59574	0.20507	2.10	0.24512	1.61472	7.40	0.07556	7.42557
0.56	0.58618	0.21807	2.15	0.24027	1.66628	7.60	0.07361	7.64929
0.58	0.57687	0.23133	2.20	0.23559	1.71803	7.80	0.07175	7.87311
0.60	0.56780	0.24483	2.25	0.23109	1.76994	8.00	0.06999	8.09702
0.62	0.55898	0.25858	2.30	0.22674	1.82201	8.20	0.06830	8.32101
0.64	0.55039	0.27256	2.35	0.22255	1.87424	8.40	0.06670	8.54508
0.66	0.54203	0.28676	2.40	0.21850	1.92661	8.60	0.06517	8.76923
0.68	0.53387	0.30117	2.45	0.21459	1.97912	8.80	0.06371	8.99344
0.70	0.52593	0.31580	2.50	0.21081	2.03175	9.00	0.06231	9.21772
0.72	0.51819	0.33062	2.60	0.20361	2.13740	9.20	0.06097	9.44206
0.74	0.51064	0.34564	2.70	0.19687	2.24350	9.40	0.05969	9.66645
0.76	0.50328	0.36085	2.80	0.19055	2.35001	9.60	0.05846	9.89090
0.78	0.49610	0.37624	2.90	0.18460	2.45690	9.80	0.05727	10.11539
0.80	0.48910	0.39180	3.00	0.17900	2.56414	10.00	0.05614	10.33993
0.82	0.48227	13.40754	3.10	0.17372	2.67169			
0.84	0.47560	0.42344	3.20	0.16873	2.77954			
0.86	0.46909	0.43950	3.30	0.16401	2.88766			
0.88	0.46274	0.45571	5.40	0.15954	2.99602			

If we either admit that the investments associated to this process are liquidated or include the share of liquidation together with the share concerning the other expenses necessary to carry on the process into the cost C_s per unit of thermal energy injected, the following value balance equation can be used as a criterion for defining the economically limited duration of the steam injection process

$$q_r\, C_s = Q_o\, v_o\ , \tag{19}$$

where v_o is the produced oil specific value (\$/m^3). By introducing expression (18) into equation (19) we get the value

$$e^{u_l^2}\,\mathrm{erfc}(u_l) = \frac{C_r\,C_s\,h\,\Delta T}{v_o\,V_o}\ , \qquad (20)$$

to which, in *table 1*, a specific argument u_l corresponds, that allows the calculation of the economically limited duration of the process, according to relationship (14) as follows

$$t_l = \left(\frac{u_l\,C_r\,h}{2\lambda_s}\right)^2 a_s\ . \qquad (21)$$

On the other hand, by putting into relationship (11) $u = u_l$ the economically limited area A_l is obtained, which, replaced into equation (15), yields to the final oil cumulative production ΔN_{pf}, whom corresponds the increase of the recovery factor

$$f_r = \frac{\Delta N_{pf}}{N}\ , \qquad (22)$$

where N is the oil resource.

In case of the cyclic steam injection, for anticipating the effect of the well stimulation process, we can use the estimative maximum value of the ratio between the productivity indexes I_{ps} of the stimulated well and I_{pn} of the non-stimulated well, defined as

$$R_{sn} = \frac{I_{ps}}{I_{pn}} = \frac{\ln\dfrac{r_c}{r_w}}{\dfrac{\mu_{os}}{\mu_{or}}\ln\dfrac{r_s}{r_w} + \ln\dfrac{r_c}{r_s}}\ , \qquad (23)$$

where r_w, r_c are the well and drainage zone radiuses respectively, μ_{os}, μ_{or} – oil viscosities in the zone of radius $r_w \le r \le r_s$ heated by steam, and in the zone of radius $r_s < r \le r_c$ unaffected, with

$$r_s = \sqrt{A(t_i)/\pi}\ , \qquad (24)$$

for $A(t_i)$ given by relationship (11).

Case Study

We intend to study the producing behavior of an oil reservoir in which it was proposed to inject, through a single well, saturated steam, at a mass flow M = 54,432 kg/day and an absolute pressure p = 3.55 MPa, assuming that the generator produces steam having the quality x_g = 0.80, and the tubing is thermally insulated. We also know the following data: porosity m = 0.25, initial water saturation s_{wi} = 0.20, initial oil saturation s_{oi} = 0.60, remaining oil saturation s_{or} = 0.10, initial formation temperature T_r = 26.67 °C, saturated steam temperature at the injection pressure p = 3.55 MPa, T_s = 243.33 °C, average formation thickness h = 6.1 m, steam energy specific cost $C_s = 0.4739\cdot10^{-6}$ \$/kJ, produced oil specific value, according to a recovery factor f_r = 0.80, v_o = 12.58 \$/m^3, rock matrix, water and oil specific mass heats c_r = 879.16 J/(kg·K), c_w = 4,186.5 J/(kg·K), c_o = 2,093 J/(kg·K), rock matrix, water and oil densities ρ_r = 2,675 kg/m^3, ρ_w = 999.57 kg/m^3, ρ_o = 800.9 kg/m^3, thermal conductivity of the strata bounding upwards and downwards the producing formation λ_s = 2.596 W/(m·K), thermal diffusivity of the layers adjacent to the reservoir $a_s = 1.244\cdot10^{-6}$ m^2/s.

The study proposed involves the determining of the following parameters:

a) area of the steam-flooded zone, at the injection time t = 1,000 hours;

b) flow rate of oil displaced by steam at the injection time t = 1,000 hours;

c) economically limited area of the considered steam-flood process;

d) duration of the process, admitting a volumetric sweep efficiency E_{vo} = 0.97;

e) final recovery factor.

To perform this case study, the Marx–Langenheim model previously presented can be used as follows.

a) Because the tubing is thermally insulated, the supposition that the heat losses into the well are negligible can be accepted. Moreover, if the steam generator is placed near the injection well, heat losses on the steam carrying pipeline to the well head are insignificant. These considerations make the thermal flux q_r injected into the reservoir to be identical to the thermal flux q_g of the steam at generator's outlet, according to the equation

$$q_r = q_g = M\,i\ , \tag{25}$$

where i is the available specific energy of the steam, defined as

$$i = x_g\, i_v + (1 - x_g) i_l\ , \tag{26}$$

in which x_g is the steam quality at the generator, i_v – specific mass enthalpy of water vapors, and i_l – specific mass enthalpy of liquid water, whose values are listed in *table 2*.

Table 2. Values of specific mass enthalpy of vapor and liquid water in saturation conditions

T_v, K	T_v, °C	p_v, kPa	i_l, kJ/kg	i_v, kJ/kg	l_v, kJ/kg
273.15	0	0.6108	–0.04	2,501.6	2,501.6
273.16	0.01	0.6112	0.00	2,501.6	2,501.6
283.15	10	1.2270	41.99	2,519.9	2,477.9
293.15	20	2.337	83.86	2,538.2	2,454.3
313.15	40	7.375	167.45	2,574.4	2,406.9
333.15	60	19.920	251.09	2,609.7	2,358.6
353.15	80	47.36	334.92	2,643.8	2,308.8
373.15	100	101.33	419.06	2,676.0	2,256.9
393.15	120	198.54	503.72	2,706.0	2,202.2
413.15	140	361.4	589.10	2,733.1	2,144.0
433.15	160	618.1	675.47	2,756.7	2,081.3
453.15	180	1,002.4	763.12	2,776.3	2,013.1
473.15	200	1,554.9	852.37	2,790.9	1,938.6
483.15	210	1,907.7	897.74	2,796.2	1,898.5
493.15	220	2,319.8	943.67	2,799.9	1,856.2
503.15	230	2,797.6	990.26	2,802.0	1,811.7
513.15	240	3,347.8	1,037.6	2,802.2	1,764.6
523.15	250	3,977.6	1,085.8	2,800.4	1,714.6
533.15	260	4,694.3	1,134.9	2,796.4	1,661.5
543.15	270	5,505.8	1,185.2	2,789.9	1,604.6
553.15	280	6,420.2	1,236.8	2,780.4	1,543.6
563.15	290	7,446.1	1,290.0	2,767.6	1,477.6
573.15	300	8,592.7	1,345.0	2,751.0	1,406.0
593.15	320	11,280	1,462.6	2,703.7	1,241.1
613.15	340	14,605	1,595.5	2,626.2	1,030.7
633.15	360	18,675	1,764.2	2,485.4	721.3
643.15	370	21,054	1,890.2	1,342.8	452.6
647.30	374.15	21,120	2,107.4	2,107.4	0

According to the data in table 2, we get by interpolation, for the temperature T_s = 243.33 °C, the values i_l = 1,053.6 kJ/kg and i_v = 2,801.6 kJ/kg, which, introduced into equation (26), give the value i = 2,452 kJ/kg and then, using the relationship (25), we obtain q_r = 1,544.76 kW.

From relationship (4) the volumetric heat capacity of the rock–fluid system C_r = 2,224.5 kJ/(m^3·K) is found, and equation (14) gives, for t = 1,000 hours, the parameter u = 0.651, whom corresponds, in *table 1*, the value 0.28037 of the function

$$F(u) = \mathrm{e}^{u^2}\mathrm{erfc}(u) + \frac{2u}{\sqrt{\pi}} - 1\ . \tag{27}$$

Consequently, from the expression (11) we obtain for the area of the steam-swept zone at t = 1,000 hours the value A = 1,251.7 m^2.

b) According to the relationships (17) and (18), in association with *table 1*, for u = 0.651 we get the values $e^{u^2}\operatorname{erfc}(u) = 0.5458$, V_o = 0.7625 m^3/m^2 and the oil flow rate Q_o = 18.89 m^3/day.

c) From equation (20) we will obtain the value $e^{u_l^2}\operatorname{erfc}(u_l) = 0.145$, whom corresponds, in *table 1*, the argument u_l = 3.762 and the function $F(u_l)$ = 3.39. Then, using the expressions (11) and (27), we can write the equality

$$\frac{A}{A_l} = \frac{F(u)}{F(u_l)}, \tag{28}$$

which gives the economically limited area A_l = 15,134.5 m^2.

d) Equation (21) yields the value t_l = 1,391.87 days for the economically limited duration of the steam-flood.

e) According to relationship (22), the final recovery factor of oil by steam-flood has the expression

$$f_r = \frac{m\,A\,h\,E_{vo}(s_{oi} - s_{or})b_{oi}}{m\,A\,h\,s_{oi}\,b_o}, \tag{29}$$

which, for $b_o = b_{oi}$, reduces to the form

$$f_r = E_{vo}\left(1 - \frac{s_{or}}{s_{oi}}\right), \tag{30}$$

yielding f_r = 0.808.

Conclusions

The experiments showed that all oils which, in reservoir conditions, have high dynamic viscosities, ranging between 10^2 mPa·s and 10^6 mPa·s, can reduce their viscosities under 10 mPa·s when heated up to 93 °C by steam injection, thus allowing the mobilizing and recovery of important amounts of oil.

The transfer of latent vaporization heat supplied by the steam generator, in the case of a cyclic steam injection, defined by three steps: steam injection, condensation and production, can increase oil production by cyclic fluidization of oil and make the wells in the pattern communicate each other, thus reaching the conditions needed to start the continuous steam injection.

The specific studies achieved showed that the efficiency of a process of well productivity stimulation by cyclic steam injection depends on the following parameters: quantity of steam injected per cycle, steam flow rate and characteristics, condensation process duration, as well as performance of production process, defined by the initial stimulated flow rate, the shape and the length of the production decline curve, the cumulative oil produced per cycle, and the variation of the process performance from a cycle to another.

The most important applications of the cyclic steam injection were realized in the oil fields Cat Canyon, Coalinga, Huntington Beach, Kern River, Midway Sunset and Yorba Linda from California, as well as in the reservoirs Bachaquera, Lagunillos and Tia Juana from the Bolivar Coast in Venezuela. Large-scale applications of the cyclic and continuous steam injection were also performed in the viscous oil reservoirs situated in eastern and western China.

Interesting steam-flood tests were carried on in the oil fields Schoonebeck from Holland (1968), Georgsdorf from Germany (1975) and Lacq Supérieur from France (1977).

The process of steam-flood initiated in the year 1968 and accomplished by Chevron in the reservoir Kern River led to a recovery factor value of 37% which, by the following cold water injection, increased with 22% until the beginning of the year 1981, with the hope of a final recovery factor reaching 78%.

The appreciation can be made that, for estimating the performance of a steam-flood process, the model Marx–Langenheim, based on the decoupling of the heat balance equation and the fluid (water, oil, and steam) flow equations, according to the supposition that the thermal energy injected is retained into the steam-invaded region of the producing layer and given up to the strata bounding upwards and downwards the reservoir, can be used.

We underline that, between the 14 field applications of oil recovery by steam injection presented in the work [7], the cyclic steam injection process initiated in the year 1971 in the Levantine reservoir from Moreni, Romania is also described.

The case study accomplished in this work, based on the Marx–Langenheim model, allowed us to estimate the area of the steam-swept zone, the oil flow rate at a specified time, the economically limited area of the process, the total duration of the steam-flood and the final oil recovery factor, under conditions specific to the application of this kind.

References

1. Crețu, I. – *Hidraulica zăcămintelor de hidrocarburi*, vol. 2, Editura Tehnică, Bucureşti, 1987;
2. Crețu, I., Ionescu, E.M., Grigoraş, I.D. – *Hidraulica zăcămintelor de hidrocarburi. Aplicații numerice în recuperarea secundară sau terțiară a petrolului*. Editura Tehnică, Bucureşti, 1996;
3. Boberg, T.C. – *Thermal Methods of Oil Recovery*. John Wiley and Sons, New York, 1987;
4. Wan Ren Pu – *Why Production Keeps Increasing in China*. World Oil, Dec., 1990;
5. Burger, J., Sourieau, P., Combarnous, M. – *Thermal Methods of Oil Recovery*, Éditions Technip, Paris, 1985;
6. Marx, J., Langenheim, R.N. – *Reservoir Heating by Hot Fluid Injection*. Trans. AIME, 216, 1959;
7. Cârcoană, A., Aldea, Gh. – *Mărirea factorului final de recuperare la zăcămintele de hidrocarburi*. Editura Tehnică, Bucureşti, 1976.

Cercetări privind recuperarea țițeiului prin injecție de abur în zăcământ

Rezumat

Procesele de recuperare îmbunătățită a țițeiului bazate pe injecția de fluide fierbinți în zăcământ au fost aplicate în ultima jumătate de secol, în special la zăcămintele de mică adâncime, care conțin țițeiuri cu vâscozitate mare. Atât injecția ciclică de abur cât şi spălarea cu abur s-au dovedit procese eficiente atât din punct de vedere tehnic cât şi economic, atunci când au fost aplicate la zăcăminte care se pretează la recuperarea țițeiului prin metode termice. Lucrarea de față are ca obiect prezentarea unei proceduri de estimare a performanței procesului de spălare cu abur a unui zăcământ de țiței, ilustrată printr-un studiu de caz.