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A Probabilistic Method to Estimate the Initial Oil Rates of the Horizontal Wells Stimulated by Steam

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Abstract

To accelerate the oil production and increase the recovery factor for heavy oil reservoirs, since 1992, in the world is often used the SAGD method (SAGD – Steam Assisted Gravity Drainage). This method, which was not applied for Romanian oilfields, it's an advanced kind of stimulation using steam. In fact, a pair of horizontal wells are drilled into the reservoir, one few meters above the other one. In each well pair, steam is injected into the upper well, to heat heavy oil, which allows it to flow into the lower well, where it is pumped to the surface.

It's known that in Dealu Batran, an old Romanian oil field there is a heavy oil reservoir located Drader II, where natural drive mechanism is associated with a thermal method (continuous steam injection) to increase recovery factor. Taken into account the positive effect of seam in this zone and the fact that there is an area where cannot be applied this process because of any surface restrictions, the possibility of applying and implementing SAGD has been researched.

One of first steps was to estimate one hand the initial oil rate for a horizontal well produced without steam and on the other hand the initial oil rate in case the well will be stimulated by steam. Based on Butler and Joshi equations and playing with any uncertain parameters as permeability, effective thickness, horizontal length, oil viscosity there were established a range of initial oil rates in both cases.

Key words: *oil, heavy, steam, horizontal wells, initial oil rates, SAGD.*

SAGD – Steam Assisted Gravity Drainage

In the SAGD process, two parallel horizontal oil wells are drilled in the formation, one about 4 to 6 meters above the other (fig. 1). The upper well injects steam, and the lower one collects the heated crude oil or bitumen that flows out of the formation, along with any water from the condensation of injected steam. The basis of the process is that the injected steam forms a "steam chamber" that grows vertically and horizontally in the formation. The heat from the steam reduces the viscosity of the heavy crude oil or bitumen which allows it to flow down into the lower wellbore.

Solvents like butane are used to help to reduce the viscosity of the petroleum. The steam and gases rise because of their low density compared to the heavy crude oil below, ensuring that steam undefined is not produced at the lower production well. The gases released, which include methane, carbon dioxide, and usually some hydrogen sulfide, tend to rise in the steam chamber, filling the void space left by the oil and, to a certain extent, forming an insulating heat blanket above the steam. Oil and water flow is by a countercurrent, gravity driven drainage into the lower well bore. The condensed water and crude oil or bitumen is recovered to the surface by pumps such as progressive cavity pumps that work well for moving high-viscosity fluids with suspended solids.

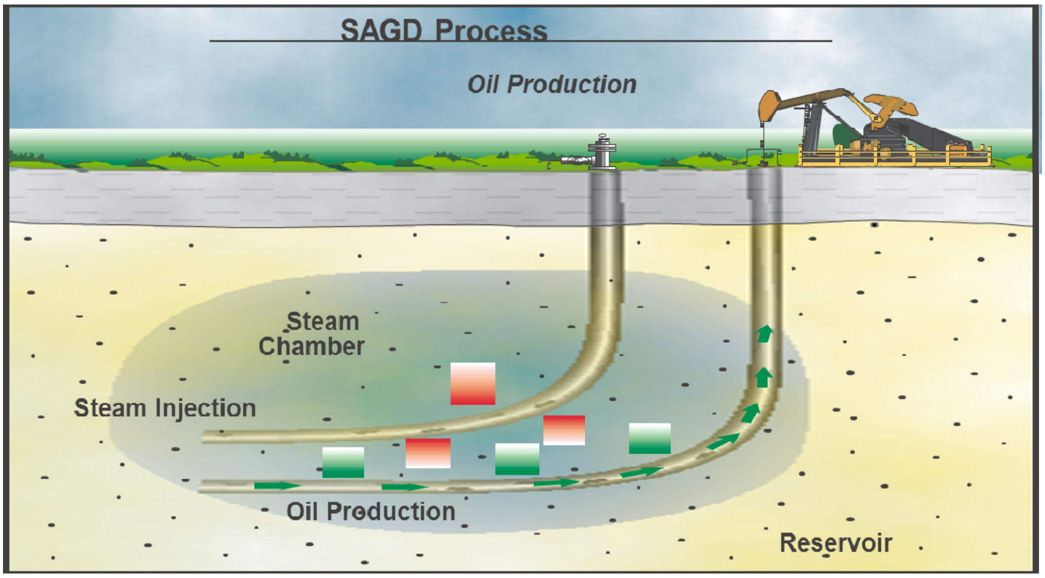

Fig. 1. The concept SAGD (Steam Assisted by Gravity Drainage)

This technology is now being exploited due to increased oil prices. While traditional drilling methods were prevalent up until the 1990's, high oil prices are encouraging more unconventional methods as SAGD to extract crude oil.

Romanian Applications

Dealu Batran is an old Romanian oil field. A heavy oil reservoir is located Drader II and here the natural drive mechanism is associated with a thermal method (continuous steam injection) to increase recovery factor. Taken into account the positive effect of seam in this zone and the fact that there is an area where cannot be applied this process because of any surface restrictions, the possibility of applying and implementing SAGD has been researched.

The density of crude oil is 955 kg/cm and the viscosity 200 – 600 cP in reservoir conditions. The productive layer Drader II, with a dip of 20 – 25 degrees N-S, consist of sands, marls and unconsolidated sandstones from lithological point of view and is located to a depth of 350 m. The total thickness of the layer is 33 – 37 m, with a effective thickness of 30 m.

The initial pressure estimated to be 35 bar and the reservoir temperature 25 C degree. The bubble point pressure considered to be equal with the initial pressure, initial gas – oil ratio evaluated to a value of 25 Scm.cm. The pressure measurements show an actual value of reservoir pressure to 15 – 20 bars. The average porosity is 33%, connate water saturation 26,5% and the average value of absolute permeability is 320 mD.

The continuous steam injection process initiated in 2002 in the panels was proved as efficient due to the fact of liquid rate increase from 50 cm/day to 150 – 200 cm/day and oil rate increase from 20 tons/day to 40 – 50 tons/day. These results already have demonstrated the steam effect on efficiency of oil recovery.

Butler and Joshi Analytical Equations

Butler and Stephens equations

Butler developed in 1981 using Darcy's equation an analytical model and equation (1) to predict the drainage rate for a stimulated horizontal well by steam. The assumptions made in his gravity drainage theory include that only steam flows in the steam chamber, oil drains along the vertical steam chamber boundary, the steam pressure is constant in the steam chamber, oil saturation is residual and heat transfer ahead of the steam chamber to cold oil is only by conduction.

According to the experiments, during the process of SAGD, the steam chamber (SC) appeared more like a mushroom which would experience upward, horizontal expansion, steady and coming down stage. To simplify the estimations, the steam chamber was considered an inverted triangle (fig. 2)

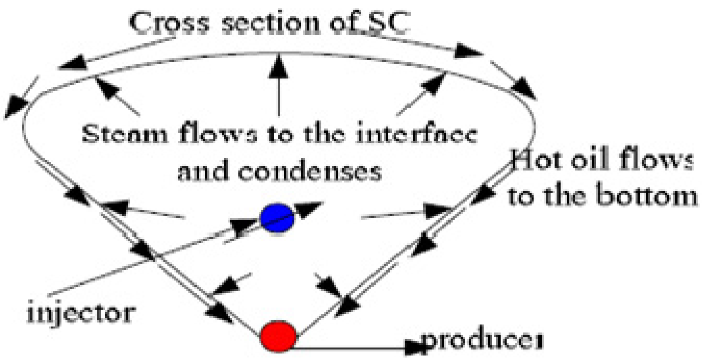

Fig. 2. Profile of SAGD steam chamber

For a horizontal well, taken into account that this is producing from both parts of steam chamber, Butler proposed in 1981 the following equation:

$$q = 2L\sqrt{\frac{2\Phi\Delta S_o kg\alpha h}{m\nu_s}} \tag{1}$$

In the above equation L is length of the horizontal section, Φ is the porosity, ΔSo is the mobile oil saturation, k is the reservoir permeability, g is equal with 9.81, h is reservoir thickness, m is a constant of 3.5 and ν_s velocity of steam.

On the same year 1891, Butler and Stephens modified the equation 1 in order to take into account the adjacent wells (2). Initially the steam oil interface was considered horizontal to infinite and now it is to a limit situated to a half distance between the horizontal well and the adjacent well.

$$q = 2L\sqrt{\frac{1{,}5\Phi\Delta S_o kg\alpha h}{m\nu_s}} \tag{2}$$

The following reveals the estimations based on SAGD concept and equations (1) and (2) for a horizontal well with a length of 250 m, and the reservoir condition and oil characteristics of the reservoir Dealu Batran – Drader II, like Φ = 33%, ΔS_o = 0.485 (Sti = 0.735, Srt = 0.25), k = 4E-13 m^2, g = 9.81 m/s^2, α = 8.1E-7 m/s, h = 30 m, m = 3,5 and v_s = 7.8E-6 m^2/s.

Solving the equation (1) results:

$$q = 2(250)\sqrt{\frac{2(0.33)(0.485)(4E-13)(9.81)(8.1E-7)(30)}{(3.5)(7.8E-6)}} = 0.000529\ \text{m}^3/\text{s}$$

$$q = (0.000529\ \text{m}^3/\text{s})x(86400\ \text{s}) = 45.679\ \text{m}^3/\text{day} = 43.623\ \text{tons/day}$$

Solving the equation (2) results:

$$q = 2(250)\sqrt{\frac{1.5(0.33)(0.485)(4E-13)(9.81)(8{,}1E-7)(30)}{(3.5)(7.8E-6)}} = 0{,}000458\ \text{m}^3/\text{s}$$

$$q = (0.000458\ \text{m}^3/\text{s})x(86400\ \text{s}) = 39.559\ \text{m}^3/\text{day} = 37.779\ \text{tons/day}$$

Joshi equation for an anisotropic reservoir (*kv ≠ kh*)

The horizontal well productivity under steady – state conditions is given by the following equation:

$$Q_{oh} = J_h \Delta p \tag{3}$$

where Q_{oh} – horizontal well flowrate, bbl/day, Δp – pressure drop from the drainage boundary to wellbore, psi and J_h – the productivity index of horizontal well, STB/day/psi.

Joshi proposed in 1991 an equation for the productivity index of horizontal well in case of anisotropic reservoir:

$$J_h = \frac{0.00708\ hk_h}{\mu_o B_o \left[\ln(R) + \left(\frac{B^2 h}{L}\right)\ln\left(\frac{h}{2\pi r_w}\right)\right]} \tag{4}$$

where $R = \frac{a + \sqrt{a^2 - (L^2/2)}}{L/2}$; $B = \sqrt{\frac{k_h}{k_v}}$

and $a = L/2\left[0.5 + \sqrt{0.25 + (2r_{eh}/L)^4}\right]^{0.5}$

where h – thickness, ft, k_h – horizontal permeability, mD, k_v – vertical permeability, mD, L – length of horizontal well, ft, r_{eh} – drainage radius of horizontal well, r_w – wellbore radius, ft.

The probabilistic Method to Estimate the Initial Ol Rates for Stimulated Horizontal Wells by Steam

Taken into consideration the uncertainty related to reservoir data, the estimation of initial rates for non-stimulated or stimulated horizontal wells by steam were done according to Joshi equation for anisotropic reservoirs, based on sensitivities of input parameters and given them different values from a minim to maxim admissible as the followings:

- the length of horizontal well between 100 m to500 m;
- horizontal permeability considered with values from 300 mD and 1200 mD, the rapport Kv/Kh equal with a value of 0,5;
- pressure drop from the drainage boundary to wellbore from 5 at to 15 at;
- the thicknes of productive layer between 10 m and 30 m;
- the Kv/Kh rapport considered with values between 0.2 to 1;

In case of the horizontal well non-stimulated by steam the oil viscosity is 350 cP and for a stimulated horizontal well the viscosity of oil is 100 cP (according to laboratory tests).

The results of estimations were distributed in classes of values and plotted function absolute frequency and percentiles. On this way it was estimated the probability to achieves these values.

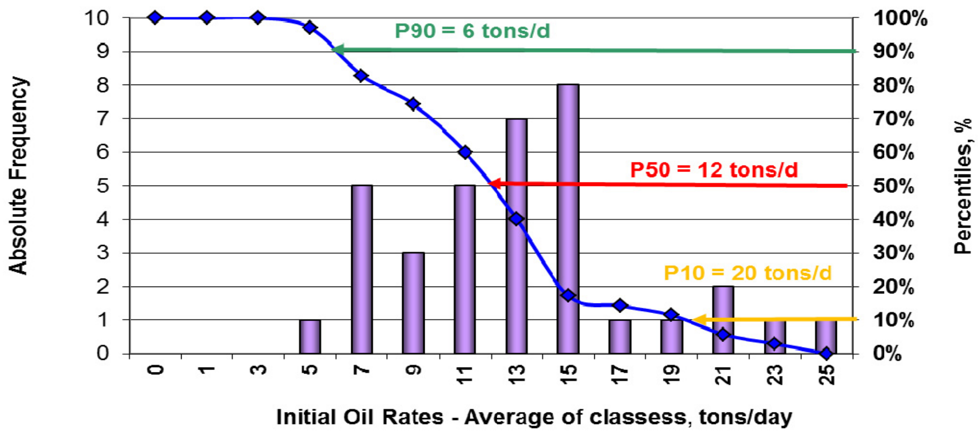

Fig. 3. The probabilistic estimations (case of non-stimulated horizontal well)

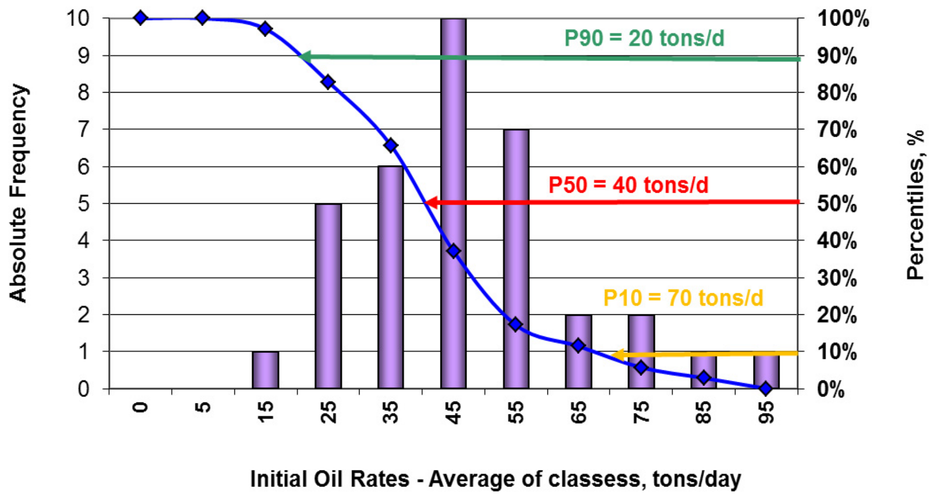

Fig. 4. The probabilistic estimations (case of non-stimulated horizontal well)

As can be saw in the above figures, for instance for the case of non-stimulated horizontal well the expected oil rate is 12 tons /day and for the case of stimulated horizontal well by steam the expected oil rate is about 40 tons /day.

Conclusions

An initial oil rate was estimated according to Butler and Stephens equations for a horizontal well stimulated by steam. Accordingly, the results of computations were 43.623 tons/day and 37.779 tons/day.

Taken into consideration the uncertainty related to reservoir data, the estimation of initial rates for non-stimulated or stimulated horizontal wells by steam were done according to Joshi equation for anisotropic reservoirs, based on sensitivities of input parameters and given them different values from a minim to maxim admissible.

The results of estimations were distributed in classes of values and plotted function absolute frequency and percentiles. According to a probability of 50% as situation to happen, for the case of non-stimulated horizontal well the expected oil rate is 12 tons /day and for the case of stimulated horizontal well by steam the expected oil rate is about 40 tons /day. The average initial oil rate is between the bounds given by Butler and Stephens equations.

Recently the two horizontal wells of 250 m length were drilled on this area, but are not stimulated yet. The first "cold production" in one case was 17.4 cm/day liquid rate, 21% of water cut and an oil rate of 13 tons/day and in the second case was 19 cm/day liquid rate, 40% of water cut and an oil rate of 10.8 tons/day. Therefore, the initial values for non-stimulated obtained in the field were close to the estimated values. The proximate future it's scheduled to stimulate at least one of the wells.

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O metoda probabilistică de estimare a debitelor inițiale de țiței în cazul unei sonde orizontale stimulată cu abur

Rezumat

Pentru accelerarea producției şi creşterea factorului de recuperare în zăcăminte de țiței greu, începând cu anul 1992, în lume este tot mai des aplicată metoda SAGD – Steam Assisted Gravity Drainage (injecția de abur în sonde orizontale asistată de curgerea gravitațională). Această metodă, neaplicată încă pe zăcăminte din România, este de fapt o formă avansată de stimulare abur în care o pereche de sonde orizontale sunt forate în zăcământul de țiței, una câțiva metri deasupra celeilalte. Aburul de o înaltă calitate este injectat în mod continuu de sonda de deasupra pentru a încălzi țițeiul şi a reduce vâscozitatea acestuia, țițeiul încălzit urmând să se scurgă în gaura de sondă inferioară, ca urmare a curgerii gravitaționale, de unde acesta este pompat afară.

Este ştiut faptul că la Dealu Batran, un vechi zăcământ din Romania există țiței greu, cantonat in Drader II, un obiectiv productiv în care pe lângă mecanismul natural de dezlocuire s-a asociat şi o metodă termică (injecția continuă de abur) pentru a mări factorul de recuperare al țițeiului. Luând în considerare faptul că procesul termic a avut efect şi că există zone care nu pot fi exploatate datorită condițiilor de suprafață, a fost luata in considerare implementarea metodei SAGD.

Ca prim pas, s-a încercat estimarea pe de o parte a debitului ini-ial al unei sonde orizontale produsă fără a fi stimulată cu abur, iar pe de altă parte debitul ini-ial al unei sonde orizontale stimulată cu abur. Bazat pe ecuațiile lui Butler şi Joshi şi ținând cont de incertitudinea parametrilor care intră in calcul precum permeabilitatea, grosimea efectivă, lungimea drenei, viscozitatea țițeiului, au fost estimate diverse valori ale acestor debite în ambele cazuri.

Pe baza ecuațiilor lui Butler şi Stephens, au fost estimate debite inițiale ale țițeiului de 43,623 tone/zi, respectiv 37,779 tone/zi.