International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 11, November 2018, pp. 1952–1961, Article ID: IJMET_09_11_205
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=11
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

ELECTROTHERMAL COMPLEX FOR HEAVY OIL RECOVERY: ANALYSIS OF OPERATING PARAMETERS

ViacheslavZyrin
SaintPetersburg Mining University, SaintPetersburg, Russia

ABSTRACT

This paper is aimed to show the growing importance of economically effective and environmentally clean technologies for heavy oil recovery, which reserves in several times higher than light oil. Physical properties of heavy oil (high viscosity and density) makes traditional technologies inefficient, oil recovery factor reaches only 7-15% and without special methods its extraction impossible. According to the numerous researches and field tests thermal methods proves higher efficiency. In paper is proposed to use the electrothermal complexes with downhole heating devices for various heating technologies – cyclic steam stimulation, impulse-dozen heating and other. Program for the main constructive and technological parameters of downhole electrosteam generators has been designed, and obtained results of formation depth on total electrode number. Impact of mixture flow rate on downhole steam generator parameters has shown.

Keywords: Heavy Oil, Enhanced Oil Recovery, Electrothermal Complex, Downhole Electroheating Generator.

Cite this Article: ViacheslavZyrin, Electrothermal Complex for Heavy Oil Recovery: Analysis of Operating Parameters, International Journal of Mechanical Engineering and Technology, 9(11), 2018, pp. 1952–1961.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=11

1. INTRODUCTION

Nowadays the whole world faces with a problem of reducing traditional energy sources, like conventional oil and gas. Besides, a huge problem is increasing share of hard-to-recover reserves, and consequently falling of oil recovery factor.

British Petroleum Company (BP Statistical Review of World Energy) makes an annual monitoring of oil resources containing and distribution in the world. According to the statistical review [1-3], world energy consumption is growing, and such traditional energy source like oil and gas has the same tendency – oil demand increase at 2017 on 1.8%.

High production rate, changing of oilfield structure, physical properties worsening leads to increasing attention to unconventional reserves, and mostly to heavy oil reserves.

Unconventional oil which includes heavy oil, extra heavy oil, oil sands and bitumen estimates about 70% of the world's total oil resources, and heavy oil itself takes 15% (Figure 1). Most part of heavy oil are located in Venezuela, Canada, United States and Russia [4,5].

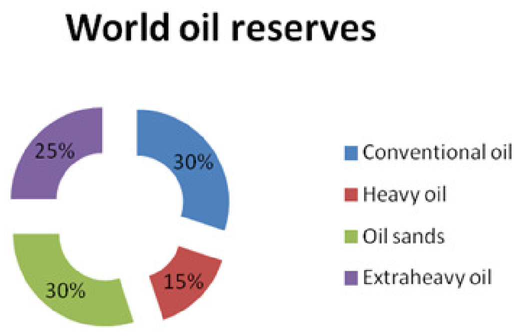


Figure 1 World oil reserves distribution by types

The largest deposits of high viscosity oil (HVO) were founded in Canada, and Venezuela (Orinoco). Resources of two of these countries amount to more than 60% of the world heavy oil reserves. Oil deposits in Orinoco (Venezuela) and Alberta (Canada) contains mostly extra heavy oil or bitumen.

Russia, however, has more than 6-7 billion tonnes of heavy oil, primarily in Siberia region [6] and in Tatarstan. Nowadays, oil reserves in Tatarstan contain almost 1 billion tons (67% are heavy), it's almost 5% form the whole Russia oil reserves. The biggest deposits in this region are Romashkinskoe, Novo-Elhovskoe, Bavlinskoe, Sabachinskoe.

2. REVIEW

2.1. Enhanced oil recovery

Physical properties of heavy oil (high viscosity and density) makes traditional technologies inefficient, oil recovery factor reaches only 7-15% and without special methods its extraction impossible. Another factor which influence on the heavy oil recovery is high depth of formation.

Total period of oilfield operation can be divided into the following stages.

On the first stage oil is extracted with the help of the natural reservoir energy. Energy, removed from reservoir oscillation, solution gas and edge water drive towards the well. These methods are named "primary".

With the reservoir energy decreasing the problem of its obtaining is growing. That is why next exploitation stage involves water or gas injection into the well for reservoir pressure support. Such methods are named "secondary".

On the following stage enhanced oil recovery (EOR) methods are used for the increasing of exploitation efficiency. EOR are methods, involving the various working substances injection to a well, which improve oil flow from the reservoir to a well.

EOR technologies include [9-12]:

- Cold production
- Heating methods (vapor extraction, cyclic steam stimulation, in-situ combustion, steam flooding, steam-assisted gravity drainage)

- Chemical methods (surfactant flooding, polymer flooding, solvent flooding etc.)
- Gas injection
- Microbiological methods.

A lot of factors influence on technology choosing – formation depth, physical properties, reservoir lithology - for instance, thermal and chemical projects are the most frequently used in sandstone reservoirs compared to other lithologies (e.g., carbonates and turbiditic formations) [4].

According to the numerous researches and field tests thermal methods proves higher efficiency than others, despite wide using of chemical flooding. The main advantage of thermal technologies is combination of hydrodynamic and thermodynamic impact on formation. Heat into reservation effects on all of it components and changes bonds and filtration properties, what leads to viscosity decreasing, improving mobility and, in result, to increasing oil recovery factor.

Thermal methods could be implemented at formation with difficult physical and geological conditions and can be used for oil with viscosity up to 10000 MPa•s, increasing final recovery in several times, which is unreachable for any other technologies [7-9].

Temperature growth leads to the decrease of viscosity, especially within the interval 20-80°C. And due to fact that production rate is proportional to viscosity, the well productivity can be increased in 10-30 times or more.

Cyclic steam stimulation(CSS) is three-step process – injection of steam under high pressure, soak time, extraction. The production rate stays at a high level for a short period before declining gradually over several month. CSS has been operated in Canada, Venezuela, Brazil, USA.

There is an oilfield in Russia – Usinskoe (Komi Republic) where has been tested and applicated the cyclic steam stimulation technology, which includes following stages:

- steam injection (10-20 days). Steam is produced with ground steam generator, working on the hydrocarbon (natural gas mostly) fuel burning;
- soak and discharge period, when the downhole temperature decease till the level, acceptable for pump usage;
- oil recovery (10-11 month) [13-16].

Gain in recovery for this technology have amount 8000 tons per well.

Effect from dispersed steam injection is complicated by the well watering rate that is why nowadays it is seldom applied.

Steam assisted gravity drainage (SAGD) include pair of horizontal wells 4-6 m one a few metres above the other. High pressure steam is continuously injected into the upper well bore to heat the oil and reduce its viscosity, causing the heated oil to drain into the lower wellbore, where it is pumped out. Due to SAGD applicability in unconsolidated reservoirs with high vertical permeability, this EOR method has received attention in countries with heavy and extra-heavy oil resources, especially Canada and Venezuela, owning vast oil sands resources. However and despite SAGD pilot tests reported in China, U.S. and Venezuela, commercial applications of this EOR process have been reported in Canada only and more specifically those implemented in McMurray Formation, Athabasca (e.g., Hanginstone, Foster Creek, Christina Lake and Firebag, among others) [4,12].

Applied steam stimulation technologies has a lot of drawbacks: high capital cost, heat loss during steam flowing from surface steam generator to the wellbore and consequently low steam dryness, which determines the thermal effect.

2.2. Electrothermal technology

As alternative for traditional heating technologies and surface steam generators in Mining University has been proposed the downhole electrosteam generator (DEG) [17] and has been designed the electrothermal complex with the downhole electrosteam generator [18].

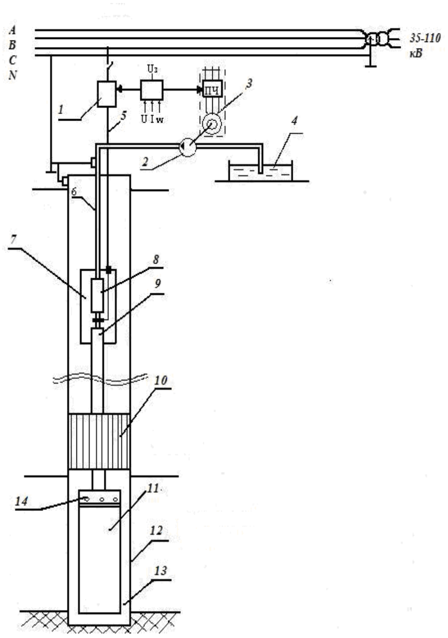


Figure 2 Electrothermal complex
1– current regulator; 2 –pump; 3 –controllable electrical drive; 4 –working liquid; 5 – power cable; 6 – tubing; 7 – oil-flooded incoming arrangement; 8 – dielectric insertion; 9 – heat-resistant input lead; 10 – packer; 11 –downhole heating generator; 12 –casing string; 13 –oil-field water; 14 –steam port

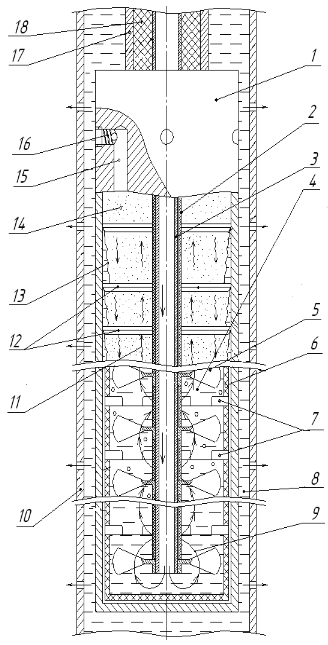


Figure 3 Downhole electrosteam generator-separator
1 – metal housing (zero electrode); 2 - thermoresistant insulating jacket; 3 - central electric conductor; 4 – heating zone; 5 - phase electrode; 6 – sidewall of fluoroplastic insulator; 7 – current-conducting openings; 8- oil-field liquid; 9 – convective flow of working fluid; 10 – production string; 11 – steam direction; 12 – condensate remover; 13 - condensate; 14 –steam zone; 15 – steam opening; 16 – valve; 17 – tubing string; 18 – bushed insulator

The complex provides the following thermal treatment modes: steam flooding, hot and cold-water flooding, cyclic steam stimulation, impulse-dosing thermal treatment.

Electrothermal complex consists of DEG, water supplying system (tank with cold water, pump for water injection into DEG, pipeline), transformer and current control system. Automatic control of desired technological parameters (voltage, current, water consumption, pump speed) are provided by control system.

The downhole electrical heating device [18] installed on the level of geological formation inside production casing 10, includes a downhole electrosteamgenerator-separator (ESGS), suspended by a tubing string 17 (Figure3).

ESGS consist of cylindrical metal housing 1 (drill pipe), which is besides a zero electrode. Cylindrical input lead 3 with heat resistant insulating jacket 2 is attached to upper housing part 1 through bushing insulator 18. On the inner housing surface 1 locate condensate remover 12, made as steel rings. Inside the housing on the input lead 3 the phase electrode 5 are fixed through equal intervals, divided by thermal resistant insulators 2. Each phase electrode has a form of multithread screw with attack angles 200-400.

Special form of the phase electrodes (multithread screw) gives opportunity to create a rotational motion 9 relative to ESGS axis and have a tangential speed part and steam separation.

Interelectrode interval determines by device power, feeding voltage, current density and working liquid specific resistance. Each phase electrode placed inside fluoroplastic housing, with sidewall 6 and current conducting opening 7. The housing upper part is a steam zone 14, it has no electrodes, but include steam emission channel 15 with emission valve 16.

Rotational motion of steam-water mixture leads to mixture separation along radial component. Central steam volume will have a high steam dryness, because the tangential speed components create a motion which remove suspended microdrops to an end part of electrode, where they evaporate and separate from steam flow by condensate removers 5.

After DESG assembling and disposing in the level of geological formation, the phase electrodes 5 starts supplying with voltage (3-6 kV and 50 Hz) from a power cable to the central electric conductor 3. The housing is filled with working fluid (technical water).

Then current flows from the phase electrode through working fluid and current-conducting openings (which area S is equal to the area of phase electrodes) to the metallic housing 1 (zero electrode), causing intensive heating of working fluid 4, boiling and vaporization 11. In figure 3 arrows indicated current direction.

Steam, during its vertical flowing, getting tangential velocity component which leads to steam-water mixture swirling around central axe of DESG, steam separation and output through steam openings 15 with a valve 16 inside zone 8, filled with oil-field liquid.

3. METHOD

Operation of downhole electrical steam generators is based on heating of current conductive liquid (water). The main current carriers in electrolytes are ions, which occur in result of dissolved salt, acids and alkali decay. Passing the current through such liquid, ions starts it moving towards corresponding electrodes, generating current with ion conductivity. With it moving, positive and negative ions accumulate electrical power. As results of encounter with atoms and molecules, ions transmit to it excess of energy, which is transferred to heat. Electrolytes heating inside DESG process is described below.

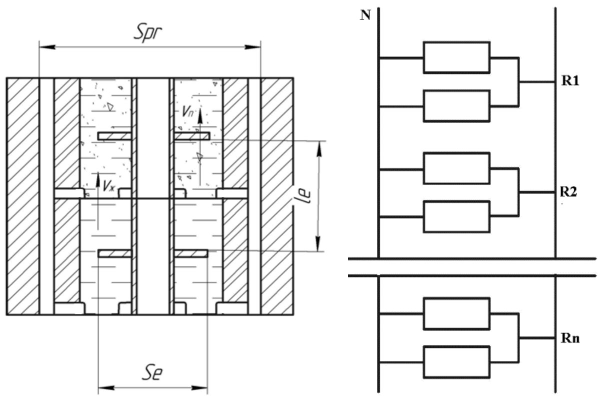
Heating rates inside the interelectrode interval determines with interval power, interelectrode length and electrode area(Figure 4). Required power is reached with changing height and number of interelectrode intervals.

On the base of the reasoning above calculation program for the main constructive and technological parameters of downhole electrosteam generators for taken initial conditions has been designed.

Basic initial parameters for calculation are:

- Cable line type;
- Supply voltage of DSG – kV;
- Downhole steam generator depth – m;
- Steam injection pressure – mpa;
- DSG diameter – mm;
- Resistance-temperature curve $\rho_в = f(T°C)$.

Calculation program include: determination current rating; specific energy value for boiling zone and for steam-formation zone; assessment of specific energy and power sharing for both zones (from «water-steam» state tables for taken depth); choosing interelectrode length (no less than 100 mm); determination of electrode area, according to condition that current density j must be less than 2 A/cm2; calculation of electrode amount for both zones.



a) b)

Figure 4 a) interelectrode interval, b) electrical scheme

Calculation algorithm is shown in Figure 5.

Detailed equations are shown in [19,20]

This article aimed to underline the main parameters and its impact on the downhole steam generator operation.

Electrodeareaconsistof 3 main variables:

$$S_e = \frac{l_e \cdot \rho}{R_0}, \quad (1)$$

wherele-interelectrodeinterval, Ro – one interelectrodeinterval resistivity, сопротивлениеодногомежэлектродногопромежутка, ρ – specific resistivity of interval.

R_0calculatesasfollows:

$$R_0 = \frac{U^2}{P_0}, \qquad (2)$$

whereP_0 – interelectrode capacity, U- power supply voltage.

After calculation of electrode area and ESG flow part area next stage is evaluation of interelectrode interval number. Length of steam generators is divided into two zones – heating zone and steam zone, basing on different physicals processes.

Heatingzone

Heatingzonemaincharacteristicisconstantwatertemperaturegrowthfrominitialtoboilingtemperature, with decreasing of current conductive intervalsresistivity.

Duringh eating process specific resistivity is decreasing. Takingintoaccountconsiderableresistivitychangingandthefactthatthemaintemperatureincrease willoccurintheinterelectrodearea, it is reasonable to expand the electrode area till 70% of flow area for preventing mitigation of fluid circulation.

$$S_{e1} = S_{pr} \cdot 0.7, \qquad (3)$$

whereS_{pr} – DESG flow area.

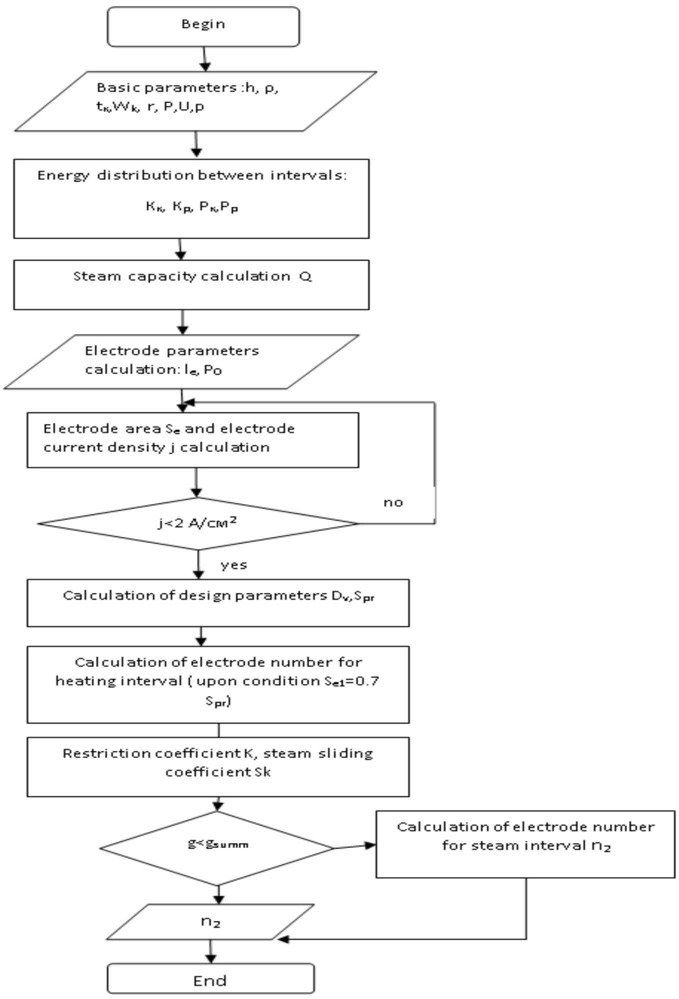


Figure 5 Calculation algorithm

Interelectrode interval length takes in accordance with current standards.

If the curve specific resistance-temperature is specified, sothe zone divides into two parts with conductivities g_{1cp} u g_{2cp} accordingly. In result, whole heating zone power can be calculated as:

$$P_к = U^2 g_\Sigma = U^2 (g_{1cp} + g_{2cp}) \quad (4)$$

Average interelectrode interval conductivity is:

$$G_{icp} = \frac{Se}{\rho_{icp} l_э}, \quad (5)$$

Where *se*- electrodearea, *le*-interelectrode interval.

Consequently, interelectrode interval number for heating zone equation is:

$$n_i = \frac{g_{cpi}}{G_{cpi}} = g_{cpi} \frac{\rho_{cpi} l_э}{S_э} \quad (6)$$

Totalamountofinterelectrodeintervalscalculatesbysummarisingofresultant value n_i for each interval of averaging.

Steam zone

Liquidtemperatureinsidesteamzoneisstableandequaltoboilingtemperature.

Duringheatingprocessoneachinterelectrodeintervaldefiniteamountofsteamisproduced. As steamisnon conductive medium, total conductivity of interval decreases. Dueto water-steam mixture upstream moving more part of electrodes will be occupied with steam and less will stay in conductive mode. Thelastinterval will have the massive amount of steam and will be almost non-conductive.

For evaluation process following assumptions is made:

- Steam producing has constant boiling temperature
- Steam bubbles rising rate is close to rate of water flow,$\upsilon_w = \upsilon_s$.

During vertical flow of steam and water mixture it rates are not equal. This fact is explained with considerable difference of steam and water density. Under boiling temperature 300˚C steam density is 46,93 kg/m^3, but for water density is 712 kg/m^3.

Difference between steam and water flow rate is described as sliding process. Results of this process arethatreal characteristic sofwater-steam mixture will differ from the ones, obtained during the homogenous model analysis. Inthepaperisprovidedresearchofvariousslidingfactorsonelectrodenumbers and other ESG parameters according to algorithm Figure 5.

4. RESULTS

The main process for down hole electro steam generator is steam producing. Due to fact that vapour formation is carried into the steam zone, steam production needs to be calculated for each interelectrode interval and be summarized.

Steam productivity is defined with electrode area and flow rate values. Changing sliding co efficient from 2% till 5%, the following results was obtained (Figure6). With sliding increase number of electrodes is less, because steam flow is faster.

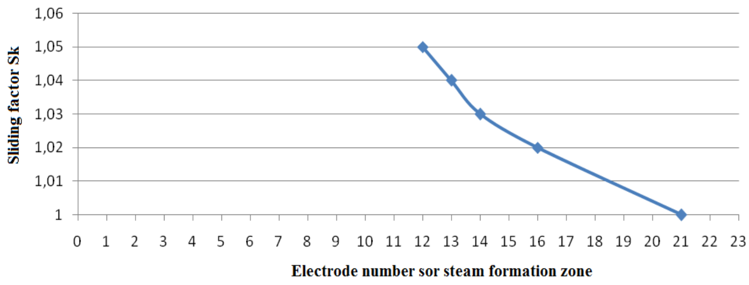


Figure 6 Electrode quantity – sliding factor curve

Usingobtainedresultsandcalculationalgorithmtheformationdepthimpactonelectrodenumber sandpowerdistributionbetweenintervalscanbeinvestigated.

Results for 2 MVt complex with voltage 6 kVis shown in Figure7.

For small depth (till 900m) power mostly consumed at heating interval, because of boiling temperature rising (from 230 to 350ºC). On the depth 900 m power distribution is equal for both intervals, and after 1000 m steam zone power starts decreasing.

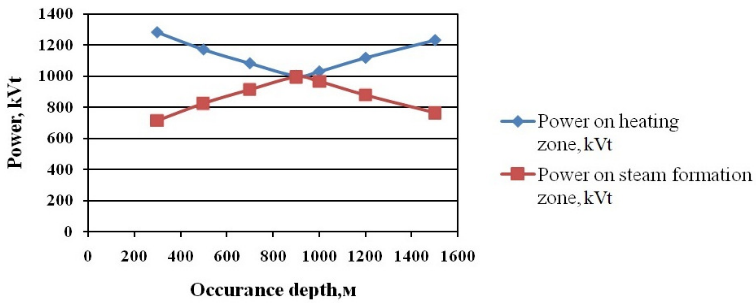


Figure 7 Power sharing in dependence of occurance depth

5. CONCLUSION

Thus, we can conclude: with an increase of the formation depth range of power distribution at intervals changes, the output power at heating zone increases and the evaporation power decreases. Together with these number of interelectrode intervals changes.

Analyzing the obtained results, the optimal design for any depth is proposed- 6 heating intervals and 13 steam intervals when steam sliding is 5%.

Based on the dependencies obtained and the calculated model, it is possible to build an algorithm for control the electro thermal complex.

The dependence of the power distribution on the formation depth has shown showed that up to 900 m with increasing depth, the power for heating decreases, for vaporization increases. After 900 m more energy is used for heating, the power for vaporization decreases.

The number of electrodes with depth increases in the heating interval, and decreases in the steam zone.

REFERENCES

[1] BP.BP Statistical Review of World Energy. 2018. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

[2] BP. *BP Statistical World Energy*.2017. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2017-full-report.pdf

[3] BP.*BP Statistical World Energy*.2016. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2016-full-report.pdf

[4] Alvarado, V. and Manrique,E. Enhanced Oil Recovery: An Update Review. *Energies*, **3**, 2010, pp. 1529-1575.

[5] Guo, K.,Hailong, L. and Zhixin, Yu. In-situ heavy and extra-heavy oil recovery: A review. *Fuel*,**185**, 2016, pp. 886-902.

[6] E.A. Zagrivniy, V.I. Malarev, O.B. Lakota, V.O. Zyrin. Environmental and economic prospects for the use of electrothermal complex for the extraction of heavy oil. *Neftyanoekhozyaystvo – Oil Industry*,**11**, 2012, pp. 118-122.

[7] Lager, A, Webb, K. J, Black, C. J. J, Singleton, M, Sorbie, K. S.Low salinity oil recovery—an experimental investigation.*Petrophysics,***49**, 2008, pp. 28–35

[8] Barillas, J. L.M.,Dutra, T.V.Jr. and Mata,W. Improve oil recovery process for heavy oil: a review. *Brazilian Journal of Petroleum and Gas*, **2**(1),2008, pp. 45-54.

[9] Babadagli, T. Evaluation of EOR methods for heavy-oil recovery in naturally fractured reservoirs. *Journal of petroleum science and Engineering*, **37**(1-2), 2003, pp. 25-37.

[10] Speight, J. G. Thermal methods of Recovery. In: *Heavy Oil Production Processes*. Elsevier,2013, pp. 93-130.

[11] Galvão, E. V.P.,Rodrigues,M. A.F., Barillas, J.L.M.,Dutra Jr.T.V. and Mata, W. Optimization of steam and solvent injection as an improved oil recovery method for heavy oil reservoirs. *Computer Aided Chemical Engineering*,**27**, 2009, pp. 863-1868.

[12] Barillas, J.L.M.,Dutra, Jr.T.V. andMata, W. Reservoir and operational parametes influence in SAGD. *Journal of Petroleum Science and Engineering*,**54**(1–2),2006, pp. 34-42.

[13] Davletbaev, A.,Kovaleva, L. andBabadagli,T. Mathematical modeling and field application of heavy oil recovery by radio-frequency electromagnetic stimulation. Journal of Petroleum Science and Engineering, **78**(3-4), 2011, pp. 643-653.

[14] Rangel-German, E.R.,Schembre, J.,Sandberg, C. andKovscek, A.R. Electrical-heating-assisted recovery for heavy oil. *Journal of Petroleum Science and Engineering*, **45**(4-5), 2004, pp. 213-231.

[15] Zyrin, V. andIlinova, A. Ecology safety technologies of unconventional oil reserves recovery for sustainable oil and gas industry development. *Journal of Ecological Engineering*,**17**(4),2016, pp. 35-40.

[16] Nikolaev, N. andTianli, L. The modern technology of drilling and casing of well during the exploration of gas hydrates. *Journal of Mining Institute*, **218**, 2016, pp. 206-214.

[17] Zagrivniy, E.A., Malarev, V.I., Melnikova, E.E. *Device for wellbore heat treatment*. RU patent 2368760, September 27,2009.

[18] Zagrivniy, E.A., Malarev, V.I., Lakota, O.B. andZyrin, V.O. *Downhole electrosteam generator-separator*. RU patent 2451158. May 20, 2012.

[19] Zagrivniy, E.A., Ustinov, D.A.,Malarev, V.I. andZyrin, V.O. The work effect of downhole electothermal complexes on electric power quality. Russian Electrical Engineering, **82**(10), 2011, pp. 537-540.

[20] Zagrivniy, E.A., Kozyaruk, A.E.,Malarev, V.I. andMelnikova,E.E. Prospects of applying bottom-hole electrothermal complexes to increase oil recovery of layers with high-viscosity oil. *Russian Electrical Engineering*, **81**(1), 2010,pp. 31-36.