TECNOLOGIA DE INDUÇÃO NA PRODUÇÃO DE PETRÓLEO DE ALTA VISCOSIDADE NO CAMPO DE TAZOVSKOYE

INDUCTION TECHNOLOGY IN HIGH-VISCOSITY OIL PRODUCTION AT TAZOVSKOYE FIELD

ИНДУКЦИОННЫЕТЕХНОЛОГИИВВОПРОСАХДОБЫЧИВЫСОКОВЯЗКОЙНЕФТИТАЗОВСКОГОМЕСТОРОЖДЕНИЯ

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RESUMO

O artigo aborda os métodos de produção de petróleo viscoso e de alta viscosidade que também são relevantes para o campo de condensado de óleo e gás de Tazovskoye. As zonas afetadas pelo calor foram identificadas para garantir o desenvolvimento mais eficaz do campo de petróleo viscoso e de alta viscosidade. Estudos e resultados de pesquisas de patentes têm sido usados para determinar quatro métodos térmicos mais eficazes de controle de propriedades reológicas de alta viscosidade: aquecimento local, aquecimento por co-corrente, aquecimento de estágio local e aquecimento co-corrente local. Os sistemas térmicos existentes para a implementação destes métodos térmicos foram analisados e os sistemas eletrotérmicos baseados na tecnologia de indução foram escolhidos. A eficiência da tecnologia de indução é devido a uma alta gama de fluxo térmico formado e implementação de dois modos: manutenção de temperatura e aquecimento de emergência. O aquecimento local pode ser assegurado por um aquecedor de indução no fundo da área da face ou um gerador de vapor elétrico de indução para a ação térmica não apenas na área da face, mas em toda a formação de produção. Um dispositivo de aquecimento foi proposto com base nos resultados da pesquisa de patentes de sistemas de aquecimento por indução para óleo de alta viscosidade. Um componente versátil operado por um ímã foi proposto como um corpo de aquecimento do sistema de aquecimento por indução.

Palavras-chave: *Óleo de alta viscosidade, Aquecimento por indução, Corrente parasita, Eletrotécnica, Linha de fluxo, Tubulação de processo, Tanque.*

ABSTRACT

The article addresses viscous and high-viscosity oil production methods that are also relevant to Tazovskoye oil-gas condensate field. Heat-affected zones have been identified to assure the most effective development of the viscous and high-viscosity oil field. Study and patent research results have been used to determine four most effective thermal methods of high-viscosity oil rheological properties con-trol: local heating, cocurrent heating, local stage heating, and local cocurrent heating. Existing thermal systems for the implementation of these thermal methods have been analyzed and electrothermal systems based on induction technology have been chosen. The efficiency of induction technology is due to a high range of the thermal flow formed and implementation of two modes: temperature maintenance and emergency heating. Local heating may be ensured by an induction downhole heater of the face area or an induction electric steam generator for the thermal action not only on the face area, but the entire producing formation. A heating device has been proposed based on results of the patent research of induction heating systems for high-viscosity oil. A versatile magnet-operated component has been proposed as a heating body of the induction heating system.

Keywords: *high-viscosity oil, induction heating, eddy current, electrotechnics, flowline, process pipeline, tank.*

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АННОТАЦИЯ

В статье рассмотрены способы добычи вязких и высоковязких нефтей, актуальные, в том числе, для разработки Тазовского нефтегазоконденсатного месторождения. Определены зоны теплового воздействия для обеспечения наиболее эффективного режима разработки месторождения с вязкой и высоковязкой нефтью. По результатам исследований и патентной проработки определены четыре наиболее эффективных тепловых метода регулирования реологических свойств высоковязкой нефти: локальный нагрев, попутный нагрев, локально-ступенчатый нагрев, локально-попутный нагрев. Проведен анализ существующих термических систем для реализации данных тепловых методов и сделан выбор в пользу электротермических систем на основе индукционных технологий. Эффективность применения индукционных технологий обусловлена высоким диапазоном формируемого теплового потока и реализации двух режимов: поддержания температуры и аварийного разогрева. При этом локальный нагрев может быть выполнен в виде индукционного скважинного нагревателя зоны забоя, либо индукционного электропарогенератора для теплового воздействия не только на зону забоя, но и на продуктовый пласт в целом. На основе результатов патентных исследований индукционных систем нагрева для высоковязких нефтей предложено устройство для реализации процесса нагрева. В качестве нагревательного элемента индукционной нагревательной системы предложен многофункциональный электромагнитный компонент.

Ключевые слова: *высоковязкая нефть, индукционный нагрев, вихревой ток, электротехнологии, промысловый трубопровод, технологический трубопровод, резервуары*.

INTRODUCTION

The relevance of abnormal oil production is conditioned by the promising nature of viscous and bituminous oil field development, which is evidenced by numerous treatises and developments of scientists from the countries that have proven reserves of abnormal oil (Konesev *et al.,* 2013b, c, d). Research and development of the devices is ongoing to facilitate viscous minerals extraction, their further transportation and processing. Many oil companies such as Gazprom JSC, LUKOIL JSC, Tatneft JSC, Bashneft JSC, etc. have viscous oil fields. Possession of such natural resources urges companies to fund research and development of technical solutions.

However, at the present stage of technology development, devices used in Russia to produce, pump and process viscous and high-viscosity oil have been borrowed from foreign countries such as Canada, Norway and US.

Analytical review of existing advanced recovery and oil preconditioning methods based on electrophysical systems has shown that these systems may be divided into three groups based on the area of influence: wellhead and surface field equipment, linear well portion, face with producing formation (Konesev and Sadikov, 2012; Konesev *et al.,* 2011a, b, 2014; Konesev, 2005; Makulov *et al.,* 2008, 2009).

MATERIALS AND METHODS:

Oil and gas producer Gazprom dobychaYamburg LLC has in as its asset a license area at Tazovskoye oil-gas condensate field (TOGCF) with reserves of high-viscosity oil with dynamic viscosity of up to 170 MPa·s. This oil complicates the processes of hydrocarbon production, preparation and transportation.

The authors use the data of Gazprom dobychaYamburg LLC on physical and chemical properties of the oil produced to as-sess efficiency of the fluid rheological properties control technology. Oil chemistry depends on a field to a large extent and it ranges from paraffin hydrocarbons to naphthene and asphaltene hydrocarbons containing cycloparaffin hydrocarbons. Oil viscosity is mainly affected by gum content (at TOGCF – 7.16%), with the freezing point of minus 25 °C.

Plot of fluid kinematical viscosity against temperature has been built based on the physical and chemical composition of the oil produced (fig. 1). The plot shows borders of the heated fluid state in dotted horizontal lines. It turns into high-viscosity oil at a fluid temperature of under 50 °C. In the temperature range of 50 to 80 °C, oil acquires the state typical of high-viscosity oil. This range is the optimal thermal regime for viscous oil production and pumping. At a temperature of over 80 °C, oil viscosity goes down insignificantly, but it is accompanied with oil light fractionation and there is a risk of coking.

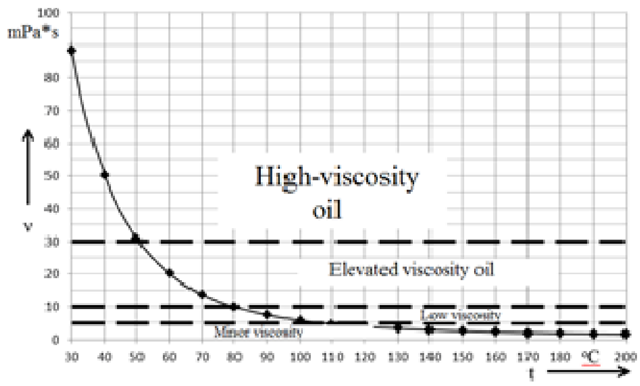


Figure 1.*Kinematical viscosity dependence on temperature*

Analysis results have been used to determine three focus areas for the design of technical solutions for the systems of thermal action on wellhead and field equipment, well, face and producing formation. The most effective, safe and energy-efficient heat formation and transfer systems are electrothermal systems that have been used in the oil industry since the middle of the last century. They include heating cables and constant and variable power tapes (self-adjusting), skin-systems for cocurrent temperature maintenance and industrial frequency induction systems.

Viscous and high-viscosity oil heating is subject to the temperature range and thermal action gradient, fire and industrial safety regulations. Existing heating systems have low energy efficiency and response rate; they do not yield efficient heat transfer and do not enable control over the heating process all through the facility. Besides, OGBAs require heating system operation in two major modes: emergency heating and temperature maintenance; thus, heating systems must have deep (10-15-fold) power adjustment (Thorat *et al.,* 2016; Pan *et al,.* 2012; Erikson *et al.,*1990; Khlyupin, 2015). Fire and industrial safety of viscous and high-viscosity oil heat transfer at oil and gas complex facilities may be assured through the design and implementation of induction heating systems.

The methods and systems implemented using induction heating technology are discussed below.

2.1. Local face heating method and system

Several technical solution options are available:

- electric steam generator (ESG);

- induction downhole heater.

An induction downhole heater comprising a wellhead-assembled power and control unit, supply cable and heat exchanger down the hole is proposed for local heating. Compared to existing devices, induction downhole heater enables local fluid heating without interrupting the oil extraction process (Konesev *et al.,* 2013a).

Results of simulation analysis have been used to develop a local face heating system, which represents ESG. This device may be used for thermal treatment of high-viscosity oil producing formations, to re-establish formation's hydraulical connection with the well, enhance recovery of high-viscous oil formations, increase well debit and resume operation of non-commercial oil, natural gas, fresh, mineral and thermal water producers.

2.2. Local cocurrent heating method and system

The authors propose the method and induction heating system for its implementation. According to this method, heating is conducted to the scale formation depth using the heating system that comprises a line heating body as a running steel guide and a running supply core. Electric current is supplied to this core. This current is closed at the heating system's head to the line heating body. High-frequency electrical current is supplied to the supply core to affect the line heating body's metal with high-frequency field of the supply core. Electric currency frequency is set at the lower threshold so that the penetration depth of the high-frequency field into the line heating body's metal is lower than its thickness. Primary heat release is arranged along the length of the line heating body by increasing the electric current frequency. Electric current is closed at the heating system's head between the line heating body and supply core with a locking dog. The locking dog is arranged on a ferromagnetic core. The temperature of the ferromagnetic core and its medium is controlled with the temperature sensor installed at the heating system's head and is adjusted by the control system in the required range when running the heating system. Next, after the heating system has been completely run into the well, the heating control system puts the ferromagnetic core into the saturation mode and heat mainly releases along the length of the line heating body as the locking dog features decreasing dependence of resistance on saturation of its ferromagnetic core (Konesev *et al.,* 2015).

This method and its implementing device may be used for the preventive maintenance and repair of oil and gas producers and for the elimination of hydrate-wax plugs and maintenance of optimal thermal conditions in wells for the prevention and elimination of hydrate-wax and asphaltic resinous deposits on the inside of the tubing. The heating system proposed has broader functionality in terms of its application when removing DARP as it may be used to eliminate deposits with different fusing points. Enhanced reliability of the heating system is conditioned by a possibility to use magnetic materials that are stronger than ferrites.

2.3. Local stage heating method and system

The authors propose the method and induction heating system for its implementation that implies heating of the bottom-hole and linear portion of the tubing. The linear portion is heated with the local heaters that maintain the pumped fluid temperature in the range between DARP crystallization and oil emulsion coking temperature. Their location through the well is determined based on an operating procedure (Konesev *et al.,* 2016).

The proposed viscous fluid heating device to be used during oil field development comprises a heating system consisting of the bottom-hole zone heater, line heaters and control system. The bottom-hole zone heater and line heaters are local heating inductors arranged on the tubing throughout the length of the well and spaced according to an operating procedure.

In the method and its implementing device proposed, inductors are wrapped around the tubing, which ensures better magnetic coupling with the tubing compared to the lateral arrangement of the inductor. This inductor's arrangement ensures more effective absorption of the inductor-generated electromagnetic field by the tubing with resulting increase in the heating rate and heat efficiency. The required temperature conditions of well operation are ensured by the control system by way of activating and deactivating inductors subject to operating practices. Besides, process controllability is enhanced by controlling the heat flow generated by each inductor. Since multiple inductors are engaged in operation with individual control enabled, installation has better controllability.

This method and its implementing device are to be used to heat borehole fluids, in particular, paraffin oil and high-viscosity mixtures directly in wells, to eliminate and prevent scale and plug formation in oil and gas producers and ensure rheological properties of viscous fluids.

RESULTS:

The team of authors have proposed a method of electrothermal stimulation of extended pipelines that implies pipeline heating using heating bodies designed as a versatile integrated electromagnetic component (VIEC) arranged on the pipeline. These heating bodies maintain the pumped fluid temperature in the range between DARP crystallization and pumped fluid coking temperature. Heating bodies are designed as two coiled conducting plates divided by an insulator. They are arranged on the pipeline and spaced according to temperature conditions and pumping operating procedure. Each heating body is additionally fitted with a switch connected to the end of the first and start of the second plate of the heating body.

The proposed device of electrothermal stimulation of extended pipelines comprises a power supply, control system, heating bodies arranged on the pipeline and designed as two coiled conducting plates divided by an insulator. They are arranged on the pipeline and spaced according to temperature conditions and pumping operating procedure. The positive pole of the power supply is connected to the start of the first plate of the heating body and the negative pole of the power supply is connected to the end of the second plate of the heating body. Each heating body is additionally fitted with a switch connected to the end of the first and start of the second plate of the heating body. Switches may be both controlled and uncontrolled by the control system.

Another design option is a device with the negative pole of the power supply and the end of the second plate of the heating body electrically connected to the pipeline.

Fig. 2 shows the induction heating system with heating bodies (НЭ1 – НЭ$_n$): L_{cn} is the width of the n^{th} heating body (subject to the required local heating power), $L_{МС(n-1)}$ is the interval between the $(n-1)^{th}$ and nth heating bodies (subject to the environmental heat output properties of pipeline section 1 between the $(n-1)^{th}$ and nth heating bodies), where n is the total number of the heating bodies arranged on the pipeline 1, К1 – Кn are switches of the corresponding heating bodies. The heating process is controlled by control system 3, which determines switching frequency, and ИП 2 that sets the power value, to which heating bodies are charged. In case of an uncontrolled switch, the heating body is charged to the breakdown voltage equal to Uzmax, which is followed by electrical breakdown of the switch. Breakdown voltage of the uncontrolled switch is determined by required heat power.

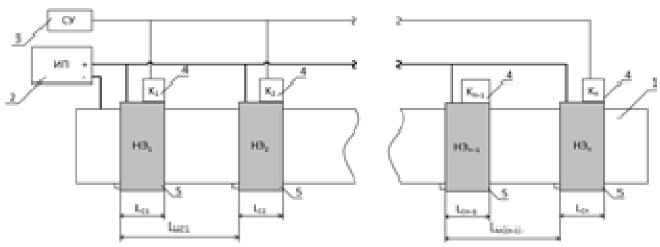


Figure 2. *Induction heating system diagram*

The device operates with an auxiliary main and may be powered by two wires from the positive and negative poles of the power unit. Another design option is a device with the negative pole of the power supply and the end of the second plate of the heating body electrically connected to the pipeline.

The device may operate with various control algorithms set by the control system and implement various thermal action modes subject to switching frequency of each heating body's switch.

The pumped fluid heating rate depends on the following parameters: fluid rate, electric power accumulated by the heating body, switching frequency and discharging circuit parameters.

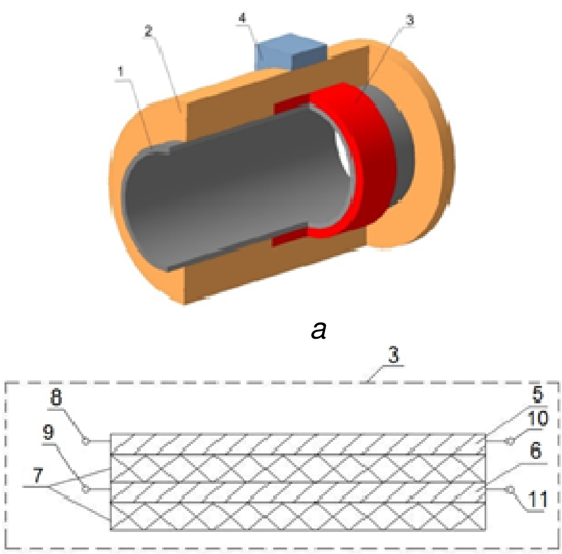
The method proposed and its implementing device are to be used to heat viscous fluids, eliminate and prevent scale and plug formation in pipelines of various applications, in particular, directly in producers, field and main oil lines and processing product lines. Besides, this device may be used at oil and gas, chemical, food industry facilities and other industries engaged in pipeline transportation of viscous fluids.

Thus, the method proposed and its implementing device may apply to oil and gas, chemical, food industry facilities and other industries engaged in pipeline transportation of viscous fluids.

The team of authors have proposed the device for viscous fluid transportation based on viscous oil induction heating (Konesev *et al.,* 2015).The device proposed comprises a carrier pipe, heat-insulating layer, heating body arranged on the pipe. The heating body is designed as two coiled conducting plates divided by an insulator. Each heating body's plate has outputs at the start and end of the plate brought out to a terminal block.

Another design option is a pipe with its terminal at the end of the second plate of the heating body electrically connected to the carrier pipe.

Fig. 3.a shows the pipe for viscous fluid transportation that comprises carrier pipe 1, heat-insulating layer 2, heating body 3, terminal block 4.



b

Figure 3. *Elements of the induction heating system*

a) pipe for viscous fluid transportation;

b) heating body (expanded view)

Fig. 3.b shows heating body 3 in expanded view that comprises two plates 5 and 6 divided by insulator 7. Each plate of the heating body has outputs 8,9 at the start and 10,11 at the end of the plate.

The pipe for viscous fluid transportation is made as follows: heating body 3 designed as conducting plates 5, 6 divided by insulator 7 is arranged on carrier pipe 1 (it is directly wrapped around the pipe or first wrapped around a cylinder-shaped frame and then slipped over the pipe). Outputs at the start 8, 9 and at the end 10, 11 of each conducting plate 5 and 6 are brought out to terminal block 4. Heat-insulating layer 2 is applied over carrier pipe 1 and heating body 3.

The pipeline comprising the pipes of the design described is assembled as follows. Adjacent pipe ends are connected; some pipes may be free of the heating body. Number and location of pipes with heating bodies are subject to an operating procedure.

Thus, heat losses during viscous fluid transportation are reduced thanks to the heat-insulating layer, efficiency of heat transfer to the carrier pipe is enhanced by the design and location of the heating body, assembly is made easier and more reliable due to an independent pipe and electrical connections and broader functionality is offered when designing pipelines with different viscous fluid transportation temperature conditions.

DISCUSSION:

Induction heating is traditionally used in the iron and steel industry for metal fusing, soldering and welding, base metal thermal treatment, shallow quenching. Outstanding scientists such as L. R. Neuman, A. V. Donskoy, N. M. Rodigin, A. B. Kuvaldin, V. B. Demidovich, S. A. Gorbatkov, A. E. Slukhotskiy, N. P. Glukhanov, K. Z. Shepelyakovsky, Yu. I. Blinov, V. V. Tsarevsky, S. V. Dzliev, M. N. Kudryash, G. I. Babat, A. M. Wineberg and others have made a major contribution to the study of theoretical and practical tasks in this field.

Compared to conventional induction heating, a focus on the study and settlement of tasks in fluid induction heating is lacking. Scientists A. N. Danilushkin, A. M. Batischev, D. A. Zinatulin, M. L. Strupinsky, N. N. Khrenkov, S. K. Zeman, S. G. Konesev, I. A. Makulov, Yu. A. Nikitin and others are engaged in active research and settlement of practical tasks in this field.

The following enterprises are engaged in the development and industrial production of fluid induction heating systems in the Russian Federation and CIS: Gas-Project Engineering LLC, Ufa, Vikhr RDTB FSUE, Ufa, Induction Heater Factory LLC, Moscow, Special Systems and Technologies, Mytishchi, Siberian Engineering Machine Building Plant CJSC, Novosibirsk, Energodiagnostika Co. Ltd ERC, Ufa, etc.

CONCLUSIONS:

1. Use of electrophysical methods of thermal action in viscous fluid production, pumping and transportation is recognized as relevant. Analytical review of advanced recovery methods based on electrothermal systems shows that these systems are classified as follows in terms of their impact areas: wellhead zone, linear well portion and face area.

2. The following induction heating system design options have been proposed by the example of the well tubing: local, cocurrent, local cocurrent and local stage.

3. Considering increased complexity of installation and low operating reliability of concurrent and local cocurrent heating systems due to peculiarities of location of heating bodies for extended pipelines, the local stage heating method proposed by the authors is the most effective in terms of reliability, energy indicators and ease of installation.

4. A distinctive feature of the methods and devices designed is the use of VIEC as a heating body of the induction heating system, the operation algorithm of which is determined by the control system that adjusts switching frequency of each heating body, which, in its turn, determines the heating rate.

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REFERENCES:

1. Konesev, S. G.; Mavlitbayev, R. V.; Sadikov, M. R.; Kondratiev, E. Yu. *Russian patent 2569102* **11/20/2015.** *Bulletin 32.*
2. Konesev, S. G.; Kirillov, R. V.; Sadikov, M. R.; Kondratiev, E. Yu.; Khaziyeva, R. T. *Russian patent 2584137* **5/20/2016**. *Bulletin 14.*
3. Konesev, S. G.; Kirillov, R. V.; Khaziyeva, R. T.; Kondratiev, E. Yu.. *Russian utility model 154768* **9/10/2015**. *Bulletin No. 25.*
4. Konesev, S. G.: Sadikov, M. R., Magzyumov V. M. *Russian patent 2458853* **8/20/2012**. *Bulletin 23.*
5. Konesev, S. G.; Khlyupin P.A. *Current issues of science and education,* **2015**, *2.* www.science-education.ru/122-21282, accessed August 2015.
6. Konesev, S. G.; Khlyupin, P. A. *Current issues of science and education* **2015**, 2. www.science-education.ru/122-21341, accessed August 2015.
7. Konesev, S. G.; Kirillov, R. V.; Kondratiev, E. Yu.; Sadikov, M. R.; Khaziyeva, R. T.; Khlyupin, P. A *Oil and Gas Business: scientific and technical journal.* **2014**, 12, 4, 40-47.
8. Konesev, S. G.; Kondratiev, E. Yu.; Rizvanova, S. I. *Collected works of the I international (IV national) scientific and technical conference "Electric drive, electrotechnics, and industrial electric equipment". Conference proceedings*. Oil and gas business, Ufa, 2013, 183-186. (2013a)
9. Konesev, S. G Khaziyeva, R. T.; Khlyupin, P. A.; Kondratiev, E. Yu *Oil and Gas Business: electronic scientific journal* **2013,** 5, 11. http://ogbus.ru/authors/KonesevSG/KonesevSG_1.pdf, accessed October 2014.(2013 b)
10. Konesev, S. G.; Khakimyanov, M. I.; Khlyupin, P. A.; Kondratiev, E. Yu. *Electrotechnical systems and complexes* **2013,** 21, 301-307.(2013 c)
11. Konesev, S. G.; Khlyupin, P. A. *Oil and Gas Business: scientific and technical journal* **2012**, 12, 3, 92-95.
12. Konesev, S. G. *Challenges and methods to ensure reliable and safe systems of oil, petroleum products, and gas transportation'. Proceedings of the VI Congress of oil and gas producers of Russia: Abstracts of the research and practical conference,* 2005, 31-32.
13. Konesev, S. G.; Khlyupin, P. A.; Muslimov, K. I.; Kondratiev, E. Yu. *Electric drive, electrotechnics, and industrial electric equipment: Collection of studies of the I international (IV national) scientific and technical conference.*Oil and Gas Business: Ufa, 2013, 194-199.(2013 d)
14. Konesev, S. G.; Khlyupin, P. A. *Life safety*. **2012**, 7, 43–47.
15. Makulov, I. A.; Konesev, S. G.; Khlyupin, P. A. *Electric drive, electrotechnics, and industrial electric equipment: Collection of studies of the II national scientific and technical conference.* UGNTU: Ufa, 2009, 2, 21-25.
16. Makulov, I. A.; Mamayev, N. M.; Konesev, S.G. *Oil and Gas Business*, **2008**, 2. http://www.ngdelo.ru/2008/2/75-79.pdf.
17. Konesev, S. G.; Khlyupin, P. A.; Makulov, I.A.;Nikitin, Yu.A. *Russian patent 2417563* **4/27/2011**. *Bulletin 12.*(2011a)
18. Konesev, S. G.; Khlyupin, P. A.; Makulov, I. A.; Nikitin, Yu. A. **3/27/2011**. *Bulletin* 9. (2011b)
19. Thorat, S.; Thibodeau, C.; Collier, B.; Ngo, H. *Proc. IEEE Industry Applications Magazine*. **2016,** 23, 2, 62-73,doi: 10.1109/MIAS.2016.2600687.
20. Pan, Y.; Zhang, J.; Wang, X.; Yang, S. *IOSR Journal of Engineering.* **2012**, 2, 8, 39-44.
21. Erikson, C. J.;Lyons, J. D.; Rafferty, N. R.; Sandberg, C. *Proc. Industry Applications Society 37th Annu. Petroleum and Chemical Industry Conf.*1990, 9-17.
22. Khlyupin, P. A. Induction heating system for oil pipelines. *PhD Thesis,* Ufa State Aviation Technical University,Ufa, 2015.