PERM JOURNAL OF PETROLEUM AND MINING ENGINEERING
ВЕСТНИК ПНИПУ. ГЕОЛОГИЯ. НЕФТЕГАЗОВОЕ И ГОРНОЕ ДЕЛО
ISSN 2224-9923
Volume / Том 20 №1 2020
http://vestnik.pstu.ru/geo/

UDC 622.276+622.245:622.248.3

Article / Статья

PREVENTING AND ELIMINATING WELL-COMPLETION PROBLEMS

Mariia V. Nutskova, Vyacheslav N. Kuchin, Vlada S. Kovalchuk

Saint Petersburg Mining University (2 21st line, Vasilyevsky island, Saint Petersburg, 199106, Russian Federation)

ПРОФИЛАКТИКА И ЛИКВИДАЦИЯ ОСЛОЖНЕНИЙ, ВОЗНИКАЮЩИХ ПРИ ЗАКАНЧИВАНИИ СКВАЖИН

М.В. Нуцкова, В.Н. Кучин, В.С. Ковальчук

Санкт-Петербургский горный университет (199106, Россия, г. Санкт-Петербург, Васильевский остров, 21-я линия, 2)

Received / Получена: 02.10.2019. Accepted / Принята: 10.01.2020. Published / Опубликована: 02.03.2020

Key words:
well-drilling, completion, complications, laboratory analysis, rheology, viscoelastic compositions, temporary isolation, cementing, interstratal cross-flows, water inflow, water shut-off, filtration, carbon materials, cements, graphene.

The article reflects the importance of improving the quality of oil and gas well completion. The problem of improving well operational efficiency sets the requirement for a high-tech approach to solving the whole range of tasks from the design and construction of an oil and gas well to its completion, workover and abandonment. The article mentions the major problems arising at the well completion stage. In particular, it provides a review of poor-quality cementing consequences, including the formation of filtration channels resulting in a cross-flow and increased watercut; the contraction effect; and the mismatched cement compositions that affect the formation isolation and the oil, gas and water showing. The authors outline the methods for repair and renewal operations aimed at well uploading. In addition, they show existing technologies for recovering well casing integrity during remedial insulation, as well as the methods to improve the quality of a well casing at its construction. Moreover, the article presents the developed technology of temporary aquifers in-process isolation with compositions of viscoelastic systems. Studying water shut-off techniques for the existing wells determines the focus for the scientists, who work on creating new and improving the existing blocking agents to get better result from their application and lower operational costs. The authors recommend using the advanced compositions of viscoelastic systems to shut-off aquifers while drilling. In order to strengthen the cement stone and, as a consequence, the well casing, the following fields could be proposed for further study: upgrading the cement slurry quality with carbon additives, such as soot, carbon black, graphite, oxidized graphite, graphene, graphene oxide, and carbon nanotubes.

Ключевые слова:
бурение скважин, заканчивание, осложнения, лабораторные исследования, реология, вязкоупругие составы, временная изоляция, крепление, межпластовые перетоки, водопритоки, ограничение притока, фильтрация, углеродные материалы, цементы, графен.

Отражена актуальность повышения качества заканчивания нефтегазовых скважин. Проблема повышения эффективности работы скважины формирует потребности в высокотехнологичном подходе к решению поставленных задач, начиная от проектирования и строительства нефтегазовой скважины до ее заканчивания, ремонта и ликвидации. Рассмотрены основные направления осложнений, возникающих при заканчивании скважин, в особенности представлен обзор последствия некачественного цементирования – образование каналов фильтрации, приводящих к межпластовым перетокам и повышению обводненности скважинной продукции, контракционный эффект и неправильно подобранные тампонажные составы, влияющие на разобщение пластов и нефте-, газо-, водопроявление. Кратко представлены методы проведения ремонтно-восстановительных работ по возвращению скважины к жизни. Показаны существующие технологии восстановления герметичности крепи скважины при проведении ремонтно-изоляционных работ, а также пути повышения качества крепи скважины на этапе ее строительства. Представлена разработанная технология временной изоляции водоносных горизонтов на этапе бурения в виде составов вязкоупругих систем. Изучение механизмов водоизоляции пробуренных скважин определяет вектор деятельности ученых, которыми ведутся работы по созданию новых и улучшению уже имеющихся блокирующих составов с целью повышения технического результата от их применения и снижения затрат на проведение работ подобного рода. Авторы рекомендуют применять перспективные составы вязкоупругих систем для блокирования водоносных горизонтов в процессе бурения. Для повышения прочности цементного камня и, как следствие, крепления ствола скважины предлагаются пути дальнейшего изучения – повышение качества тампонажного раствора путем ввода углеродных добавок, таких как сажа черная, сажа техническая, графит, окисленный графит, графен, оксид графена, углеродные нанотрубки.

Mariia V. Nutskova (Author ID in Scopus: 57191341737) – PhD in Engineering, Associate Professor at the Well Drilling Department (tel.: +007 965 014 97 85, e-mail: Nutskova_MV@pers.spmi.ru, turitsyna_maria@mail.ru). The contact person for correspondance.
Vyacheslav N. Kuchin (Author ID in Scopus: 57202346922) – PhD student at the Well Drilling Department (tel.: +007 921 366 76 23, e-mail: cuchin.vya4eslaw2013@yandex.ru).
Vlada S. Kovalchuk – PhD student at the Well Drilling Department (tel.: +007 981 708 79 88, e-mail: vlada.1995@inbox.ru).

Нуцкова Мария Владимировна – кандидат технических наук, доцент кафедры бурения скважин (тел.: +007 965 014 97 85, e-mail: Nutskova_MV@pers.spmi.ru). Контактное лицо для переписки.
Кучин Вячеслав Николаевич – аспирант кафедры бурения скважин (тел.: +007 921 366 76 23, e-mail: cuchin.vya4eslaw2013@yandex.ru).
Ковальчук Влада Станиславовна – аспирант кафедры бурения скважин (тел.: +007 981 708 79 88, e-mail: vlada.1995@inbox.ru).

Introduction

Drilling oil exploration and production wells is one of the most high-tech processes. Within a well construction cycle, the drilling stands between the design (encompassing the entire range from an investment project to a well-construction one) and the completion. Thus, the drilling links a production formation (a reservoir) with a technology (as the key efficiency factor) – technically, economically and administratively.

Stable profitability of field development can only be achieved by reducing the produced oil cost, which depends on the volume of operating and energy costs by 30-50 %, as well as on the workover costs. The completion, including the innovative one, is becoming increasingly important for the efficiency improvement [1]. In 2017, the well completion equipment market turnover exceeded RUB 15 billion despite being at a relatively early development stage (liner hangers accounted for approximately 50 % of the market). ‘Horizontal’ facilities and systems – new wells, sidetracks, multistage hydraulic fracturing, and others – constitute 55 % of the demand [2, 3].

At each stage from the drilling to production operations, a well is exposed to various process loads. Perforation, hydraulic fracturing, corrosive environment, tripping and other operations inside the casing string have a strong impact on the well casing integrity and, above all, on the cement stone, which is one of the key elements in a well.

A poor cementing quality may be a reason for incorrect estimate of the explored area potential; identifications of ‘new’ oil deposits and, especially, gas ones in the reservoirs; fluid cross-flows; gryphon formations; and oil, gas and water showing. This is one of the most hazardous complications as it often results in accidents. The fluid cross-flows are quite common in wells. The most complicated and lossmaking emergencies were registered in the fields of Ukraine and Uzbekistan. An enormous cross-flow of formation gas into a string resulted in a well blow-out. In that case, the drillers addressed the issue by drilling an additional relief well for a nuclear explosion, which prevented the gas migration into the well [4]. The given examples illustrate low qualifications of the drilling technicians and their failure to observe the well-drilling regulations and standards.

An increased watercut is one of the adverse effects of the poor-quality well-casing related to making passages for the formation fluid migration. Currently, the watercut level of the Russia's oilfields exceeds 90%. A quality isolation of oil and gas wells and reduced cross-flows remain the principal conditions for a well effective operation. Sealing compounds and devices used in this process should ensure accident-free performance in compliance with operational, environmental and economic requirements [5, 6].

Today, due to the highly problematic situation the scientists are getting focused on studying the shut-off mechanisms (root causes, process, and solutions) for the drilled wells. Despite the wide range of the existing technologies and compositions for remedial insulation to shut-off the water, progress is being made to create new blocking agents and to upgrade the existing ones in order to get better result from their application and to reduce the operational costs.

Methods for Eliminating Water Showings and Inter-casing Cross-flows

At present, a number of trends indicate an increasingly crucial need to address the existing problems in the cementing quality of oil and gas wells. These trends are associated with the growth in production drilling, the development of fields at their late development stage, and the development of new fields with difficult geological and technical conditions. The absence of high-quality and long-term formation isolation, the inter-casing and interstratal showings of oil, gas and water, the cross-flows, the lost circulations and low cement top – all these problems result in the reduced well productivity and low field development efficiency. These in general increase the cost of the workover process in the well development and operation. For a high-quality well support, at all stages from well conditioning to casing running and further cementing, it is necessary to ensure a competent choice of technologies, equipment and materials applied to such operations.

The main reasons that affect the cementing quality of oil and gas wells include:

a) wellbore geometry and drilling mud properties;

b) casing positioning relative to the wellbore axis;

c) reciprocating of the rock destruction tool;

d) time optimization for drilling and cementing the well;

e) performance specifications of the cement injection pump.

The poor well cementing quality can result in interstratal cross-flows and watercuts. This problem can be solved through a remedial insulation in the existing wells and by upgrading the quality of new well casings. The immediate proximity of water and oil-bearing horizons, as well as the geological settings at the well drilling sites, complicated by various formation pressure intervals, result in the wellbore displacement from the given direction and require the use of new technologies and modifying additives for cementing the oil and gas wells.

The studies on water shut-off classify the remedial insulation by its complexity, and suggest feasible technologies to eliminate the watercut reasons. As a result, the authors have classified the remedial insulation into four categories by complexity [7–10]. The easiest remedial insulation include:

– fixing the wellbore leaks

– reducing and preventing the interstratal fluid migration completely

– building a tight cofferdam to isolate the water horizon from the producing formation

The well insulation and workover are performed to shut the extraneous waters off the production zone, to prevent gas migration, and to strengthen the wellbore. The remedial insulation in the oil and gas wells employ wellbore cementing technologies including those under pressure, installation of a mechanical clad (a profile packer), and sometimes injection of special polymeric compositions.

Since the high-quality isolation of pressure horizons at the construction stage can determine the durability of wells as permanent structures, special attention should be paid to their cementing quality. Insufficient cement strength may result in a reduced well performance, a damage of wellbore integrity, a reduced integrity, and a breach of environmental requirements, safety rules and regulations. The improved cement performance, primarily, its compressive and bending strength properties, are a priority. It is conventionally addressed by modifying the cement with various natural and artificial chemical additives. In addition, to isolate the formations with saturating fluids of different properties, it is a good practice to temporary isolate them at the drilling stage, especially with regard to the intervals of possible water inflows.

Technology of Temporary Pressure Horizon Isolation

The development of new compositions and technologies enabling engineers to shut-off water inflows are covered in the studies of a number of scientists both in Russia [11–16] and overseas [17, 18]. The scientists including V.A. Blazhevich, V.G. Umetbayev, N.A. Abdrakhimov, V.A. Strizhnev, I.I. Kleshchenko, S.S. Demichev, K.V. Strizhnev among others paid special attention to the study and adaptation of synthetic resins [19–30]. There are several technology trends to address the problem of trouble-proof aquifers shut-off. For example, the most frequently applied technology is a selective water inflow shut-off, which combines temporary formation isolation during remedial insulation, and the PBL technology (a circulation sub). The circulation sub contains a circulation valve, which enables a fluid flow multiple switching from the drill string inner space to the annular space, bypassing all the elements of the bottom-hole assembly (BHA) below the PBL [31]. However, this technology does not allow for pressure control in the annular space [32]. For the operations that increase the efficiency of well completion in the intervals of uncontrolled inflow, it is suggested to use a pressure regulating device in the drilling with simultaneous injection of a blocking agent at the aquifer drill-in [33].

Currently, the agents based on oil-well cement with various polymer additives improving their adhesion and strength properties, special powder materials, mixtures containing silicon and/or organic materials, polymeric and gelling agents, etc. are used for the water shut-off. Various combinations of reinforcing compositions are also used. They have an advantage due to the possibility to adjust their properties to the geological and technical conditions of a particular application. Of all the proposed waterproofing agents, the viscoelastic compounds are among the most promising materials for the aquifers in-drilling shut-off to control water inflow and inter-casing cross-flows. According to this method, a gelling agent, which at the initial moment is a low-viscosity fluid, is pumped into a well. After a certain period of time the viscosity sharply increases up to the system thickens. In other words, the solution loses its fluidity and right in the formation turns into a gel capable of shutting-off the water-bearing horizons. However, the most viscoelastic waterproofing compounds known to date have a number of drawbacks, such as low permeability, instability in the formation settings, toxicity and high cost. Elimination of such shortcomings may significantly increase the competitiveness of this water shut-off method [5, 6, 34, 35].

Increasing the Formation Isolation Quality during Well Cementing

Providing high sedimentation stability of cementing solutions is one of the most effective methods to improve the formation isolation quality. Otherwise, the permeability of the cement stone may increase, and heavy water inflow may result in cracks in the cement stone [36].

The drilled well quality primarily depends on the integrity of a cemented well. The gas and other formation fluids flow along the inner diameter of a cement ring subject to two critical conditions: the pressure, which is essentially present in the gas presence, and a channel. The channels are formed in the cement stone mainly due to the cement slurry ability to form a vacuum on its surface. Such a decrease in pressure (contraction effect) contributes to the fluids inflow from the wellbore adjacent area, and the dewatering of the static mud and filter cake. The channel appearance in a cement stone during the cement hardening is unavoidable [37].

Reducing the contraction effect is one of the demanding but solvable problems. It is impossible to entirely get rid of the contraction effect, as well as to replace the cement with some other mineral binder. Such technologies are not yet known to-date. Due to the discovery of the contraction effect, scientists were able to comprehend the mechanism of channel formation in a cement stone, identify the affecting factors and formulate the ways to minimize the negative impact of the contraction effect on a well casing.

Adding various additives into the cement slurry is one of the generally accepted methods to reduce the contraction effect. Most often this solution results in a substantial decrease in the mechanical properties of a cement stone. Cement modification with the additives that have a positive influence on the cement stone properties is popular for the primary well cementing.

The study by prof. A.I. Bulatov ‘Determining the Role of the Cement Stone Strength’ shows that the cement stone strength as per the GOST standard does not provide any insight into the potential of the cement application under the conditions of a specific deposit, but only reflects the requirements for cement specifications. After solving the above problems, it is now possible to use cement slurries modified with various additives for oil and gas wells. It has been determined that the cement modification reduces the contraction effect [36].

The standard additives to cement comprise silicates (SiO_2, nanoSiO_2), blast-furnace slag and metallurgical waste; densifiers (baryte, hematite); light-weight additives (hollow plastic microspheres and pellets; air).

At the HPHT (High Pressure High Temperature) conditions we recommend using silicon-containing materials such as quartz sand. Being added to the cement and spacer fluid, the SiO_2 contributes to extra cleaning of the well walls [36, 38].

In case of a well casing insulation, the cement with various property-improving additives is used: polymeric materials and other inexpensive and easily available chemicals of organic and inorganic origin.

Using the cement upgraded with additives for well casing gives a number of advantages:

1) An extensive upgrade to physical and mechanical properties of a homogeneously hardened cement stone, which is characterized by high compressive and bending strength, corrosion and pressure-and-temperature resistance.

2) The impermeability properties of the cement stone prevent the formation fluids from migrating into the well and the drilling mud – into the adjacent wellbore area. Thus, the cement stone prevents a decrease in the bottom-hole zone permeability upon cementing and also contributes to the complete formation isolation [39, 40].

The cement slurry prepared from the standard cement often does not comply with the drilling settings due to its low ability to penetrate into the smallest pores, to prevent formation fluids and gases from migration [39, 40] and to reinforce the wellbore walls.

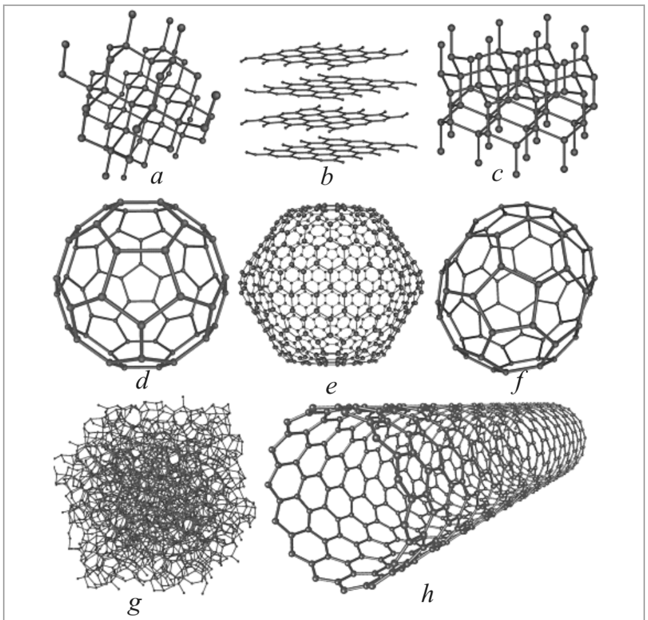

Fig. Modern carbon modifications: *a* – diamond; *b* – graphite; *c* – lonsdaleite; *d* – C60 (fullerenes); *e* – C540; *f* – C70; *g* – amorphous carbon; *h* – single-wall carbon nanotube

The researchers have a reason to believe that the destruction of the annulus cement is always accompanied by caverns and cracks of any size.

In recent years, the carbon-based materials have been actively used as modifiers. By the beginning of the 21st century, three-dimensional (graphite, diamond), one-dimensional (single-wall and multi-wall carbon nanotubes) and zero-dimensional (fullerenes) allotropic modifications of the carbon were known [41]. The figure above shows all studied carbon modifications.

Carbon is a truly unique chemical element, capable of forming a wide variety of chemical structures with improved structural, electrical and mechanical properties.

After the discovery of graphene in 2004, the scientific world has been taking interest in carbon modifications.

The physicists A. Geim and K. Novoselov from the University of Manchester (UK) have synthesized graphene by successive separation of graphite layers using adhesive tape [42]. The inventors were awarded the Nobel Prize in Physics in 2010 for the pioneering experiments with graphene, a two-dimensional form of carbon.

Today, graphene is widely used by not only chemists and physicists but also by doctors, builders, miners, process engineers in all spheres, and even by designers. The new material is becoming increasingly popular due to its unusual mechanical, thermal, electrical and optical properties.

Graphene has quickly found its place in the oil and gas industry. It is widely used to increase the lubricating properties of drilling mud, create corrosion-resistant coatings, cement wells, reinforce rock destruction tools, separate water from oil, clean-up oil spills, complete wells and in many other operations in the well drilling and construction processes [43–45]. Graphene and its derivatives improve cement compositions, which makes their application in well cementing a priority.

Thanks to the graphene boom in the scientific community, researchers from all over the world are now paying attention to various modifications of carbon. Just like grapheme, a three-dimensional modification of carbon – graphite – can be used as nanoscale reinforcement of a cement stone to improve its mechanical properties, integrity and durability. Despite the amazing properties of graphene, the application of graphite and its derivatives in the oil and gas industry is more reasonable due to low cost and high availability of the material.

The analysis of researches conducted abroad [46–55] allowed concluding that the carbon materials improve the pore structure of the cementing matrix, and increase the compressive and bending strength compared to the neat cement. According to the studies, the fluidity of the new hydrophobic and environmentally friendly cement slurry increases, as does the hardness of the cement stone.

The studies by Russian research institutes on well cementing quality have shown complete or partial destruction of the cement stone in the casing string annulus in 15–30 years [36]. Thus, the principal task for the scientists is to study why the cement slurry state changes over time and how to reverse this process.

Conclusions and Recommendations

The application of up-to-date technologies to shut-off water inflows significantly reduces the well repair and operational costs and increases the oil production. The production rate of a single well largely depends on geology, operation modes and stimulation methods as much as on the technical condition of the well structure.

At the same time, new, more efficient insulating materials with low viscosity, higher filterability and adhesion should remain readily available and relatively inexpensive. However, even the most successful waterproofing technologies provide only a temporary solution. When comparing the insulation potential, the insulation ability to restrict the produced water and the duration of this technological effect are the key criteria. Consequently, the quality of creating the additional filtration resistance in the water-saturated reservoir's portion and the reduced water inflow are the basic indicators of the reservoir's oil-saturated portion improvement.

Carbon materials will surely have a very strong impact on the technology in the coming years. A high-quality well casing requires continuous upgrading of the construction and modification materials. The sustainability of introducing the carbon additives into cement compositions is evident from their safe extraction, production and hardening in the cement stone. Using new cement compositions with the carbon additives enables engineers to better address the whole range of global problems, including the drilling mud overflow and lost circulation, equipment sticking, flowability of unstable rock intervals, water, oil and gas showing, formation isolation, etc.

The carbon materials application as additives for the well cementing slurries has not been fully studied yet. Thus, there is a pressing need for further studies in order to successfully apply the new materials in the production of upgraded cement compounds.

References

1. Alekseev A. Innovatsii na gorizonte [Innovation on the horizon]. *Sibirskaia neft*, 2017, no.139, pp.16-23.

2. Britanov F. Rynok vozmozhnostei [Market of opportunities]. *Sibirskaia neft*, 2019, no.162, pp.44-49.

3. Lebedeva N.E. Tendentsii razvitiia neftegazovogo mashinostroeniia RF v usloviiakh realizatsii politiki importozameshcheniia [Trends in the development of oil and gas engineering in the Russian Federation in the context of the implementation of the import substitution policy]. *Innovatsii i investitsii*, 2019, no.11, pp.329-334.

4. Bogoiavlenskii V.I. et al. Katastrofa na Kumzhinskom gazokondensatnom mestorozhdenii: prichiny, rezultaty, puti ustraneniia posledstvii [Kumzhinskoye gas condensate field disaster: reasons, results and ways of eliminating the consequences]. *Arktika: ekologiia i ekonomika*, 2017, no.1, pp.32.

5. Dvoynikov M.V., Nutskova M.V., Kuchin V.N. Analysis and justification of selection of fluids to be used for water shut-off treatment during well completion. *Perm Journal of Petroleum and Mining Engineering*, 2017, vol.16, no.1, pp.33-39.

6. Kuchin V.N., Dvoinikov M.V., Tsygelniuk E.Iu., Nutskova M.V. Sovershenstvovanie tekhnologii izoliatsii vodopritokov pri burenii v intervale anomalnykh plastovykh davlenii [Improving the technology of isolation of water inflow during drilling in the range of abnormal reservoir pressure]. *Neftegazovoe delo*, 2018, vol.16, no.4, pp.51-58.

7. Seright R.S., Lane R.H., Sydansk R.D. A strategy for attaching excess water production. *SPE Production and Facilities*, 2003, vol.18, no.03, pp.158-169. DOI: 10.2118/84966-PA

8. Chen J. et al. Joint operation and dynamic control of flood limiting water levels for cascade reservoirs. *Water Resources Management*, 2013, vol.27, no.3, pp.749-763.

9. Strizhnev K.V. Klassifikatsiia tamponazhnykh materialov dlia remontno-izoliatsionnykh rabot v skvazhinakh [Classification of backfill materials for repair and insulation works in the wells]. *Oil industry*, 2010, no.12, pp.63-65.

10. Kurbanov Ia.M. et al. Opyt provedeniia remontno-izoliatsionnykh i likvidatsionnykh rabot na starom fonde geologo-razvedochnykh skvazhin [Experience of performing repair-insulation and liquidation operations of old exploration wells]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2013, no.12, pp.33-38.

11. Beili B. et al. Diagnostika i ogranichenie vodopritokov [Diagnosis and limitation of water inflows]. *Neftegazovoe obozrenie*, 2001, vol.6, no.1, pp.44-68.

12. Dubinskii G.S. O planirovanii tekhnologii stimuliatsii skvazhin i ogranicheniia vodopritoka [On planning well stimulation technologies and water inflow restrictions]. *Neftegazovye tekhnologii i novye materialy. problemy i resheniia*, 2015, pp.138-146.

13. Kadyrov R.R. et al. Ogranichenie vodopritoka v treshchinovato-poristykh karbonatnykh kollektorakh s ispolzovaniem vodonabukhaiushchikh elastomerov [Water shutoff jobs in porous-fractured carbonate reservoirs using water-swellable elastomers]. *Oil industry*, 2014, no.4, pp.70-72.

14. Zemtsov Iu.V. et al. Retrospektivnyi analiz metodov ogranicheniia vodopritokov, perspektivy dalneishego razvitiia v Zapadnoi Sibiri [Retrospective analysis of methods applied for water inflows limiting, prospects of further development in the Western Siberia]. *Neftepromyslovoe delo*, 2014, no.4, pp.17-22.

15. Kadyrov R.R. et al. Ogranichenie vodopritoka v gorizontalnykh skvazhinakh na mestorozhdeniiakh s trudnoizvlekaemymi zapasami nefti [A novel water shut-off technique for horizontal wells at fields with hard-to-recover oil reserves]. *Oil industry*, 2017, no.5, pp.44-47.

16. Iliushin P.Iu., Galkin S.V. Possibilities of technological indicators accounting of oil fields development within dynamics prediction of products watering from producing wells. *Perm Journal of Petroleum and Mining Engineering*, 2012, no.4, pp.64-74.

17. Ouyang L.B. et al. Practical consideration of an inflow-control device application for reducing water production. *SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers*, 2009, pp.1128-1146.

18. Inikori S.O. et al. Water control in oil wells with downhole oil-free water drainage and disposal. *SPE Annual Technical Conference and Exhibition. Society of Petroleum Engineers*, 2002, pp.1967-1976.

19. Fattakhov I.G., Kadyrov R.R., Markova R.G. Sovershenstvovanie sposoba prigotovleniia tamponazhnogo sostava na osnove sinteticheskikh smol dlia remontno-izoliatsionnykh rabot v skvazhinakh [Improving the method of preparation of grouting composition based on synthetic resins for repair and insulation works in wells]. *Fundamentalnye issledovaniia*, 2014, vol.10, no.12.

20. Arkhireev V.P. et al. Tamponazhnye materialy na osnove atsetonoformaldegidnoi smoly [Grouting materials based on acetone-

formaldehyde resin]. *Plasticheskie massy*, 2007, no.8, pp.49-51.

21. Apasov G.T. Laboratornye issledovaniia sinteticheskoi smoly dlia provedeniia izoliatsionnykh rabot v skvazhinakh [Laboratory studies of synthetic resin to be used for carrying out isolation work in wells]. *Neftepromyslovoe delo*, 2013, no.12, pp.29-33.

22. Strizhnev K.V., Nigmatullin T.E. Razrabotka retseptur kompozitsii na osnove sinteticheskikh smol dlia izoliatsii vodopritoka v neftianye skvazhiny [The development of resin based compositions for water shutoff in oil wells]. *Bashkirskii khimicheskii zhurnal*, 2011, vol.18, no.1, pp.42-48.

23. Kadyrov R.R. et al. Novye tekhnologii krepleniia skvazhin i likvidatsii negermetichnosti ekspluatatsionnykh kolonn s ispolzovaniem sinteticheskikh smol [New technologies for fastening wells and eliminating leaks in production casing using synthetic resins]. *Sbornik nauchnykh trudov TatNIPIneft*, 2013, pp.343-353.

24. Kadyrov R.R. et al. Primary cementing and repairing of leaks in a production string using synthetic resins. *Oil & Gas Technologies*, 2013, vol.84, no.1, pp.49-54.

25. Apasov G.T. Prakticheskoe primenenie remontno-izoliatsionnykh rabot s kombinirovannymi sostavami [Practical usage of repair-isolation works with combined compositions]. *Neftepromyslovoe delo*, 2013, no.12, pp.18-24.

26. Kuznetsova O.N., Arkhireev V.P. Gidroizoliruiushchie materialy na osnove fenol-formaldegidnykh smol [Waterproofing materials based on phenol-formaldehyde resins]. *Vestnik Kazanskogo tekhnologicheskogo universiteta*, 2004, no.2, pp.230-233.

27. Strizhnev K.V. Sovershenstvovanie tekhnologii rir v usloviiakh otsutstviia nepreryvnoi priemistosti i intervala izoliatsii [Perfection of repair-insulation technologies in conditions of steady response absense of isolation interval]. *Oborudovanie i tekhnologii dlia neftegazovogo kompleksa*, 2011, no.3, pp.72-76.

28. Lanchakov G.A., Ivakin R.A., Griguletskii V.G. O materialakh dlia remontno-izoliatsionnykh rabot gazovykh i neftianykh skvazhin [About materials for repair and insulation works of gas and oil wells]. *Vesti gazovoi nauki*, 2011, no.2(7), pp.52-68.

29. Apasov T.K., Apasov G.T., Sarancha A.V. Provedenie v skvazhinakh vodoizoliatsionnykh rabot na osnove karbamidoformaldegidnoi smoly [Performance of water insulation works in wells on the basis of carbamide formaldehyde resin]. *Territoriia “NEFTEGAZ”*, 2015, no.6, pp.84-88.

30. Apasov T.K., Apasov G.T., Sarancha A.V. Tekhnologiia i sostavy dlia provedeniia v skvazhinakh vodoizoliatsionnykh rabot na osnove karbamidoformaldegidnoi smoly [Technology and compositions for use in wells waterproofing works on the basis of carbamide formaldehyde resin]. *Neftegazovoe delo*, 2015, no.6, pp.277-291.

31. Gasumov R.A., Kashapov M.A. Razrabotka penoobrazuiushchikh sostavov dlia bureniia i remonta skvazhin [Development of foam coating compositions for wells drilling and repair]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2009, no.12, pp.30-32.

32. Kuchin V.N. Obosnovanie i razrabotka tekhnologii izoliatsii vodopritokov pri burenii v intervale anomalnykh plastovykh davlenii [The study and development of water influx isolation technologies during drilling in the range of abnormal reservoir pressures]. *Neft i gaz – 2018: sbornik trudov 72 mezhdunarodnoi molodezhnoi nauchnoi konferentsii*, 2018, pp.199-204.

33. Viakhirev V.I., Ovchinnikov V.P., Ovchinnikov P.V., Ippolitov V.V., Frolov A.A., Kuznetsov Iu.S., Iankevich V.F., Urosov S.A. Oblegchennye tamponazhnye rastvory dlia krepleniia gazovykh skvazhin [Lightweight cement slurries for fixing gas wells]. Moscow, Nedra-biznestsentr, 2000, pp.3-4.

34. Kuchin V.N. Obosnovanie i razrabotka tekhnologii izoliatsii vodopritokov pri burenii v intervale anomalnykh plastovykh davlenii [Development of water influx isolation technologies during drilling in the range of abnormal reservoir pressures]. *Neft i gaz*, 2018, pp.199-204.

35. Nutskova M.V., Dvoynikov M.V., Kuchin V.N. Improving the quality of well completion in order to limit water inflows. *Journal of Engineering and Applied Sciences*, 2017, vol.12, no.22, pp.5985-5989.

36. Bulatov A.I. Kontseptsiia kachestva proburennykh neftianykh i gazovykh skvazhin [The concept of quality of oil and gas wells drilled]. *Burenie i neft*, 2015, no.12, pp.15-19.

37. Mazurok P.S. Vliianie tsementirovaniia neftianykh i gazovykh skvazhin na ekonomiku. Otsenka ekonomicheskikh i ekologicheskikh riskov – programmnoe obespechenie CEM EXPERT [The influence of cementing oil and gas wells on the economy. Assessment of economic and environmental risks - software CEM EXPER]. *Burenie i neft*, 2015, no.12, pp.32-36.

38. Asfandiiarov I.R. Vysokotekhnologichnoe kreplenie skvazhin s tekhnologicheskoi osnastkoi obsadnykh kolonn ZAO "ART-Osnastka" [High-tech well fixing with technological equipment of casing strings of ZAO "ART-Equipment"]. *Burenie i neft*, 2015, no.5, pp.50-53.

39. Gulov A.R., Novikov S.A., Zhuravchak V.G., Akhmetov M.A. Noveishie tekhnicheskie resheniia dlia krepleniia skvazhin [The latest technical solutions for fastening wells]. *Burenie i neft*, 2018, no.01, pp.55-57.

40. Samsonenko A.V., Samsonenko N.V., Simoniants S.L. Mekhanizmy vozniknoveniia i tekhnologii ustraneniia oslozhnenii protsessa tsementirovaniia obsadnykh kolonn [Mechanism of complications occurrence and technology of their elimination when cementing casing strings]. *Stroitelstvo neftianykh i gazovykh skvazhin na sushe i na more*, 2016, no.11, pp.35-42.

41. Bulatova I.M. Grafen: svoistva, poluchenie, perspektivy primeneniia v nanotekhnologii i nanokompozitakh [Graphene: properties, preparation, application prospects in nanotechnology and nanocomposites]. *Vestnik kazanskogo tekhnologicheskogo universiteta*, 2011, iss.10, pp.45-48.

42. Geim A.K., Novoselov K.S. The rise of grapheme. *Nature Materials*, 2007, vol.6(3), pp.183-191.

43. Al-Shiblavi K.A., Pershin V.F., Pasko T.V. Modifitsirovanie tsementa maloslovnym grafenom [Modification of cement by few-layer graphene]. *Vektor nauki TGU*, 2018, iss.4(46), pp.6-11.

44. Neuberger N., Adidharma H., Fan M. Graphene: A review of applications in the petroleum industry. *Journal of Petroleum Science and Engineering*, 2018, vol.167, pp.152-159.

45. Sanchez F., Sobolev K. Nanotechnology in concrete: a review. *Constr. Build. Mater*, 2010, no.24(11), pp. 2060-2071. DOI: 10.1016/j.conbuildmat.2010.03.014

46. Peyvandi A., Taleghani A.D., Soroushian P., Cammarata R. The use of low-cost graphite nanomaterials to enhance zonal isolation in oil and gas wells. *SPE Annual Technical Conference and Exhibition*, 9-11 October. San Antonio, 2017. DOI: 10.2118/187105-MS

47. Shawgi A. Chinedum P.E., Saeed S. Improvement in cement sealing properties and integrity using conductive carbon nano materials: from strength to thickening time. *SPE Annual Technical Conference and Exhibition*, 24-26 September. Dallas, 2018. DOI: 10.2118/191709-MS

48. Alkhamis M., Imqam A. New cement formulations utilizing graphene nano platelets to improve cement properties and long-term reliability in oil wells. *SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition, Conference Paper*. 2018. DOI: 10.2118/192342-MS

49. Khan W.A., Rahman M.K., Mahmoud M.A., Sarmah P. MWCNT for enhancing mechanical properties of oil well cement for HPHT. *Applications SPE/IADC Middle East Drilling Technology Conference and Exhibition*, 26-28 January. Abu Dhabi, 2016. DOI: 10.2118/178175-MS

50. Rahman M.K., Khan W.A., Mahmoud M.A., Sarmah P. MWCNT for enhancing mechanical and thixotropic properties of cement for HPHT. *Applications Offshore Technology Conference Asia*, 22-25 March. Kuala Lumpur, 2016. DOI: 10.4043/26465-MS

51. Yunusov F., Bobrynina E., Ma T.J., Larionova T., Okrepilov M., Mazin V.,

Kravchenko S., Yakovlev V., Chulkin S., Zaripova D. Aluminum-based composite reinforced with fullerene soot. *IOP Conf. Series: Earth and Environmental Science*, 2019, 337. DOI: 10.1088/1755-1315/337/1/012085

52. Li G.Y., Wang P.M., Zhao X. Pressure-sensitive properties and microstructure of carbon nanotube reinforced cement composites. *Cement and Concrete Composites*, 2007, no.29, pp.377-382. DOI: 10.1016/j.cemconcomp.2006.12.011

53. Bai H., Li C., Shi G. Functional composite materials based on chemically converted grapheme. *Advanced Materials*, 2011, vol.23, pp.1089-1115. DOI: 10.1002/adma.201003753

54. Huang X., Boey X., Qi F., Zhang H. Graphene-based composites. *Chemical Society Review*s, 2012, vol.41, pp.666-686. DOI: 10.1039/C1CS15078B

55. Bai S., Shen X. Graphene-inorganic nanocomposites. *RSC Advances*, 2012, vol.2, pp. 64-98. DOI: 10.1039/C1RA00260K

Библиографический список

1. Алексеев А. Инновации на горизонте // Сибирская нефть. – 2017. – № 139. – С. 16–23.

2. Британов Ф. Рынок возможностей // Сибирская нефть. – 2019. – № 162. – С. 44–49.

3. Лебедева Н.Е. Тенденции развития нефтегазового машиностроения РФ в условиях реализации политики импортозамещения // Инновации и инвестиции. – 2019. – № 11. – С. 329–334.

4. Катастрофа на Кумжинском газоконденсатном месторождении: причины, результаты, пути устранения последствий / В.И. Богоявленский [и др.] // Арктика: экология и экономика. – 2017. – № 1. – С. 32.

5. Кучин В.Н., Двойников М.В., Нуцкова М.В. Анализ и обоснование выбора составов для ограничения водопритоков при заканчивании скважин // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2017. – Т. 16, № 1. – С. 33–39.

6. Совершенствование технологии изоляции водопритоков при бурении в интервале аномальных пластовых давлений / В.Н. Кучин, М.В. Двойников, Е.Ю. Цыгельнюк, М.В. Нуцкова // Нефтегазовое дело. – 2018. – Т. 16, № 4. – С. 51–58.

7. Seright R.S., Lane R.H., Sydansk R.D. A strategy for attaching excess water production // SPE Production and Facilities. – 2003. – Vol. 18, № 03. – P. 158–169. DOI: 10.2118/84966-PA

8. Joint operation and dynamic control of flood limiting water levels for cascade reservoirs / J. Chen [et al.] // Water Resources Management. – 2013. – Vol. 27, № 3. – P. 749–763.

9. Стрижнев К.В. Классификация тампонажных материалов для ремонтно-изоляционных работ в скважинах // Нефтяное хозяйство. – 2010. – № 12. – С. 63–65.

10. Опыт проведения ремонтно-изоляционных и ликвидационных работ на старом фонде геолого-разведочных скважин / Я.М. Курбанов [и др.] // Строительство нефтяных и газовых скважин на суше и на море. – 2013. – № 12. – С. 33–38.

11. Диагностика и ограничение водопритоков / Б. Бейли [и др.] // Нефтегазовое обозрение. – 2001. – Т. 6, № 1. – С. 44–68.

12. Дубинский Г.С. О планировании технологий стимуляции скважин и ограничения водопритока // Нефтегазовые технологии и новые материалы. Проблемы и решения. – 2015. – С. 138–146.

13. Ограничение водопритока в трещиновато-пористых карбонатных коллекторах с использованием водонабухающих эластомеров / Р.Р. Кадыров [и др.] // Нефтяное хозяйство. – 2014. – № 4. – С. 70–72.

14. Ретроспективный анализ методов ограничения водопритоков, перспективы дальнейшего развития в Западной Сибири / Ю.В. Земцов [и др.] // Нефтепромысловое дело. – 2014. – № 4. – С. 17–22.

15. Ограничение водопритока в горизонтальных скважинах на месторождениях с трудноизвлекаемыми запасами нефти /

Р.Р. Кадыров [и др.] // Нефтяное хозяйство. – 2017. – № 5. – С. 44–47.

16. Илюшин П.Ю., Галкин С.В. Возможности учета технологических показателей разработки нефтяных месторождений при прогнозе динамики обводненности продукции добывающих скважин // Вестник Пермского национального исследовательского политехнического университета. Геология, нефтегазовое и горное дело. – 2012. – № 4. – С. 64–74.

17. Practical consideration of an inflow-control device application for reducing water production / L.B. Ouyang [et al.] // SPE Annual Technical Conference and Exhibition / Society of Petroleum Engineers. – New Orleans, 2009. – P. 1128–1146.

18. Water control in oil wells with downhole oil-free water drainage and disposal / S.O. Inikori [et al.] // SPE Annual Technical Conference and Exhibition / Society of Petroleum Engineers. – San Antonio, Texas, 2002. – P. 1967–1976.

19. Фаттахов И.Г., Кадыров Р.Р., Маркова Р.Г. Совершенствование способа приготовления тампонажного состава на основе синтетических смол для ремонтно-изоляционных работ в скважинах // Фундаментальные исследования. – 2014. – Т. 10, № 12.

20. Тампонажные материалы на основе ацетоноформальдегидной смолы / В.П. Архиреев [и др.] // Пластические массы. – 2007. – № 8. – С. 49–51.

21. Апасов Г.Т. Лабораторные исследования синтетической смолы для проведения изоляционных работ в скважинах // Нефтепромысловое дело. – 2013. – № 12. – С. 29–33.

22. Стрижнев К.В., Нигматуллин Т.Э. Разработка рецептур композиций на основе синтетических смол для изоляции водопритока в нефтяные скважины // Башкирский химический журнал. – 2011. – Т. 18, № 1. – С. 42–48.

23. Новые технологии крепления скважин и ликвидации негерметичности эксплуатационных колонн с использованием синтетических смол / Р.Р. Кадыров [и др.] // Сборник научных трудов ТатНИПИнефть. – 2013. – С. 343–353.

24. Primary cementing and repairing of leaks in a production string using synthetic resins / R.R. Kadyrov [et al.] // Oil & Gas Technologies. – 2013. – Т. 84, № 1. – С. 49–54.

25. Апасов Г.Т. Практическое применение ремонтно-изоляционных работ с комбинированными составами // Нефтепромысловое дело. – 2013. – № 12. – С. 18–24.

26. Кузнецова О.Н., Архиреев В.П. Гидроизолирующие материалы на основе фенолформальдегидных смол // Вестник Казанского технологического университета. – 2004. – № 2. – С. 230–233.

27. Стрижнев К.В. Совершенствование технологий РИР в условиях отсутствия непрерывной приёмистости и интервала изоляции // Оборудование и технологии для нефтегазового комплекса. – 2011. – № 3. – С. 72–76.

28. Ланчаков Г.А., Ивакин Р.А., Григулецкий В.Г. О материалах для ремонтно-изоляционных работ газовых и нефтяных скважин // Вести газовой науки. – 2011. – № 2 (7). – С. 52–68.

29. Апасов Т.К., Апасов Г.Т., Саранча А.В. Проведение в скважинах водоизоляционных работ на основе карбамидоформальдегидной смолы // Территория «НЕФТЕГАЗ». – 2015. – № 6. – С. 84–88.

30. Апасов Т.К., Апасов Г.Т., Саранча А.В. Технология и составы для проведения в скважинах водоизоляционных работ на основе карбамидоформальдегидной смолы // Нефтегазовое дело. – 2015. – № 6. – С. 277–291.

31. Гасумов Р.А., Кашапов М.А. Разработка пенообразующих составов для бурения и ремонта скважин // Строительство нефтяных и газовых скважин на суше и на море. – 2009. – № 12. – С. 30–32.

32. Кучин В.Н. Обоснование и разработка технологии изоляции водопритоков при бурении в интервале аномальных пластовых давлений // Нефть и газ – 2018: сб. тр. 72-й Междунар. молодежной науч. конф. – 2018. – С. 199–204.

33. Облегченные тампонажные растворы для крепления газовых скважин / В.И. Вяхирев, В.П. Овчинников, П.В. Овчинников,

В.В. Ипполитов, А.А. Фролов, Ю.С. Кузнецов, В.Ф. Янкевич, С.А. Уросов. – М.: Недра-Бизнесцентр, 2000. – С. 3–4.

34. Кучин В.Н. Обоснование и разработка технологии изоляции водопритоков при бурении в интервале аномальных пластовых давлений // Нефть и газ – 2018. – 2018. – С. 199–204.

35. Nutskova M.V., Dvoynikov M.V., Kuchin V.N. Improving the quality of well completion in order to limit water inflows // Journal of Engineering and Applied Sciences. – 2017. – Т. 12, № 22. – P. 5985–5989.

36. Булатов А.И. Концепция качества пробуренных нефтяных и газовых скважин // Бурение и нефть. – 2015. – № 12. – С. 15–19.

37. Мазурок П.С. Влияние цементирования нефтяных и газовых скважин на экономику. Оценка экономических и экологических рисков – программное обеспечение CEM EXPERT // Бурение и нефть. – 2015. – № 12. – С. 32–36.

38. Асфандияров И.Р. Высокотехнологичное крепление скважин с технологической оснасткой обсадных колонн ЗАО «АРТ-Оснастка» // Бурение и нефть. – 2015. – № 5. – С. 50–53.

39. Новейшие технические решения для крепления скважин / А.Р. Гулов, С.А. Новиков, В.Г. Журавчак, М.А. Ахметов // Бурение и нефть. – 2018. – № 01. – С. 55–57.

40. Самсоненко А.В., Самсоненко Н.В., Симонянц С.Л. Механизмы возникновения и технологии устранения осложнений процесса цементирования обсадных колонн // Строительство нефтяных и газовых скважин на суше и на море. – 2016. – № 11. – С. 35–42.

41. Булатова И.М. Графен: свойства, получение, перспективы применения в нанотехнологии и нанокомпозитах // Вестник Казанского технологического университета. – 2011. – Вып. 10. – С. 45–48.

42. Geim A.K., Novoselov K.S. The rise of graphene // Nature Materials. – 2007. – Vol. 6(3). – P. 183–191.

43. Аль-Шиблави К.А., Першин В.Ф., Пасько Т.В. Модифицирование цемента малослойным графеном // Вектор науки ТГУ. – 2018. – Вып. 4 (46). – С. 6–11.

44. Neuberger N., Adidharma H., Fan M. Graphene: A review of applications in the petroleum industry // Journal of Petroleum Science and Engineering. – 2018. – Vol. 167. – P. 152–159.

Sanchez F., Sobolev K. Nanotechnology in concrete: a review // Constr. Build. Mater. – 2010. – № 24 (11). – P. 2060–2071. DOI: 10.1016/j.conbuildmat.2010.03.014

46. The use of low-cost graphite nanomaterials to enhance zonal isolation in oil and gas wells / A. Peyvandi, A.D. Taleghani, P. Soroushian, R. Cammarata // SPE Annual Technical Conference and Exhibition, 9–11 October. San Antonio, 2017. DOI: 10.2118/187105-MS

47. Shawgi A. Chinedum P.E., Saeed S. Improvement in cement sealing properties and integrity using conductive carbon nano materials: from strength to thickening time // SPE Annual Technical Conference and Exhibition, 24–26 September. – Dallas, 2018. DOI: 10.2118/191709-MS

48. Alkhamis M., Imqam A. New cement formulations utilizing graphene nano platelets to improve cement properties and long-term reliability in oil wells // SPE Kingdom of Saudi Arabia Annual Technical Symposium and Exhibition, Conference Paper. 2018. DOI: 10.2118/192342-MS

49. MWCNT for enhancing mechanical properties of oil well cement for HPHT / W.A. Khan, M.K. Rahman, M.A. Mahmoud, P. Sarmah // Applications SPE/IADC Middle East Drilling Technology Conference and Exhibition, 26–28 January. – Abu Dhabi, 2016. DOI: 10.2118/178175-MS

50. MWCNT for enhancing mechanical and thixotropic properties of cement for HPHT / M.K. Rahman, W.A. Khan, M.A. Mahmoud, P. Sarmah // Applications Offshore Technology Conference Asia, 22–25 March. – Kuala Lumpur, 2016. DOI: 10.4043/26465-MS

51. Aluminum-based composite reinforced with fullerene soot / F. Yunusov, E. Bobrynina,

T.J. Ma, T. Larionova, M. Okrepilov, V. Mazin, S. Kravchenko, V. Yakovlev, S. Chulkin, D. Zaripova // IOP Conf. Series: Earth and Environmental Science. – 2019. – 337. DOI: 10.1088/1755-1315/337/1/012085

52. Li G.Y., Wang P.M., Zhao X. Pressure-sensitive properties and microstructure of carbon nanotube reinforced cement composites // Cement and Concrete Composites. – 2007. – № 29. – P. 377–382. DOI: 10.1016/j.cemconcomp.2006.12.011

53. Bai H., Li C., Shi G. Functional composite materials based on chemically converted graphene // Advanced Materials. – 2011. – Vol. 23. – P. 1089–1115. DOI: 10.1002/adma.201003753

54. Graphene-based composites / X. Huang, X. Boey, F. Qi, H. Zhang // Chemical Society Reviews. – 2012. – Vol. 41. – P. 666–686. DOI: 10.1039/C1CS15078B

55. Bai S., Shen X. Graphene-inorganic nano-composites // RSC Advances. – 2012. – Vol. 2. – P. 64–98. DOI: 10.1039/C1RA00260K

Please cite this article in English as:
Nutskova M.V., Kuchin V.N., Kovalchuk V.S. Preventing and eliminating well-completion problems. *Perm Journal of Petroleum and Mining Engineering*, 2020, vol.20, no.1, pp.14-26. DOI: 10.15593/2224-9923/2020.1.2

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Нуцкова М.В., Кучин В.Н., Ковальчук В.С. Профилактика и ликвидация осложнений, возникающих при заканчивании скважин // Вестник Пермского национального исследовательского политехнического университета. Геология. Нефтегазовое и горное дело. – 2020. – Т.20, №1. – С.14–26. DOI: 10.15593/2224-9923/2020.1.2