КЛЮЧЕВЫЕ СЛОВА воздушные фильтры, очистка, давление, устройство для очистки фильтров, двигатель внутреннего сгорания.

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ANALYSIS OF CAUSES AND METHODS OF SOLVING COMPLICATIONS IN URANIUM IN-SITU IN-SITU LEACHING TECHNOLOGY

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ABSTRACT The study examines the operational features of in-situ leaching (ISL) technology applied to the extraction of non-ferrous metals. The process chain is characterized by the injection of a leaching solution through specially drilled wells into the ore-bearing horizon, followed by the dissolution of target minerals and their subsequent recovery to the surface via production wells. In the course of ISL system operation, a number of typical complications arise, including clogging of the near-well zone, gas breakthrough, sanding phenomena, and scaling in tubing strings. These factors significantly influence the filtration regime and hydrodynamic behavior of the productive formation, which makes it necessary to regularly adjust and optimize the operating parameters. The paper highlights different categories of interventions aimed at enhancing system efficiency: chemical treatments, combined physico-chemical methods, as well as mechanical cleaning and rehabilitation of wells and downhole equipment. It is argued that sustainable and long-term operation of ISL systems can only be ensured through integrated application of these approaches, which reduces the risks of failures and extends the service life of wells. The research outcomes provide a methodological basis for improving the design and further optimization of ISL systems at both operating and newly developed deposits.

KEYWORDS in-situ well leaching, bottom-hole zone, colmatization, sanding, salt deposition, well cleaning, technological efficiency.

INTRODUCTION

When operating wells subject to the influence of mechanical impurities and colmatation, one of the key complications is the clogging of the bottomhole, well equipment, and the bottomhole formation zone (BFZ). This inevitably leads to a decrease in the well’s production potential, expressed in lower withdrawal volumes of productive solutions. Similar difficulties are also observed during technological operations.

The deposits forming in filters and near-filter zones are usually of a complex multicomponent composition. They often include salts and hydroxides of iron and manganese, carbonates of calcium and magnesium, compounds of silicic acid, sulfides, as well as sand and clay particles. These substances are deposited on filter surfaces and in the pores of adjacent rocks, being fixed either by gravitational settling or due to surface tension forces.

In downhole pumping systems, the presence of mechanical impurities is considered the primary factor leading to failures and defects in construction. Statistical data indicate that the proportion of failures caused by solids in the pumped medium significantly exceeds the influence of other geological and technical factors, such as corrosion or salt scaling. For most uranium ISL deposits in Uzbekistan, mechanical impurities account for 30–45% of all major pump failures, while corrosion is responsible for 22–35%, and salt formation for 15–20%. Additionally, sand carryover often results in the formation of sand plugs that block the entire perforated interval of the casing. This causes complete shutdown of the well, since the inflow of productive solutions from the ore-bearing horizon is effectively terminated.

MATERIALS AND METHODS

In order to sustain the planned level of uranium production, it is sometimes necessary to increase the withdrawal rates of operating wells. However, this inevitably results in higher filtration velocities, which intensify the processes of reservoir destruction and removal of impurities from weakly cemented rocks in the near-bottomhole zone. Under such conditions, the structural framework of the reservoir is gradually degraded, and the fracture process becomes continuous due to the constant migration of rock particles into the well.

The primary reasons for this phenomenon include: disturbance of geomechanical equilibrium in the borehole zone caused by rock pressure and bottomhole pressure; variable mechanical loads acting on the formation; hydraulic stresses resulting from fluid filtration; as well as dissolution of the cementing material under the influence of formation waters. The intensification of these processes explains the frequently observed effect of increased solids entrainment at downhole pressures lower than the saturation pressure.

The genesis of solid particles entering the pumping equipment is diverse. A considerable proportion originates directly from the formation during well operation, while a significant fraction has non-reservoir origins. These include corrosion products of underground equipment, particles introduced during repair or geological-technical interventions, insoluble inclusions from well-killing fluids, proppant remnants after hydraulic fracturing, and reaction products formed during the mixing of chemically incompatible fluids. The overall percentage composition of mechanical impurities in produced solutions is typically dominated by particles of reservoir origin (Table 1) [1–5].

To systematize the causes of reservoir destruction and sand production, a classification is proposed that distinguishes three groups of factors based on conditions of occurrence:

Geological factors, related to bedding and lithology of the reservoir: burial depth and pressure; horizontal stress component; degree of cementation, compaction and natural permeability of rocks; physicochemical properties and phase state of the produced fluid; morphology of reservoir sands (grain angularity, clay content); water encroachment into the deposit and dissolution of cementing agents; duration of sand removal processes.

Technological factors, determined by well operation and reservoir opening conditions: well flow rate; magnitude of overbalance or underbalance pressure; deterioration of natural permeability (skin effect); hydraulic loads and weakening of capillary cohesion of sand grains.

Technical factors, related to well and bottomhole construction: design of the lower completion, characteristics of the filtration interval, type of perforation (open, damaged, or plugged channels), and other design features affecting flow distribution.

Table 1.

Classification of causes of reservoir fracture and sand removal

Nature origins	Percentage share	Particle composition	Percentage share
Stratum	50-60	Magnetic andiron particles	25-65
Mixed (reservoir-surface)	15-25	Mineral particles from the formation	20-25
Surface	10-20	Surface particles	10-50

The evaluation of filtration-capacity properties (FCP) of reservoirs, including: total and open porosity; absolute, phase and relative permeability; water-, rock- and gas saturation, is not insignificant. According to the totality of these properties, reservoirs are subdivided into corresponding groups [6-9] (Table 2).

The content of clayey and carbonate cement determines the FCP of the reservoir (Table 2). In the first group, the average content of clayey (particle size d<0.01 mm) and siltstone (d=0.1-0.01 mm) fractions is about the same and the total is about 97%. Carbonation of rocks varies from 0 to 18%.

Table 2

Filtration-capacitance properties (FCP) of reservoirs

Collector Properties, FCP	Open porosity coefficient, %	Gas saturation coefficient	Permeability coefficient, mcm^2	Clay and carbonate content, %
Lowes	19,9-24,2	0,04-0,25	0,002	42-62
Averages	24,2-29,5	0,25-0,60	0,002-0,21	30-42
Highs	29,5-40,7	0,60-0,90	0,21-3,5	15-30

In the second group of reservoirs characterized by average filtration-capacitance properties (FCP), the siltstone fraction is dominant, accounting for approximately 55% on average, while the clay fraction makes up 24%, and the sandy fraction about 9%. The average carbonate content in this group is close to 12% [10–12].

The third group of rocks demonstrates the most favorable FCP. This improvement is associated with a decline in the clay fraction to around 25%, accompanied by an increase in the sandy fraction to an average of 26%.

On this basis, the key factors influencing impurity concentration can be distinguished as follows: depth of formation bedding and reservoir pressure; filtration-capacitance characteristics of rocks and formation permeability; physical and chemical parameters of the produced fluid; water cut; granulometric composition and morphology of sand grains; well flow rate; perforation density; pressure differential (underbalance or overbalance); and the type of working fluid employed in remedial operations.

During well start-up, complications are typically associated with high levels of suspended solids (HFC), which, in the initial period following underground repair or hydraulic fracturing, may reach 200–1000 mg/L [13–15]. Such concentrations often exceed the design limits of pumping units, even those with wear-resistant construction. Mechanical particles passing through the working components of pumps produce abrasive wear, causing plunger sticking in cylinders, rod breakage, valve pair failure, and filter clogging.

According to M.A. Shashkin [16–17], in many newly commissioned pumping wells, a substantial share of impurities originates from the formation only within the first days of operation. Approximately 80% of equipment failures due to clogging occur in wells after commissioning, drilling of a sidetrack, underground repairs, or hydraulic fracturing.

Filling of the perforation interval with formation fracture products occurs not only immediately after hydraulic fracturing but may also be repeated during subsequent operation. At the final stage of hydraulic fracturing, a significant amount of proppant often remains in the wellbore without being fully injected into the formation, ranging from several hundred kilograms to tens of tons.

It is widely recognized that reinforcement of the bottomhole zone during well completion immediately after drilling provides the most reliable results [18–24]. The most effective sand control technologies are those based on preventing sand production into the wellbore. For this purpose, various approaches are applied—chemical, physico-chemical, mechanical, as well as combined methods—aimed at stabilizing reservoir rocks in the bottomhole zone.

Mechanical methods [25–27] include the use of filters of various designs: gravel-packed, frame-gravel, multilayer mesh, and composite structures.

Physico-chemical methods are based on consolidation of formation rocks in the bottomhole zone, including proppant filter creation and hybrid treatments.

Chemical methods rely on artificial hardening of the reservoir through the injection of resins, cement slurries, and other binding agents with special fillers.

From this perspective, two principal strategies of well operation in sand-prone reservoirs are identified:

Production with controlled sand removal to the surface.

Production with complete prevention of sand migration from the formation.

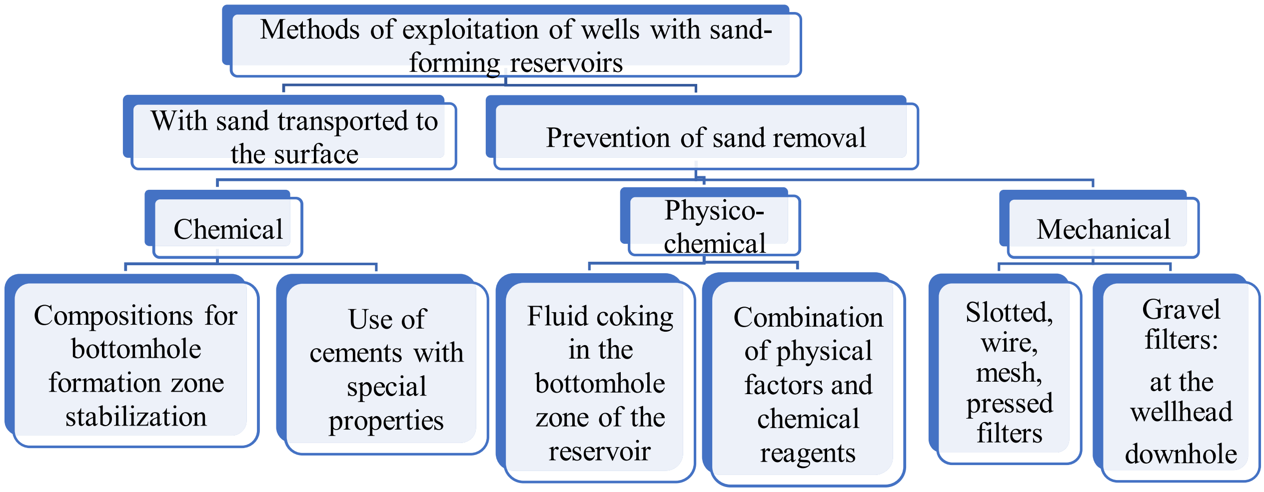

Figure 1. Methods of well exploitation in sand-bearing massifs

Table 3 [28-30] presents rational areas of applicability of each method depending on the conditions of sand penetration. When selecting a method of sand control in the well, a number of factors are taken into account depending on the bottomhole design. When completing openhole wells, mechanical or combined methods are typically used. Chemical methods of sand consolidation are used mainly in new wells, where caverns have not yet had time to form due to sand removal.

Table 3.

Rational areas and applicability criteria for sand protection methods

Protection methods		The essence of the technology	Protection area	Application criteria
Without protection		-	-	Low thickness formations composed of low-permeability rocks
Mechanical	Application of filtering systems, sludge collectors	Installation of filters and other equipment below and above the pump to prevent sand from entering the pump	Pump reception, Pump	Mild to moderate sand removal without overfilling of the face
Chemical	Pumping resins and their compositions in the FZS	Creating a porous screen in the reservoir to prevent reservoir fracture	Perforation interval, Pump Intake, pump	Intensive sand removal overburden
	Application of special cements			
Physico-chemical	RCP proppant application	Creation of proppant packing behind the production string and in the reservoir	Perforation interval, pump intake, pump	Intensive sand removal with overfilling of the face and formation of caverns

RESULTS AND DISCUSSION

The first group of sand control methods is based on the application of technical and technological solutions that either clean sand entering the well in the bottomhole zone or reduce its harmful effects on downhole equipment.

In the course of this study, existing approaches and tools for mechanized elimination of sand plugs were analyzed. When formations composed of unconsolidated rocks are developed, the structural framework of the bottomhole zone is disrupted. As formation fluid moves through the reservoir, it entrains significant amounts of sand into the wellbore. If the upward velocity is insufficient to transport sand grains, they settle at the bottomhole, creating plugs that completely block the inflow of productive fluids. To restore normal operation, it becomes necessary to clean the bottomhole and the wellbore of sand accumulations.

The most widely applied methods for sand plug elimination include:

Direct flushing of the wellbore – sand is removed by pumping flushing fluid through the run-down tubing. The eroded rock is carried upward via the annulus. The lower end of the tubing is often equipped with a nozzle, cutter, or pencil-type cutter to facilitate erosion.

High-speed direct flushing – similar to direct flushing, but carried out without interruption during the extension of flushing pipes. This prevents redeposition of sand and minimizes the risk of tubing string sticking.

Backwashing – washing fluid is injected into the annulus, while the upward flow is directed through the washing pipes. Because of the smaller cross-section of these pipes, higher flow velocities are achieved, which improves sand removal efficiency.

Jetting-based washing – applied when defects exist in the casing string. The setup includes a jet pump, concentric tubing, and surface equipment (hoses, swivel joints, and fluid intake devices).

Cleaning with aerated liquids, foams, or compressed air – effective for wells with low fluid columns and loosely compacted plugs. The wellhead is sealed with a gland, and aerated fluids, foams, or compressed air are used as the working medium. Advantages include: reduced absorption of flushing fluid by the formation, shorter recovery time after plugging, and the possibility of cleaning below filter or sump intervals.

Aerated fluid flushing with surfactants – applied in low-pressure reservoirs where plugging frequently occurs and elimination is complicated by fluid losses into the formation. The addition of surfactants reduces surface tension and enhances plug removal efficiency.

Flushing with surfactant solutions – surfactants (e.g., sulfanol, sodium sulfonates, demulsifiers) are added to water to decrease interfacial tension and promote faster, nearly complete removal of fluid from the bottomhole zone during well development.

Foam washing – a stable foam is formed at certain concentrations of surfactant solutions, which is then used to clean the wellbore.

A universal washing scheme (Fig. 2) can be applied to all of the above methods. The main difference lies in the composition of the flushing fluid, which is selected according to reservoir and well conditions.

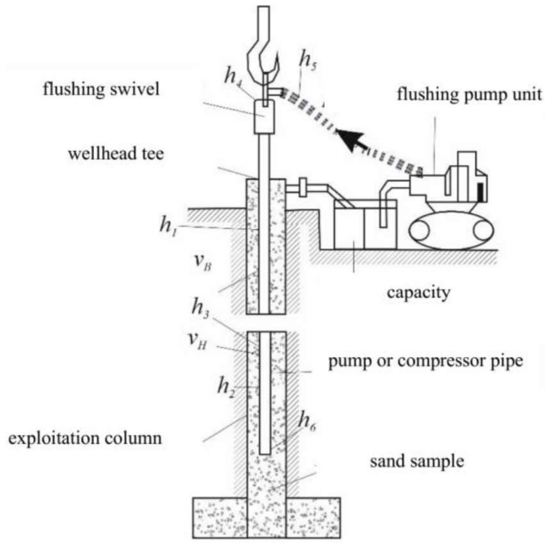

Figure 2. Typical scheme of well flushing

Cleaning of Wells from Plugs with Chutes and Hydro-Drills

Chute-based cleaning. This method is carried out by repeatedly lowering, filling, and raising a chute inside the wellbore. Depending on design, chutes are categorized as simple, piston, or automatic. Despite the structural simplicity, chute cleaning has several disadvantages: long operation duration, risk of casing wear, potential rope or cable breakage, and contamination of the working area with removed material.

For loose plugs and wells with a small liquid column, simple chutes are generally applied.

For dense plugs, piston chutes provide higher efficiency.

For most other situations, automatic chutes are recommended, as they allow more continuous operation with reduced manual effort.

Hydro-drill cleaning. Sand plugs may also be eliminated without running flushing pipes by using a hydro-drill lowered into the well on a rope. Once the tool reaches the plug, it is lifted by 2–3 meters and then repeatedly struck against the plug surface with the bit. During upward strokes, the plunger draws liquid mixed with sand into the device: the sand is retained in the chute, while the liquid is expelled into the piston pump. In several successive cycles, the hydro-drill gradually removes the plug accumulated at the bottomhole.

To prevent complications such as rope looping, excessive rope tension, or accidental breakage, it is strongly recommended to operate the hoist at reduced speeds.

CONCLUSION

In the technology of in-situ leaching (ISL) using wells drilled from the surface, a leaching reagent is injected into the ore-bearing zone. Moving from the injection wells to the production wells, the reagent dissolves the target minerals and, with the help of submersible pumps, is brought to the surface. The recovered solutions are then collected in technological units for reception and distribution, after which they are transported via pipelines to processing plants.

It has been established that during operation of the system well–formation–well–pump, the filtration properties of reservoir rocks, the hydrodynamic conditions in the near-wellbore area, and the performance of electric submersible pumps (ESPs) are subject to constant variation. These changes are accompanied by complications such as colmatation of the bottomhole zone, gas liberation, sand ingress, and salt scaling in the equipment. Effective management of such complications requires the application of specialized treatments of the reservoir rocks, regulation of operating regimes, and optimization of downhole equipment performance, all of which directly affect the efficiency of the system as a whole.

Therefore, to enhance the efficiency of production wells in ISL operations, a combination of chemical, physico-chemical, and mechanical methods—as well as their integrated application—is employed. These approaches are aimed at preventing complications, consolidating formation rocks, stabilizing the bottomhole zone, and ensuring effective well cleaning

АНАЛИЗ ПРИЧИН ВОЗНИКНОВЕНИЯ И МЕТОДОВ РЕШЕНИЯ ОСЛОЖНЕНИЯМИ В ТЕХНОЛОГИИ ПОДЗЕМНОГО СКВАЖИННОГО ВЫЩЕЛАЧИВАНИЯ УРАНА

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АННОТАЦИЯ Статья посвящена рассмотрению особенностей эксплуатации системы подземного скважинного выщелачивания (ПСВ) цветных и радиоактивных металлов. Описан технологический процесс подачи выщелачивающего реагента через нагнетательные скважины в рудный пласт, последующего растворения полезного компонента и его транспортировки на поверхность через откачивающие скважины. Выявлены основные осложнения, возникающие в процессе эксплуатации системы: кольматация приствольной зоны, газовыделение, пескопроявление, солеотложения в насосно-компрессорном оборудовании. Отмечено, что данные процессы изменяют фильтрационные и гидродинамические характеристики пород продуктивной зоны, что требует регулярной корректировки технологических параметров. Представлены методы повышения эффективности эксплуатации, включая химические, физико-химические и механические воздействия на приствольную зону и скважинное оборудование. Обоснована необходимость применения комбинированных подходов для стабилизации работы системы, предупреждения осложнений и продления эксплуатационного ресурса скважин. Полученные результаты могут быть использованы при проектировании и оптимизации систем ПСВ на действующих и перспективных месторождениях.

КЛЮЧЕВЫЕ СЛОВА подземное скважинное выщелачивание, приствольная зона, кольматация, пескопроявление, солеотложения, очистка скважин, технологическая эффективность.

URANNI YER OSTIDAN SKVAJINALAR ORQALI ISHQORLASH USULI BILAN QAZIB OLISH TEXNOLOGIYASIDA YUZ BERUVCHI MURAKKABLIKLARNING YUZAGA KELISH SABABLARINI VA ULARNI HAL QILISH USULLARINI TAHLIL QILISH

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ANNOTATSIYA Maqola rangli va radiaktiv metallarni yer osti skvajina orqali qazib olish tizimi ekspluatatsiyasi xususiyatlarini ko‘rib chiqishga bag‘ishlangan. Bosim skvajinalari orqali ruda qatlamiga yuvuvchi reagent yuborilishi, foydali komponentning eritilishi va so‘ngra uni sathga chiqaruvchi skvajinalar orqali tashilishi kabi texnologik jarayon tasvirlangan. Tizim ekspluatatsiyasi davomida yuzaga keladigan asosiy murakkabliklar aniqlangan: skvajina og‘ziga yaqin zonaning kolmatatsiyasi, gaz ajralishi, qum ko‘rinishi, nasos-kompressor uskunalarida tuzlar cho‘kishi. Ushbu jarayonlar ishlab chiqaruvchi qatlam jinslarining filtrlash va gidrodinamik xususiyatlarini o‘zgartirishi qayd etilgan, bu esa texnologik parametrlarni muntazam ravishda tuzatishni talab qiladi. Ekspluatatsiya samaradorligini oshirish usullari bayon etilgan bo‘lib, ular kimyoviy, fizik-kimyoviy va mexanik ta’sirlarni o‘z ichiga oladi. Skvajina og‘ziga yaqin zonaga va uskunalarga kompleks ta’sir ko‘rsatish orqali tizimning barqaror ishlashini ta’minlash, murakkabliklarning oldini olish va skvajinalarning xizmat muddatini uzaytirish zarurligi asoslab berilgan. Olingan natijalar mavjud va istiqbolli konlarda YOSOQO tizimlarini loyihalash va optimallashtirishda qo‘llanilishi mumkin.

KALIT SO‘ZLAR yer ostidan skvajinalar orqali qazib olish, skvajina og‘ziga yaqin zona, kolmatatsiya, qum ko‘rinishi, tuz cho‘kindilari, skvajinalarni tozalash, texnologik samaradorlik

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