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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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MODERNIZATION OF WATER WELL DRILLING TECHNOLOGY WITH DRILLING FLUID REVERSE CIRCULATION

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Abstract. This article presents a novel method for restoring the circulation of drilling fluid during well drilling using a back-suction technique. Unlike traditional methods, this innovative approach eliminates the need for a vacuum pump, significantly reducing both capital and operational costs associated with drilling operations. The study analyzes the proposed technology's effectiveness, highlighting its ability to accelerate the operations of extending drill pipes, thereby decreasing the time required for these processes by nearly 2.5 times compared to conventional techniques. This improvement is particularly critical in complex hydrogeological conditions, such as those found on the Mangistau Peninsula, where freshwater resources are limited.

The flexibility of the proposed method allows for effective adaptation to various working scenarios, including a temporary switch to direct circulation, enhancing the equipment's operational performance. The research demonstrates that the improved technology is a promising solution for increasing the productivity of drilling operations, which has significant implications for freshwater availability in resource-constrained regions.

Future studies are encouraged to focus on optimizing this method and tailoring it to different geological conditions to further enhance drilling efficiency and reliability. Overall, this work contributes valuable insights into advancing drilling technology for water supply wells, aiming to improve sustainability and efficiency in the sector.

Keywords: reverse circulation; water well drilling; check valve; drill string extension; large diameter wells.

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ҰҢҒЫМАЛАРДЫ КЕРІ СОРҒЫШ ЖУУМЕН СУҒА БҰРҒЫЛАУ ТЕХНОЛОГИЯСЫН ЖАҢҒЫРТУ

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Аннотация. Бұл мақалада кері сору технологиясын қолдана отырып, ұңғымаларды бұрғылау кезінде жуу сұйықтығының айналымын қалпына келтірудің жаңа әдісі ұсынылған. Дәстүрлі тәсілдерден айырмашылығы, бұл инновациялық әдіс вакуумдық сорғыға қажеттілікті жояды, бұрғылау жұмыстарының күрделі және операциялық шығындарын айтарлықтай азайтады. Бұл зерттеу ұсынылып отырған технологияның тиімділігіне талдау жасайды және оның бұрғылау құбырларын біріктіру операцияларын жылдамдатуға, бұл процестерді орындау уақытын дәстүрлі әдістермен салыстырғанда 2,5 есеге жуық қысқартуға мүмкіндік береді. Бұл жақсарту әсіресе тұщы су ресурстары шектеулі Маңғыстау түбегі сияқты күрделі гидрогеологиялық жағдайларда өте маңызды.

Ұсынылған әдістің икемділігі оның әртүрлі операциялық сценарийлерге, соның ішінде тікелей айналымға уақытша өтуге тиімді бейімделуге мүмкіндік береді, ол өз негізінде жабдықтың өнімділігін жақсартады. Зерттеу жетілдірілген технология бұрғылау өнімділігін арттыру үшін перспективалы шешім екенін растайды, бұл ресурстары шектеулі аймақтардағы тұщы судың қолжетімділігіне айтарлықтай әсер етеді.

Бұл әдісті оңтайландыру және оны әртүрлі геологиялық жағдайларға бейімдеу үшін қосымша зерттеулер ұсынылады, бұл бұрғылау жұмыстарының тиімділігі мен сенімділігін одан әрі арттыруға мүмкіндік береді. Тұтастай алғанда, жұмыс осы саладағы тұрақтылық пен тиімділікті жақсартуға ұмтыла отырып, су ұңғымалары үшін бұрғылау технологиясын дамытуға құнды идеялар әкеледі.

Түйін сөздер: кері айналым, суға ұңғымаларды бұрғылау, тексеру клапаны, бұрғылау бағанасын құру, үлкен диаметрлі ұңғымалар.

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МОДЕРНИЗАЦИЯ ТЕХНОЛОГИИ БУРЕНИЯ СКВАЖИН НА ВОДУ С ОБРАТНО-ВСАСЫВАЮЩЕЙ ПРОМЫВКОЙ

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Аннотация. В данной статье представлен новый метод восстановления циркуляции промывочной жидкости при бурении скважин с использованием обратно-всасывающей технологии. В отличие от традиционных подходов, этот инновационный метод устраняет необходимость в вакуум-насосе, что существенно снижает как капитальные, так и эксплуатационные затраты на буровые работы. В исследовании анализируется эффективность предложенной технологии, подчеркивая ее способность ускорять операции наращивания бурильных труб, что позволяет сократить время выполнения этих процессов почти в 2,5 раза по сравнению с обычными методами. Это улучшение особенно критично в сложных гидрогеологических условиях, таких как полуостров Мангистау, где ресурсы пресной воды ограничены.

Гибкость предлагаемого метода позволяет эффективно адаптироваться к различным рабочим сценариям, включая временный переход на прямую циркуляцию, что улучшает эксплуатационные характеристики оборудования. Исследование подтверждает, что усовершенствованная технология является многообещающим решением для повышения производительности буровых работ, что имеет значительные последствия для доступности пресной воды в ресурсно ограниченных регионах.

Дальнейшие исследования рекомендуются для оптимизации данного метода и его адаптации к различным геологическим условиям, что позволит еще больше повысить эффективность и надежность буровых операций. В целом, работа вносит ценные идеи в развитие буровой технологии для водозаборных скважин, стремясь улучшить устойчивость и эффективность в этой области.

Ключевые слова: обратная циркуляция, бурение скважин на воду, обратный клапан, наращивание бурильной колонны, скважины большого диаметра.

Introduction

A significant shortage of drinking and technical water exists across the vast territory of the Mangystau Peninsula, greatly hindering agricultural activities in the region. At the same time, exploratory studies (Umirova, 2023: 13; Biletskiy, 2022: 12) have revealed the presence of several aquifers located at shallow depths, covering nearly the entire area of the peninsula. In many cases, the quality of this water meets the requirements for domestic water supply (Togasheva, 2023: 9; Yessendossova, 2023: 17). The aquifers in the Mangystau Peninsula are characterized by a low filtration coefficient, which is why water wells, typically drilled with diameters not exceeding 200 mm, have low flow rates. This makes it impractical to transfer them for use by local industries (Khomenko, 2023).

During pumping, the maximum filtration rate in m/h is determined as (Abdeli, 2018: 9):

$$U_F = 2.71\sqrt[3]{K_F} \quad (1)$$

where K_F is the filtration coefficient in m/day.

Thus, the maximum possible flow rate in m³/h can be determined as (Mendebaev, 2024: 14):

$$Q_{MAX} = L\pi DU_F \quad (2)$$

where L is the length of the filter, m, and D is the diameter of the filter, m.

Formula (2) shows that the solution to the problem of low flow rates can be achieved by adopting the global practice of drilling water wells with increased diameters—up to 1.5 m or more (Piriverdiyev, 2019: 9).

Such wells are drilled using reverse circulation. The upward flow of drilling fluid, which carries cuttings to the surface, moves through the drill string. After being separated from the cuttings in the settling tank, the fluid returns as a downward flow in the annular space. This ensures efficient bottomhole cleaning since, with conventional direct circulation, achieving such effective cleaning would require an impractically high flow rate of drilling fluid.

Typically, reverse circulation is performed using one of two methods (Hou, 2024; Istekova, 2022: 9): by injecting compressed air into the upward flow (airlift method) or by connecting the suction line of the circulating pump to the upward flow of drilling fluid in the well—this is the reverse-suction method (Fig. 1).

The airlift method, with sufficiently powerful compressors, allows drilling to depths of 300 meters or more (Stavychnyi, 2024).

The depth limit for the reverse-suction method is constrained by the fact that circulation relies on atmospheric pressure. Therefore, as depth increases, the efficiency of bottomhole cleaning and the drilling rate decrease sharply (Ratov, 2024: 8). However, at depths of around 100 meters, the drilling rate with this method still differs little from that achieved by the airlift method (Hou, 2024).

Under the drilling conditions mentioned above on the Mangystau Peninsula, where aquifers are located at depths ranging from a few meters to several tens of meters from the surface, the reverse-suction method has several advantages over the airlift method.

The most important advantage is the absence of the need to use non-standard, bulky drill strings, where the drill string serves both as the channel for drilling fluid circulation and for air injection (Deryaev, 2024: 11). Such strings feature complex connections, and working with them is characterized by a significant increase in tripping time and adding operations.

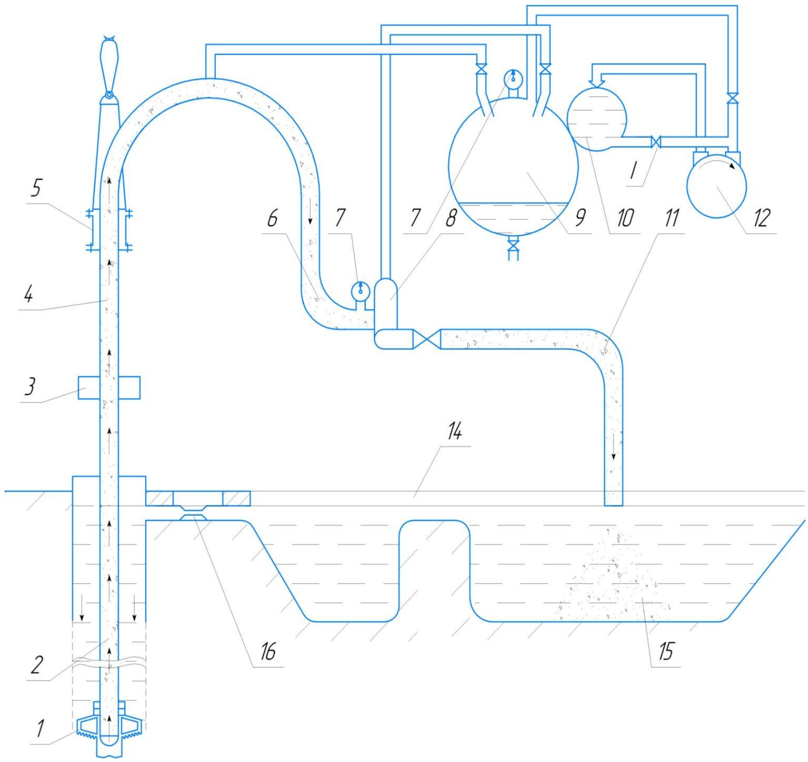

Fig. 1. Reverse-suction circulation diagram (Hapich, 2024: 12)
1 – bit; 2 – drill string; 3 – rotary table; 4 – kelly; 5 – swivel; 6 – suction hose; 7 – vacuum gauges; 8 – centrifugal pump; 9 – vacuum tank; 10 – fluid tank; 11 – discharge line; 12 – vacuum pump; 13 – gate valve; 14 – receiving tank; 15 – cuttings; 16 – trough

In the reverse-suction method (Fig. 1), there is no need for constant operation of a compressor during the drilling process, which reduces additional costs for fuel, lubricants, and equipment wear.

Due to the shallow depths of the aquifers, the main drawback of the reverse-suction method – slower drilling rates as depth increases – loses its relevance under the conditions being considered.

However, a second major drawback remains: the need for complex and expensive equipment, designed solely to restore the drilling process after every necessary operational stop (Davydenko, 2015: 9).

This problem arises because, when circulation stops, for example, to add sections to the drill string 2 (Fig. 1), the column of drilling fluid, held at the height of the swivel 5, drops to the fluid level in the well under its own weight. When drilling resumes and circulation must be restored, the centrifugal pump 8, which provides circulation, cannot generate enough vacuum to raise the fluid back to the swivel and through the suction hose 6, feed it to its suction (Ratov, 2023: 10). As a result, the centrifugal pump alone is incapable of initiating circulation.

The objective of this work is to improve the reverse-suction drilling fluid circulation technology by accelerating the restoration of fluid circulation after the necessary operational stops during the drilling process.

To achieve this objective, the following tasks were undertaken: – Analysis of the hydrogeological conditions of the Mangystau Peninsula and the results of previous water well drilling projects; – Identification of the shortcomings of traditional water well drilling technology under the conditions of the Mangystau Peninsula; – Development of a new method for reverse-suction circulation and a device for its implementation; – Justification of the efficiency of the developed technology.

Materials and basic methods

Research Object – the water well drilling technology with reverse-suction circulation.

The research was based on the idea of eliminating the need for a vacuum pump and instead using a check valve to restore drilling fluid circulation after the necessary operational stops in the drilling process.

The following research methods were used to address the set tasks.

A systematic analysis of existing reverse circulation technologies for water well drilling, presented in literature and patent sources. Examination of the local hydrogeological conditions with regard to using large-diameter water well drilling technology. Critical analysis of the results of previous water well drilling projects on the Mangystau Peninsula to identify the causes of the region's unsatisfactory groundwater supply. A review of the existing technologies for large-diameter water well drilling and the development of proposals for their improvement.

Results

In modern drilling rigs where the reverse-suction method of drilling fluid circulation is used, the problem of lifting the column of fluid and filling the centrifugal pump is addressed by employing a special vacuum pump 12, capable of creating a vacuum with an absolute value close to atmospheric pressure (Chudyk, 2023: 8; Hou, 2024).

The vacuum pump, along with its necessary components (vacuum tank 9, fluid collection tank 10, vacuum gauge 7, valves, and additional piping), must be perfectly sealed, requiring high precision in manufacturing, which significantly increases the overall cost of the system.

In addition to the mentioned drawbacks of the reverse-suction method, there is also the issue of increased time costs for adding sections to the drill string, as using a vacuum pump necessitates significant shortening of the drill pipes.

The pressure of the fluid PPP can lift its column to a height of

$$H = \frac{P}{\rho g} \tag{3}$$

According to this formula, when an ideal vacuum is created in the pipeline, atmospheric pressure P = 98000 Pa pushes water with a density ρ = 1000 kg/m³ (with gravitational acceleration g = 9.8 m/s²) to a height of H = 10 m. This is the maximum achievable height for the suction of the vacuum pump under the specified conditions.

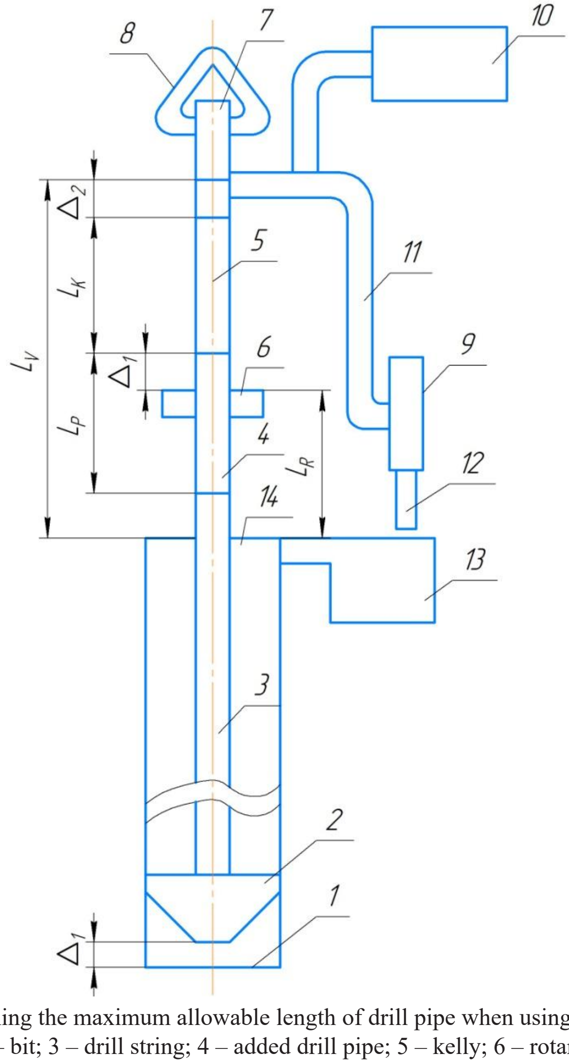

Fig. 2. Determining the maximum allowable length of drill pipe when using a vacuum pump
1 – bottomhole; 2 – bit; 3 – drill string; 4 – added drill pipe; 5 – kelly; 6 – rotary table; 7 – swivel; 8 – sling; 9 – centrifugal pump; 10 – vacuum pump unit; 11 – suction hose; 12 – discharge hose; 13 – settling tank; 14 – fluid level at the wellhead; L_V – maximum height of fluid lift by the vacuum pump; L_K – length of the kelly; L_P – length of the drill pipe; L_R – distance from the rotary table to the fluid level; Δ_1 – distance from the bit to the bottomhole; Δ_2 – distance from the suction hose to the kelly

The vacuum pump is turned on when, after completing the operation of adding sections, the drill string 3 is suspended by the sling 8 in the rigging system such that the bit 2 is positioned at a certain distance Δ_1 from the bottomhole 1 (Fig. 2). This is necessary to avoid the influence of the cuttings that have settled on the bottom during the addition process, i.e., to move out of the zone of increased fluid density (from formula (3), it follows that the suction height H is inversely proportional to the density of the drilling fluid).

From the situation presented in Fig. 2, we derive the formula for determining the allowable length of the drill pipe 4:

$$L_V = L_R + \Delta_1 + L_K + \Delta_2 \qquad (4)$$

Since the length of the drill pipe must always be less than the length of the kelly, its length can be expressed as:

$$L_P = L_K - \Delta_3 \qquad (5)$$

where Δ_3 is the reduction in length of the ordinary drill pipe compared to the kelly.

Then, taking into account (4) and (5), the allowable length of the drill pipe can be expressed as:

$$L_P = L_V - (L_R + \Delta_1 + \Delta_2 + \Delta_3) \qquad (6)$$

In this formula, the allowable length L_P of the drill pipe is determined by subtracting four values from the maximum possible suction height L_V of the vacuum pump 10 under the given conditions:

– the height L_R of the rotary table 6 above the fluid level (since after removing the clamps that support the rotary table, the kelly 5 is raised above the rotary table with the sling 8 and rigging system);

– the height of the bit 2 above the bottomhole Δ_1, as well as the distances from the suction hose to the kelly Δ_2 (see Fig. 2) and the reduction in length of the ordinary drill pipe compared to the kelly Δ_3.

When operating installations with a vacuum pump, the density of the drilling fluid must not exceed 10% of the density of water for which it is recommended to control the drilling speed (Deryaev, 2023: 14). This means that, at the limit, drilling with a density of saturated cuttings water is allowed, equal to 1100 kg/m³. At this density, according to formula (3), the actual suction height will be $L_V = 9$ m.

In the water drilling rigs of type 1BA15V, the location of the clamp on the rotary table, where the drill string is suspended, is approximately $L_R = 1.5$ m above the wellhead (Ihnatov, 2023b).

When restoring circulation, the recommended height of the bit above the bottomhole is $\Delta_1 = 1.5$ m (Ihnatov, 2023a: 15).

The distance Δ_2 is determined by design considerations and is usually so small that it can be neglected in calculations.

The length of an individual drill pipe must not exceed the depth of the well. Otherwise, after adding sections and lowering the drill string to the bottomhole, the kelly will be above the rotary table, making it impossible to rotate the drill string. The reduction in length of the ordinary drill pipe compared to the kelly is taken to be $\Delta_3 = 1$ m.

As a result, taking into account the values provided above, formula (6) gives the maximum allowable length of the drill pipe $L_P = 5$m.

$$L_P = 9 - (1.5 + 1.5 + 0 + 1) = 5 \text{ m.}$$

The study of drilling fluid circulation conditions using the reverse-suction method has led to the development of a new method for restoring circulation after necessary interruptions, as well as a device for its implementation (see Fig. 3).

The method consists of eliminating the need to lift the drilling fluid from its level at the wellhead to the swivel when circulation is resumed. Instead, the position of the fluid that existed before circulation stopped is fixed.

Throughout the time required for operations that necessitate halting fluid circulation, the columns of fluid in the kelly and the suction hose are maintained in the highest position they had when the kelly was separated from the rest of the drill string, using a check valve and a valve.

This idea forms the basis for preparing materials for the invention application. The application was submitted to the Committee for Inventions of the Republic of Kazakhstan on October 17, 2023.

The device operates as follows:

During drilling, the centrifugal pump 6 creates a vacuum level accessible to this pump and draws fluid from hose 5. As a result, a high-speed upward flow is generated in the drill string 2, which, while carrying the cuttings produced during rock destruction, cleans the bottomhole surface and contributes to a high mechanical drilling speed. A low-speed downward flow is formed in the space between the well wall 1 and the drill string.

When fluid is drawn from the drill string, its level at the wellhead tends to drop below the level in tank 14, causing fluid from the settling tanks to flow by gravity into the well. The volume of fluid flowing from tank 14 into the well is compensated by centrifugal pump 6 through the discharge line with open valve 9.

Thus, the vacuum created by the centrifugal pump is used to overcome the hydraulic resistance encountered by the fluid during circulation.

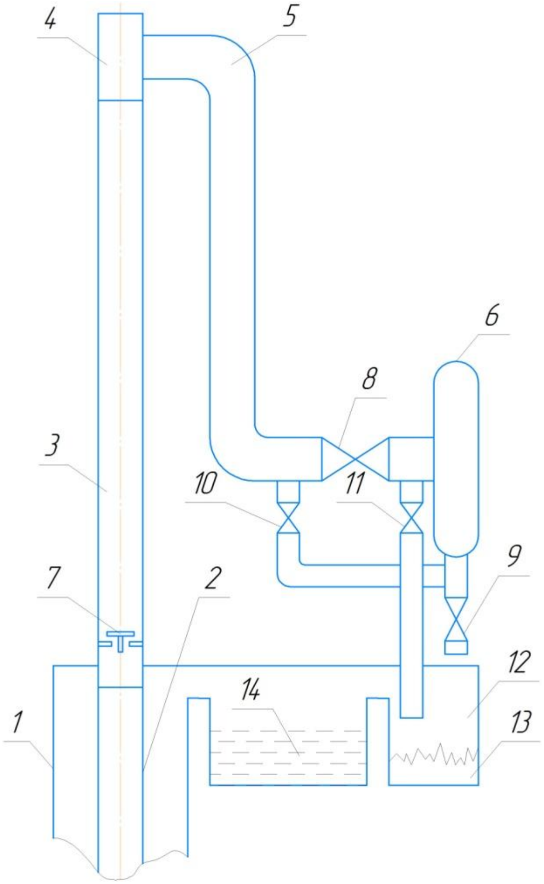

Fig. 3. Proposed device for large diameter well drilling with reverse circulation
1 – well; 2 – drill string; 3 – kelly; 4 – swivel; 5 – suction hose; 6 – centrifugal pump; 7 – check valve; 8, 9, 10, 11 – valves; 12 – settling tank; 13 – cuttings; 14 – tank with clean fluid

During drilling, the check valve 7 installed at the bottom of the kelly 3 is kept in the «open» position by the upward flow of fluid.

Before adding sections, drilling is stopped and the well is flushed until the returning drilling fluid becomes clear. The drill string is lifted and suspended on the rotary table using a clamp. Next, valve 9 is closed, and the centrifugal pump is stopped. At this moment, the column of fluid in the kelly closes the check valve due to its weight, thereby maintaining the column in its upper position.

The column of fluid located in the suction hose 5 between the swivel 4 and the centrifugal pump 6 is kept in its upper position by valve 9. In this state, pump 6 remains filled and ready for operation.

When adding sections, the drilling tool is raised above the bottomhole with a drawworks, and the upper part of the drill string is placed below the connection with the kelly onto the clamp. The fluid-filled kelly is unscrewed from the drill string, moved aside, and placed on a stand.

The elevator brings the new pipe to the suspended drill string, which is then screwed onto the upper thread of the drill string. After this, the clamp is released, and by lowering the drill string with the drawworks, it is caught again on the clamp below the upper thread of the added pipe. The fluid inside the new pipe rises to its level at the wellhead.

The kelly is screwed onto the new pipe, ensuring that before unscrewing, the empty section (located above the fluid level at the wellhead) is filled with fluid to avoid the formation of an air bubble in the suction line. After connecting to the kelly, the drill string is removed from the clamp and suspended above the bottomhole on the brake of the drawworks.

Next, the centrifugal pump is started, and simultaneously valve 9 is opened. The fluid begins to flow down the hose 5 and, in doing so, creates a vacuum that draws in the portion of the fluid located in the leading pipe. As this fluid moves upward, it opens the check valve. After circulation is restored, the drilling tool is placed on the bottom, and drilling resumes.

There are variations, for example, during drilling, repair of the swivel, and in other similar cases when the circulation channels are initially empty. For such cases, a temporary transition to direct fluid circulation is provided. This is achieved by additional piping consisting of two short pipelines equipped with valves 10 and 11.

During normal drilling operations with reverse circulation, valves 8 and 9 are open, while valves 10 and 11 are closed.

If it becomes necessary to fill the empty channels of the leading drill pipe 3 and hose 5, valves 8 and 9 are closed, and valves 10 and 11 are opened. Valve 11 opens the pipeline through which fluid is drawn from the settling tank 12, while valve 10 connects the pump's discharge line to hose 5, which becomes the discharge line.

As it rises through the hose and passes through swivel 4, the fluid flows down the internal channel of the leading drill pipe until it meets the check valve 7 and closes it. This moment is indicated by an increase in pressure on the gauge located on the pump's discharge line. This signals that the channels of the hose and leading pipe are filled, and the valves can be switched to the reverse circulation position.

If the period of circulation stoppage is used for preventive maintenance or replacement of the centrifugal pump, before stopping, valve 8 is closed while leaving valve 9 open. In this case, the fluid will remain in hose 5 but will drain from pump 6, allowing access for necessary operations. After these are completed, the pump is started, and valve 8 is opened. The fluid from hose 5 will fill the pump, and it will begin to draw in.

Thus, the developed device eliminates the drawbacks of the traditional method of drilling large-diameter wells using reverse circulation, thereby significantly increasing the speed of necessary technological operations. The most important advantage of the improved technology is the removal of restrictions on the length of drill pipes, which significantly reduces the time for screwing and unscrewing operations. Let's illustrate this for typical drilling conditions for water supply in rural areas of the Mangistau Peninsula.

The calculation based on the following initial conditions (Table 1).

Table 1 Initial data for calculating the duration of extension operations

Parameter	Unit of measurement	Value
Well Depth, m	H	110
Length of drill pipe with standard technology, m	L_s	5
Length of drill pipe with improved technology, m	L_n	11
Time for one extension, min	t_t	10
Time to raise drilling fluid from level established in well to swivel, min	t_l	1

During the extension process, it is necessary to perform three operations of screwing and unscrewing (unscrewing the drill pipe, screwing on the extension pipe, and screwing on the drill pipe).

The number of extensions will be:

– with standard technology

$$N_s = \frac{H}{L_s} = \frac{110}{5} = 22 \text{ pcs.}$$

– with new improved technology

$$N_n = \frac{H}{L_n} = \frac{110}{11} = 10 \text{ pcs.}$$

The time spent on extension work with standard technology consists of time ttt_ttt for the screwing and unscrewing operations and time tlt_ltl for raising the drilling fluid from the level established in the well to the swivel, which is necessary to resume the reverse circulation process.

Thus, the total duration of operations required to resume drilling after extension can be determined as follows:

– with standard technology

$$T_s = N_s \cdot (t_t + t_l) = 22 \cdot (10 + 1) = 242 \text{ min.}$$

– with new improved technology

$$T_n = N_n \cdot t_t = 10 \cdot 10 = 100 \text{ min.}$$

Thus, under these conditions, the speed increase coefficient will be:

$$K_V = \frac{T_s}{T_n} = \frac{242}{100} = 2.42 .$$

Figure 4 shows the duration of extension operations with standard and improved technology for well depths up to 300 m.

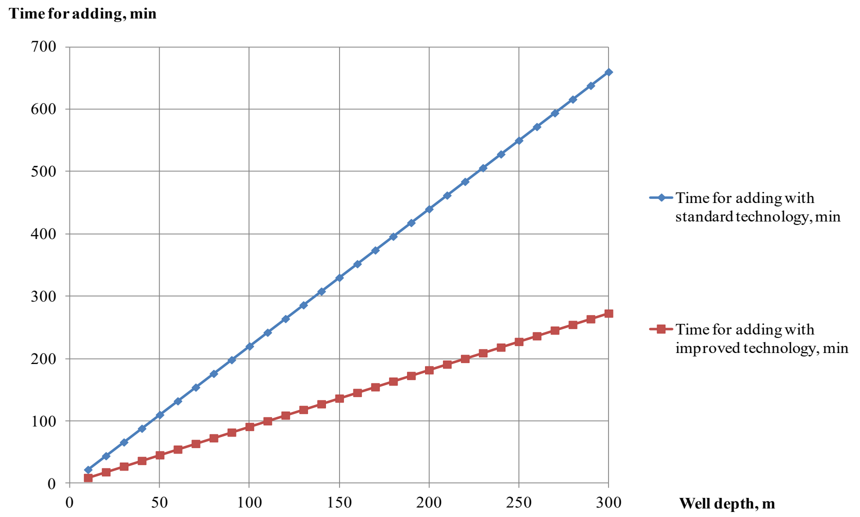

Fig. 4. Dependence of the duration of operations for adding with standard and improved technology on the well depth

As can be seen from the graph presented in Figure 4, the duration of extension operations with standard and improved technology is directly proportional to the depth of the well. The developed technology ensures a speed-up of the operations for extending drill pipes during drilling with reverse circulation by almost 2.5 times.

Discussion

The development of a new method for restoring the circulation of drilling fluid in drilling using the back-suction method represents a significant advance in well-drilling technology. Unlike traditional approaches, this method eliminates the need for a vacuum pump, which not only reduces capital and operational costs but also simplifies the process of extending the drill string.

Analysis of the results showed that the proposed technology significantly reduces the time required for extension operations, which in turn increases the overall productivity of drilling activities. The acceleration of the screwing and unscrewing processes of the drill pipes, along with the simplification of procedures for filling empty channels, leads to decreased time expenditures, especially when drilling to significant depths. This can be critical for regions like the Mangistau Peninsula, where freshwater resources are limited, and drilling efficiency directly impacts agriculture and other sectors of the economy.

However, the developed technology has its limitations. Firstly, its effectiveness may decrease when working with high-density drilling fluids. As the density of the fluid increases, the suction height decreases, which may require additional adjustments to the process.

Secondly, the use of a check valve in the system requires reliable maintenance, as its blockage or damage can lead to operational disruptions. This necessitates regular inspections and potential replacement of the valve.

In conclusion, despite some drawbacks, the proposed technology has clear advantages that can significantly enhance the productivity and reliability of water well drilling. This makes it a promising candidate for further research and practical implementation.

Conclusion

1. The developed method for restoring the circulation of drilling fluid using the back-suction method eliminates the need for a vacuum pump, thereby reducing capital and operational costs associated with drilling activities.

2. The application of the new device and technology significantly accelerates the operations for extending drill pipes, reducing the time required for these processes by nearly 2.5 times compared to traditional methods. This is particularly important for drilling water supply wells in challenging hydrogeological conditions.

3. The flexibility of the proposed method allows for effective adaptation to various working conditions, including the possibility of temporarily switching to direct circulation, which enhances the operational characteristics of the equipment and increases drilling efficiency.

4. The results of the study confirm that the improved technology is a promising solution for increasing the productivity of drilling operations, which can substantially impact the availability of freshwater in resource-limited regions such as the Mangistau Peninsula.

5. Future research in this area could focus on optimizing the proposed method and adapting it to different geological conditions, ensuring even greater efficiency and reliability in drilling operations.

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