Assessment of professional risks in the operation of mud pumps

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Abstract. Assessment of professional risks in the performance of basic technological operations in drilling oil and gas wells is today an important scientific and practical task in the field of labor protection. The article discusses the main negative production factors that lead to damage to the health of workers during the operation of the mud pump. To exclude injuries, employees should have information about the main occupational risks in carrying out technological operations and have the competence in labor protection and production safety. The conclusion is drawn on the need for further scientific research in the field of analysis and assessment of professional risks in the drilling of oil and gas wells.

1. Introduction
The decline in occupational injuries because of accidents and accidents has long been one of the pressing problems throughout the world. Statistics show that in Russia in recent years there has been a steady trend towards a decrease in the number of cases of industrial injuries at enterprises (Figure 1).

Figure 1. The dynamics of changes in injuries in Russia (according to the Ministry of Labor of the Russian Federation)
The main reasons for this are the mechanization of production, the development of new safe technologies, innovative solutions in the field of PPE. However, the proportion of accidents with severe and fatal outcomes remains high; the Russian economy loses 1.5 trillion rubles annually due to losses caused by occupational diseases, injuries and compensation [1].

To reduce the number of accidents and occupational diseases and, as a result, ensure production stability and financial efficiency of enterprises, it is necessary to search for new approaches and effective solutions in the field of labor protection. In the human-machine system, it is the individual who is the weak link, therefore, occupational risk management as a system for identifying, assessing, eliminating or minimizing production hazards is an important component in the formation of new approaches to improving the level of labor protection and safety culture in the enterprise, as it determines the management approach and personnel to preserve life and health and other values of the organization [2].

The results of investigations of most accidents tell us that their main reason is the inability of employees to anticipate, eliminate or minimize occupational risks in advance, although it is always easier to prevent an accident than to deal with the consequences. A common problem with standard professional risk management systems is the complexity of the methodology and isolation from reality, the lack of clear and effective methods that involve each employee in the process. Local staff are more aware than many managers of the possible dangers in the workplace, and what could lead to a failure in the performance of a particular technological operation.

The practice of developed countries shows that technological modernization of the economy alone is not able to effectively ensure industrial safety if, in the “man-machine” system, the human factor from the point of view of forecasting interaction remains a weak link. To solve problems related to the human factor, it is necessary to teach and, most importantly, motivate the employee to anticipate dangerous situations or working conditions analyze professional risks and prevent them in a timely manner. A special role in the formation of a conscious safety culture for a motivated transition from an attitude to labor protection “we were ordered – we do to complete the assignment on time” to the attitude “we do this because we need it to maintain life, health and receive decent wages” assigned to everyone in their workplace.

The most typical reason for intentional violations of labor protection requirements is the desire to achieve any benefits (make work easier, faster and easier). Despite the possible punishment, under such conditions, the employee will continue to violate until they cease to be a source of benefits. In such cases, for the effective application of the incentive mechanism for the labor protection worker, it should be done so that the costs of violating safety rules exceed the benefits received from this. Then it will be unprofitable to break them. At the same time, it is most expedient and effective to use not negative (punishment), but positive and individual (based on the motivation mechanism of the professional risk management system) incentives for safe work, which, according to international experience, is the most effective way to increase the level of labor protection. The safe behavior of the employee must be conscious, while his qualifications (knowledge), experience (skills) and skills that determine competence are the foundation of the labor protection system in the organization [3].

2. Assessment of professional risks during operation of drilling pumps

Technological safety is a way of managing facilities throughout their entire life cycle in order to prevent the inadvertent exit of hazardous materials or energy from the process. Process Safety Management (PSM) is part of the organization’s occupational risk management system, giving the employee in-depth understanding and structured tools to prevent and manage hazards. Failures of equipment, deviations in technological processes can lead to tragic consequences associated with human lives and significant financial losses of the enterprise. A proactive approach to identifying and accounting for occupational risks associated with technological safety, the use of an advanced set of methods, approaches and tools for managing all types of processes that affect the safety of the enterprise, which will prevent the implementation of negative events (including design stages, the use of appropriate technical and operational standards and “barriers”).

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Assessment of professional risks when performing basic technological operations in drilling oil and gas wells is today an important scientific and practical task in the field of labor protection. According to the results of studies, working conditions for 96% of the jobs of personnel servicing drilling rigs are harmful or dangerous [4]. The ability to identify hazards at any stage of the production process, determine their characteristics, determine the intensity and duration of exposure, the cause of the occurrence and the possible outcome of the negative impact, which will minimize the risk of accidents, is of great importance today to ensure the safety of personnel working on the rig.

Mud pumps are designed to pump flushing fluid into the well through the drill string and to remove the rock destroyed by the bit from the well [5]. In the vast majority of cases, a clay solution is used as a flushing fluid, the injection of which is carried out using piston mud pumps. The main hydraulic quantities – the necessary supply and pressure – determine the choice of type (brand) of mud pumps and their number. In turbine drilling, in addition to cleaning the bottom, the energy of the flushing fluid is used to rotate the turbodrill and the bit fixed on its shaft. When operating mud pumps, hazardous and harmful production factors can affect workers, which are divided into physical, chemical, psychophysiological and biological factors that create occupational hazards for working personnel. The largest number of accidents occurs in the following main groups of negative factors.

The operation of piston pumps, due to their kinematic features, is associated with uneven supply of fluid and the resulting pressures, which leads to shocks in the discharge line, significant structural vibrations, weakening and rupture of the joints and discharge line. An increase in pressure above the permissible level leads to rupture of the connections or the hydraulic part of the pump – cylinders, air cap, discharge line, valves, expansion joints, and mud hose. When workers are in the danger zone, such accidents can be accompanied by severe or fatal accidents [6].

In connection with the pulsation of liquid in the pipeline, instrumentation (in particular, pressure gauges) prematurely wears out, which affects the accuracy of its readings. Faultless operation of pressure gauges (there should be pressure gauges in the piping of the pumps: on the riser
  - to monitor the pressure of the pumped fluid during drilling and in the pumping room
  - to monitor the pressure change during the start-up of each pump and the operation of paired pumps in the system) is one of the decisive conditions safety when operating mud pumps.

The causes of pulsations and, as a consequence, increased pressure can be:
  - wear of the working surfaces of the valve couples of the pump, the working surfaces of the pistons or pump sleeves or their unreliable reinforcement, the presence of a gap between them due to the ingress of a foreign object, a broken valve spring;
  - a large number of gate valves on the discharge line, creating local resistance to the moving fluid flow, with the presence of sharp (90° or more) turns and contractions;
  - failure or contamination of the downhole motor and bit, as well as the presence of sharp narrowing in the wellbore;
  - overlapping channels through which flushing fluid circulates with ice plugs, cuttings, and foreign objects;
  - fishing work;
  - forcing the solution in the initial period of circulation;
  - start-up of the pump with closed starting or passage valves, or untimely closing of the starting valve or start of the second pump until the circulation in the pump-well system and others is restored (human factor).

In order to suppress pulsations and equalize the flow of the drilling fluid in the injection line, pneumatic compensators are used in modern designs of mud pumps. When the pressure in the discharge line of the pump is greater than the pressure inside the gas, the pneumatic compensator works like an air cap. When carrying out the procedure for filling pneumatic compensators with air or inert gas, the possibility of oil and other combustible substances entering the cavity of the compensators should be excluded [7].
The discharge line from the riser to the pump outflow should be as rectilinear as possible or without sharp turns, should have slopes to ensure that the mud flows from the entire line when the pumps are stopped. This is especially important in areas with a cold climate, since freezing of the solution remaining in the line can lead to its rupture when starting the pumps. For safety reasons, to prevent breaks in the discharge pipe or pump when the pressure is higher than the permissible near the pump outlet, a plate-type safety device is mounted in the factory. The safety plate should only be a standard sample with a working pressure digit stamped on the peripheral section. Its groove should be directed towards the discharge of the solution. The drainpipe from the safety device is sent to the receiving tank. Such an installation eliminates the contamination of workplaces in the pump room and injuries to workers from a direct impact by a stream of clay solution or flying fragments of the plate during its destruction [10].

Figure 2. Scheme of the UNB-600 mud pump with safety devices: 1 – receiving box; 2 – hydraulic box; 3 – safety valve; 4 – discharge tee; 5 – compensator; 6 – drive part; 7 – bed

High-quality cleaning of washing liquid with the help of modern cleaning devices, closed external circulation system, installation of receiving tanks and maintaining the liquid level in them so that it does not fall below the axis of the piston bushings of the pump. The correct installation and operation of the intake and discharge lines of the pumps, the filter in at the end of the receiving line – the necessary measures to minimize dangerous situations from possible pulsations with increasing pressure and accidents leading to accidents.

During drilling during the operation of mud pumps, when the bottomhole pressure exceeds the static pressure of the liquid column in the well, oil and gas manifestations are possible. Especially dangerous is gas saturation during a long break in the operation of boreholes. When the circulation is restored, the output of packs of drilling fluid saturated with gas, an increase in the liquid level in the receiving tanks of the drilling pumps, is likely. Excessive pressure is achieved by weighting the drilling fluid, but sometimes this is not enough. The air of the working area in the pump room is polluted by oil and gas components (methane, ethane, propane, hydrogen sulfide, carbon dioxide, etc.). In the summer, the evaporation of harmful substances increases. Since pumps and mortar systems are located in sheltered blocks in the North, the content of hydrocarbons and other harmful gases in these conditions can be several times higher than the maximum permissible concentration, and therefore the possibility of acute poisoning, mainly hydrocarbons and hydrogen sulfide, is not ruled out. At elevated concentrations, chronic intoxication may also develop. It is known that in the process of working on the clothes of workers, static electricity accumulates. A discharge of static electricity, including in the presence of oil and gas manifestations, can lead to ignition of the oil or gas explosion and irreparable consequences. When a fire occurs during combustion, harmful substances are released, a large level of thermal radiation occurs, collapse of structures is possible, etc.

If horizons with a possible oil and gas manifestation are revealed during the operation of two pumps, it is necessary to provide for the possibility of their simultaneous operation from one tank. In the harness between the tanks of the circulation system must be locking devices. Pressure pipelines, their parts and fittings after assembly at the plant, as well as after repair using welding, are subject to pressure testing,
in other cases, the pressure of pressure testing should be equal to the working one, multiplied by the safety factor. Each shift must be controlled by an oil lubricator, regularly inspecting the installation equipment, wiping and cleaning the external surfaces from dust and dirt. Exhaust gases from diesel engines rotating the drill string, which pollute the air environment in the breathing zone of workers (they mainly contain hydrocarbons, sulfur dioxide and carbon monoxide), have a negative impact on the health of workers.

To protect labor and manage occupational risks, drilling workers should know and correctly apply personal respiratory protection equipment, tools and methods for monitoring the air of the working area in rooms and outdoor installations, an emergency response plan and conditional alarms for workers to communicate, techniques and methods providing first aid to victims.

During the operation of the mud pump, due to the abrasive action of sand in the mud, its cylinder bushings, pistons, rods, valves and seats wear out most quickly, which leads to disruption of the normal pump operation and a decrease in the flow of drilling mud to the bottom of the well. Intense wear occurs when working with heavier flushing fluid. It is necessary to check the condition of the surface of the stem, as well as the gaskets of the stuffing box packing. Worn or disconnected rods should be removed from the pump, since they exclude the possibility of creating a reliable seal [8].

The operation and repair of mud pumps is associated with the implementation of a large complex of labor-intensive and hazardous operations for their maintenance. Moving parts of the pump (pulley, V-belt drive, gears, crank mechanisms) create a danger to workers. The inspection hatches of the oil bath and chambers must be tightly closed with metal shields. Moving and rotating parts of the pump (shaft ends, V-belt drive, etc.) should be securely enclosed (the protruding end of the transmission shaft with a continuous casting, the V-belt drive with a mesh fence). When fencing V-belts should also provide fender frontal metal shields of sufficient rigidity and strength, able to withstand the impact of a broken texture belt.

Removing the pneumatic compensator, replacing a failed wickel is associated with significant physical effort and requires caution when releasing the residual amount of the working agent. Wickel (rubber element), as if vulcanized to the neck of the compensator, does not allow to release the residual amount of the working agent. In winter, the release of the agent from the pneumatic compensator block may be prevented by an ice plug formed at the bottom of the block from the washing liquid accumulated during the wickel rupture, which blocks the passage opening. It is necessary to replace the pneumatic compensator under pressure, which does not exclude the occurrence of an accident. To facilitate working conditions and reduce the risk when removing the cylinder of the pneumatic compensator should use special devices.

The labor intensity of workers is due to neuro-emotional overloads associated with high responsibility for the result of their own activities and the significance of the error, the likelihood of risk for their own lives and increased responsibility for the final result. Significant physical and neuro-emotional stresses lead to diseases of periarthritis of the shoulder and shoulder blade, shoulder epicondylitis, arthrosis of the cervical spine and polyneuritis of the upper extremities [9].

During the operation of the mud pumps, the worker has to tighten the stem seal of the stem with the sleeve by pressing the cover, tightening the nuts through the window of the bed. This operation is often repeated and, as a rule, is carried out during the operation of the pump, which is unacceptable, as this may result in an accident due to pressing the worker’s hand with the cutter against the gland. When loosening the gaskets, the cylinder bushing may be pushed out of the pump. Periodically check the pressure of the cylinder liners. Valves and seats with significant wear should be replaced. Otherwise, erosion of the valve box and failure of the pump may occur. To safely change wear parts of a mud pump and increase the level of mechanization of operations to change parts of a hydraulic unit (valve, valve seat, stem with piston, piston, cylinder bushing), unscrew and tighten the retaining screw of the valve box, remove and install the stem seal housing, and remove crosshead finger it is necessary to use complex devices developed by VNIITB [10]. Before repairing any pump, the pressure in the piping should be reduced to atmospheric.
Sites and equipment of the drilling rig pumping unit are slippery, causing a danger of falling, including from a height during repair operations without special devices or personal protective equipment [1, 7]. Sharp edges, burrs and roughness on the surfaces of the mud pump elements can lead to cuts and infection of workers.

When personnel use electric motors to drive drilling pumps, non-conductive parts of electrical equipment in the event of an emergency can be energized, touching which becomes deadly if there is no or malfunctioning protective ground connecting the metal and current-carrying parts of the equipment to the ground. The cause of leaks should be fixed immediately. For electrical safety, employees must use tested dielectric gloves without damage, insulating supports before pressing the Start button or turning on the oil switch drive, and when the motor is turned off, the Stop button. There should be no people in the danger zone before giving a start signal. If at start-up of the electric motor any extraneous noises, crackles or obvious malfunctions of the electric motor are found, as a rule, the second assistant to the driller should immediately turn off the electric motor, then hang up a poster on the starting device: “Do not turn it on – people work!” and call electrical personnel.

The insufficient illumination of the working area of the drilling pump unit is one of the dangerous factors due to the technology of the drilling process. Industry standards for illuminating workplaces in drilling oil and gas wells (10–100 lux) are underestimated by 3-5 times in comparison with the requirements of SNiP 23-05-95 “Natural and artificial lighting”. This is because the drilling rig is not considered as a production building, but as a construction site (table 1). In the territory of the drilling rig, in open areas for equipment during work, floodlighting with dustproof luminaires in explosion-proof design, equipped with a protective mesh from mechanical damage, is widely used.

| Table 1. Pump unit workplace lighting rits at the drilling rig |
|---------------------------------------------------------------|
| Workplaces to be covered | Discharge and subdischarge- visual work | Lighting locations | Illumination rate, lx |
|--------------------------|----------------------------------------|--------------------|---------------------|
| Pump room                | 3                                      | At a height of at least 3 m | 75                  |
| Clay mixers              | 3                                      | At a height of at least 3 m | 75                  |
| Gutter system            | 5                                      | At a height of at least 3 m along the entire length of the gutters | 10                  |

Lack of light and irrationally arranged production lighting can distort the information received by the employee through vision, impair spatial orientation, coordination of movements, speed of reactions, cause fatigue, which will lead to reduced attention, errors in the application of safe working methods and increase the risk of accidents and industrial injuries. According to statistics, on average, for various types of production activities, the number of accidents associated with poor lighting is 30–50 % of the total. In addition to injuries, adverse lighting conditions can cause fatigue of the visual analyzer (with systematic exposure, the development of visual defects) and lead to occupational diseases. On the contrary, rational, satisfying hygienic requirements, lighting has a positive psychophysiological effect on the staff, contributes to increased productivity and safety, is an important stimulator not only of the visual analyzer, but also of the body as a whole, makes the employee’s movements more confident, which reduces his level of professional risk.

The leading place in the complex of harmful production factors that form professional risks during the operation of mud pumps belongs to industrial noise and vibration. Noise sources are rotating and moving parts of pump mechanisms. The excess of noise levels over the standards in accordance with GOST 12.1.003-83 in the pump compartment reaches up to 10 dBA, for vibrating screens – up to 18 dBA, which has a harmful effect on the human body and leads to irreversible hearing loss, disrupts the normal activity of the nervous, cardiovascular and digestive system, causes fatigue, decreased performance and slowed mental reactions.

The causes of vibration in the discharge system can be poor fastening of the pumps and their drive to the foundations, misalignment of the pump and drive, wear or weakening of individual parts of the pump (elements of the crank mechanism, rods, pistons, bushings, etc.), pulsation of the flushing fluid.
The most common two-piston pumps in drilling send the pumped fluid into the injection system with jerks. Therefore, with sixty double strokes in one minute, four powerful pulses occur in the discharge system within one second. The existing damping system for these pulses (pneumatic compensators) cannot completely smooth out the pressure in the pumped liquid. For example, the total vibration during maintenance of the vibrating screen reaches 112 dB at the workplace at the maximum permissible level of 92 dB. The harmful effects of vibration are expressed in the occurrence of a vibratory disease and a breakdown of the nervous system.

| Workplace location                  | Noise Levels, dBA | Excess noise level, dBA |
|------------------------------------|-------------------|-------------------------|
| Pump compartment                    | 88–90             | 8–10                    |
| Capacitive compartment              | 88–89             | 8–9                     |
| Circulation system for vibrating screens | 91–98             | 11–18                   |

It is customary to subdivide methods and means of noise control into methods of reducing noise along the path of its propagation from the source, in the source of its formation and personal protective equipment against noise. In order to reduce the harmful effects of noise and vibration on the drilling rig, it is necessary to carry out timely preventive inspection and repair, tighten the weakened joints, timely lubricate rotating parts. If it is impossible to suppress noise in the source of origin, then PP-80, PA/O, PA/S soundproofing and soundproofing screens should be used. To combat vibration, the following methods are used:

- suppression at the source of occurrence (centering, adjustment);
- change in design;
- the use of spring shock absorbers, vibration dampers.

Existing technologies for the operation and repair of equipment of mud pumps determine the performance of work under adverse effects (depending on the season) of the air temperature of the working area. At high temperatures, the employee’s attention and reaction speed decrease, persistent changes in the cardiovascular system occur, at low – mobility of the extremities decreases, diseases of the respiratory tract and joints occur. Working in the field exposes the drilling personnel to the negative effects of biological factors (blood-sucking poisonous insects – ticks, midges, mosquitoes), which can lead to occupational diseases (tick-borne encephalitis).

3. Conclusion
An employee’s professional risk can be estimated as the probability of harm to health as a result of exposure to hazardous and (or) harmful production factors in the performance of labor duties or other legitimate activities carried out in the interests of the organization or individual entrepreneur. Assessment of professional risks is the most effective preventive measure, which takes into account not only adverse events and accidents that occurred earlier, but also dangers that have not yet caused adverse effects. The basis of the risk assessment procedure is the identification of hazardous and harmful production factors in the performance of the labor functions of the organization’s employees. If these dangers cannot be eliminated, their risk to the health and safety of personnel should be assessed in order to make informed decisions to increase the level of labor protection. The proposed measures should be specific and feasible. The constancy of the risk assessment also implies an assessment of the effectiveness of the implemented measures, constant monitoring of changes in risk levels and the effectiveness of communications.

Based on this brief scientific review of the main negative production factors that arise during the operation of mud pumps, we can conclude how relevant today are studies to identify and assess occupational risks, establish the nature of their impact on personnel, and develop measures to ensure the safety of work in well construction. The development of an effective mechanism for identifying and assessing professional risks, increasing the competence and motivation of employees will reduce the number of injuries caused by hazardous activities of personnel engaged in drilling oil and gas wells.
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