ABSTRACT

dissertations for the academic degree of Doctor of Philosophy (PhD)
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Toktamissova Saltanat

COMBINED PUMPING UNITS FOR IMPROVING THE EFFICIENCY OF OPERATION OF EXTRACTION WELLS OF URANIUM DEPOSITS

Assessment of the current state of the scientific or scientific-technical problem (task) being solved. In the Republic of Kazakhstan, the development of uranium deposits is carried out mainly by the method of underground borehole leaching. This is due to the fact that the deposits are composed of porous rocks with good permeability. Productive horizons are located at a depth of several tens to several hundred meters, which requires the use of equipment with a wide range of capabilities. A solution of sulfuric acid is injected into the formation through injection wells, which leaches uranium. The productive solution enriched with uranium is pumped out by submersible pumps from pumping wells and sent for processing.

In the technology of uranium mining by the method of underground borehole leaching, installations of electric centrifugal pumps, which are equipped with the entire fund of pumping wells, are widely used. This was due to their advantages - high productivity and pressure, ease of automation and control, compactness, and so on.

However, the experience of operating wells with submersible electric centrifugal pumps at uranium deposits in the Republic of Kazakhstan has revealed a number of problems that need to be addressed - high energy costs per unit of produced product and insufficient reliability of the elements of the flow part of the pumps.

Thus, the experience of operating extraction wells with submersible electric submersible pumps at the Khorasan-2 uranium deposit shows that the operation of submersible electric submersible pumps is one of the most energy-intensive industries and the issue of increasing their energy efficiency is one of the priority tasks of production.

There are other related problems, in particular, high wear of parts of the pump flow parts due to mechanical impurities in the pumped out productive solution and frequent malfunctions of the pump electric drive. The use of various downhole filters does not completely solve the problem of wear of the elements of the flow part of pumps.

Insufficient service life of the equipment leads to the need to reduce the allowable loads and frequent repairs. All this leads to an increase in overhead costs for their operation, maintenance and repair, as well as an increase in well downtime for underground repairs to replace the pump. Ultimately, this affects the cost of production.

The basis and initial data for the development of the topic of the dissertation work. In modern designs of electric centrifugal pumps, the maximum possible indicators have been achieved, and a further cardinal increase in their efficiency is not expected in the near future.

However, recent studies have shown that one of the ways to expand their functionality can be a combination of electric centrifugal pumps with jet devices - the so-called combined pumping units. At the same time, the jet pump is designed to increase the overall efficiency and productivity of the entire combined system by pumping an additional volume of liquid from the annulus.

In this regard, in recent years, interest has increased in the development of new designs of jet pumps and their application in technological processes and in the practice of downhole fluid production. Especially this advantage of jet pumps is manifested in complicated operating conditions, for example, when producing reservoir fluid with a high content of mechanical impurities, corrosive substances and from directional wells. Their advantages include simplicity of design, absence of moving parts, high reliability, small dimensions, high productivity.

Another important advantage is the automatic adjustment of combined pumping units when operating conditions of wells change (changes in reservoir pressure and dynamic level in the well, product properties, well productivity, etc.).

The calculation of the operation of a jet pump in downhole conditions is quite complicated and requires taking into account many factors. The variety of processes with the use of ejection systems led to the development of a large number of calculation methods that require a numerical solution due to their complexity in the absence of regulatory documents regulating the types and parameters of jet devices.

Most of these methods consider special cases of their application and contain a large number of empirical coefficients that limit their wide application.

The experience of using tandem pumping units in the oil industry, as well as the results of operating submersible pumps at one of the large and promising fields of the Republic of Kazakhstan Khorasan-2, where the issue of increasing energy efficiency and reliability of electric pumping equipment of wells is acute, were used as initial data for conducting these studies.

The relevance of the dissertation topic. Kazakhstan is the largest supplier of uranium raw materials to the world markets and the development of work in the field of production intensification with a simultaneous increase in the energy efficiency of the process is an important and timely direction of research.

Submersible electric centrifugal pumps used in the fields no longer meet the requirements of energy efficiency and reliability due to the variety of downhole operating conditions (constantly changing conditions in the reservoir and dynamic levels of liquids, high aggressiveness of the pumped liquid, high content of mechanical impurities, etc.). Therefore, there is an urgent need to find alternative ways to pump out productive solutions and improve the energy-efficient performance of downhole pumping units.

Since the main share of the production cost consists of the cost of electricity and underground workover of wells, it is very important to optimally select pumps

and the technological mode of operation not only for an individual well, but also for the block of pumping wells as a whole. As practice shows, the optimization of the operation of the pumping fund is a significant reserve for improving the technical and economic indicators of operation.

Optimization implies a coordinated combination of elements of the «reservoir - well - pumping unit» system, and the main criterion should be to minimize the cost of production.

The analysis carried out to assess the efficiency and reliability of downhole pumping equipment at the pumping wells of a number of uranium deposits showed that a further increase in the efficiency of submersible electric pumps can be achieved by combining them with jet pumps. This will increase the total flow of the pumping unit, significantly expand the range of regulation of the operating mode of the electric centrifugal pump, or use a pump with a lower flow. It is also important that with an increased content of mechanical impurities in the well fluid, part of it will pass through the jet pump, bypassing the electric centrifugal pump, which will also increase its service life.

Thus, the topic of this dissertation research is caused by the relevance of the problem of improving the energy efficiency and reliability of deep-well pumping equipment in the technology of underground well equipment and is of applied importance.

The purpose of the work is to study and improve the energy efficiency of the process of pumping out productive solutions and the reliability of downhole pumping equipment using combined pumping units.

Object and subject of research. As an object of study, a jet pump was chosen as part of a Grundfos submersible electric centrifugal pump, which is widely used for pumping productive uranium solutions in the technology of underground well leaching. The subject of the study is the optimization of the design parameters of the jet pump and its operating modes in conjunction with an electric centrifugal pump to improve the energy efficiency of the process of pumping out the productive solution.

Research objectives. In accordance with the goal, this work provides for the solution of the following tasks:

- collection, analysis and generalization of materials on the practical application of tandem pumping units in industry;
- substantiation of the hydro-jet pump model and operating modes of the combined pumping unit in pumping wells during underground downhole uranium leaching;
- analysis of existing methods for calculating and designing a downhole pumping unit;
- selection and substantiation of the initial parameters and development of a methodology for computational modeling of the operating modes of a jet pump in combination with an electric centrifugal pump in the system «productive formation - well - pumping unit», which allows to establish rational design parameters of its elements to ensure the optimal value of the ejection coefficient and cavitation-free operation;

- carrying out computational and experimental studies of the operating modes of a virtual model of a combined pumping unit with simulation of well conditions using computer simulation;

- substantiation and selection of the design of high-pressure nozzles and jet pump elements for a combined pumping unit. Evaluation of its effectiveness in bench conditions;

- technical study and production of a working model of a jet pump and a test stand with a set of instrumentation for testing a combined pumping unit with simulation of downhole conditions; - carrying out bench tests of a jet pump as part of a combined pumping unit with an assessment of its effectiveness and verification of the adequacy of the methodology for simulating well conditions;

- analysis and generalization of the results of experimental studies with clarification of the parameters of the methodology for calculating the operating modes of the jet pump in downhole conditions and the development of practical recommendations for the design and manufacture of industrial structures of the jet pump.

Research methods. The methodological basis of the dissertation is analytical and computational-experimental research based on the fundamental laws of hydraulics and fluid mechanics, based on the Bernoulli equation. The following methods were used as the main methods: mathematical modeling using applied computer programs and comparison of their results with the results of bench experimental studies on a full-scale installation.

The main scientific provisions submitted for defense. The following provisions are put forward for defense:

1. An increase in the energy efficiency of submersible pumps at pumping wells can be achieved by using combined pumping units (ESP + jet pump), which makes it possible to achieve a rational mode of pumping out the productive solution with an increase in average flow by 25% and an increase in overall efficiency by 8-10%.

2. The method of computational modeling of the operating modes of the OPU in downhole conditions in the system "productive formation - well - pump" and the results of complex theoretical and experimental studies to verify its reliability.

3. Recommendations on the practical application of the methodology of computational modeling and design of downhole jet pumps to improve the energy efficiency of downhole pumping equipment in uranium mining technology.

Scientific novelty of the work:

1. Experimental studies have established that the use of a combined pumping unit in pumping wells for the extraction of uranium by the method of underground borehole leaching makes it possible to achieve a rational mode of pumping out the productive solution with an increase in flow by an average of 25% and an increase in overall efficiency by 8-10%.

2. An original technique for computational modeling of the operating modes of a tandem pumping unit in downhole conditions in the system «productive formation - well – pump» has been developed, which makes it possible to

determine, with sufficient accuracy for practical application, the rational depth of its immersion under the dynamic fluid level in the well and the design parameters of the main elements of the jet pump to ensure optimal operating modes of the combined pumping unit.

3. Calculation and experimental studies have established a significant influence of the profile and cleanliness of the working surface of a high-pressure nozzle on the formation of the jet profile and the energy loss of the working fluid and its relative position relative to the mixing chamber.

Practical significance of the study:

1. Theoretically and experimentally confirmed the practical possibility of using a combined pumping unit (electric centrifugal pump + jet pump) for pumping productive uranium solutions from wells in the technology of underground well leaching.

2. For practical application, a mathematical model of the operation of a jet pump as part of an electric centrifugal pump has been developed, which makes it possible in practice to determine the rational design parameters of the jet pump for docking with an electric centrifugal pump, the immersion depth of the combined pump unit under the dynamic fluid level in the well and evaluate its operational and technical indicators for specific downhole operating conditions.

3. An original experimental stand with an intelligent control station (SCADA) was developed and created for testing a combined pumping unit simulating real well conditions.

4. Practical recommendations have been developed for the design of industrial structures for downhole variants of a jet pump for operation in tandem with an electric centrifugal pump.

Approbation of work. The results of theoretical and experimental studies were reported at international scientific-practical conferences (including foreign countries) and seminars of the department.

Subdivisions of National Atomic Company Kazatomprom (JSC Volkovgeologiya) have shown interest in the results of the research, and they can serve as a basis for joint research work on a contractual basis.

The results of the work were reported and discussed at the Scientific and Technical Council of National Atomic Company Kazatomprom and published in a joint scientific report with them at the IX International Scientific and Practical Conference «Actual Problems of the Uranium Industry» in November 2019 in Almaty.

Publications. During the period of the work, 10 scientific articles and reports were published, including: 2 articles - in peer-reviewed publications recommended by the control committee in the field of education and science; 4 articles - in international scientific journals with Q2 and Q3 quartiles, included in the Scopus database; 4 reports - at international conferences, including 1 report at a foreign international conference.

Also, 2 patents of the Republic of Kazakhstan for a utility model and 1 patent of the Republic of Kazakhstan for an invention were received; a textbook

«Jet and tandem pumping units» was published for use in the educational process in the preparation of undergraduates and doctoral students.

The structure and scope of the dissertation. The dissertation consists of an introduction, 4 sections, a conclusion, a list of references and applications.

The volume of the dissertation is 126 typewritten pages, 16 tables, 67 figures, 57 references.