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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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SYSTEM OF THE OIL PUMPING STATIONS' EQUIPMENT PROTECTION FROM HYDRAULIC LOADS

Abstract. In the work analysis of existing systems, methods and devices on protection of the oil pumping station equipment from waves of the high pressure has been made. Mainly, there are equalizations tanks, which are widely used in pipeline systems of low pressure for protection from hydraulic loads. Air chamber allows to smooth waves of the different pressure by the transmission of high frequency pressure fluctuations to the low frequency pressure fluctuations with decreased amplitude. Automated regulation system, implementing the smoothing of pressure waves by throttling of flow with control valves etc. Despite the advantages on struggle with hydraulic loads, they have plenty of existing defects, related to process modes of the oil transportation. For their elimination, it is proposed the protection system, on the basis of which there is a method on smoothing of the pressure pulsation on counter flows. Average speed of the pressure growth, supported by the system does not exceed the allowed, specified in the process regulation of volume 0.03 Mpa/sec. The system can operate in several smoothing modes for provision of reliable protection with different waves intensity of high pressure and switches on self-regulation mode of emission-discharge processes. System efficiency is supported by the automated control system.

Keywords: oil pipeline, pumping station (PS), hydraulic loads, pulsation smoothing, pressure waves, air chamber, equalization tank, flap, valve.

Introduction. For protection of the pipeline from high and low pressure waves, there are existing different technologies, methods, and technical devices, which are permanently being advanced and added with new developments. At the same time, despite the existing progress in solution of the put assignment, many of issues are left open [1-3]. Due to this, advancement of famous and creation of new pressure surge relief system is a crucial task. For comparative analysis, we will consider basic methods and protection devices from hydraulic loads [4].

Methods. *Equalization tank.* Equalization tanks [5,6] are frequently used in pipeline systems of low pressure for protection from high and low pressure waves, appearing in transitional process. In figure 1, there is an example of unidirectional equalization tank, which is vertical pipe of small diameter, connected with basic pipeline. Usually, equalization tank is located near the regulation device, which can be a source of undesirable appearances. Closing of the control element leads to braking of the leakage, in the result of which, pressure in the pipeline is increased. Herewith, leakage starts to leak to equalization tank.

As soon as the leakage arrives to equalization tank, level of the leakage is increased. Because of the reason that the part of leakage gets to the equalization tank, braking of flow slows down and pressure wave amplitude is significantly decreased.

Similar, with opening of control element, the leakage is speed up, and the pressure in the pipeline is decreased, that is why, leakage from equalization tank flows out, partially compensating pressure fall in the internal cavity of pipeline.

In figure 2, there are curve amendments of total head in the pipeline, equipped with equalization tanks, with transitional process, evoked by shut-down of pump. It is shown that with shut-down of pump, at its outlet, pressure is down fast and down the flow, wave of the low pressure is distributed. Taking into

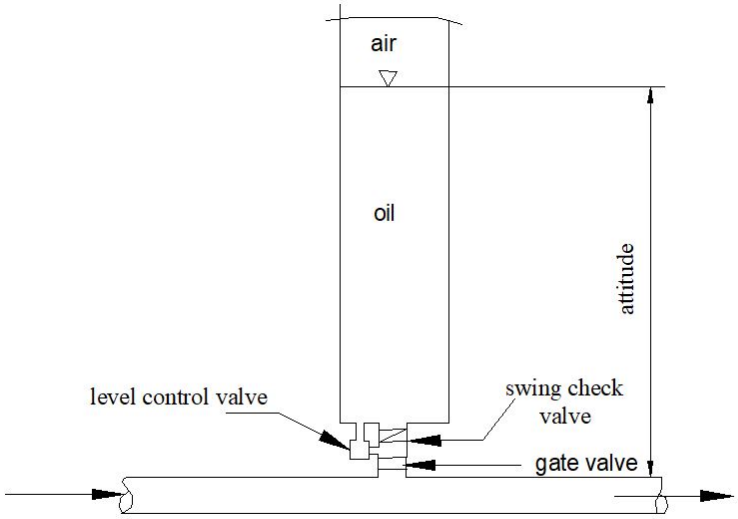

Figure 1 – Unidirectional equalization tank

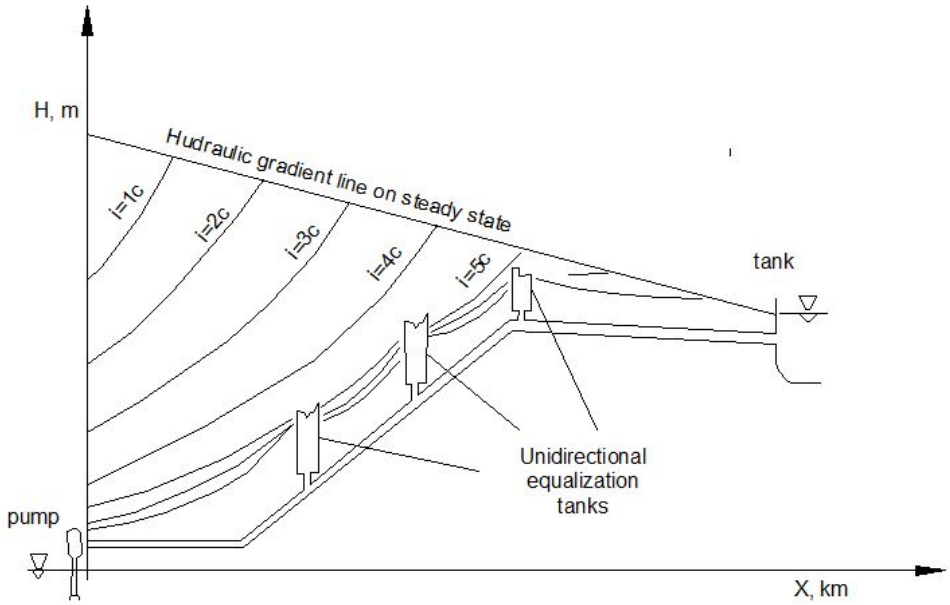

Figure 2 – Amendment of head on length of the pipeline, equipped with three unidirectional equalization tanks

account profile of the considered pipeline, appeared wave leads to pressure decrease in pipe up to the pressure of elastic leakage steams, leading for boiling, which is unacceptable. In order to exclude the possible boiling of leakage in the considered case, three unidirectional equalization tanks are installed on pipeline, which do not allow the pressure in the connected pipeline to decrease lower than the static pressure, which is determined by height of the container innage [7, 8].

Air chamber. Air chamber, (figure 3) is one of the types of popular equalization tanks. This device allows to smooth waves of high and low pressure, appearing in the pipeline in transitional processes. Also, air chamber allows transducing high-frequency vibrations in short pipes to low-frequency vibrations with small pressure amplitudes [9].

In general, air chamber is closed content, part of which is filled with pumped fluid, and other space with pressurized gas. Gas can be in free contact with liquid or separated with flexible divider.

Let's consider the principle of operation of the air chamber as an example of the transitional process, evoked by start up/shut-down of the pumping station. With start-up of pumping station, pressure on its outlet is increased fast and down the flow high pressure wave is distributed. For smoothing of such a wave, air chamber is installed on outlet of the station.

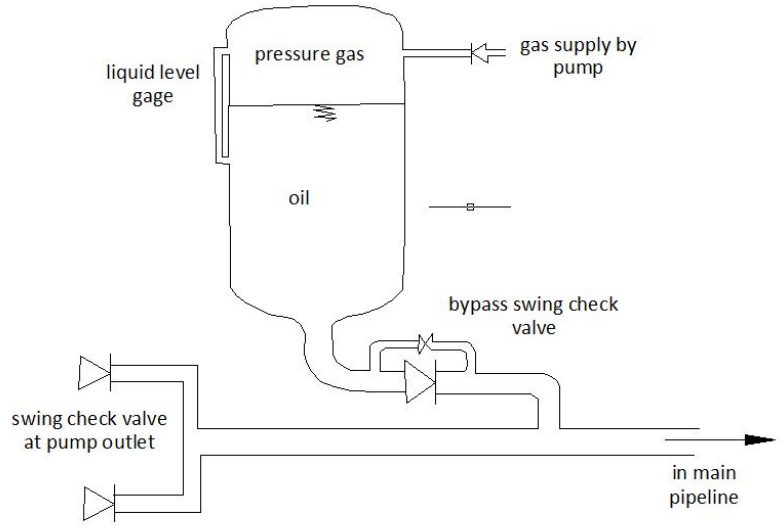

Figure 3 – Air chamber on outlet of the pumping station

After start-up of pump units, leakage consumption in the pipeline is increased, herewith part of the leakage starts to arrive at the air chamber, and the other part to the basic pipeline. As soon as it is filled up, gas into it is pressurized and pressure is increased, as a result, the pressure in the pipeline is increased to the relevant volume. Depending on size of the air chamber, for pressurization of gas, it is required to pump into the chamber different quantity of liquid. With relevant sizes of the air chamber, we can get the gradual increase of pressure on outlet of the Pumping Station with its start up.

With shut-down of the Pumping Station, it is observed the backward situation – pressure in inlet station is increased fast and up to the flow, high pressure wave is distributed.

Herewith, braking of flow is performed, id. est decrease of the pumping consumption. For protection of the pipeline from such pressure wave, air chamber is installed on entrance of the station. After shut-down of the pumping station, liquid is braked not immediately, it starts to enter the air chamber, thus gas pressure is increased. As the pressure in the chamber is increased, liquid is braked more and more up to the full shut down. Thus, air chamber of the relevant volume can smooth the appearing pressure wave on entrance of the Pumping Station with shut down.

However, air chambers have a significant defect. For smoothing of the pressure waves in trunk pipelines, volume of the air chamber shall compound no less than 100 m^5, which with accounting of the sufficient high pressure into the chamber, makes its using difficult in trunk pipelines. Effective using of air chambers is possible on short pipes of small diameter. In such cases, the necessary volume of air chamber compounds several cubic meters.

Pressure automatic control system (PACS). Maximum pressure on outlet of the pumping station is determined with carrying capacity of the pipeline, following after this station, and the minimum pressure on entrance – positive suction head of pump units, installed on the station. In transitional processes, in the pipeline, pressure in the inlet and outlet of Pumping Station can get out of the specified ranges. For purpose of avoiding this dangerous occurrence, system of automated pressure control is foreseen at the station. Pressure control on pumping station can implemented with following methods: throttling of flow; bypass of the flow part from discharge line to suction line of the station; amendment of rotation frequency of pumping units [10, 11].

Throttling of flow with purposes of pressure regulation is implemented by control valves, which are installed on discharge line of pumping station. Throttling of the liquid flow in the control valve of Butterfly type is shown in figure 4.

There is a cover of valve with increase of pressure on outlet of the pumping station higher than maximum or decrease of pressure on inlet lower than minimum, thus, the artificial local resistance is created. It leads to that the leakage consumption through the Pumping Station is decreased, pressure on entrance of station is decreased. Fast effect of control valves on trunk pipelines compounds 20–40 sec.

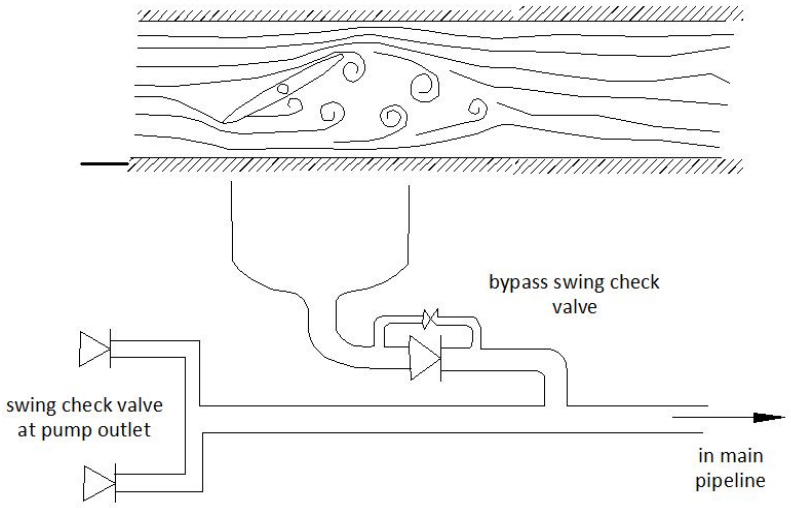

Figure 4 – Throttling of liquid flow in control valve of Butterfly type

Basic defect of such a regulation method is high losses of capacities during transitional processes, with which the necessity of throttling creates, as well as the inertance of control valves.

Amendment of rotation frequency of pumping units can be implemented by power actuator with regulating rotation frequency or installation of hydraulic coupling on shaft between the electric motor and pump. Decrease of rotation frequency of pump units leads to decrease of the differential head, created by the pumping station, that is why, pressure on inlet of the station is increased, and on outlet – is decreased. Advantage of this method is low losses of capacity; high fast effect.

With bypass, part of the liquid from discharge line is returned on special bypass to the suction line. Partial bypass of liquid can be implemented on one unit or through the whole pumping station. Taking into account downward characteristics of centrifugal pumping units, during the oil bypass through the pump, differential head, created by pumping station is decreased, that is why, pressure on inlet of the station is increased, and on outlet is decreased [12].

Pressure surge relief system. For pressure surge relief, created on inlet of pumping station with its shut down, it is used pressure surge relief system [13, 14]. Principle scheme of the pressure surge relief system is shown in figure 5. Pressure wave smoothing is implemented by partial discharge of oil from pipeline through the pressure surge relief system *4* to the container *5*. As distinct from safety valves, pressure surge relief system reacts if not to absolute volume of pressure, than to speed of its amendment. It is provided by control system of the pressure surge relief system, which compounds of orifice valve *2* and hydro pneumatic accumulator *3*. Pressure surge relief system does not restrict the pressure on inlet of pumping station on the certain level, pressure is continuously increased, but with lower adjusted speed.

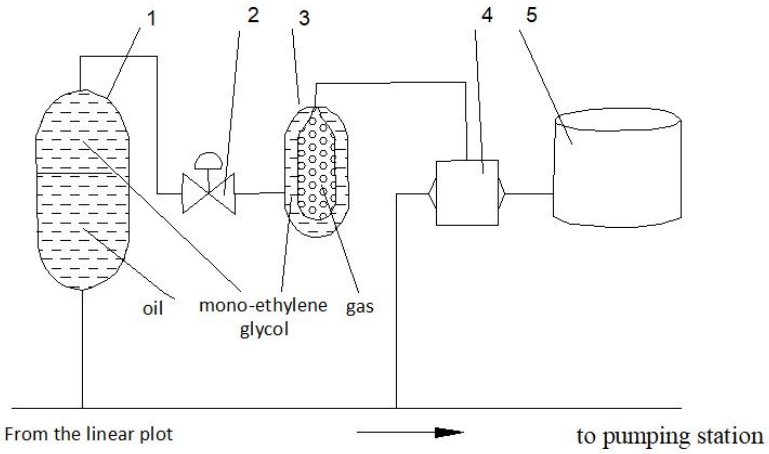

Figure 5 – Principle scheme of operation of the pressure surge relief system

Pressure surge relief system, installed on trunk pipelines, provides the average speed of pressure growth on inlet of pumping station with its termination 0.01–0.03 MPa/sec. For purpose of increase of reliability of the pressure surge relief system with its working liquid is in general ethylene glycol, which gets to the system through the dividing capacity *1*. Installation of necessary pressure growth speed on inlet of the pumping station is implanted by orifice valve and hydro-pneumatic accumulator. Pressure surge relief system 5.

One of the basic advantages of pressure surge relief system is its independence from power supply. Oil discharge volume through the pressure surge relief system valve with its operating on trunk pipelines compounds 30–100 m [15-17].

Fast-response valves with adjustable drive. Also, for smoothing of the pressure waves, appearing on inlet of pumping station, with its termination, fast-response valve with adjustable drive can be used. With shut down of pumping station, such a valve opens fast, and then closes slowly. Such property of valve operation is provided by "smart" drive, operation of which is implemented on special algorithm.

Specified system is similar with pressure surge relief system, however its basic defect is dependence on source of the power energy, whereas frequently the basic reason of emergency shut-down of pumping station is disruption in supply of the power energy. Of course, in such cases, this system does not operate [18, 19].

Results. For decrease of hydraulic loads and protection of oil pumping station equipment from negative influence of pressure waves, as power fluctuations, resistance moment, hydro dynamic moment and leading to possible loss of working capacity of the basic equipment, fast wear out and unjustified expenditures in Kazakh National Research and Technical University, risks control system was developed during transportation through the main pipeline.

The system is assigned for control and management of transportation mode with the purpose of prevention or minimization of risks situation consequences and supposes:

– prevention of passing of high pressure wave to operation zone of oil pumping station on timely operation of discharge valves;

– possibility of regulation of quantity and direction of coming and leaving leakage in ring shaped pressure surge relief system by discharge valves on adjusted algorithm depending on amplitude of form and wave period of the impact pressure. It means that system has in its compound pressure ring pipe waves smoother, operating based on the energy dissipation by counter flows and connected with main pipeline on discharge line of oil pumping station by means of two discharge valves.

Fast-response valves with pneumatic and power drive are controlled by automated control system, consisting of several boards. Differentiating unit on time allows to determine size of consumption jump, comparison unit detects difference of consumption in two points of the pipeline, delay unit on time serves for timely opening of the valve in time of wave coming to its section, regulation unit provides necessary volume of opening of valve and smooth close on the adjusted algorithm. Pressure regulation unit of the air smoother. Basic system of risks management is protection method of oil pumping station equipment from pressure waves, operation scheme of which is shown on the drawing 6.

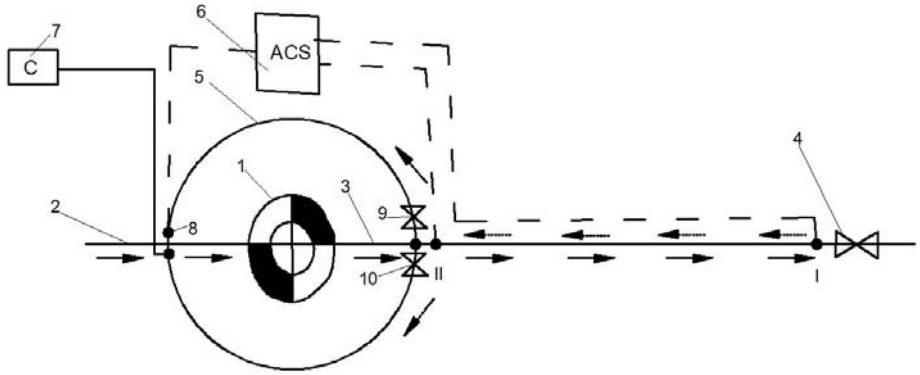

Figure 6 – Scheme of protection system from the pressure waves: 1 – pump station; 2 – station supply line; 3 – station discharge line; 4 – fastener on linear part of the pipeline; 5 – ring smoother; 6 – automated control system; 7 – compressor; 8 – pressure sensor; 9, 10 – smoother valves; I, II – flow meters

Waves smoothing is implemented in three modes, depending on amplitude of length of the form front and wave period, which is conditionally divided to 3 level. Value of parameters, in accordance with each level is entered to the program of control system. In the installed flow condition, when the consumption in point 1 equals to consumption in point 2, both smooth valves are closed during appearance of the high pressure wave (for example, in the result of close of the fastener 4) low consumption wave appears, which with pressure wave is distributed in the direction of pump station. When the wave achieves the section I, it is registered by the flow meter, signal of which is received to the control system. Automated control system determines the level of wave and by the adjusted delay, determined by the pressure wave speed gives the signal for opening until the first level of wave parameter of two smoothing valves. Oil from the main pipeline, under the effect of shock pressure intensively fills the smoother with two flows, moving towards each other. Herewith, pressing with liquid flow of the air, in the ring pipe of smoother is performed while the pressure in the air lock will not be equal to the pressure, discharged by the liquid shock wave. Air pressure of smoothers is controlled by pressure sensor, signal of which receives to the control system, if necessary, Automated Control System switches on the Compressor for increase of the pressure.

Process of the air pressing because of the transience can be deemed adiabatic [20]:

$$P_0 V_0^{\gamma} = P_{сж} V_{сж}^{\gamma}, \tag{1}$$

where P_0, V_0 is initial pressure and volume; $P_{сж}, V_{сж}$ – pressure and volume with air compression in the smoother.

Relevantly, work fulfilled by liquid flow with gas loading is equal to:

$$A = \frac{P_0 V_0}{\gamma - 1}\left[1 - \left(\frac{V_0}{V_{сж}}\right)^{\gamma - 1}\right]; \tag{2}$$

$$\text{or } A = \frac{P_0 V_0}{\gamma - 1}\left[1 - \left(\frac{P_{сж}}{P_0}\right)^{\frac{\gamma - 1}{\gamma}}\right]. \tag{3}$$

Protection of the equipment from negative influence of shock wave in the developed method is conditioned by decrease of wave energy before working zone by the managed discharge of part of the liquid flow to the smoother. During the passing of section by the low pressure wave discharge, air lock presses the oil from the smoother to the trunk pipeline, by increasing the pressure in the flow. By equalization of pressure in the flow and air lock, oil discharge from the smoother is terminated. Thus, the device can smooth the pressure pulsation in self- regulation mode of the oil emission/discharge process from the smoother to oil pipeline and conversely.

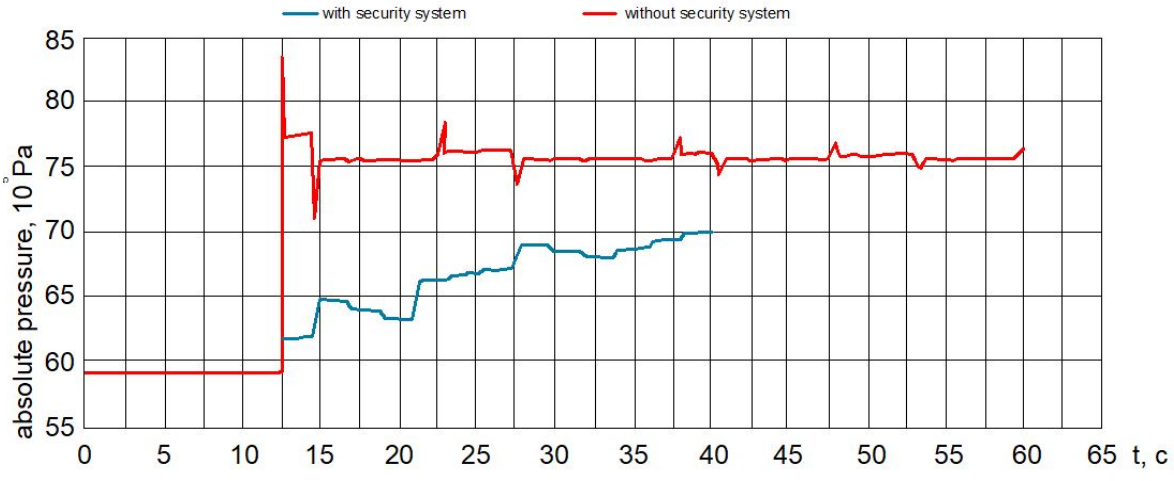

Figure 7 – Measurement charts of the pressure amendment in the section after the pump station

Control system during recovery of the flow stationary mode, by following the signals closes valves.

Using in researches of imitation of hydraulic stroke on section of the trunk pipeline allowed to increase work efficiency of the protection system in the result of prediction of development phase of the pressure wave, selection of optimum configuration and sizes of active part of the smoother, determination of flow parameters and their value for the sustainable management.

Effect from proposed protection system is specified on the drawing 7, from which is shown that average speed of the pressure increase, supported by the system does not exceed the permissible volume, specified in the process regulation as 0.03 MPa/sec.

Conclusion. Developed system fulfills all necessary functions on control and management of transportation modes with the purpose of prevention or minimization of hazardous situations consequence, which provides:

– prevention of passing of high pressure wave to operation zone of oil pumping station by the timely discharge vales,

– regulation of quantity, speed, and direction of coming – leaving leakage by discharge valves o the adjusted algorithm,

– possibility of the system to operate in several modes of smoothing, including the self-regulation mode of emission-discharge processes, for provision of reliable protection with different values of the pressure waves.

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МҰНАЙ АЙДАУ СТАНЦИЯЛАРЫНЫҢ ЖАБДЫҒЫН ГИДРАВЛИКАЛЫҚ ЖҮКТЕМЕЛЕРДЕН ҚОРҒАУ ЖҮЙЕСІ

Аннотация. Жұмыста мұнай айдау станциясының жабдықтарын жоғары қысым толқынынан қорғайтын әдістер мен құрылғылардың және қолданыстағы жүйелердің талдауы жүргізілген. Негізгі жүйе ретінде гидравликалық жүктемелерден қорғау үшін төмен қысымды құбыр жүйелерінде кеңінен қолданылатын теңестіруші резервуарлар қарастырылған. Ауа қалпағы қысымның жоғары жиілікті тербелістерін кішірейген амплитудағы төмен жиілікті қысымға түрлендіру арқылы әртүрлі қысымдағы толқындарды тегістеуге мүмкіндік береді. Автоматты реттеу жүйесі реттегіш жапқыштардың құралдары және т.б. бойынша ағысты шектеу арқылы қысым толқындарын тегістеуді жүзеге асырады. Гидравликалық жүктемелерге қарсы күрес бойынша бірқатар артықшылықтарға қарамастан, олар мұнайды тасымалдаудың технологиялық режимдеріне байланысты бірқатар елеулі кемшіліктерге ие. Осы кемшіліктерді жою үшін қысымның пульсациясын қарсы ағында тегістеу тәсіліне негізделген жаңа қорғаныс жүйесі ұсынылады. Жүйе қолдайтын қысым өсуінің орташа жылдамдығы технологиялық регламентте көрсетілген 0,03 Мпа/с шамасынан аспайды. Жүйе жоғары қысым толқындарының әр түрлі қарқындылығы кезінде сенімді қорғауды қамтамасыз ету үшін бірнеше тегістеу режимдерінде жұмыс істей алады және лақтыру-шығару процестерімен өзін-өзі реттеу режимін қамтиды. Жүйенің тиімділігі автоматты басқару жүйесімен қамтылады.

Түйін сөздер: мұнай құбыры, айдау станциясы, гидравликалық жүктемелер, пульсацияны тегістеу, қысым толқындары, ауа қалпағы, теңестіргіш резервуар, жапқыш, клапан.

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СИСТЕМА ЗАЩИТЫ ОБОРУДОВАНИЯ НЕФТЕПЕРЕКАЧИВАЮЩИХ СТАНЦИЙ ОТ ГИДРАВЛИЧЕСКИХ НАГРУЗОК

Аннотация. В работе проведен анализ существующих систем, методов и устройств по защите оборудования нефтеперекачивающей станции от волн повышенного давления. В качестве основных систем рассмотрены уравнительные резервуары, которые широко используются в трубопроводных системах низкого давления для защиты от гидравлических нагрузок. Воздушный колпак позволяет сглаживать волны различного давления за счет преобразования высокочастотных колебаний давления в низкочастотные с пониженной амплитудой. Система автоматического регулирования, осуществляющая сглаживание волн давления дросселированием потока по средствам регулирующих заслонок и т. д. Несмотря на ряд достоинств по борьбе с гидравлическими нагрузками они имеют ряд существенных недостатков, связанные с технологическими режимами транспортирования нефти. Для их устранения предлагается система защиты, в основе которой

лежит способ по сглаживанию пульсации давления на встречных потоках. Средняя скорость роста давления, поддерживаемая системой не превышает допустимой, указанной в технологическом регламенте величины 0,03 МПа/с. Система может работать в нескольких режимах сглаживания для обеспечения надежной защиты при различной интенсивности волн повышенного давления и включает режим саморегулирования процессами выброса-сброса. Эффективность системы поддерживается автоматической системы управления.

Ключевые слова: нефтепровод, перекачивающая станция, гидравлические нагрузки, сглаживание пульсаций, волны давления, воздушный колпак, уравнительный резервуар, заслонки, клапан.

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