RESULTS OF INDUSTRIAL TRIALS OF NEW SAFETY DEVICES IN PETROLEUM-INDUSTRY PUMP UNITS

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Safety devices in portable petroleum-industry pump units should be reliable, trouble-free, and safe for performing such technological operations as hydraulic fracturing, hydraulic abrasion drilling, well cementing, etc.

Single-acting safety devices, namely, valves with split stems [1], do not fully meet the demands for continuity and, consequently, quality of the above operations. A reusable continuously pressure-adjusting KPM-32 × 400 safety device efficient at both minimum and maximum consumptions of abrasive-containing, rapidly hardening, and other fluids [2-4] has been developed at the Azerbaidzhan Scientific-Research Institute of Petroleum Machinery (AzINmash).

The device (Fig. 1) provided with a free shut-off seal has consumption-pressure delivery characteristics.

Technical Specifications of the KPM32 × 400 Safety Device

Pressure, MPa:	
adjustment	12-40
manual actuation	0-40
Diameter of conventional channel, mm	32
Maximum consumption, liters/sec	33
Dimensions, mm	190 × 105 × 550
Weight, kg	18

The device operates as follows. At a pressure of the medium above the fixed value the plungers rise and, as a result, the spring is compressed and the seal goes out of the seat. Under the pressure of the medium the seal opens up the channel section of the device completely. After pressure release the seal is brought back to the original position manually by a lever which also permits emergency pressure release from the system.

The design, operating principle, and results of bench trials of prototype safety devices were described in [5].

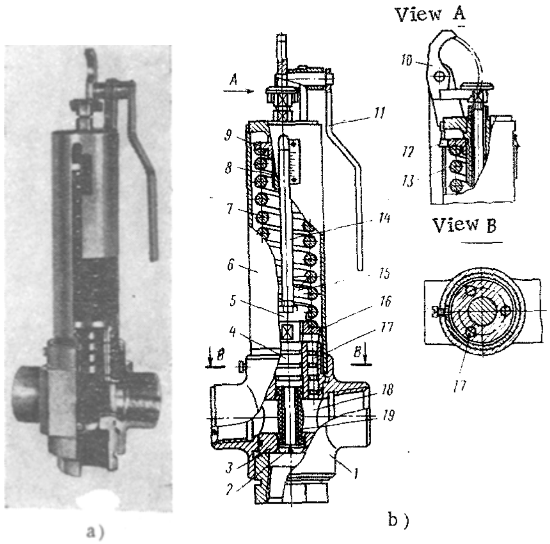

Fig. 1. Reusable KPM32 × 400 safety device: a) external view; b) schematic design; 1) housing; 2) screw; 3) valve seat; 4) piston seal; 5) head; 6) casing; 7) lifting spring; 8) regulating bolt; 9, 16) plates; 10) C-shaped clamp; 11) lever; 12) lug; 13) groove; 14) rod; 15) collar; 17) set of plungers; 18) high-pressure chamber; 19) cup.

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TABLE 1

Technological operation	Medium to be pumped	Density of the medium, N/m^3	Pressure, MPa	Duration of operations, h
Hydraulic fracturing	Sand-containing industrial water, oil, drilling mud	$(1.3\text{-}1.6)\ 10^4$	12-40	2-3
Hydraulic sandblast drilling	Sand-containing industrial water, drilling mud	$(1.5\text{-}1.8)\ 10^4$	20-40	6-10
Well cementing	Cement and drilling mud	$(1.2\text{-}2.0)\ 10^4$	0-24	0.6-2.5
Acid treatment of wells	Inhibited hydrochloric acid mixed with hydrofluoric and acetic acids	$(1.1\text{-}1.2)\ 10^4$	10-35	2-3
Installation of oil tanks	Oil, industrial water	$(0.8\text{-}1.1)\ 10^4$	20-30	3-6
Well plugging, determination of intake capacity	Industrial water, drilling mud	$(1.0\text{-}2.2)\ 10^4$	20-35	2-8
Completion of wells	Oil, water, drilling mud	$(0.7\text{-}1.6)\ 10^4$	10-20	5-10
Molding of columns and equipment	Water	$1 \cdot 10^4$	20-40	1-6

TABLE 2

p, MPa	p_a, MPa	Δ_i^n, %	$\sum_{i=1}^{N} \Delta_i^n$, %	$a_1 + bN$	$a_2 + bN$
12	12,57	4,8	4,8	1,73	10,71
16	17,18	7,4	12,2	9,41	18,39
20	21,0	5,0	17,2	17,09	26,07
24	24,87	3,6	20,8	24,77	33,75
28	29,18	4,2	25,0	32,45	41,43
32	32,70	2,1	27,1	40,13	49,11
36	37,20	3,4	30,5	47,81	56,79
40	42,0	5,0	35,5	55,49	64,47

After successful bench trials the KPM32×400 prototype safety devices were subjected to prolonged industrial trials in the pump units UNB2-100KhL, TsA320M, and 4AN-700 under operating conditions in the oil fields of the Azneft', Kaspmorneft', and Glavtyumenneftegaz associations. The operational characteristics of the units equipped with the devices tested are given in Table 1.

At low well pressure, after the technological operation is complete, the safety device under trial was actuated artificially by throttling the discharge line of the pump with the help of a flow regulator. The regulating pressure of the device was changed from 12 to 40 MPa in steps of 4 MPa and the pump feed, from 3 to 22 liters/sec. The actuating pressure of the safety valve was fixed by a self-recording manometer and a manometer with a control pointer. If necessary, the pump feed was determined by measuring the volume of the medium to be evacuated from the volumetric tank of the portable unit at least for 60 sec.

At the first stage of the industrial trials the device developed was tested for its efficiency and reliability under operating conditions and was compared with the devices used commonly for ascertaining their mutual advantage with sufficient reliability. As a criterion of comparison we took the reliable operation of the safety devices, i.e., the divergence of the actual actuating pressure p_a from the given (calculated) pressure p [1], as follows:

$$\Delta = \frac{p_a - p}{p}\ 100\%.$$

As is well known, sound data on the advantages of one design over another can be obtained with minimum number of trials by applying Wald's method of systematic analysis [6]. It was shown in [1] that the actuating pressure distribution in the devices employed obeys the standard law. In this event, the mean absolute error of the actuating pressure $\bar{\Delta}^a = 12.36\%$ and its standard deviation $S^a = 3.52\%$. It was expected that the deviations of the actuating pressure of the devices made also obey the Gaussian distribution law and have $\bar{\Delta}^n = 3\%$ with the same value of $\sigma \approx S^n = 3.52\%$.

Accepting the hypothesis H_1 for which the observed values of $\Delta_1^n, \Delta_2^n, \ldots, \Delta_i^n, \ldots, \Delta_N^n$ were taken from the aggregate, the $\bar{\Delta}^n$ and $\bar{\Delta}^a$ values were compared with the average value of $\bar{\Delta}^n$ and accepting the hypothesis H_2 for which the observed values of $\Delta_1{}^n$, $\Delta_2{}^n$, ..., $\Delta_i{}^n$, ..., $\Delta_N{}^n$ were taken from the aggregate, the $\bar{\Delta}^n$ and $\bar{\Delta}^a$ values were compared with the average value of $\bar{\Delta}^a$ (here N is the number of observations; Δ_i is the value observed in the i-th experiment; and i is the number of the experiment).

The probability α for accepting the hypothesis $\bar{\Delta} = \bar{\Delta}^a$ was taken as 0.1 when, in reality, $\bar{\Delta} = \bar{\Delta}^n$ ("rejection" risk) and the probability β for accepting the hypothesis $\bar{\Delta} = \bar{\Delta}^n$ was taken as 0.01 when, in reality, $\bar{\Delta} = \bar{\Delta}^a$ (risk of accepting the "rejected" device). As we find, the verification of the hypothesis H_1 and H_2 was so planned that the error probabilities α and β were minimum. These probabilities indeed governed the risk of accepting the wrong hypothesis.

For the normally distributed random value, the number of the requisite observations for accepting one of the hypotheses can be determined from the condition of nonfulfillment of the inequality

$$a_1 + bN < \sum_{i=1}^{N} \Delta_i < a_2 + bN,$$

where

$$a_1 = \frac{\sigma^2}{\delta} \ln \frac{\beta}{1-\alpha}; \quad a_2 = \frac{\sigma^2}{\delta} \ln \frac{1-\beta}{\alpha};$$
$$b = \bar{\Delta} = 0,5\ (\bar{\Delta}^a + \bar{\Delta}^n); \quad \delta = \bar{\Delta}^a - \bar{\Delta}^n$$

For the referred conditions this inequality has the form

$$-5,95 + 7,68N < \sum_{i=1}^{N} \Delta_i^n < 3,03 + 7,68N.$$

The values of p_a having maximum deviation of $\Delta_i{}^n$ were chosen for determining $\sum_{i=1}^{N} \Delta_i^n$ from the set of data obtained in one of the first eight operations of a 4AN-700 unit. Calculated results show (Table 2) that the hypothesis H_1 stood confirmed after the fourth experiment.

During the whole period of trials the safety devices were actuated over 800 times, including 66 times at 40 MPa pressure, for performing 160 different operations. Analysis of the experimental data reiterated the standard distribution law for the deviation Δ^n and showed its maximum value to be not less than 8%, which conforms to the safety precaution norms [7]. The devices were noted to be trouble-free, highly stable, and dynamically steady when actuated automatically under operating conditions in which the consumption is variable in the whole range of the regulation pressures. The force applied to the lever in compulsory manual actuation was about 15 kgf, which is much lower than the force required to open, under pressure, a stopcock with the conventional channel diameter $D_n = 25$ mm generally used for these purposes. After actuation the device was quickly brought to the operating state without stopping the pump.

The suitability of the tested devices for further use was ascertained by examining the parts of the shutting-off components of the devices dismantled after the tests for checking scratches, damages, marks, cracks due to hydraulic abrasion, loss of air-tightness of the seals, etc.

The tests proved that KPM32×400 safety devices function reliably not merely in multiple use, but also as emergency pressure-releasing valves easily regulatable under pressure and permit to efficiently intensify yield and cementing of oil and gas wells. In technical specifications KPM32×400 safety devices conform to the modern technical level, can compete with the best foreign prototype and permit to guarantee trouble-free and safe operation of pump units and allied high-pressure equipment, to substantially reduce the time for bringing the units to the operating state after actuation of the devices and, consequently, to reduce the probability of complications and breakdowns during oil-field operations, to raise the reliability of the units and, through this, to reduce equipment standbys in many cases, to release pressure from the systems in emergency situations and, consequently, to increase the life of the equipment to be saved, to raise labor efficiency in molding casings and drilling pipes and other equipment as a result of automatic pressure release from the hydraulic systems, to reduce expenditure on preventive servicing of the units, and to alleviate and improve working conditions.

The annual economic gain from the introduction in oil and gas industry of KPM32×400 safety devices, which are being mass-produced by the Yu. Kasimov Machinery Manufacturing Plant, is 1 million rubles calculated on the basis of annual production of portable pump units.

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A REFRIGERATOR FOR DISSOLVING $^3He - ^4He$

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Refrigerators for dissolving ^3He [1, 2] are designed for ultralow temperatures (0.2°K and lower). A new simpler, reliable refrigerator meeting the basic needs of users of ultradeep refrigeration was designed by "Geliimash" Scientific-Production Association, basing on the experience of construction and use of a refrigerator designed by the Institute of Physical Problems, Academy of Sciences of the USSR [3].

The operation of the refrigerator for dissolving $^3He-^4He$ is based on the use of the following unique properties of the two helium isotopes: 1) a region of coexistence of two liquid phases of $^3He-^4He$ solution below 0.87°K (the lighter upper phase is rich in ^3He and the lower phase, in ^4He; 2) finite solubility of ^3He in ^4He at zero temperature $\lim_{T=0} x_3 = 0.064$ (where x_3 is the molar concentration of ^3He); 3) wide difference of saturated-vapor pressures of pure isotopes (p_3 and p_4) at $T < 1°K$ ($p_3/p_4 > 1000$ at $T = 0.6°K$).

The first of the noted properties suggests that a refrigeration of $Q = T(S_d - S_c)$ can be achieved in transition of ^3He atoms from the concentrated to the dilute phase, for the entropy of ^3He in the dilute phase S_d is higher than that in the concentrated phase S_c. The transition of ^3He atoms from the upper to the lower phase is analogous to liquid evaporation in vacuum whose role is enacted in the present case by superfluid ^4He.

The second property allows for sufficient ^3He flow through the lower phase even at the lowest temperatures.

The third property creates conditions for effective recovery of ^3He from the dilute solution.

The ^3He circulation scheme on which industrial refrigerators for $^3He-^4He$ dissolution are based is shown in Fig. 1. The ^3He atoms "evaporated" from the upper phase into the dilute (6%) solution with heat absorption pass from the dissolution chamber 1 through the reverse-flow tube of the low-temperature heat exchanger 2 into the evaporation chamber 4. During this, because of thermal osmosis, the equilibrium concentration of ^3He in the solution falls constantly with temperature rise, reaching ~ 1% in the evaporation chamber. The ^3He vapors are evacuated from the chamber at 1.33 Pa (10^{-2} torr) pressure with the aid of the steam-jet 9 and preevacuation 8 pumps.

The ^3He atoms compressed by the pump 8 to a pressure of 1.33 Pa pass through the forward-flow tubes of the heat exchangers 7, 6, and 5 where they are cooled successively to 4.2, 1.3, and 0.7°K and are condensed almost fully before reaching the throttle 3.

The liquid ^3He, cooled in the heat exchanger 2, reenters the dissolution chamber 1. The circulation speed required for the refrigerator operation is maintained by the electric heater 10 placed in the evaporator. During this, because of wide difference in the vapor pressures of ^3He and ^4He at the evaporator temperature of 0.7°K, the heavy, less volatile isotope ^4He practically ceases to circulate and acts as an inert liquid medium where ^3He transfer occurs. With restricted flow of the superfluid ^4He film through the evaporator diaphragm, the ^4He concentration generally does not rise beyond 5%. More detailed information regarding the functioning of the refrigerator is given in [4, 5].

The major components of the $^3He-^4He$ refrigerator are a cryostat (Fig. 2), a circulation unit, an array of mechanical pumps, and a measuring instrument. The cryostat is functionally the most important and cumbersome device which includes a nitrogen-screened helium Dewar flask and a low-temperature insertion piece

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