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Solution of Problems of Water-Gas Influence (WGI) on the Layer Using Jet and Electrical Centrifugal Pumping Technology

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Waterflooding – is currently the most popular method of oilfield development, but very often it does not guarantee high development effectiveness. This fact is the significant problem taking into account that the amount of hard to recover reserves is being increased constantly. The combined water and gas injection to the layer enables us to essentially increase the oil recovery ratio. Use of associated gas for water-gas influence also enables us to solve a problem of its utilization.

About 100 field applications of WGI are known since this technology was used in North Pembina (Canada 1957 year) for the first time, and only single cases failed.

Today, different technologies of WGI are applied that can be classified in two ways: alternate or simultaneous injection of water and gas (WAG or SWAG Injection). However, traditional ways of applying WGI were not widespread in Russian oil fields, but instead significant amounts of associated gas were flared.

WAG compressor technology requires the purchasing of import equipment, essential investments in the initial stage, and high operating costs. Besides compressor stations, the construction of gas treatment plants is required.

The separation of rich fraction from associated gas is required for the proper work functioning of compressors. These fractions are not always utilized and than the usage of dry gas for WGI it is less effective in terms of increasing oil recovery.

Booster piston pumps-compressors application for water-gas influence (WGI) is impossible without the generation of high gas pressure of gas on plant reception, and it also is an expensive action. Moreover, it is difficult to achieve provide with booster pumps the high efficiency necessary for realization of WGI on in a whole field with just booster pumps. The hydrate formation at injection with booster pumps complicates the process of influence essentially.

Compressor technology, as well as booster technology, requires the application of complex equipment, and qualified maintenance service and repair. Maintenance of acceptable reliability of a compressor and booster pump techniques during long operation at high injection pressure is problematic. Finally, at WAG injection in a layer, practiced in compressor and booster technologies of WGI, are possible breaks of large volumes of free gas to the bottomholes of producers that leads to the closure of their normal operation and losses in oil recovery.

Known jet technologies of SWAG do not provide the necessary injection pressure of a water-gas mixture and demanded gas phase productivity.

Therefore, the making of effective, reliable and simple in-service techniques and technologies for the generation and injection a water-gas mixture in a layer is an actual problem for Russian oil recovery.

The solution of WGI problems using jet and electrical centrifugal pumping systems has the best prospects. These systems enable us to generate a water-gas mixture on a surface and inject it in a layer the using equipment which can successfully be operated in the conditions of the Russian oilfields [1, 2, 3]. An important circumstance is that all equipment for jet and electrical centrifugal pumping technology of SWAG can be made at Russian engineering plants. It will save significant money by eliminating purchases of expensive imported technology production.

On In fig. 1, one of the possible basic technological schemes jet and electrical centrifugal pumping systems for SWAG Injection [4] is presented.

Well production proceeds through line 14 in a separator 15, where it is divided into oil, gas and water. Oil proceeds through a line 16 in an oil pipeline. Gas on a line 18 moves in the so-called jet compressor - jet and electrical centrifugal pumping plant of the first step 19 used as a supercharger for the increase of pressure of gas pressure before inlet of the jet apparatus 1. Water from a separator 15 moves on a line 17 on inlet of the pressurizing pump 23 and further in a gas-water separator 22 from which by the pump 21 it moves in a jet nozzle 20. Gas from a separator 15 proceeds into inlet of jet apparatus 20. Received water-gas mixture with the raised pressure comes in a gas-water separator 22 where there is a separation of gas from water. Gas under some raised pressure goes in inlet of the main ejector 1, and water - to the pump 4 and then - in jet nozzle of ejector 1.

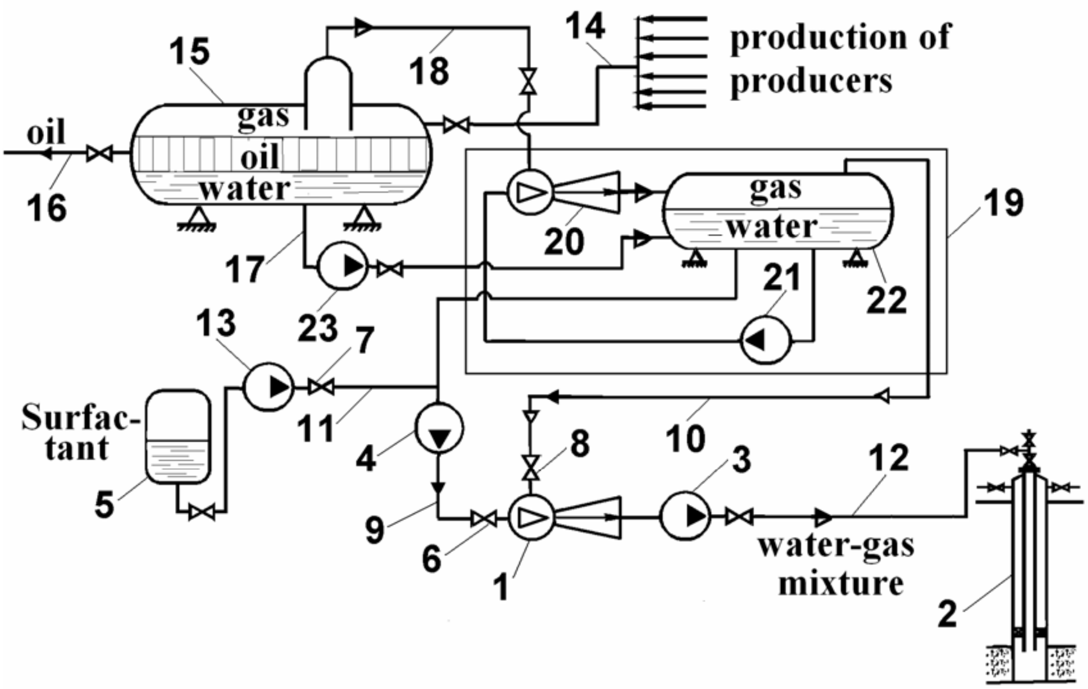

Fig. 1. The scheme of two-level jet and electrical centrifugal pumping system of SWAG.

1 - ejector (jet apparatus) of the second step, 2 – injection well, 3 and 4 - pumps, 5 – surfactant tank, 6, 7 and 8 – hydraulic valves, 9 - a line of water injection, 10 - a gas line, 11 - a line of surfactant injection, 12 - a line of water-gas mixture injection, 13 - the dosing pump, 14 - an inlet header, 15 - a three-phase separator, 16 - an oil pipeline, 17 – water line, 18 - a gas line, 19 – jet and electrical centrifugal pumping plant of the first step, 20 – ejector of the first step, 21 - the power pump of ejector of the first step, 22 – gas-water separator, 23 - the charge pump.

The part of a working liquid circulates on the closed contour in jet and electrical centrifugal pumping plant of the first step 19 and essentially heats up. Therefore there is also a heating of water, закачиваемой pumped in injectors. Hence, in the given technological scheme of WGI, it is possible to achieve reservoir pressure maintenance as well as reservoir temperature maintenance that is especially actual needed for development of high-viscosity and high-paraffinic oil fields. In addition, it is most likely to use a part of the heat allocated in jet and electrical centrifugal pumping plant 19, for heating of a water-oil-gas mixture before a separator 15 that considerably will improve conditions of its division. For this purpose, it is necessary to establish a heat exchanger before a separator 15 (on the figure it is not shown). Such heating will also allow for a decrease in hydraulic losses in the gathering system due to a decrease in the viscosity of pumped over production.

The gas flow is regulated by valve 8. On a line 11 by pump 13 surfactants are added from tank 5 in working water. In a flowing part of ejector 1 of compression second step there is are mixing streams and formation of a water-gas mixture. On an ejector output 1 water-gas mixture has some raised pressure which, however, is far not always enough for effective injection of a water-gas mixture with the necessary charge in injection wells 2. Therefore, after ejector 1 water-gas mixture is pressed by the pump 3 and is injected near high pressure on a line 12 in injectors 2.

As in ejector output 1 water-gas mixture is finely dispersed, has the raised pressure and high foaminess, there it is not necessary to be afraid of failure of work of the pump 3 failure 3 in a water-gas mixture even at high gas content values.

BENEFITS OF JET AND ELECTRICAL CENTRIFUGAL TECHNOLOGY

1. Water-gas influence is spent without expensive and labour-intensive service of high pressure compressor stations.
2. At a water-gas mixture injection using jet and electrical centrifugal pumping plant, an essentially smaller pressure of injection is required than gas injection using the compressor.

3. Jet and electrical centrifugal pumping systems are simple, compact and reliable.

4. It is reached in some times greater pressure of water-gas mixture injection in comparison with known jet technologies.

5. The problem of utilization of the associated gas which is burning down in gas flares is solved.

6. Foaming surfactants also promote the decrease in harmful influence of gas on the functioning of booster ECP, and to reduction of losses at water-gas mixture sliding on the injector, and an increase of the oil recovery ratio.

7. The problem of hydrate formation is solved.

8. Both reservoir pressure maintenance and reservoir temperature maintenance is possible.

9. Breakthroughs of gas to the producers are prevented.

10. The technology can be successfully realized both on single wells and well clusters, and on a field as a whole.

11. It is possible to use a part of the heat allocated in the first step of compression, for heating of a water-oil-gas mixture, resulting in the improvement of conditions of its division and a decrease in hydraulic losses in the gathering system.

With the purpose of acknowledgement of efficiency of the offered technological scheme of WGI with reference to conditions of Moskud'inskoye field of Limited Company "LUKOIL-PERM" are carried out stand research, whose results allow us to estimate potential opportunities and prospects of jet and electrical centrifugal technologies [5, 6].

Stand for research the features of jet and electrical centrifugal pumping systems working in broad range of flow rate and pressure was constructed with the assistance of closed company "Novomet-Perm". Stand (Figure 2) consists of two lines. The first line comprises tank 1 for working liquid, supporting electrical centrifugal pump 2, jet apparatus 3, water-gas separator 5. This line is designed to produce extra overpressure of gas in the inlet box of jet pump 7 of the second line. It consists of supporting electrical centrifugal pump 6 and jet apparatus 7. The stand also includes a system of distributing pipelines, adjusting valves, regulating valves and control and measurement equipment involving liquid and gas flow meters, pressure and temperature sensors. Besides the stand provides the system of compressors 4 for producing initial gas pressure 0,4 MPa (it is the pressure level in separator of booster pumping system in Limited Company “LUKOIL-PERM” oil field) in inlet box of jet apparatus 3 of the first line.

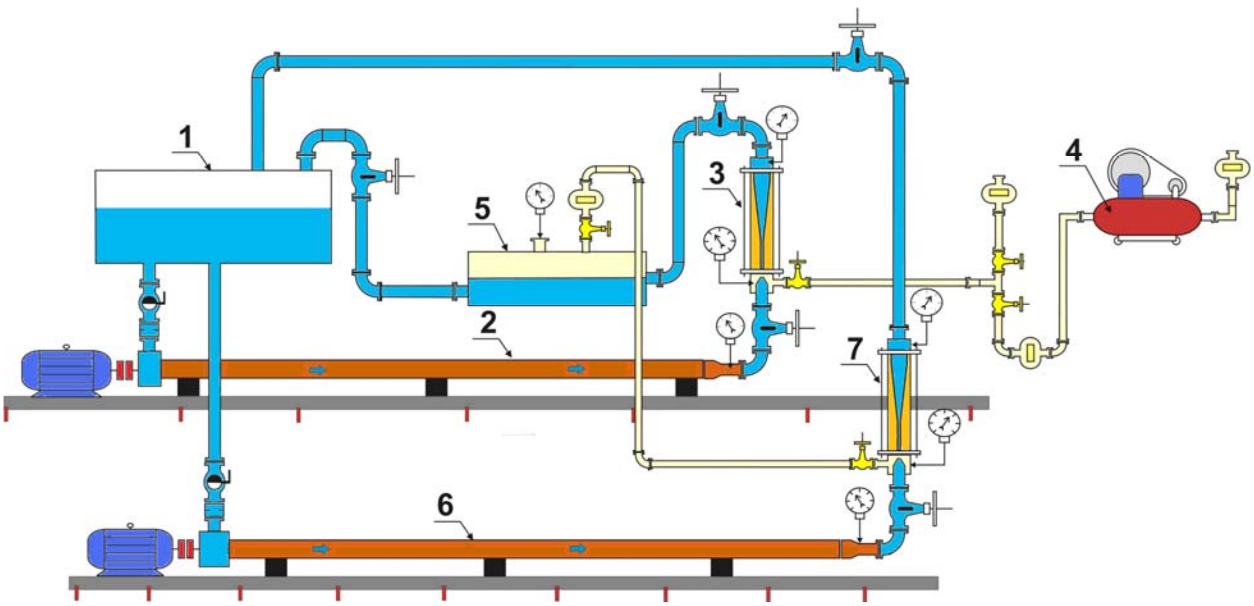

Fig. 2. Scheme of stand for jet and electrical centrifugal pumping systems research.

The liquid is pumped by booster pump from tank 1 to jet apparatus 3 nozzle and than this liguid injects the gas running from compressors 4. After that, water-gas mixture goes to separator 5. The mixture pressure in it is adjusted by valve located next to the outlet. Water-gas mixture is separated into liquid and gas in the separator 5, liquid goes to tank 1 and gas runs by pipelines to the inlet of the second ejector 7 (pump 6 serves as its drive).

Operational conditions, different in terms of flow rate and pressure, are built up using valves and also frequency regulation of pump 6 electric motor. As we can see at the stand scheme there is a possibility to fulfill two-step gas compression with ejectors 3 and 7.

Fig. 3 and 4 show pressure-power characteristics of liquid-gas ejectors of the first and the second lines (dependence of pressure ΔP_J provided with jet apparatus and coefficient of efficiency on volume consumption of injected gas Q_{IG} in the inlet box.

The pressure providing with jet pump ΔP_J equals difference between P_J and P_{in} - pressure at outlet and in the inlet box of liquid-gas ejector.

Experiments proved that the coefficient of efficiency of the jet apparatus measures up at a high level (over 40%) in the first stage of gas compression, at this time gas pressure rises from 0,4 by 3 MPa. Gas injection rates equals U_{GI} under ejector inlet conditions equals 4,4. Jet apparatus of the second line worked with the inlet gas pressure 3 MPa while pressure reached level over 10 MPa at the outlet of ejector. Maximum level of efficiency coefficient (40,7%) of high pressure ejector is comparable with efficiency coefficient level provided with high flow rate ejector of the first stage (see Fig. 3 and 4). Injection rate was 1,48 when this construction was applied, this level is significantly higher than the level of efficiency coefficient and U_{GI}, provided with ejector of the second stage with other design factors tested earlier in the paper [5].

In fig. 5 showed dependences $P_J = f(R)$ of pressure of injection of a mixture on an output of the jet device P_J from the gas-water ratio R led standard conditions resulted, at one-step (1) and two-step jet and electrical centrifugal compression (2 - with the jet apparatus which characteristics are presented on fig. 4, 3 - jet apparatus, tested in paper [5]). The gas-water ratio R is defined under the formula

$$R = \frac{Q_{G.ST}}{Q_W},$$

where $Q_{G.ST}$ - the charge of gas led standard conditions, Q_W - the charge of a working liquid through the first ejector (at one-step compression) or through the second ejector (at two-step compression).

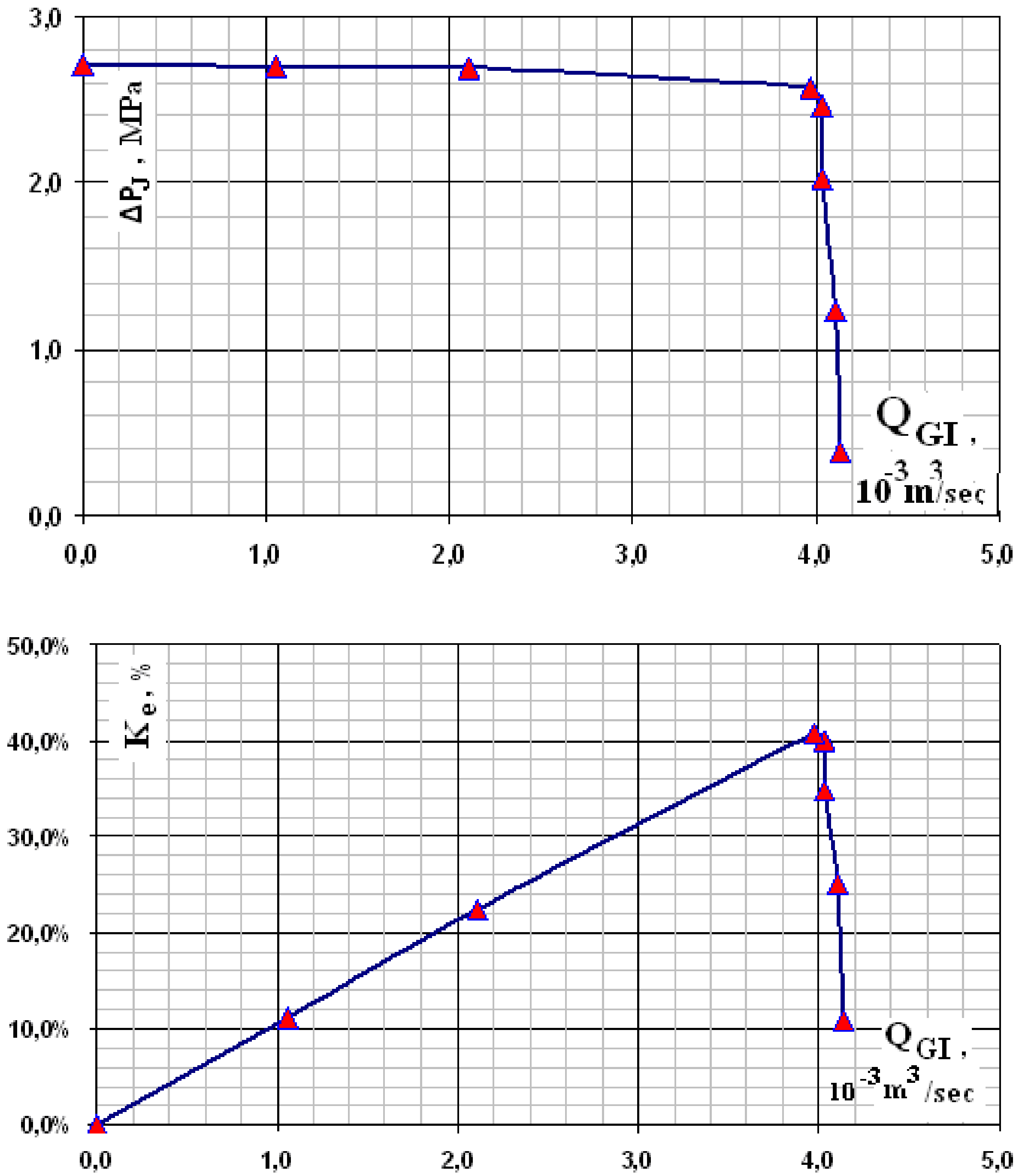

Fig. 3 Pressure-power characteristic of the first line ejector when pumping out gas with overpressure in inlet box 0,4 MPa.

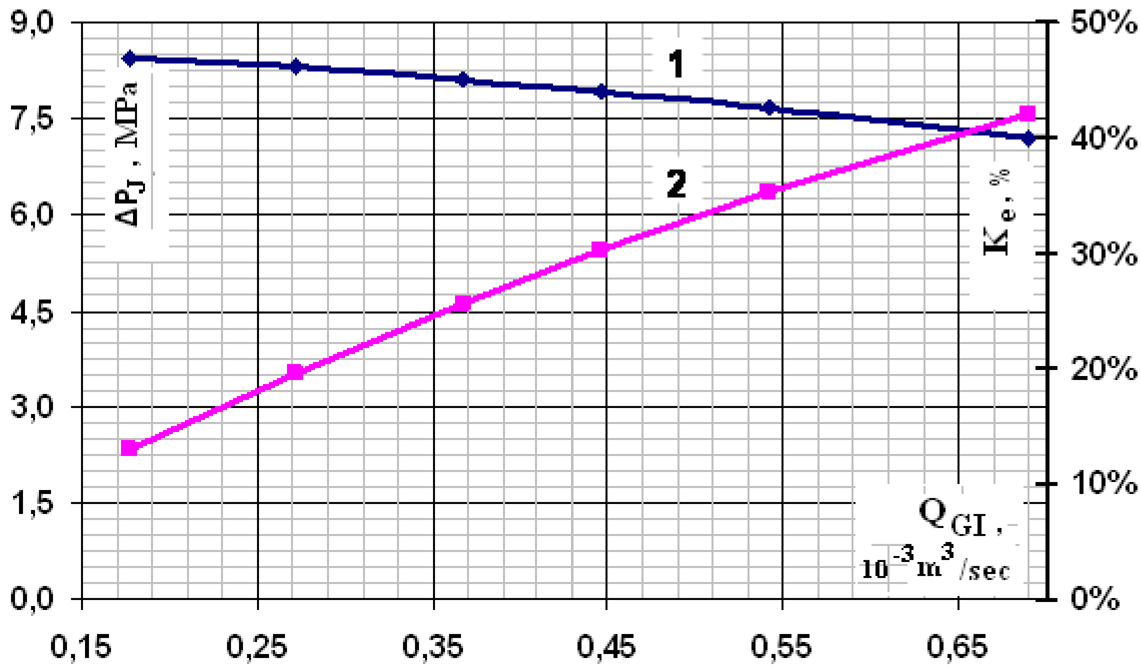

Fig. 4 Pressure (1) and power (2) characteristics of the second line ejector when pumping out gas with the overpressure in inlet box 3,0 MPa.

In fig. 5 showed dependences $P_J = f(R)$ of pressure of injection of a mixture on an output of the jet device P_J from the gas-water ratio R led standard conditions resulted, at one-step (1) and two-step jet and electrical centrifugal compression (2 - with the jet apparatus which characteristics are presented on fig. 4, 3 - jet apparatus, tested in paper [5]). The gas-water ratio R is defined under the formula

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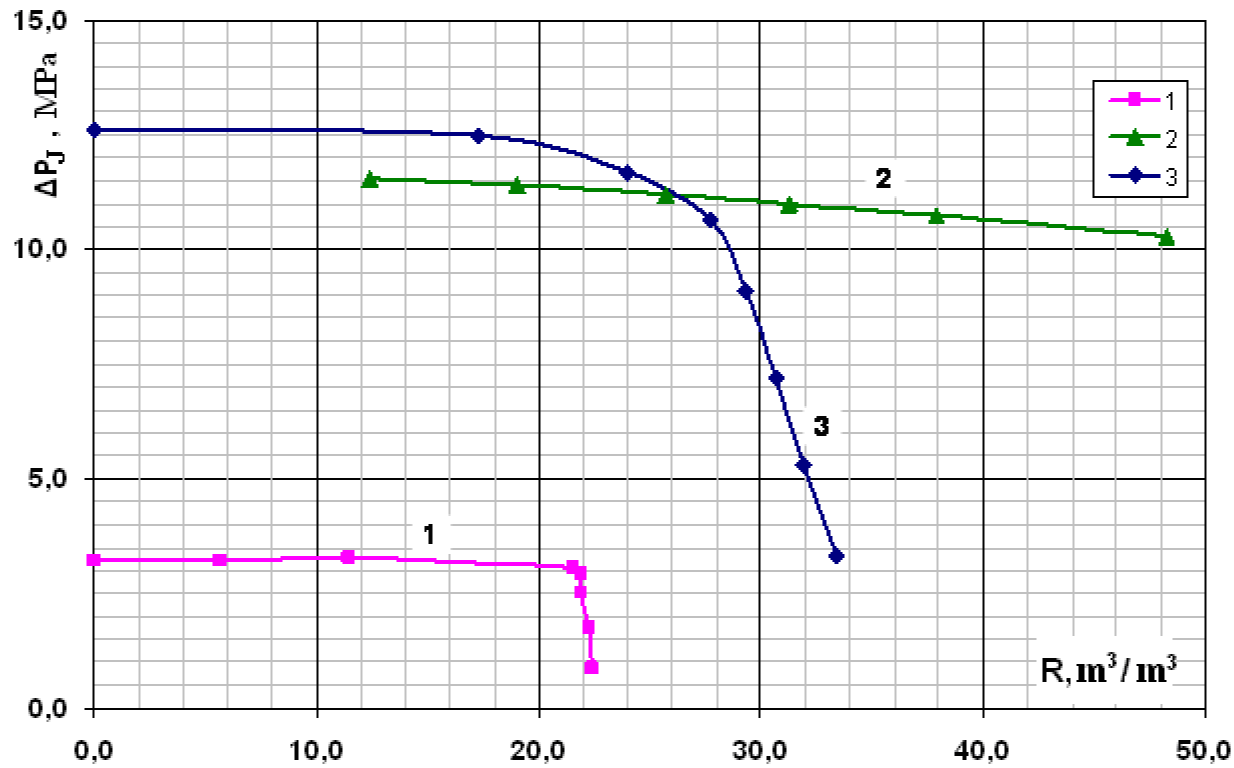

Fig.5. Dependences of pressure of mixture injection on the gas-water ratio $P_J = f(R)$ at one-step (1) and two-step jet and electrical centrifugal pumping compression (2 - with the jet apparatus which characteristics are presented on fig. 4 given appendices, 3 - with ejector, tested in paper [5]).

The results obtained from stand experiments demonstrate that using two-step jet and electrical centrifugal pumping compression allows us to reach essentially higher levels of gas-water ratio and a higher discharge pressure of water–gas mixture in comparison with the levels provided by one-step construction.

Moreover, the experiments' results prove that it is quite possible to provide conditions when the level of efficiency coefficient for high-pressure jet apparatus of the second step reaches more than 40%. This value is commensurable with the maximum efficiency coefficient provided by low-pressure high productive ejector of the first step of compression. High levels of efficiency coefficient allow us to conduct the process of water-gas mixture producing and pumping in injection wells with low costs.

Comparing the current findings with the results obtained in previous research [5] we can state the following:

Modification of the construction of the second step ejector allows us to reach significant increasing of gas-water ratio in mixture by the level $R = 43,5\, m^3/m^3$, required for Limited Company “LUKOIL-PERM” oilfield. Value of mixture pressure P_J at the outlet of second step ejector decreased slightly from 12 by 10,5 MPa. Taking into account the fact that it is necessary to produce 12 MPa level of pressure for pumping water-gas mixture into injecting wells at the trial area of Limited Company “LUKOIL-PERM” Moskud’inskoye field, the pressure of mixture should be increased from 10,5 by 12 MPa by means of multi-stage ECP (according to the scheme shown in Fig. 1) after the application of the second stage ejector.

Inclined rotor pump or centrifugal-axis pump should be used as booster pump. Gas content at inlet to booster pump will be equal to 29,4%. Addition of surfactants to the stream together with intensive dispersion of gas bubbles at ejector provides effective pump operation when using water-gas mixture.

Thus, stand research proved the applicability of suggested jet and electrical centrifugal pumping technology for the conditions of Limited Company “LUKOIL–PERM” Moskud’inskoe field.

Levels of gas-water ratio and discharge pressure obtained in the experiment undeniably are not extreme. Obviously, it is expected that a jet and electrical centrifugal pumping system capable of pumping water-gas mixture under pressure by 25 MPa when gas-water ratio is below 80 m3/m3 and efficiency coefficient of ejectors is higher than 40%.

The most prospective projects for Limited Company “LUKOIL” in terms of increasing oil recovery factor are the application of WGI at East Toloumskaya and West – Toloumskaya areas of Toloumskoe field and also at South-Tarasovkoe field in West Siberia.

Associated gas of East – Tolumskaya area contains 28,9% of carbonic acid, and associated gas of West – Tolumskaya area contains 67,6% of carbonic acid. High content of carbonic acid causes the impossibility to burn out associated gas. This gas is being dispersed into the atmosphere, which causes great damage to the environment. At the same time, associated gas of Tolum, with its unique content, can be successfully applied for increasing oil recovery rate combining effects of increasing oil recovery by means of water-gas and carbonic acid application.

Preliminary calculations made by RSU of Oil and Gas of Gubkin using data provided by Limited Company “LUKOIL–West Siberia” proved that WGI by means of jet and electrical centrifugal pumping systems are applicable at Tolumskoe and South – Tarasovskoe field.

The models of process flow sheets for WGI mixtures injection equipment at East-Tolumskaya area and South-Tarasovakoe field are shown in fig. 6 and 7.

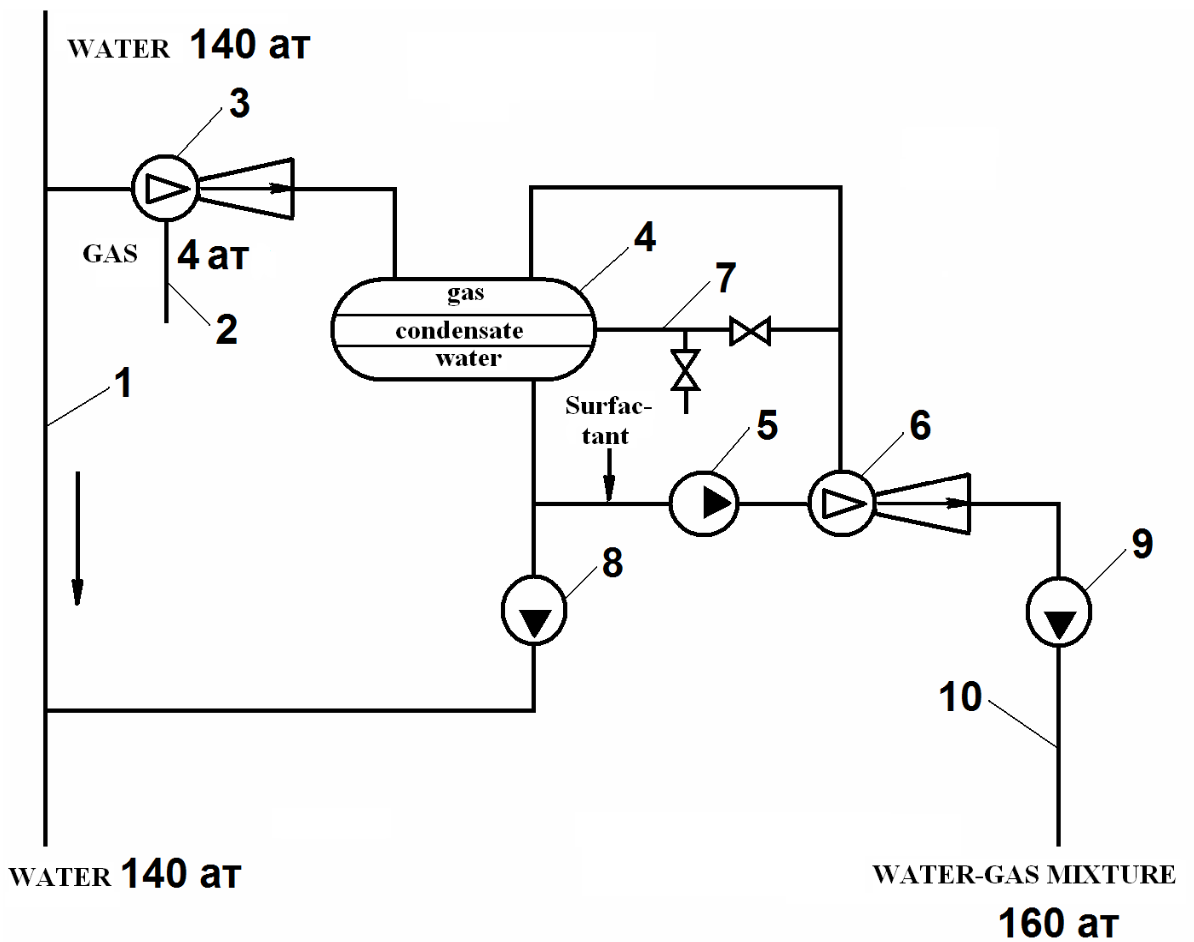

Fig. 6. Blank drawing of pump-ejector system for East-Tolumskaya area:
1 – Tolumskaya area: 1 – high pressure water line of reservoir pressure maintenance system, 2 - low pressure gas line from water pumping station, 3 – ejector (jet apparatus) of the first step of gas compression, 4 - a separator, 5 – electrical centrifugal pump (EC VNN8-1000-980, 6 – ejector of the second step of gas compression, 7 - a line of condensate drainage, 8 - ECP VNN8-1000-1250, 9 – “conical” ECP ECN8-1600/1000-1130, 10 – water line to the injection well 1548.

Conducted calculations proved that the full amount of the associated gas at East-Tolumskaya area (in standard conditions about 47769 m^3/day) can be pumped together with water in one injecting well 1548 on condition that the system is placed on the territory of group pumping station (GPS). For West-Tolumskaya area the level of gas flow is much higher – 220088 m^3/day.

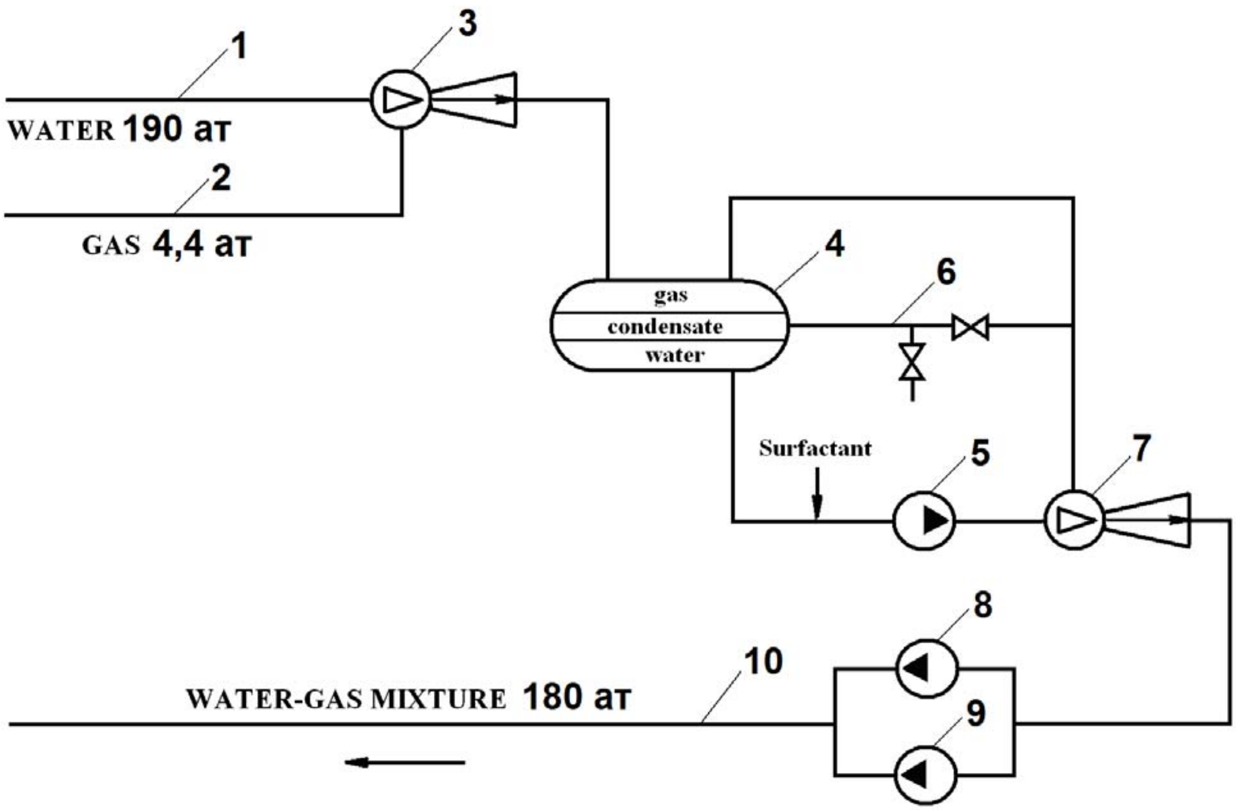

Fig. 7. Functional scheme of jet and electrical centrifugal pumping system for water-gas injection into layer in South-Tarasovskoe field.

1 – high pressure water line of reservoir pressure maintenance system; 2 – low pressure gas line from water pumping station, 3 – ejector of gas compression on the first step, 4 - a separator, 5, 8, 9 multistage ECP-pumps, 6 – pipe-bend for condensate, 7 – ejector of gas compression on the second step, 10 – water line to the injection well.

Therefore the most preferred option can be pumping gas together with water into all or to most of injecting wells of the field. Taking into consideration the high corrosiveness of carbonic acid, it is reasonable for West Tolumskaya area to place jet and electrical centrifugal pumping plants for water-gas mixture injection directly on well clusters to avoid the corrosion of water lines from GPS to well clusters. Furthermore, the initial research of the carbonic acid corrosion inhibitor provided by Kogalym chemical reagent plant proved that these inhibitors can be used as a foam agent.

Thus, there are some prospects to use these materials not only for inhibition but as a surfactant agent for WGI. It is obvious that the final decision about the way these inhibitors will influence on the WGI process will be made after a penetration test of core material.

Jet and electrical centrifugal Pumping system for water-gas mixture injection into the layer in South-Tarasovskoe field is operated in the following way:

The pump CNS 180-1900 (that is not reflected on figure) installed on GPS injects water into high pressure water line 1 of reservoir pressure maintenance with 190 atmosphere. Than water goes to the nozzle of ejector 3 of the first stage compression that pumps out gas with the initial pressure 0,44 MPa and injects water-gas mixture into separator 4 under increased pressure.

Separator 3 divides gas and water. Liquid goes to the inlet of ejector 5, and gas runs through the line 2 from the booster pumping station to the inlet of the second step compression ejector 7. Gas condensate precipitated in separator 4 can either go through the line 6 to the inlet of ejector 7 and that to the layer to increase oil recovery or can go backwards into the injecting oil pipelines of the boost pump plant.

Foaming surface active agent is pumped to the inlet of pump 5 by dosing piston pump (is not reflected in figure). Pump 5 injects water together with surfactant to the nozzle of second step compression ejector 7, pumping gas out of separator 3. After ejector 6 highly dispersed water-gas mixture with the increased pressure goes to the inlet of pumps 8 and 9, that boost mixture to the required level of discharge pressure 18 MPa. Our calculations proved that CNS 180-1660 can be used as pump 5 and VNNPIK 8-2500-1350 can be used as pumps 8 and 9.

Jet and electrical centrifugal pumping system provides water-gas mixture injection with the following characteristics: water flow 3556 m^3/day, gas flow Qg.st = 140 000 m^3/day, gas-water ratio R = 39,4 m^3/m^3 , outlet pressure Pout = 180 atmosphere, when providing efficiency coefficient of the system η_{JaECS} – 39,3%.

Useful power equals 1310 kilowatt, power consumption – 3331 kilowatt.

According to [7] levels of efficiency coefficients for quantity produced compressors classified by characteristics [8] prove the following matters. Level of efficiency coefficient for screw-rotor compressor used when collecting and field gas pumping reaches 48% under Pout = 7 atmosphere. Centrifugal pumping equipment that injects associated gas with the pressure P out = 113 atmosphere for gaslift well exploration raises 45% efficiency coefficient.

So the efficiency coefficient of simple and available jet and electrical centrifugal pumping system injecting gas-water mixture under high pressure does not yield to the level of efficiency coefficient provided by compressors that press only gas with significantly lower outlet pressure. This equipment is highly sophisticated, expensive and requires lubrication and cooling systems, well-qualified employees for maintenance, etc.

Moreover the fact that efficiency coefficient $\eta_{J\&ECS}$=39,3% means that the rest 60,7% of used power does not appear useless, it is used for heating the water-gas mixture to avoid hydrates precipitation (it makes WGI more complicated [9]) and enables it to maintain or increase layer temperature in the borehole environment.

Temperature increase in the bottomhole formation zone is particularly important for high viscosity oilfields or those with a high paraffin content.

In a number of cases, the heat evolved during jet and electrical centrifugal system operation can be used for improving the water-gas mixtures separation in the booster pumping station for decreasing oil viscosity and hydraulic losses in gathering facilities.

Taking into account the advantages of jet and electrical centrifugal pumping technology together with the fact that the efficiency coefficient of the system reaches almost 40%, and all the energy losses are used for heating up the mixture, avoiding hydrates precipitation we can conclude that this technology is going to be the main one when WGI is applied in Russian oil fields.

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