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Equipment for producing oil with high free gas content and its field study

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In this paper results of design and field studies of ESP installations for oil production from gas condensate wells are presented. Different components of ESP installation for operation in gas-saturated mediums are described: centrifugal-vortex and centrifugal-axial stages, gas separators, dipsersing devices (dispersants) and ESP-jet pump installations. Results of benchmark tests are presented. Method for equipment selection is proposed and technology of oil production with high free gas content is optimized. Examples of implementation of the obtained results in oil production practice are given.

Problem. At present, more than two thirds of the oil produced in Russia is produced by ESPs. A great deal of ESPs operate in mediums with high free gas content. Stable operation of ESPs in such conditions becomes rather complicated. The following measures are usually taken to increase ESP installations efficiency:

1. Pumping fluids from maximum possible depth.
2. Fitting ESP installations with gas separators, discharging the greater portion of free gas to the annulus.
3. Gas dispersing devices are used, whereby gas bubbles are broken into smaller ones to obtain quasihomogeneous mixture.
4. Implementation of taper pumps, consisting of stacks of stages for different nominal flowrates, the stack with highest nominal flowrate stages being at pump intake, the stack with the lowest – at the discharge.
5. Stages are developed to ensure their stable operation in gassy environments.
6. ESP-Jet pump units are used, consisting of gas separator and two consecutive pumps: ESP and jet pump. ESP generates flow of fluid through the nozzle of the jet pump, pumping gas-liquid mixture from the annulus into the tubing.
7. ESP installations are equipped with downhole telemetry systems and VSDs, allowing to control production

Technically, however realization of these measures is not adequate and the required results are not always achieved. So, the gas separators used have neither high separation characteristics nor reliability in abrasive environments. Existent dispersing devices are bulky: usually recommended number of stages should be no less than 20 – 40. There is no scientifically founded physical model of the system «well – ESP- Jet unit». Downhole telemetry systems are not reliable enough at temperatures higher than 120°C and pressures higher than 30 MPa.

The problem is still worse due to a pulsating feed of free gas through gas seams in a large number of wells. Required head for developing these wells after killing with heavy fluids could be several times more than necessary for their normal operation.

The present paper attempts to find solutions to some of the problems listed above.

New design stages for producing gas-liquid mixtures. Stages of ESP pumping gas-liquid mixture could be devided in two groups. The first one includes stages at pump intake, generating almost no head but breaking the gas bubbles. The second one - the subsequent stages operating with quasihomogeneous liquid. They develop almost the same head as is the case with homogeneous liquid. [1].

When free gas with the wellbore fluid enters the pump, liquid flowrate as well as pump's head is reduced. When the value of bulk concentration of free gas[1] is rather high (in low water cut wells 25-30%, in high water cut wells 5-15%) pump operation becomes unstable and is characterized by fluctuation of its parameters: generated pressure, power consumed, flowrate, the latter could stop altogether.

Novomet has developed two new types of stages for producing oil containing undissolved gas: centrigugal-vortex (VNN) [2]-[3] and centrifugal-axial (TSON) [4]. Their common feature are special design elements dispersing gas bubbles, see fig.1 In case of VNN stages – vertical crown/row, located in the plane of impeller's driving disk along its perimeter. In case of TSON stages – axial vanes, located from the area of liquid flow discharge from the impeller to its inlet to the diffuser.

Fig. 2 presents head characteristics of these stages in gas-liquid enviroment. Benchmark testing was done with water – air mixture and water - surface-active material (disolvan 4411) – air, having

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[1] Bulk concentration is the ratio of free gas volume to gas and liquid volume.

characteristics similar to gas-liquid mixture, produced from the well [5]. It is evident that head reduction in case of VNN and TSON stages is substantially lower than in ESP stages of traditional design. Tests proved the maximum admissible concentration of free gas to be 15% for traditional ESP, 25% for VNN and 45% for TSON.

VNN and TSON performance is introduced in reference [6].

New design gas separators and dispersing devices (dispersant). There have been three types of gas separators used in the oilfield industry in different periods of its history: gravitational, vortex and centrifugal. To separate gas from liquid their density difference is used, leading to fraction separation under the influence of gravitational or inertial forces. Gravitational gas separator has the smallest separation factor, centrifugal – the greatest. Vortex separator stands in between.
The first centrifugal gas separator in Russia was designed more than fifty years ago [7]. At a later stage, its design was modified to incorporate a supercavitational impeller [8], this leading to a major increase in efficiency. The present designs are based on the effect of gas separation in the supercavitational impeller vane trail.

Dispersing devices in Russia were developed and field-tested more than 30 years ago [9]-[11]. In these devices modified diffusers and impellers of serial ESPs were used as stages (with through axial holes, for example) or axial stages. Currently manufactured gas separators still have the same stages [12]-[13].

The authors of the present paper have designed a number of high-efficiency gas separators and separators-dispersators of the types 4, 5 and 5A (housing OD of 86, 92 and 103 мм accordingly) for flowrates (liquid) from 10 to 650 m^3/day [14]. Dispersant-gas separator overall view is given on fig. 3. Its design feature are the following: original shape cavity-forming impeller, optimally-placed vanes/blades relative to separation drum/real, abrasion-, cavitation-resistant design, axial liquid inflow and built-in short and effective dispersing device.

Rotor – screw and stator – sleeve are the stages of a dispersant [15]. On the outer cylindrical surface of the screw and on the inner cylindrical surface of the sleeve there are special profile multiple-thread, oppositely-directed cuttings/threads. In operation, relative position of cuttings' ridges of the sleeve and screw is constantly changing, this leading to considerable flow velocity gradient, dispersing gas-liquid mixture.

In the field, it was found that an ESP equipped only with a dispersing device could operate stably with free gas concentration at the pump intake amounting to 65% of the volume.

Figures 4 and 5 give a comparison of developed and currently produced gas separators. Measurements were taken on the test-bench in The Russian State Oil and Gas University, using a finely dispersed mixture of water - surface-active material – air, bubbles' size at the separator's inake being no more than 0.1 mm. The mixture was produced by a jet pump. This enables to model the most severe downhole conditions.

On fig. 4 and 5 the abscissa axis is liquid flow, the ordinate axis is maximum allowable bulk concentration of free gas at the gas separator's intake, residual concentration of gas at discharge being 25% of the volume (with this free gas concentration ESP reliable operation is still possible in wells with no water cut). It is evident that the newly developed devices have a wider range of applications and better efficiency as compared to other products.

Gas separators and gas-dispersing devices developed by the authors are produced serially and operate successfully in the Russian oil fields.

ESP-Jet pump installations. A common situation with high GOR wells is semi-free flowing when the head required to develop a well after killing it with a heavy fluid is several times more than that necessary for its operation.
In these cases it is recommended to use ESP-Jet pump systems consisting of an ESP, gas separator (with or without the dispersator) and a jet pump.

ESP-jet pump installations could also be used when the head required to develop a well after shutting it with a heavy fluid is several times more than that necessary for its operation.

Similar device for gassy liquid production in Russia was first mentioned in 1966 [16]. However, this invention proved ineffective and was never to put to practice. It was only later that more feasible designs were introduced. [17], [18].

ESP-Jet pump installations [19] (fig. 6) developed in The Russian State Oil and Gas University and manufactured by Novomet have the following design features: a special jet pump design, dispersing device application along with a gas separator.

In a jet pump unit it is proposed to use a diaphragm nozzle, in which, as has been found in the course of analysis, sound locking does not occur within a broad range of free gas concentrations.

The presence of the jet pump enables to set ESP operation mode close to BEP by selecting the corresponding diameter of the operating nozzle. ESP-jet pump system has a high efficiency due to gaslift in the tubing and often larger flowrate than is the case with ESP.

Sizing and selection program. Optimal setup of an ESP or ESP-Jet pump installation for a particular well could be achieved by means of NeoSel-Pro software package.

NeoSel-Pro is intended for optimal selection of ESPs and ESP-jet pump systems for particular wells, operational parameters control, optimization of ESP fleet/stock of a customer.

There are up to ten selection programs currently used in Russian oilfield practice. The software developed by the authors is able to solve a number of tasks due to introduction of production stimulation technology and a necessity to produce from difficult to develop wells:

1. Equipment selection to wells with nonsteady operation mode.
2. Forecasting of well productivity curve to downhole pressure values, which are considerably lower than bubble-point pressure which is necessary to determine potential of a well.
3. Necessity to calculate heating of all the components of an ESP string, especially due to increasing length of an installation and low flowrates of wells.
4. Calculation of ESP installations' bends while descending in the well and in a suspension point in a particular highly-deviated well.
5. For wells with increased gas content an optimal ESP setup is determined, incorporating a taper pump, dispersing device, gas separator and their combination. Optimal construction of a jet pump is calculated. You ca view the performance of ESP-Jet system on fig. 7.
6. The flow structure of gas-liquid flowing along and under an ESP motor is calculated in order to avoid gas lock accompanied by vibration, and possibly leading to ESP disjoint failures.

Known programs are either unable to solve these problems or do not solve them in full.

NeoSel-Pro software package was first tested on the wells of White Nights oilfield (Western Siberia) with severe production conditions (high GOR, low flowrate, highly deviated wells, mechanical impurities). Thanks singly to correct equipment selection nonfailure operation time was increased from 70 to 300 days.

At present Novomet uses NeoSel-Pro to deploy its equipment on the oilfields operated by Surgutneftegas, Yuganskneftegas, White Nights, TNK-BP, on the oilfields of Belorussia, Kazakhstan and Dagestan.

Operational examples of ESP-Jet pump installations. ESP-Jet pump installations allowed to switch to noninterrupted artificial lift of the wells 762 and 841 of Garshinskoye oil-gas condensate oilfield in Orenburg region (Russia). Attempts to introduce ESPs in these wells before had been unsuccessful. The reason was GOR of about 300 m^3/m^3 at bubble-point pressure of 29.7 MPa and reservoir pressure of 28 – 29.1 MPa. The wells were free flowing, operating unstably in a cyclic/periodic mode through battered overflow valves.

In table 1 operational parameters of the wells are presented before and after introduction of ESP-jet pump installations. Fig. 8 shows the start of the ESP-jet pump installation in well № 762 and its dynamics. You can see that after 2 days intense foam formation occurred in the annulus. Sonic depth finder started to register not boundary between gas-liquid but the foam level. Jet pump also started to operate. Despite the appearance of two kilometer foam column, pressure in the closed annulus decreased.

New generation ESP-jet pump systems are successfully used in the most severe operational conditions: at very high gas content on the intake, unstable operational modes and idle wells development, specifically in oil-gas condensate fields of «TNK-BP» in the southern part of Orenburg region with low reservoir pressures and GOR ranging between 300 – 400 m^3/m^3. ESP-Jet pump introduction allowed to develop and successfully produce from these wells «impossible» to handle for other types of equipment. Additional recovery for 13 wells amounted to 350 tons/day.

The work carried out allowed to develop several setups of ESP systems for liquid production with different free gas content, see fig. 9.

Conclusions

1. Effective components have been developed for producing mediums with high free gas content: centrifugal-vortex and centrifugal-axial stages, gas separators, dispersing devices, jet pumps.
2. A software package for selecting ESP installations to wells with varying PI (production index) and a selection method of optimal design of ESP-Jet pump components was introduced.
3. The results obtained allowed to produce fluid by ESPs and ESP-Jets with free gas content at the ESP installation intake of up to 75%.

References

1. Drozdov A.N. Development of calculation method of ESP characteristics in operation of wells with low intakes pressures.: Thesis abstract M., 1982.
2. Patent 2133878 Russian Federation, F04 D 13/06. Electric multi-stage pump/ *Vidrina I.V.,*

Shtennikova G.A., Semenov Y.L. and others. №97119549/06; Patent application. 25.11.97;Published 27.07.99. Bulletin. №21. 4 pages.:illustrated.

3. Patent application №99/27257 F04 D 5/00. Stage in a submerged multiple-stage pump/ A.I.Rabinovich, O.M. Perelman, P.B.Kuprin etc.; Zakrytoe Aksionernoe Obschestvo "Novomet-Perm" (Russian Federation). №98/00396; Patent application 24.11.98; Published 03.06.99; Priority 25.11.97, № 97120198 (Russian Federation).
4. Patent application № 2003126094/06 Russian Federation, F04 D 13/10. Stage of submersible multi-stage pump / Gusin N.V., *Rabinovich A.I., Perelman O.M. and others.* Patent application 25.08.2003; Patent granted 11.01.2005.
5. reference to thesis abstract of Igrevskiy
6. *Ageev Sh.R., Kuprin P.B., Maslov V.N., Melnikov M.Y., Perelman O.M., Pescherenko S.N., Rabinovich A.I.* Reliable centrifugal pumping installations with low flowrate for oil production in complicated conditions // ESP Workshop 2005
7. *Bogdanov A.A.*. Submersible centrifugal electric pumps. Gostoptekhizdat, 1957.
8. Patent №2027912 Russian Federation F04 D 13/10. Method for pumping fluids by an ESP and a separator of an ESP / Liapkov P.P., *Drozdov A.N.,Igrevskiy V.I. and others* № 4915192/29; Patent application 28.02.91; Published 27.01.1995. Bulletin №3.
9. Author's certificate 494536 USSR, F04 D 13/06. Submersible centrifugal pump / Gafurov O.G., *Hangildin I.G.,Kaplan L.S.* №2004810/24-6; Patent application 11.03.74; Published 05.12.75. Bulletin №45. 2 pages: illustrated.
10. Afanasiev V.A.and others. Introduction of electric submersible pumping installations with dispersing devices on Western Siberia oilfields // Petroleum engineering magazine. 1979. №12.
11. Aksenov G.I., Elizarov A.V., Maksimov V.P., Perminev A.D. ESP operation with topping dispersing device with gas-liquid emulsions // GiproTiumenNeftegas Works, Issue 36. Oil production on Western Siberia oilfields. Tiumen, 1973.
12. Patent certificate 19105 Russian Federation F04 D 13/10. Submersible centrifugal pump for producing oil / Zimin A.A., Feofanov № 2001101330/20; Patent application 19.01.2001. Published 08.10.2001. 2 pages.: illustrated.
13. Patent 6,726,449 USA, 415-199.2. Pump diffuser anti-spin device/ M.James, T. Shafer, Baker Hugnes Inc. №10/100,544. Patent application 18.05.2002; Published 27.04/2004. 8 c., 4 illustrations. ил.
14. Patent № 2232302 Russian Federation F04 D 13/10. Method of pumping out gas-liquid mixture from wells and submersible pumping installation for its implementation / Drozdov A.N., Ageev Sh.R., Dengaev A.V. and others № 2003111947/06; Patent application 24.04.2003; Published 10.07.2004. Bulletin19. illustrated
15. Patent № 2232301 Russian Federation F04 D 13/10. Submersible pumping installation / Drozdov A.N., Ageev Sh.R., Dengaev A.V. and others 2003111919/06; Patent application 24.04.2003; Published 10.07.2004. Bulletin 19. illustrated.
16. Author's certificate USSR № 188424 Sporishev V.S.
17. Author's certificate 1749556 USSR F04 D 5/54. ESP-Jet pump installation / Drozdov A.N., Igrevskiy V.I., Bazhaikin S.G., Ganeev R.G. №4803082/29; Patent application 21.03.90; Published 23.07.92. Bulletin №27. 3 pages: illustrated.
18. Patent 2264147 of the UK, F 04 D 31/00. Multi – phase Pumping Arrangement / J. Allen Patent application 12.02.92; Published 18.08.93.
19. Patent №2238443 Russian Federation F04 D 5/54. Method of oil production and ESP-Jet pumping system for its implementation / Drozdov A.N., *Monakhov V.V., Tsikin I.V. and others* № 2003137737/06; Patent application 30.12.2003; Published 20.10.2004.

Table 1. Operational parameters of the Garshinskoye oilfield wells before and after introduction of ESP-jet pumps

Well №		Equipment type-size	Pump setting depth H_{sd},м		Q_{liquid}, m^3/day	$Q_{oilн}$, т/сут	W_c, %	P_{intake}, MPa	T_{intake}, ^0C
			ESP	JP					
762	Before introduction	**ЭЦН5-50-2000** Did not operate, overflow valve was battered, periodic free-flowing	2700	-	22	16	10	-	-
	After introduction	**VNNП5-59-2400+ СН-20**	2882	2782	45	31	13	6,4-7,2	32-61
841	Before introduction	**ЭЦН5-80-1800** Did not operate, overflow valve was battered, periodic free-flowing	2700	-	12	6	35	-	-
	After introduction	**VNNП5-59-2400+ СН-20**	2882	2782	39	22	29	10,6	57

Comments: $\mathbf{H_{sd}}$ – pump setting depth, $\mathbf{Q_{liquid}}$ – well's liquid flowrate, $\mathbf{Q_{oil}}$ – oil flowrate, $\mathbf{W_C}$ – water cut, $\mathbf{P_{вх}}$ and $\mathbf{T_{вх}}$ – pressure and temperature at the pump intake, **JP** – jet pump.

Fig. 1. Centrifugal (a), centrifugal-vortex (b) and centrifugal – axial (c) impellers.

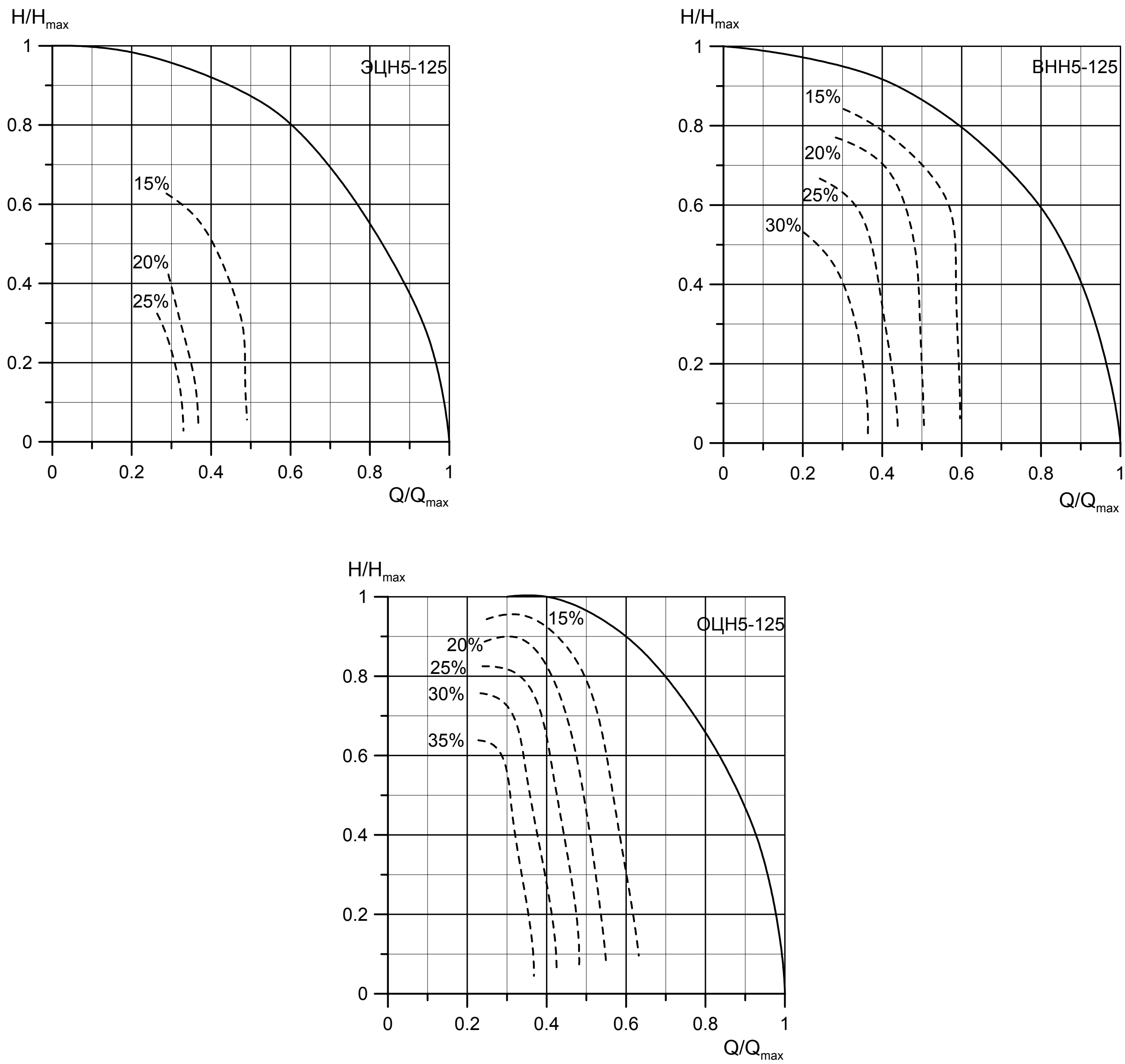


Fig. 2. Comparison of rated head characteristics of pumps ETSN5-125, VNN5-125 and OTSN5-125, operation medium: water+ surface-active material+air. Bubbles' diameter at pump intake 0.1 mm, digits on the chart – free gas volume content.

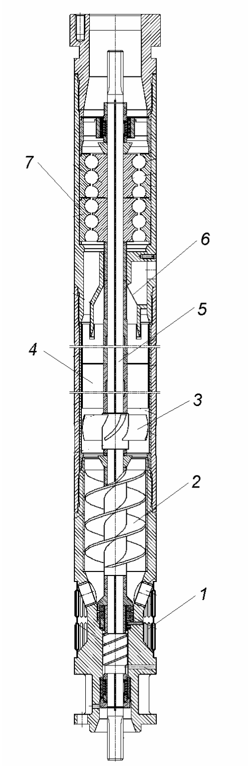


Fig 3. Gas separator – dispersing device, GDN type: 1 – GDN, 1 – reception net, 2 – screw, 3 – cavity-forming impeller/wheel, 4 – separation drums, 5 – shaft, 6 – gas discharge unit, 7 – dispersing device .

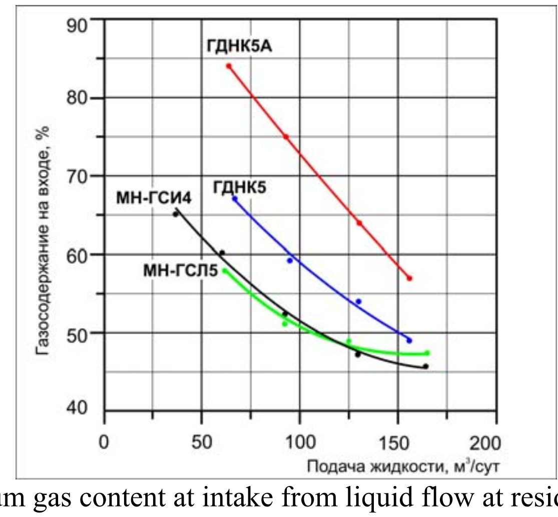
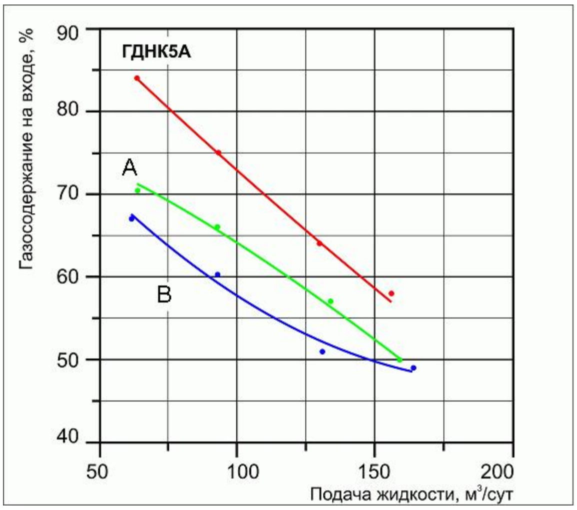


Fig. 4. Relationship of maximum gas content at intake from liquid flow at residual gas content 25% for Novomet gas separators

Fig 5. Relationship of maximum gas content at intake from liquid flow at residual gas content 25% for gas



separator – dispersing device GDNK5A and foreign gas separators, widely used in Russia (A and B)

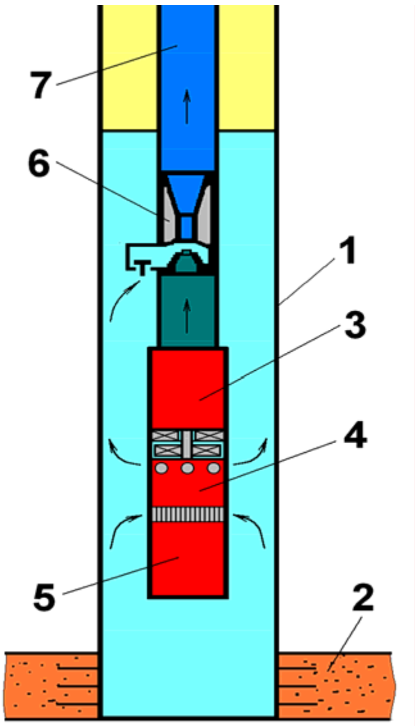


Fig 6. Scheme of ESP-Jet installation: 1 – well, 2 – layer, 3 – pump, 4 – gas separator – dispersing device, 5 – ESP motor, 6 – jet pump, 7 – tubing string

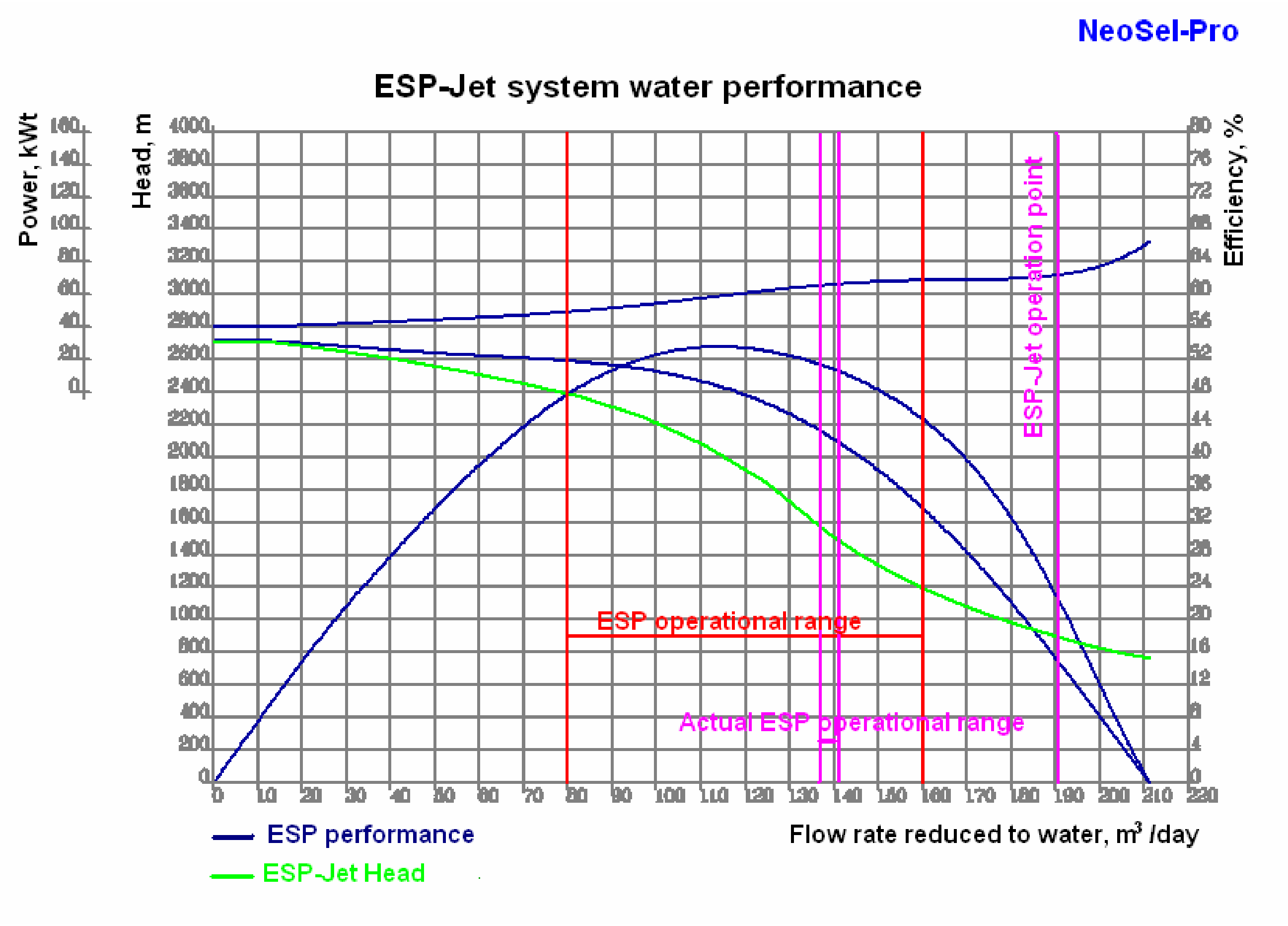
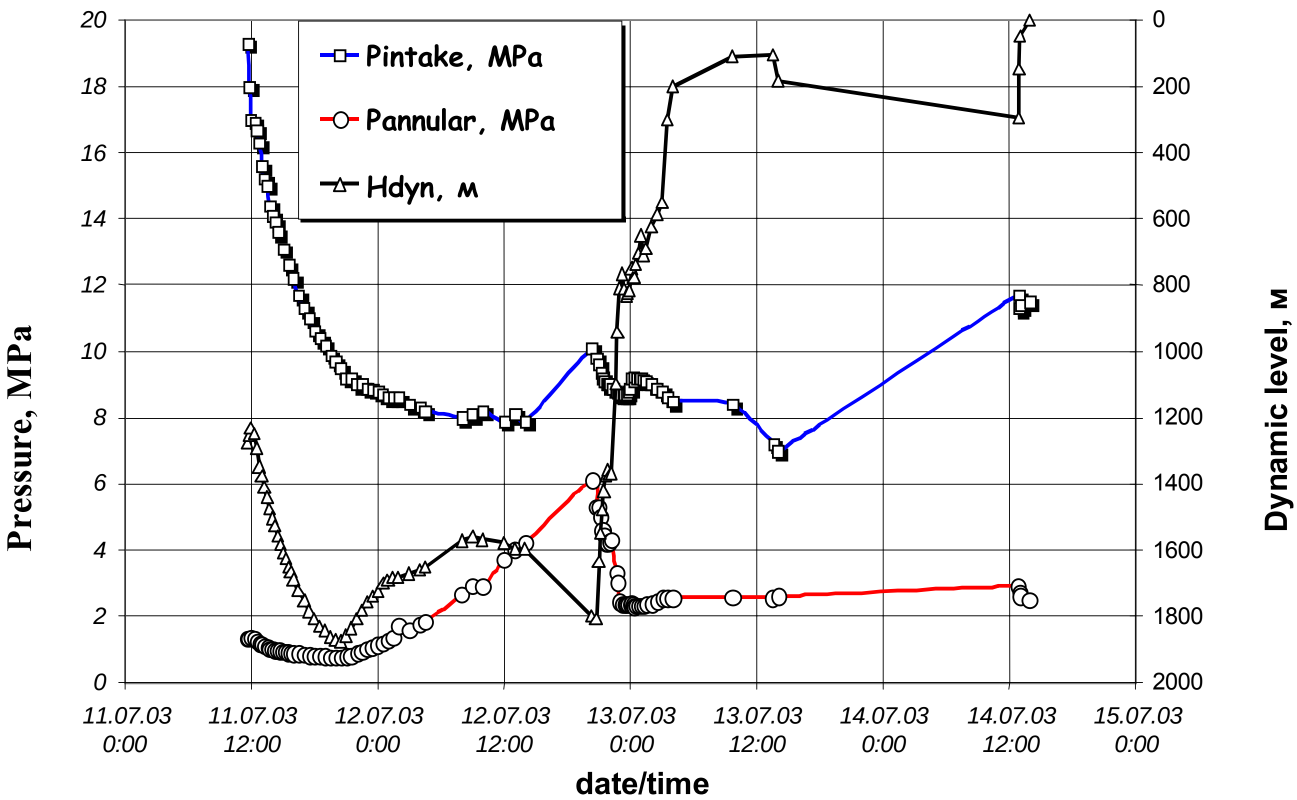


Fig. 7. ESP and ESP-Jet pump performance.

Fig 8. Startng dynamics of the well 762 of Garshinskoye gas-condensate oilfield using ESP-jet pump installation



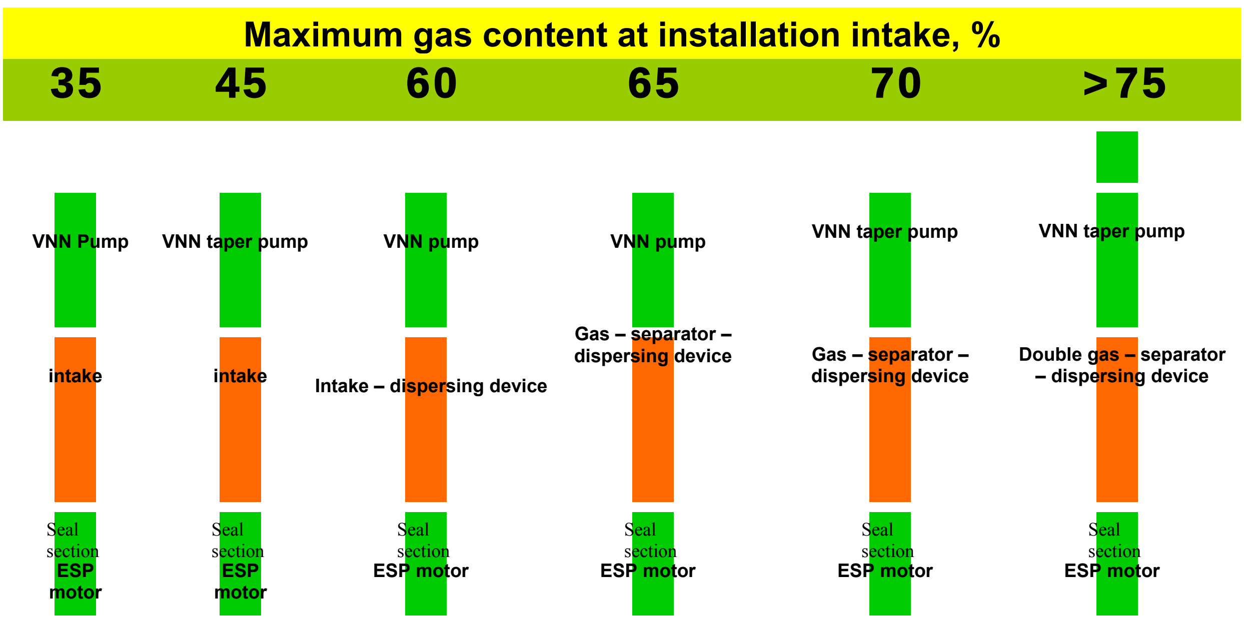


Fig 9. Setup of installations for producing fluid, containing undissolved gas at pump intake.