Analysis of Test Results of Titanium Filters for Sand Process Control when Operating Wells

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Abstract. The article analyzes the results of testing titanium filters to control sand production processes during well operation. It is shown that due to the decrease in the effectiveness of measures to strengthen the bottomhole zone with resins in the conditions of flooded wells, it was decided to carry out experimental work to combat sand production using downhole filters. The results of pilot tests have shown the fundamental possibility of using of anti-sand downhole filters with titanium filter elements (PSTFE) filters as an effective means of controlling sand production in wells, where the reservoir is represented by loose sand without clay material.

1. Introduction
In connection with a decrease in the effectiveness of measures to strengthen the bottomhole zone with resins in the conditions of flooded wells it was decided to carry out experimental work to combat sand production using downhole filters.

For this purpose, filters with tubular filtering elements made of pressed titanium powder with an outer diameter of 90 mm and a wall thickness of 6 mm began to be used. The break point when tested by hydraulic pressure according to technical conditions is 1.5 MPa, the main pore diameter is 50-200 microns, the porosity is 30-40 %, the permeability is not less than 3 Darcy.

The designs of anti-sand downhole filters with titanium filter elements (PSTFE) were developed and modifications of PSTFE-1 and PSTFE-2 were manufactured (Fig. 1).

The filter housing is a steel pipe 1370 mm long and 114 mm in diameter with eight windows 30-60 mm in size. Two filtering elements that are 600 mm long are inserted into the casing. The top of the filter is equipped with a left-hand threaded sub for 63.5 mm tubing and the bottom is equipped with a retaining valve to circulate the mud during lowering the filter into the well. After installing the filter at the bottom hole the valve is closed by pressure from above and the liquid is filtered through the filtering elements. Filters PSTFE-1 and PSTFE-2 differ from each other in valve design. Firstly, it is disc-shaped, and secondly, it is spherical.
Figure 1. Modifications of the designs of PSTFE-1 and PSTFE-2 filters:
1 – left sub; 2 – clamping ring; 3 – filter housing with windows; 4 – titanium filtering elements; 5 – centering ring; 6 – thrust collar; 7 – valve body; 8 – mounting socket; 9 – poppet valve; 10 – spring; 11 – shoe.

In order to protect the filtering element from clogging with clay solution during the lowering it is covered with a layer of paraffin before assembly. When the filter reaches the bottom, the paraffin melts and dissolves in oil and thus it is being removed from the filtration surface.

2. Actuality and scientific value
Well № 171 of the Anastasievsko-Troitskoye field (152.4 mm production casing, bottom hole 1512.6 m, perforation interval 1512.2-1511.4 m) was equipped with PSTFE-1 filter. Before lowering the filter the string was gauged with a bit with a diameter of 140 mm.

During the lowering of the filter 10 stops were observed. By turning the tubing strings it was possible to continue the lowering of the filter. The tubing was run at a speed of 10 m/min. After the filter was lowered downhole, the mud was replaced with oil by backwashing. Then 5 m³ of oil was pumped with a closed annulus. The filter had been working in the well for about three years and then was removed. During its examination the presence of a break in one of the filtering elements was found.

11 wells of the IV horizon of the Anastasievsko-Troitskoe field were equipped with PSTFE. Before equipping the wells with filters a decrease in production was observed due to a large production of sand. Tubing pipes often were stuck with sand plugs.

In wells №№ 1107, 1349, 1106, 181 and 1263, where the water cut was 30-60 %, in order to control sediments the bottomhole zone was treated with a fastener M, cement «milk», grout mix based on phenol-formaldehyde resins which did not lead to positive results.

In 8 out of 11 wells (wells №№ 1102, 181, 507, 1106, 659, 1349, 1107 and 689) before installing PSTFE filters were transferred to the overlying intervals, in wells №№ 1253 and 1154 the filter was installed after liquidation of resin plugs in tubing.
In wells №№ 181 and 1105, in which the perforation interval was moved, sand production did not stop. Well № 181 had been working for 4 months without sand production and well № 1106 – for only 14 days. In the remaining wells sand production has stopped and the duration of the effect is now more than 8 months. The effect continues.

It should be noted that wells №№ 507, 1107 and 680 after the PSTFE installation work on a choke with a smaller diameter than before the installation. This is due to the danger of pulling up the water cone and watering the wells, as well as gas breakthrough from the gas cap. This situation in some way limits the increase in oil production.

Wells №№ 1263 and 852, where sand and resin plugs were eliminated, continue to produce sand but in very small quantities. Well № 1154, where the sticking of pipes by sand was eliminated, had been working without sand production for only 1 month after which periodical pumping began due to the large production of sand and water.

Despite some negative results, an additional 10778 tons of oil was obtained after the wells were equipped with PSTFE. Observations of the operation of wells equipped with PSTFE showed that the filtering elements used are prone to clogging and destruction during pumping in order to flush the filters.

To study this phenomenon an experiment was carried out, during which a clay solution was pumped through a filtering element. Studies have shown that after 3-5 minutes the filtering surface of the element is usually covered with a dense impermeable clay crust and when a drop of 0.9-1.0 MPa is reached the element is destroyed. Thus, it was found that in the conditions of the bottomhole zone saturated with clay mud the filter clogs up and stops working very quickly. When flushing with the unit, it is practically very difficult to keep the pressure drop within the permissible range which leads to the destruction of the filtering elements.

In the work on improving the design of PSTFE the problem of equipping the filter with such a valve is being solved which would make it possible to release the bottomhole zone from clay solution through an open valve bypassing filtering elements. In addition, it is necessary to provide for the opening of the valve ability to backwash if its needed in order to clean the filter space from sand.

It is also necessary to increase the strength of the used filtering elements, for which filtering elements with increased wall thickness are being developed.

In general, the experience of using bottomhole screens in the Anastasievsko-Troitskoye field has shown the fundamental possibility of using PSTFE for effective control of sand production from operating wells.

3. Practical value and results

Currently, to control sand production, an anti-sand downhole filter with titanium filtering elements PSTFE-3, consisting of a rotary packer, plug filter sections – a shoe with a nipple-sub, – and a valve, is used. A rotary packer is required to seal the space between its casing and production casing. The packer consists of a body, a sleeve, a movable ring and a cup. The sleeve has gripping grooves for connection with tubing and drill pipes when the filter is run into the well and to enable the pipes to rotate after the filter is installed at the bottom. The sleeve is connected to the body by means of a nipple-sub with trapezoidal threads for the sleeve and metric threads for the body. Sealing of the cup is achieved by moving the sleeve along the trapezoidal thread and the movable ring along the body with the right rotation of the tool, i.e. pipes on which the filter goes down into the well. Descaling is done in reverse order using a left-hand thread tool. The design of the packer provides for the possibility of installing a cup made of oil-resistant rubber, polymeric materials or metal-asbestos-paronite heat-resistant elements.

The filter consists of a body, a nipple, carrier rings, a centering ring, titanium filtering elements and a clamping nut. The body is made of tubing with a diameter of 114 mm and has slot-like or round holes along the entire working surface. The actual filtering element of the structure is a highly permeable titanium element 0.6 m long, 0.09 m in diameter, with pores of 150-200 microns and a porosity of 0.32-0.40. It is made from titanium electric powder. The element has high strength, corrosion and thermal resistance.
Plug is a shoe with a nipple-sub is designed to support the filter at the bottom hole and keep it from rotating when sealing the packer cup.

Bottom hole equipment with PSTFE-3 filter is provided in three versions: a under-pump unit without a packer, a downhole unit with a packer and installation under a fountain lift shoe.

Pilot work on testing the PSTFE-3 filter at the Kenkiyak field (Aktobe region of the Republic of Kazakhstan) was carried out in wells №№ 374, 175, G-24 and 218 (Fig. 2).

![Diagram of PSTFE-3 filters in the wells of the Kenkiyak field](image)

**Figure 2.** Layout diagram of PSTFE-3 filters in the wells of the Kenkiyak field:
1 – well; 2 – deep-well pump; 3 – packer; 4 – filter section;
5 – plug-shoe; 6 – cement plug; 7 – extension nipples;
8 – left-hand thread sub; 9 – valve; 10 – tubing.

All selected wells were among the idle ones due to sand production. The selection of wells for testing the filter was limited by the conditions set by the geological service of the oil and gas production department «KenkiyakNeft»; the tests were carried out only in idle wells, i.e. out of order or practically not operated due to intense sand production.
Below is a brief description of the wells and the content of pilot works on equipping these wells with PSTFE-3 filters.

Well № 374 (production casing 146 mm; perforation interval – 340-332 m, 324-314 m; artificial bottom 384.5 m) was brought into production in November 2008. Until 2018, it was operated with an oil flow rate of 18.5 to 2.0 tons/day. In April the flow rate decreased to 1.1 tons/day, repeated flushing was carried out, the elimination of plunger jamming and sand sticking of the rods (simultaneous lifting of pipes and rods).

A wire screen was lowered into the well in the interval of 346-308 m with shell rock packing but the sand production did not stop. Washing did not give positive results. At the start date of the work the well was idle with a jammed plunger and rods stuck by sand.

The operation was performed using the following technology:

- assembly and preparatory work;
- lifting of downhole pumping equipment with the elimination of sticking of the rods and plunger by sand;
- flushing with oil, extraction of the wire filter with a spear casing in two tripping operations (one failure);
- lowering of the tubing to a depth of 306 m to develop the well with a compressor;
- wellhead piping with connection to the annular space of the TsA-320 unit and the UPK-80 compressor;
- well development with the UPK-80 compressor with pumping of the bottom (formation) water by the TsA-320 unit at the 1st speed for 6 hours with 2 ½” tubing hanger 306 m (operating mode for the first two hours - operating pressure 1.4-2.0 MPa with smoothing of air breakthroughs by pumping water with a unit at speed II; the last 4 hours – development only with a compressor at a pressure of 1.2-1.4 MPa; during the development an aerated emulsion with sand and various muddy pollutions were carried up, the inflow was stable for the last 2 hours, about 10 tons/day);
- smooth discharge of the well through the annulus within 30 minutes;
- bottomhole measurement (321 m) with a self-tensioning winch (when discharging, the plug is pulled);
- well flushing with tubing tolerance from 322 to 343 m, increased absorption was observed (oil consumption for flushing is 8 m³);
- lifting of tubing to the level of 308 m, wellhead piping, pressure test of the working line by 15.0 MPa;
- injection of shell rock: a mixture of shell rock with oil (viscosity 300 cP) was prepared manually in a metal tank and pumped into the well through tubing using a TsA-320 unit; oil was fed into the tank by a 4CR tanker, 1 m³ was pumped in with an open annulus, the rest of the mixture, when closed, under a pressure of 6-7 MPa; 2 m³ of shell rock were injected, oil consumption per mixture is 8 m³; The tubing was raised to a safe height, the well was left dormant for 12 hours to shrink the shell rock;
- flushing the well with light oil to remove excess shell rock with tubing tolerance from 322 to 343 m; lifting tubing, assembly of the precalculated filter assembly;
- lowering of the filter into the well with installation under the pump (Fig. 2a); the filter was lowered on 63.5 mm tubing to a depth of 340.8 m (bottom), the top of the filter – to a depth of 323.4 m;
- lowering the plunger and rods, putting the well into operation using the downhole pumping method with the reciprocating speed of 7.5 and the stroke length of 0.45 m. The initial flow rate of the well was 6.8 tons/day and after working out for 6 days increased to 10 tons/day, water content was within 10 %, sand was no more than 0.1%. Subsequently, the well worked without sand production with a reduced percentage of water cut.

Well № 175 (production casing 152.4 mm 168´10 grade D; artificial bottom-hole at a depth of 384 m; perforation interval 343-337 m; 337-339 m; 322-213 m) became operational in December 2010 (perforation interval 343-337 m) with an initial flow rate of 0.2 tons/day and worked periodically using the deep-well pumping method. In January 2016 additional perforation was made at 337-339 m (5 holes per 1 running meter), 322-313 m (10 holes per 1 running meter), and a wire filter with shell rock was
lowered. As a result, the production rate did not increase. Despite multiple flushes, it was not possible to put the well into operation. After 2 years work was carried out to sinter sand by injection of steam and air. Over 200 tons of steam was injected into the well, however, after this work, sand production did not stop – the well was idle.

The operation of equipping the well with the PSTFE-3 filter in the version of the downhole installation with a packer was carried out using the following technology:

- assembly and preparatory work;
- lifting of downhole pumping equipment with the elimination of sticking of rods by sand;
- drifting of the well to a depth of 120 m with a profile with a diameter of 128 mm;
- well flushing with tubing tolerance from 324 to 353 m;
- injection of shell rock: a mixture of shell rock with oil (viscosity 300 cP) was prepared manually in a metal container and pumped into the well through tubing at a pressure of 3.5-5.0 MPa - using a TsA-320 unit, oil was supplied by tanker truck 4 CR; 2 m³ of shell rock was injected, oil consumption was 6 m³, tubing was raised to a safe height, the well was left dormant for 12 hours;
- bottomhole measurement by a self-tensioning winch at a depth of 353 m, tubing lift with control measurement of them, bottomhole is bunced back to 353 m;
- lowering the filter into the well with installation at the bottom with a packer (Fig. 2) to a depth of 353 m (bottom), the top of the filter - to a depth of 303 m;
- lowering downhole pumping equipment: pump NGN-2 with a diameter of 43 mm, 63.5 mm tubing, 19.05 mm rods, the catching rod at the cone valve is removed, the pump is installed at a depth of 300.5 m;
- putting the well into operation with the reciprocating speed 9.5 and stroke length 0.45 m.

The initial production rate was 0.7 tons/day. Dynamograms showed liquid pumping.

Until August 24, 2018, the well worked with a flow rate of 1 ton/day of liquid, 37 % of water, 0.1 % of sand, then it stopped due to ingress of sand - the pump jammed. From 26 to 28 August 2018 the downhole pumping equipment was lifted with the elimination of sticking and PSTFE-3 filter. The cause of the sand appearance was the destruction of two filtering elements with the formation of large irregularly shaped holes with a diameter of ~ 50 mm through which sand entered. The filtering elements were silted up, the wall thickness at the break point was 3 mm, which indicates a spoilage in their manufacture.

Later, work was carried out to re-equip the well with a PSTFE-3 filter. An attempt to lower the filter in the downhole setting with a packer failed due to an abnormality of the string at a depth of 319 m (perforation interval 313-322 m), into which stabilizer leg of the shoe fell, as a result, the filter did not pass further and was removed from the well. Therefore, the well was equipped with a filter with an underpump unit. Within the re-equipment the installation technology was slightly changed. So, before pumping shell rock, the well was developed with a compressor by analogy with well № 374. During the development process mud and sand were removed and at the end the line was clogged with fragments of cement stone indicating a breakdown of the production casing. After the injection of 1.5 m³ of shell rock the well was drifted with reamers with a diameter of 115 and 120 mm. The 120 mm profile did not pass at a depth of 319 m (breakout point). Then the well was drifted with a pipe with a diameter of 114 mm with a sleeve machined to a diameter of 123 mm. Using this template, the abnormality was eliminated, and the profile passed to a depth of 346 m. The PSTFE-3 filter was lowered into the well with an underpump unit. The well was put into operation by downhole pumping method, the reciprocating speed of 9, the stroke length is 0.45 m. The initial flow rate is 6 m³/day. The well had been running for 18 hours and stopped flowing.

The filter has been raised. Inspection showed that the cause, as in the first case, was the destruction of two filtering elements with the formation of oval holes (breaks) with a size of 130×70 mm. The tubing was filled with water and the pump was clogged with sand. Thus, re-lowering the filter was ineffective.

Well № G-24 (production casing 127 mm, grade C; perforation interval 350-333 m; artificial bottom-hole 550 m) was put into operation in 2010 by downhole pumping method with an initial flow rate of 1.6 tons/day, operated periodically. Over the course of several years, major repairs were carried out with the descent of wire filters with filling with shell rock. Sand production did not stop, the well was idle.
The operation of equipping the well with a PSTFE-3 filter was carried out using the following technology:

- assembly and preparatory work;
- lifting of downhole pumping equipment;
- flushing of the well with oil to a depth of 350 m, absorption of 10 m³ in 2 hours was observed;
- extraction of the wire filter with a spear casing;
- flushing the well to a depth of 354 m, where the previously left part of the filter was located, lifting the tubing to a depth of 337 m;
- injection of shell rock, the injection process was carried out by analogy with well № 175; 2 m³ of shell rock was injected, oil consumption was 6 m³;
- flushing the well with oil to a depth of 353 m, lifting the tubing;
- lowering of the filter with an under-pump unit to a depth of 349.8 m (the layout diagram is shown in Figure 2);
- putting the well into operation using the deep-well pumping method, the reciprocating speed of 7, the stroke length is 0.45 m. The initial flow rate is 2.5 tons/day, no sands were observed.

Well № 216 (production casing 127 mm; artificial bottom-hole 324 m (abnormality of the casing); perforation interval 329-318 m) was put into operation in December 2010 and was inactive until 2013. In 2013 the well production rate was 1.6-11 tons/day, until August 2014 ~ 10-19 tons/day, from August 2014 to August 2016 – 0.5 tons/day, at the beginning of 2017 – 2.2 tons/day. In the future, it was idle due to sand production. In November 2015, the well was equipped with a wire filter, sand production did not stop. The well worked with troubles. Despite flushing and underground repairs to replace pumps, the well was not put into operation.

The operation of equipping the well with a PSTFE filter with an under-pump unit was carried out using the following technology:

- assembly and preparatory work;
- lifting of downhole pumping equipment with the elimination of sticking of the rods with sand, the tubing was filled with silt and sand (viscous silt) by about 100 m;
- flushing the well with oil to a depth of 328.3 m (below the abnormality of the string), washed out silty sand, lifting the tubing;
- drifting of the well with a profile with a diameter of 118 mm to a depth of 328.5 m;
- running tubing to a depth of 325 m;
- well development with a compressor with oil pumping by the CA-320 unit for 2 hours; it was not possible to develop the well, since the flowout line was clogged with pieces of cement stone which indicates the presence of a significant abnormality of the string; it turned out to be impossible to recompress the well due to the technical condition of the string, lack of compressor and water supply; the well was cleaned with an effort, since the air with oil formed foam; lifting tubing up to 328.8 m; within 1.5 hours, sand flowout with silty particles was observed;
- shell rock injection: injection pressure 5-6 MPa; 1.6 m³ of shell rock was injected, oil consumption was 6 m³; lifting tubing to a safe height (10 pipes);
- lowering tubing with oil flushing to a depth of 329 m; lifting tubing;
- putting the well into operation using the downhole pumping method with the reciprocating speed of 8 and the stroke length of 0.45 m.

After starting the sucker rod pumping unit the well had been working for 40 minutes, then stopped flowing – the pump failed. The sucker rod pumping unit was stopped until the reasons of the failure were clarified. It is assumed that the destruction of the filtering elements has occurred.

Thus, the technology of equipping wells № 374 and 175 (with re-equipment) is performed according to the following scheme:

- lifting the downhole pumping equipment and removing the wire filter;
- flushing the well from sand;
- development of the well with a compressor until a steady inflow of fluid from the formation is obtained;
• bottomhole measurement and flushing of the well with tubing lowering to the calculated depth;
• injection of shell rock into the bottomhole zone;
• bottom hole flushing from surplus shell rock with tubing lowering and filter running in the required version (under-pump or bottom hole installation) and calculated layout.

For wells №№ G-24 and 216, the flow diagram is similar to the flow diagram of wells №№ 374 and 175, except for their development by a compressor. The planned compressor development of well № 216 was not completed.

Scheme of the technology of filter equipment for well № 374 is the most rational and should become the standard for further testing of filters at the Kenkiyak field.

The results of pilot works at the Kenkiyak field have shown that the developed design of the PSTFE-3 filter does not require the use of special devices and units when equipping wells. The filter is quite easy to install both in the under-pump version without a packer, and in the bottomhole version with a packer. The developed packer reliably separates the space behind the filter.

As a result of testing the filter in wells №№ 374, G-24, 175 and 216, good results were obtained for wells №№ 374 and G-24.

Well № 374, after equipping it with PSTFE-3, has been operating stably for more than 3 months. At the same time, the well operation mode changed twice. After PSTFE-3 equipment, well № G-24 worked without sand flowout.

During the testing period (well № 374 – 3 months, well № G-24 – 2 months) additional oil production due to the use of PSTFE-3 filters amounted to 1070 tons, including: for well № 374 – 1010 tons, for well № G-24 – 60 tons.

Analyzing the results of pilot tests of PSTFE-3, one can come to the conclusion that the main identified weak point of the filter design is the insufficient strength characteristics of the titanium filtering elements themselves. In addition, it is also necessary to increase the requirement for quality control of filtering elements when assembling PSTFE-3. The results of the pilot work showed that the selection of wells is carried out mainly (except for well № 175) outside the experimental area of thermal treatment, and the results obtained cannot be unambiguous for the reacting wells. Tests have shown that many wells of the field do not have perfect hydrodynamic connectivity with the formation, and their productivity can be increased by various methods of stimulating the bottomhole zone. In this regard, first of all, it is recommended to completely exclude from practice the use of sump oil contaminated with mechanical impurities, especially in the cold season.

Wells №№ 1504, 798, 1229, 150, 129, 131, 100, 374 and 201 were equipped with PSTFE filters. As a result, 11 well operations were carried out. From wells №№ 798 and 131, filters were subsequently removed, and 7 wells operate with filters.

4. Conclusions

Thus, pilot tests of PSTFE were carried out for 13 wells, of which positive results were obtained for 8 wells. The success rate of the tests is over 60%.

In some wells, the between repairs period has increased significantly. So, for well № 374 – from 10 days up to 9 months when installing the filter for the first time, and up to 2 months after reinstallation. Well № G-24, inactive until the installation of the filter, has been operating for more than 13 months, well № 1504 – 5 months and after replacing the filter for 4 months, the between repairs period in well № 150 increased from 10 days up to 4 months.

During the entire testing period additional production amounted to 7,967 tons. The main additional oil was obtained from wells №№ 374 and 1504 which were one of the first equipped with filters; for the rest of the wells it is insignificant due to their low production rate and a relatively short period of operation with PSTFE filters.

The results of pilot tests have shown the fundamental possibility of using PSTFE filters as an effective means of controlling sand production in wells, where the reservoir is represented by loose sands without clay material.
5. References

[1] Bogomolov A N, Ushakov A N, Shiyam S I 2009 Solution of basic boundary problems for a semiplane by methods of the theory of functions of a complex variable (Volgograd: Volgograd State University of Architecture and Civil Engineering) 133

[2] Bulatov A I, Savenok O V 2012-2015 Capital overhaul of oil and gas wells: 4 volumes (Krasnodar: «Publishing House – South» LLC) Vol 1-4

[3] Bulatov A I, Savenok O V 2013-2014 Workshop on discipline «Completion of oil and gas wells»: in 4 volumes: textbook (Krasnodar: «Publishing House – South» LLC) Vol 1-4

[4] Bulatov A I, Savenok O V, Yaremiyuchk R S 2016 Scientific bases and practice of development of oil and gas wells (Krasnodar: «Publishing House – South» LLC) 576

[5] Bulatov A I, Kachmar Yu D, Savenok O V, Yaremiyuchk R S 2018 Development of oil and gas wells (Krasnodar: «Publishing House – South» LLC) 476

[6] Popov V V [etc.] 2018 Geoinformatics of oil and gas wells (Novocherkassk: Publishing house «Lik») 292

[7] Savenok O V, Kachmar Yu D, Yaremiyuchk R S 2019 Oil and gas engineering during well development (Moscow: Vologda: Publishing house «Infra-Engineering») 548

[8] Savenok O V [etc.] 2021 Environmental aspects in the construction of oil and gas wells: monograph (Moscow: Vologda: Publishing house «Infra-Engineering») 652

[9] Bogomolov A N, Vikhareva O A, Shiyam S I 2007 To the question about the minimum values of the lateral pressure coefficient of soils Bulletin of the Volgograd State University of Architecture and Civil Engineering, Series: Building and architecture 7 pp 6-10

[10] Bogomolov A N [etc.] 2011 On a static approach to determining the roof pressure of a horizontal underground mining Bulletin of the Volgograd State University of Architecture and Civil Engineering, Series: Building and architecture 24(43) pp 22-28

[11] Bondarenko V A, Savenok O V 2014 Development of a statistical model of deformation-spatial instability and destruction of sandy rocks in order to reduce sand production GeoEngineering 1(21) pp 84-87

[12] Bondarenko V A, Savenok O V 2014 Investigation of methods and technologies for managing complications caused by sand production Gorny information and analytical bulletin (scientific and technical journal) Separate article (special issue) 5 28

[13] Bondarenko V A, Savenok O V 2014 Analysis of existing methods of sand control and development of a statistical model of deformation-spatial instability and destruction of sandy rocks SCIENCE. TECHNICS. TECHNOLOGIES (polytechnic bulletin) 1 pp 35-42

[14] Griguletskiy V G 2016 On some factors that determine the effectiveness of hydraulic fracturing with the injection of large quantities of sand Proceedings of higher educational institutions. Oil and gas 4 pp 44-53

[15] Griguletskiy V G 2016 Directional multi-stage hydraulic fracturing. On some factors determining the efficiency of facing with large amount of sand Oil, gas and business 2 pp 3-12

[16] Klimovets V N [etc.] 2013 Experience of dealing with sand-manifestations during the operation of wells in the Anastasievsko-Trotskoe field of the Krasnodar Territory Construction of oil and gas wells on land and at sea 6 pp 17-21

[17] Shiyam S I, Bogomolov A N 2009 On the issue of singular points in solving boundary value problems of the theory of elasticity by methods of complex analysis Bulletin of the Volgograd State University of Architecture and Civil Engineering, Series: Building and architecture 13(32) pp 49-52

[18] Zhikhor P S, Dolgov S V 2017 Development of sand control technology for weakly consolidated rock Readings of A I Bulatov Vol 2 79-82

[19] Wang Hengyang, Podgornov V M 2020 The selection of downhole filter to limit sand production from the reservoir during well development Readings of A I Bulatov Vol 2 pp 408-415