ESP Workshop

SPE International
SPE-GULF COAST

Reliable low flowrate centrifugal installations for oil production in complicated conditions

Ageev[1] Sh.R., Kuprin[2] P.B., Maslov [2] V.N., Melnikov[2] M.J, Perelman [2] O.M., Pescherenko[2] S.N., Rabinovich[2] A.I.
[1]OKB KONNAS, Moscow, Russia, [2] JSC Novomet-Perm, Perm, Russia

This paper was prepared for presentation at the 2005 Society of Petroleum Engineers - Gulf Coast Section Electric Submersible Pump Workshop held in Houston, Texas 27-29 April 2005.

Submersible units with 362 and 400 series pumps and rated flowrates from 25 to 160 cubic meters a day with a warranty period of 1000 operating days have been developed by Novomet. The characteristic features of the units are as follows: a new centrifugal-vortex stage made in accordance with a new to the oil production industry powder technique; a special pump design ensuring radial stability of the shaft during the whole operating age; new gas separators-dispersing devices (dispersants) of increased efficiency. Equipment selection for the wells and calculation of the submersible units' reliability by their operational data has been put into practice with use of original methods.

One of the most important issues of the oil-producing industry today is the reliability growth of the submersible units that work in the wells with an increased concentration of solid particles (more than 500 mg/l) and a gas-oil ratio up to 300 m^3/m^3.
Novomet has developed and put into mass production submersible units capable of working stably and faultlessly in such conditions.

The suggested solutions to the reliability growth of submersible units can be grouped as follows:

1. A newcentrifugal-vortex design of the stage with an increased head has been developed. It could handle 1.5-2 times higher limiting content of undissolved gas than a centrifugal one.
2. A new to the oil production industry powder technique has been implemented. It ensures a higher accuracy of the stage production and, therefore, a higher degree of the impeller balancing adjustment and hydrodynamic smoothness of the flowing channels.
3. A pump design ensuring radial stability of the shaft during the whole operating age has been developed.
4. High efficiency gas separators-dispersants have been developed and the technique of oil production with a high GOR based on simultaneous usage of centrifugal and jet pumps has been optimized.
5. Original software for submersible equipment selection for wells and their analysis as to their operational functionality has been developed.

The present work is mainly dedicated to description of the research results in the area of the pumps durability growth. The technical solutions of Novomet oriented on the pumps durability growth for production of gas-consisting mediums are described in [1]. The method of submersible plants reliability calculation by incomplete operational data based on the mathematical reliability theory is described in [2].

A new stage design. The characteristic of the stage design is the combination of centrifugal and vortex stage features in one unit. The impeller represents a vortical row added to a centrifugal design. The vortical row is located on the driving disk directed to the diffuser (fig. 1). The diffuser has a design close to the centrifugal one. The geometrical dimensions of the flowing channels of the stage are optimized taking into account vortical row influence on the fluid flow. The design has been patented, see [3] and [4].

The vortical row produces an additional fluid flow that falls on the blades of the diffuser. The kinetic energy of this flow transforms into a head that combines with the pressure created by the centrifugal part of the impeller. It allowed us to increase the head of the stage on 15–25% (see fig. 2 and fig. 3). Besides, vortical blades reduce the longitudinal force that acts on the impeller, thus reducing friction and wear of the axial bearing.

The advantages of the inclined rotor pumps are especially visible when they are run in the wells with a high gas factor. Gas beads falling into the vortical row area are intensively dispersed, which increases the pump operational stability when transferring the oil and gas mixture. For instance, according to the results of the bench test on the air-water mixture, the limiting volume *concentration of free gas at the inclined rotor pump input can be 1.5-2 times higher that that of the centrifugal pumps (see fig. 4).*

Fig. 5 shows the dependence of the relative head from the consumption of the water- surface-active material-air mixture. This operating environment is the closest by its characteristics to oil and gas mixtures and, therefore, serves best for modeling of the beads fusion and dispersion. The relative head was calculated in parts from the head at the gas concentration equal to zero.

Figures 4 and 5 show that the higher the gas concentration, the more visible is the advantage of the centrifugal-vortical stages.

Thus, a new high performance oil stage has been developed and put into mass production. The hydrodynamic processes in these stages differ a lot from those of the centrifugal stages engineered by Arutunoff almost 70 years ago [5].

Development of a powder technology for submersible pump stages production.

Stages for submersible pumps are generally made by casting. The today's casting technology is limited by the precision of parts and the surface roughness of the flowing channels, which hinders the optimization of the stage interaction with the pumped liquid. One of the possible solutions is to apply powder technology.

The suggested method of parts' production consists of two stages. At the first stage the geometrically-complex elements of the details are formded out of powder. An original PM (powder metallurgy) tooling and an automated high-performance technology have been developed by Novomet. At the second stage the details are assembled into the required design by the diffusion method through a thermodynamically highly disbalanced separation layer. This stage is combined with the impregnation of the whole part with molten metal. This new technology is patented [6].

The powder technology ensures the surface roughness of the flow channels of about $20-30$ mkm. According to the estimates, it suffices for the channel roughness not to influence on the flow character.

Powder stages are better balanced and, therefore, produce a lower vibration, which contributes to the pump reliability. According to the bench test, the average vibration level of the pump sections is about 2-3 mm/sec.

One of the most important advantages of the powder stages is the possibility to combine several materials in one unit. For example, in one production cycle, stages of stainless steel with bearings made of antifriction materials or wear-resistant materials are produced.

Every year the company produces more than one million powder stages of 50 types with flowrates from 15 to 200 m3/a day.[7]. The main limitation to the further growth of the assortment is the unsolved problem of the labour-intensiveness of stage production with inclined cylindrical vanes having higher flowarates.

Ensuring radial stability of submersible pump shafts in complicated operating conditions

The reliability of pumps working in abrasive environments is generally defined by wear resistance of bearings. Vibration creates a periodical power impact on the friction units and increases wear. The wear is reduced by increasing the precision of the impeller and shafts production, as well as by design of wear-resistant bearings supporting the shaft.

It is generally accepted that the more abrasive there is in the pumped liquid, the smaller the distance L should be between wear-resistant bearings. Our tests have proved that it is not always the case. In fact, with L reduction the wear level is reduced, but not monotonically. There is such a spacing between wear-resistant bearings L_C, where at $L < L_C$ radial movements of the shaft are reduced dramatically. In this case, during the whole pump operating age the wear in the stages' radial bearings remains on such a low level that the hydraulic characteristics of the pump do not change. Therefore, the operating age of the pumps with such spacing arrangement of the intermediate bearings is determined only by the wear of the intermediate bearings. The choice of materials and the design allow the pumps to work no less than 1000 days.

Besides, as it was mentioned before, measures were taken for axial unloading of the stages, which resulted in reduction of the wear of the stage axial bearings.

To check the results, accelerated abrasive tests of the pump sections have been conducted in the laboratory environment. As the working fluid, water with different content of silica sand was taken.

A typical example of the obtained results is shown on picture 6, where the distribution of the maximum wear of the impeller hubs along the length of the pump section is shown, in the case when there are no intermediate bearings (fig. 6a, the dotted line).

When their number corresponds to the calculation (the solid line on fig. 6a and 6b) and when the number of intermediate bearings is 1,5 times lower than calculated (the dotted line on fig 6b). Obviously, the given results confirm the accuracy of the calculations. The durability of the pumps has become more than 10 times higher.

Besides, it has been found out, that inside every stack of stages, included between intermediate bearings, the hubs of the radial bearings of the diffusers wear out almost evenly along the length of the circle. It means that the shaft, bent by the centrifugal force, effects a circular rotation. The bends of the shaft in the adjacent blocks are mostly opposite.

NeoSel-Pro - Software for submersible equipment

selection and support – takes into account all main factors that influence operating efficiency of a given well. Below is a brief description of the main features of the software algorithm.

During the pump selection process, the indicator line is specified using the data about the previous exploitation of the well. A new approximation formula of the indicator line is used that summarizes the well-known Vogel dependence for the bottom-hole pressure that is significantly below the bubble-point pressure [8]. It allowed us to describe the operation of the well during the flowrate reduction because of the free gas emission in the layer.

When choosing the length of the unit suspension, the software minimizes its bend, which is calculated along all its length, including the tubing (probably, it was the first time it was done). The calculation of the tubing bend can have a dramatic influence on the choice of the suspension place. For instance, in well #16 of the Bielokamenni oilfield there was a straight portion where a descent unit with a diameter of 120 mm could be placed as a whole. However, because of the tubing bend the turn of the unit in this place exceeded 3 mm.

To specify the suspension place the structure of the gas-liquid flow that flow past the submersible electrical motor [9] is calculated. It is inadmissible to allow gas bubbles to form plugs and create additional vibrations of submersible centrifugal pump systems reducing reliability.

It is possible to test ESP installations in operation. The software allows getting graphical dependences by 40 parameters of the gas-liquid mixture from the distance to the wellhead: pressure, temperature, water cut, gas content, viscosity, density, flow structure, etc.

Operating tests of the pumps durability have been conducted in several oil companies of the Western Siberia: Yuganskneftegas, Surgutneftegas, Sibneft – Noyabrskneftegas and Lukoil –Western Siberia. The results are shown on fig. 7.

The durability calculations have been carried out with NeoStat-Pro - the operating data processing software developed by the company [2], which is based on the mathematical statistic methods, to be more precise, on the statistic theory of reliability.

The novelty of our approach to the calculation of the submersible equipment reliability consists in the combination of computational algorithms of the nonparametric statistic ensuring high accuracy of the reliability calculation with those of the parametric statistic, which allow forecasting the equipment performance.

The software calculates the main statistic functions that offer comprehensive data describing the submersible equipment reliability. Dependence for the reliability calculation accuracy from the sample size and running time has been obtained [10].

The results of the pumps design reliability calculation are shown on fig. 6. The standing axis shows the probability of faultless work or the portion of the faultless equipment, the horizontal axis shows the time.

The picture shows that at $T_{0.5}$ the operating time is 1000 days. Therefore, on average (taking into account that $T_{0.5}$ almost equals MTBF, see [2]) the wear-resistant units and pumps work faultlessly no less than 1000 days even in the most complicated conditions that could be found in the Western Siberia.

The pumps reliability in the conditions of the Yuganskneftegas and Sibneft oil companies is lower than that in Surgutneftegas and Lukoil –Western Siberia, because in the first two companies fracs are a common practice. In the layer fractures highly abrasive particles are injected to prevent the fracture healing. During the oil production these particles are washed out from the layer and fall into the pumps in considerable amounts.

Conclusion

A new oil production stage of the centrifugal-vortex type has been developed and put into mass production by a new for the oil industry method of powder metallurgy.

A wear-resistant design of the pump is developed that ensures radial and axial stability of the shaft for more than 1000 operating days in abrasive environments. Today more than 6000 pumps of this type are run in the oilfields of the Russian Federation.

The selection of pumps for wells and their reliability analysis by their maintenance data is conducted with use of the advanced methods that allow setting and controlling the operating environment with high precision. These methods, put into practice in the software NeoSel-Pro and NeoStat-Pro, offer an objective analysis of the operating results and completely exclude the human factor.

The comprehensive approach to the reliability of the produced equipment that includes the unit design optimization, control over the manufacturing technology, selection of the equipment for the given well, and maintenance, allowed the Novomet company to increase the warranty period of the equipment to 1000 operating days.

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a) б)

Fig. 1. Impellers of the oil stages: a) centrifugal-vortical, б) centrifugal.

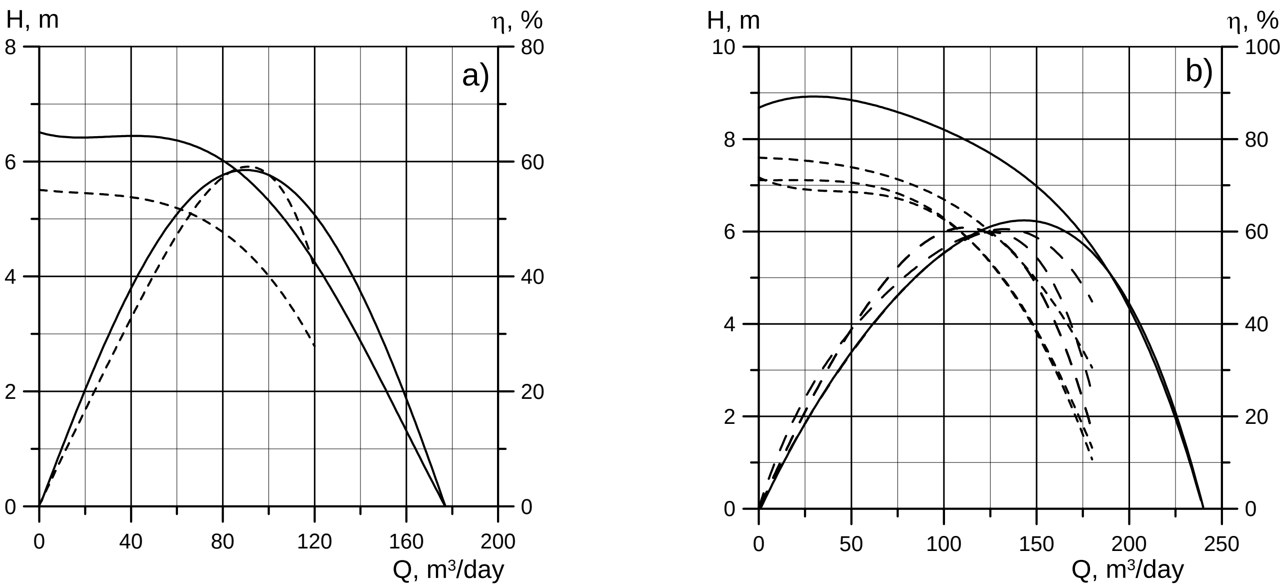

Fig. 2. Comparison of the operational behavior of centrifugal-vortex stages (solid lines) and centrifugal stages (dotted lines) at frequency of 50 Hz: a) – VNN5-79 and a pump stage of the 362 series, the operating characteristics of which are calculated by the similitude method by the best pump stages of the 338 and 400 series; b) – VNN5A-124 and the best stages of the 400 series pump.

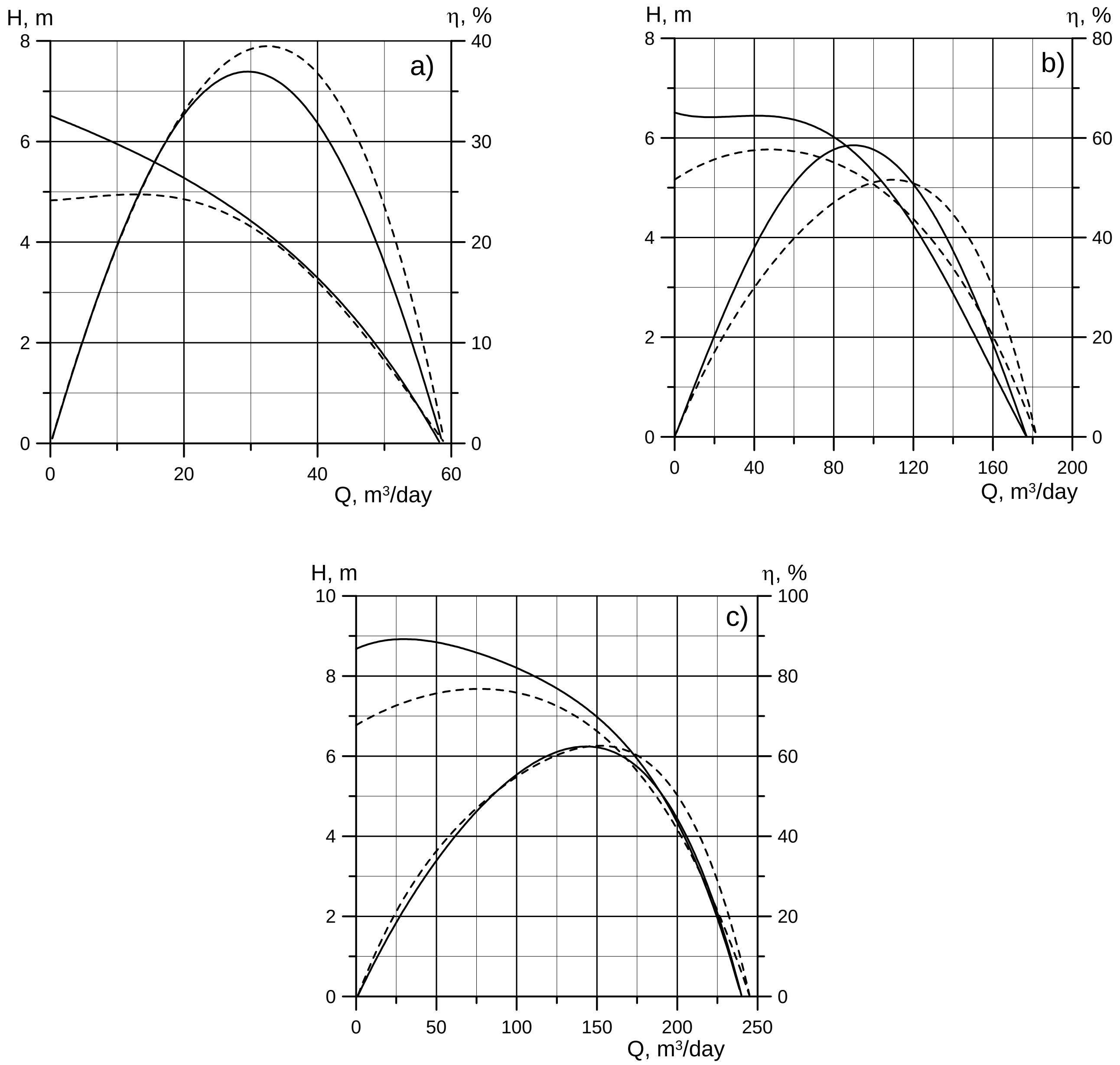

Fig. 3. Operating characteristics of centrifugal-vortex stages VNN5-25 (a), VNN5-79 (b) and VNN5A-124 (c) at frequency of 50 Hz. The solid line corresponds to the stage with a vortex row, the dotted line – without the vortex row.

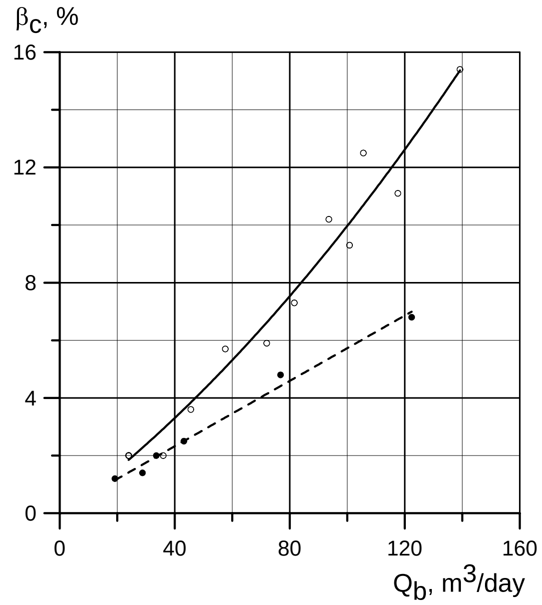

Fig. 4. Dependence of the critical volume gas concentration from the initial feeding of the VNN5-79 centrifugal-vortex stage at frequency 50 Hz: the solid line corresponds to the stage with a vortex row, the dotted line – without the vortex row (on water-air mixture).

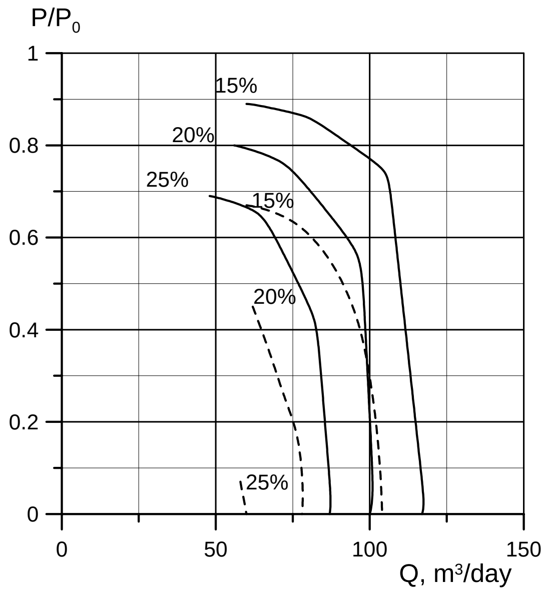

Fig. 5. Dependence of the relative head of the VNN5A-124 stages from the undissolved gas content at the input at frequency of 50 Hz: the solid line corresponds to the stage with a vortex row, the dotted line – without the vortex row (on water-surfactant-air mixture).

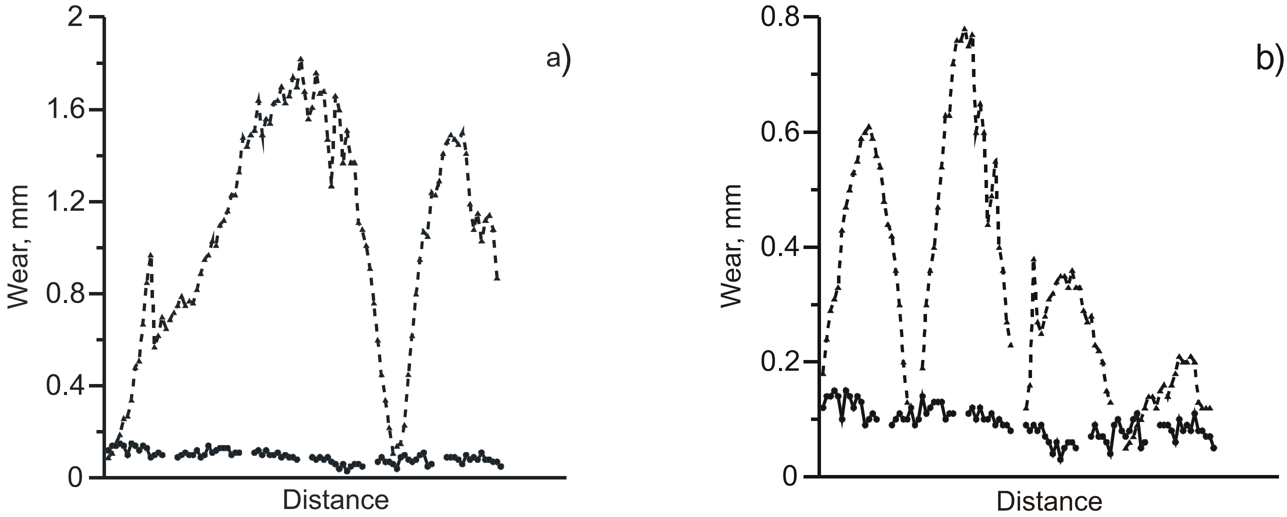

Fig. 6. Comparison of deteriorations of the stage radial bearings: a) the dotted line: without intermediate bearings (IB), the solid line: 5 IB; b) the dotted line: 3 IB, the solid line: 5 IB.

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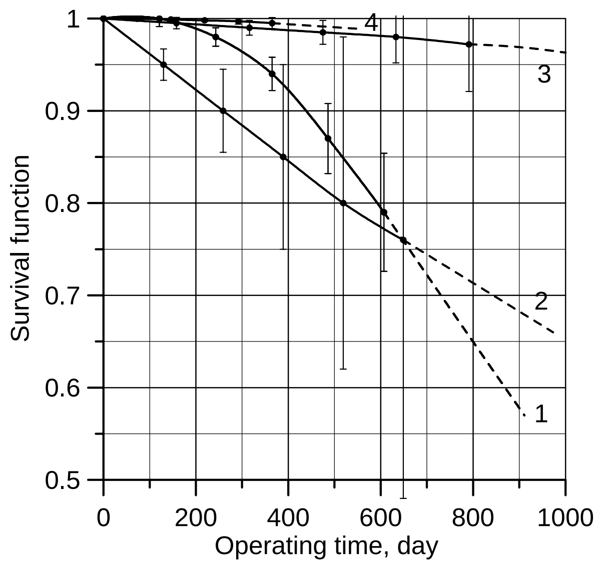

Fig. 7. Design reliability of the Novomet wearproof pumps: 1 – Sibneft – Noyabrskneftegas, 2 – Yuganskneftegas, 3 – Surgutneftegas, 4 – LUKOIL – Western Siberia»