Evaluation of dependability indicators of NK, NKV and NPS type pumps

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Abstract. *One of the strategic areas of development of all oil refineries (OR) in the Russian Federation is the improvement of equipment dependability and safety. The regulatory framework often does not take into consideration the design features of devices which, on the one hand, standardizes the service conditions, but, on the other hand, may cause inefficient maintenance of individual types of equipment. Due to the unpreparedness of the Russian oil refining complex to migration from scheduled preventive maintenance to condition-based maintenance, a large number of obsolete equipment and unceasing growth of technology complexity in modern ORs, it is required to improve and update the statistical and analytical base of dependability indicators of the equipment in operation. Russian and foreign experience of OR operation shows that damaged OR pump equipment can cause significant material damage and human casualties. A fair share of faults and failures that can cause accidents in ORs is concentrated in pump and compressor facilities. Ensuring safety of equipment operation and ORs as a whole requires reducing the probability of accidents. To that effect, technical condition monitoring facilities are deployed and equipment diagnostics are performed. A priori information analysis is also an option.* **Results.** *The article presents the results of documental inspection of performed maintenance of NK, NKV and NPS type pumps of a Russian OR conducted for the purpose of improving dependability and safety of pump operation. Probabilistic and statistical methods were used. The article presents an analysis of dependability indicators based on Gomertz-Makeham parametric distribution. This distribution is widely used in survival analysis and characterizes both system deterioration, and the influence of factors that do not depend on operation time. The authors analyze maintenance operations and repair cycles, identify the least dependable pump components and most frequent repair operations, show the influence of total operation time on pump dependability indicators. For the inspected pumps, the availability factors, utilization factors and average time between maintenance have been defined. The analysis identified that the availability factor of pumps depends not only on the average time between maintenance (that in turn depends on the frequency of required maintenance), but also on the utilization factor of the pumps. Beside the conventional dependability indicators, i.e probability of no-failure and failure rate, based on pump failure rate analysis ultimate times to failure for the inspected pumps were identified. Ultimate time to failure is the operation time beyond which gradual deterioration process significantly accelerates and causes a growth of the number and/or quality of partial failures. A significant accumulation of partial failures results in the loss of function or destruction of equipment. This dependability indicator is the most important in insuring the normal operation from the point of view of operating services.* **Conclusions.** *The article shows taht the identification of the ultimate time to failure for improved dependability and reliability of equipment operation must involve regular updates of input data in order to identify the beginning of the process of equipment "aging" for prevention of accidents caused by out-of-limit tear and wear of equipment.*

Keywords: *oil pumps, dependability, probability of no-failure, failure rate, availability factor, utilization factor, expected time to failure, average time between maintenance.*

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Introduction

In the Russian Federation, there are a large number of oil refineries of various purpose and oil conversion rate. The rising demand for refined products stimulates the growth of the existing ORs and construction of new ones.

The state of the art of pump equipment operation is characterized by the following trends:

- most equipment failures are caused by its unsatisfactory condition;
- inadequacy of obsolete equipment modernization and reconstruction mechanisms causes its significant inferiority to foreign counterparts;
- unreliable operation of pump equipment is also due to non-optimal operating modes: for years, most pumps

output 50 – 60 % of the nominal value with increased pressure.

Therefore, there is a growing necessity to accumulate and analyze statistical data on pump failures.

Analysis of the scope of activities

In total, the inspection covered 37 NK type pumps, 25 NKV type pumps and 24 NPS type pumps. Picture 1 shows the percentages of the total number and types of the considered repair operations on NK, NKV and NPS type pumps. Table 1 shows the scope of the analyzed repair operations on pumps of various types.

NK and NKV are centrifugal horizontal overhung pumps designed for oil and oil products pumping with horizontal and vertical upstream ends respectively. NPS are centrifugal horizontal injection pumps with flat barrel connectors for oil and oil products pumping.

Evaluation of pumps availability factor

For preliminary evaluation of maintenance quality and dependability of pumps, the availability factor has been calculated. This is a composite indicator that characterizes an element's readiness for intended use at a random moment of time except planned maintenance periods when the element's intended use is impossible [1]:

$$K_G = \frac{T}{T+T_R},$$

whereT is the mean time to failure, h;

T_R is the mean failure recovery time, h.

Due to unavailability of pump recovery time records at the inspected refinery, the indicator has been evaluated based on guideline values [2-4].

The matters of oil refinery centrifugal pumps repair are presented in [5-7]. The analysis of the performed repair operations and evaluations of the availability factor of NK, NKV and NPS type pumps are presented in figure 2. Pumps 1-33 are of the NK type, 34-46 of the NKV type, 47-60 of the NPS type.

The minimal values of mean time between failures for the NK type pumps and thus low dependability factors are observed in the following pumps:

- No. 2 on the list – N-11a of installation TK-1 (mean time between repairs is 1 003 h, availability factor is 0.964);

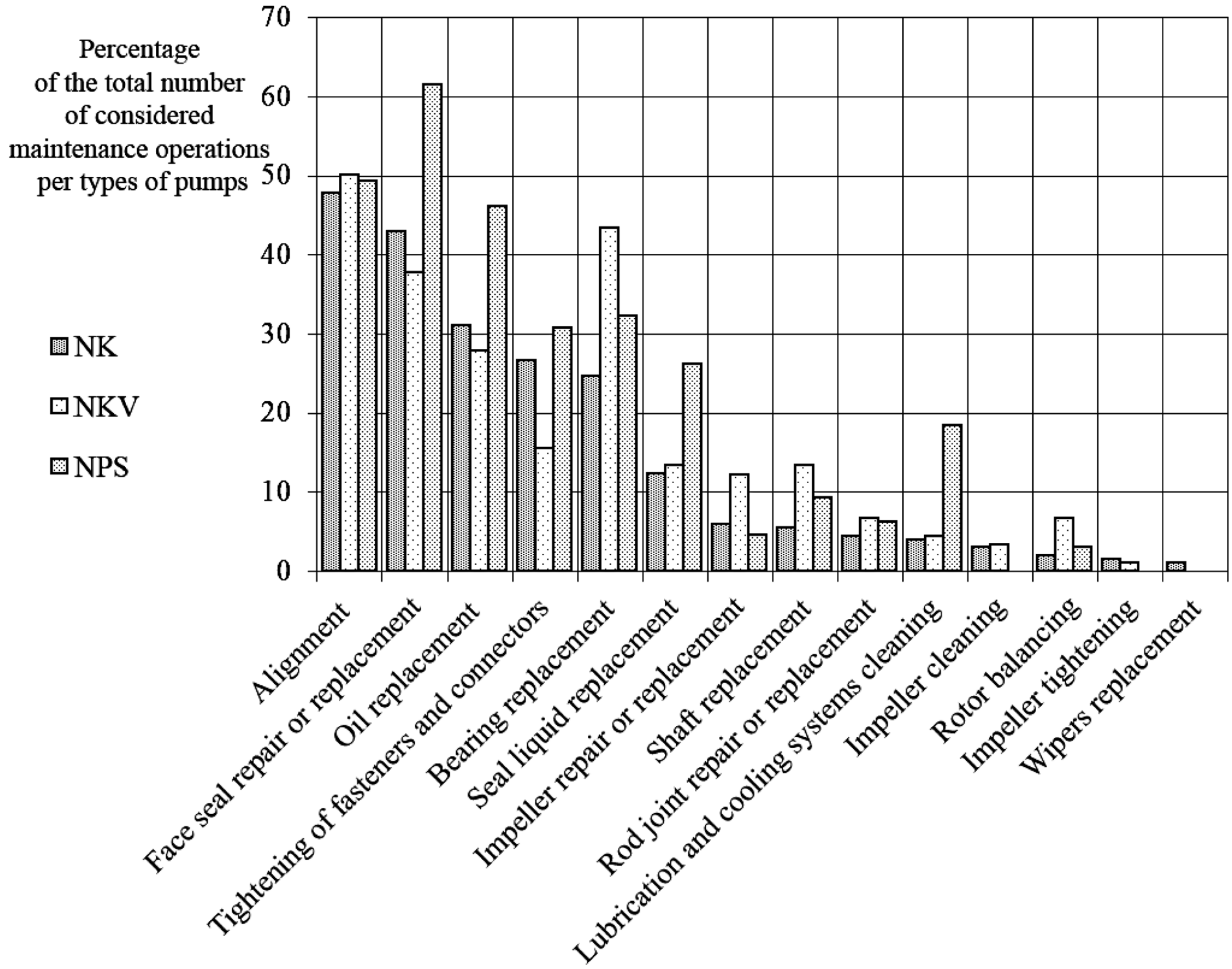

Figure 1 – Percentages of types of pump repair operations

Table 1. Scope of the analyzed repair operations on pumps of various types

Type of repair operation	Repairs of NK type pumps		Repairs of NKV type pumps		Repairs of NPS type pumps	
	Q-ty, units	Percentage	Q-ty, units	Percentage	Q-ty, units	Percentage
Total number of considered repair operations, incl.:	203	100.0	90	100.0	65	100.0
- current	110	54.2	44	48.9	42	64.6
- medium	77	37.9	39	43.3	17	26.2
- overhaul	16	7.9	7	7.8	6	9.2

- No. 3 on the list – N-11b of installation TK-1 (1 117 h and 0.968);
- No. 19 on the list – N-39 of installation AVT-3 (504 h and 0.947);
- No. 30 on the list – N-2 of installation AT-6 (797 h and 0.968);

Pump N-39 of installation AVT-3 is paired with pump N-20 of AVT-3 and pumps desalted oil into column K-1 in three flows. According to the provided data for the year 2013, the pump operates without rapid changes in process parameters: oil temperature is 94.7 °C – 115.0 °C (104.9 °C average), fluid usage is 420.0– 489.4 m^3/h (464.6 m^3/h average), upstream pressure is 4.3 – 6.0 kg/cm^2 (5.3 kg/cm^2 average). Total time of operation at the end of the analyzed period is 51 260 h. The pump's operating pattern within the analyzed range (time to failure with subsequent repair is given within brackets) is: T – C (344) – T (548) – T (509) – T (1 493) – C (75). According to the work and repairs schedule, current repairs are to be conducted after 4 680 h, medium repairs must be conducted after 14 040 h (after last repair operation). Non-observance of the schedule and frequent shutdowns for maintenance can be explained by poor maintenance or lack of quality control of spare parts.

Similar analysis can be provided for pump N-2 of installation AT-6 and pumps N-11a and N-11b of installation TK-1. In all cases there are no objective reasons for low time to failure.

An analysis of figure 2 brought out a connection between the utilization factor and availability factor. The correlation factor for the utilization and availability factors of NK type pumps is 0.753 (0.536 for all considered pumps). The cor-

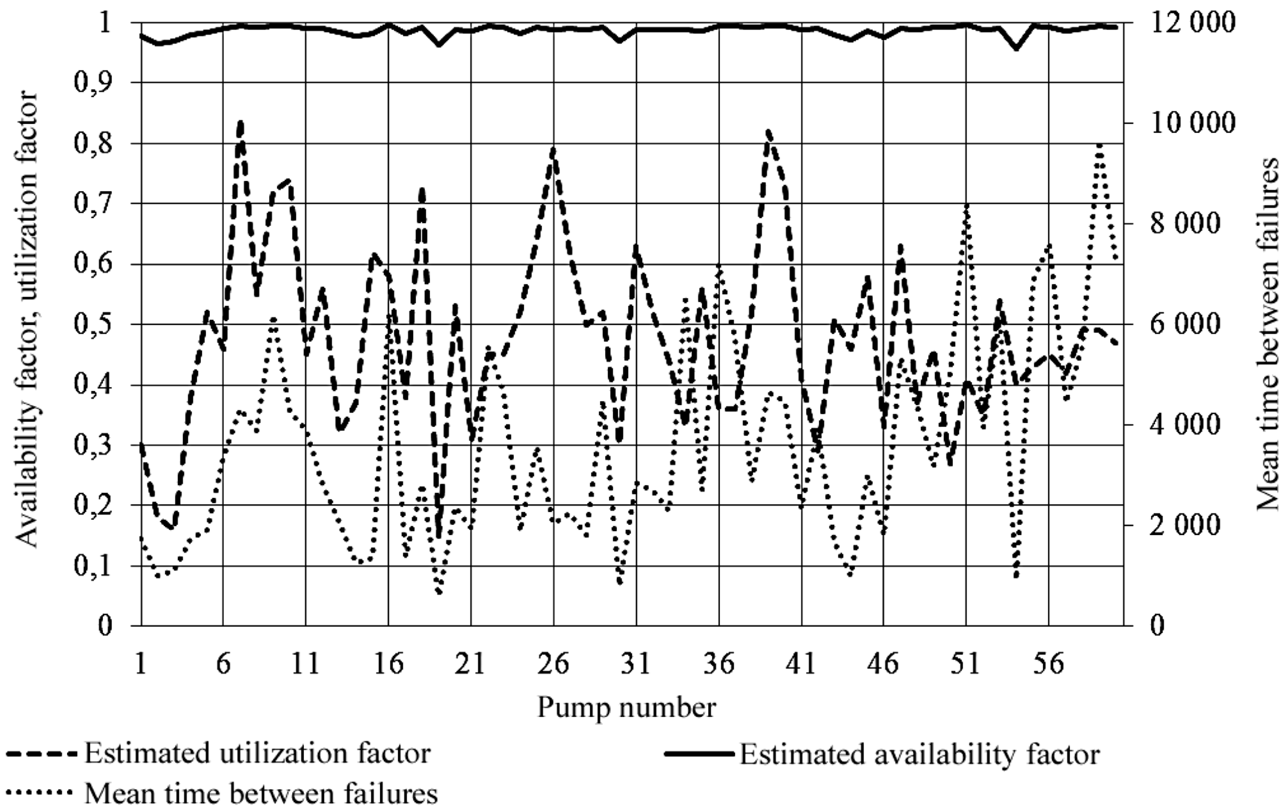

Figure 2. Evaluation of the availability factor, utilization factor and average time between pump failures

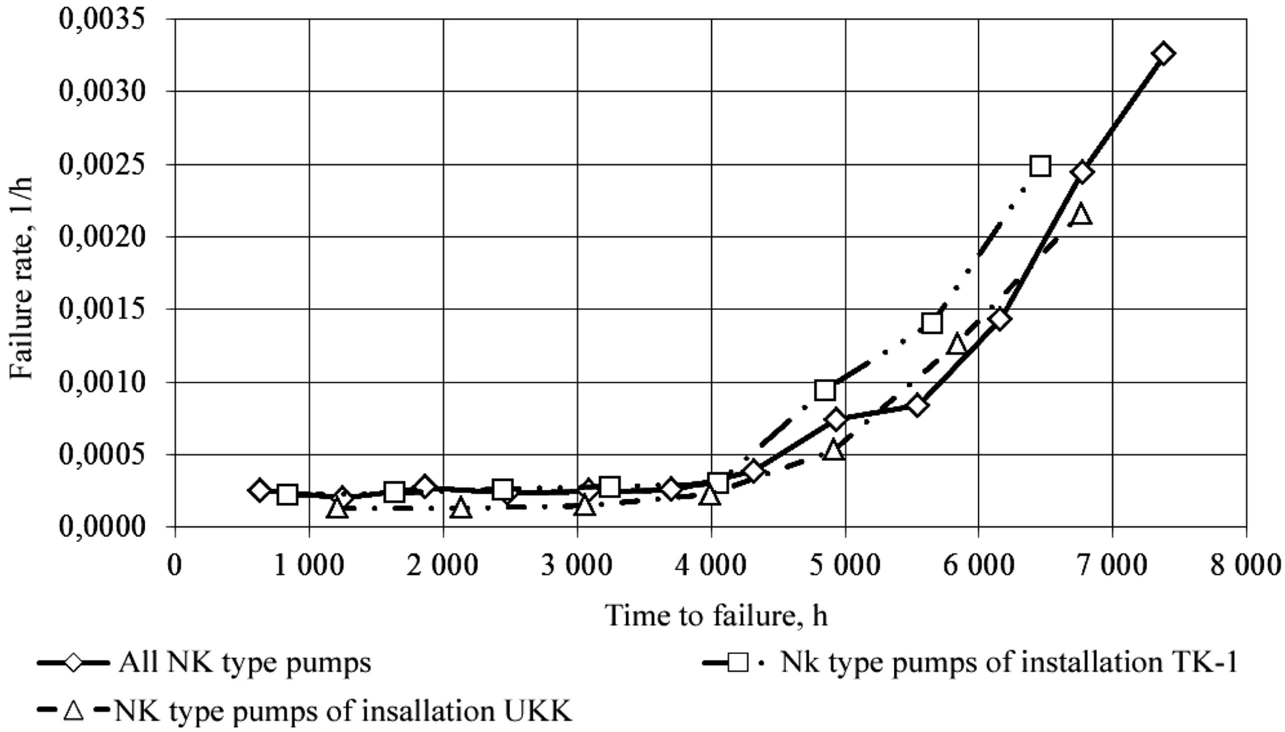

Figure 3. Failure rate of pumps

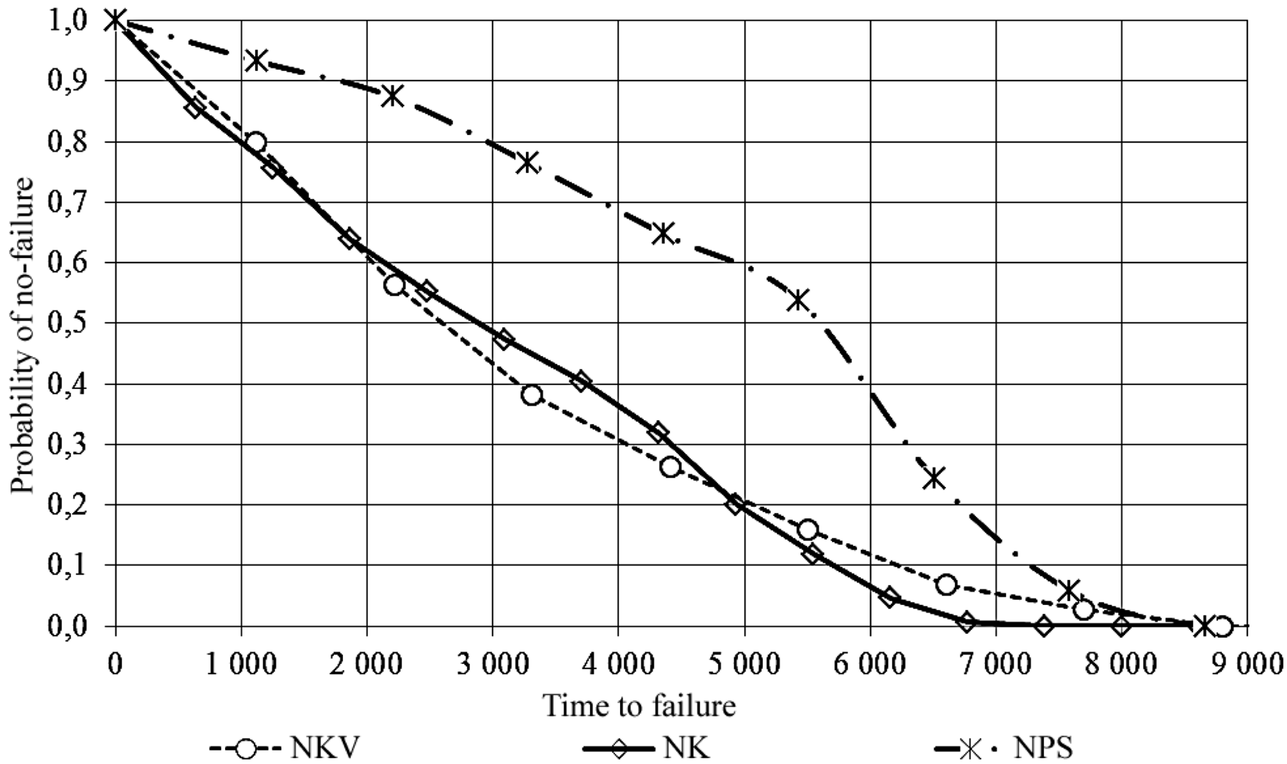

Figure 4. Probability of no-failure of pumps

relation factor for the availability factor and mean time to failure of NK type pumps is 0.737 (0.623 for all considered pumps).

The high correlation factor for the utilization factor and availability factor allows predicting an increase of the availability factor as the utilization factor grows.

Identification of probability of no-failure and ultimate time to failure

Figure 3 shows the failure rate of the analyzed pumps.

In Figure 3, it can be seen that the failure rate of the pumps in different installations matches the failure rate of all pumps

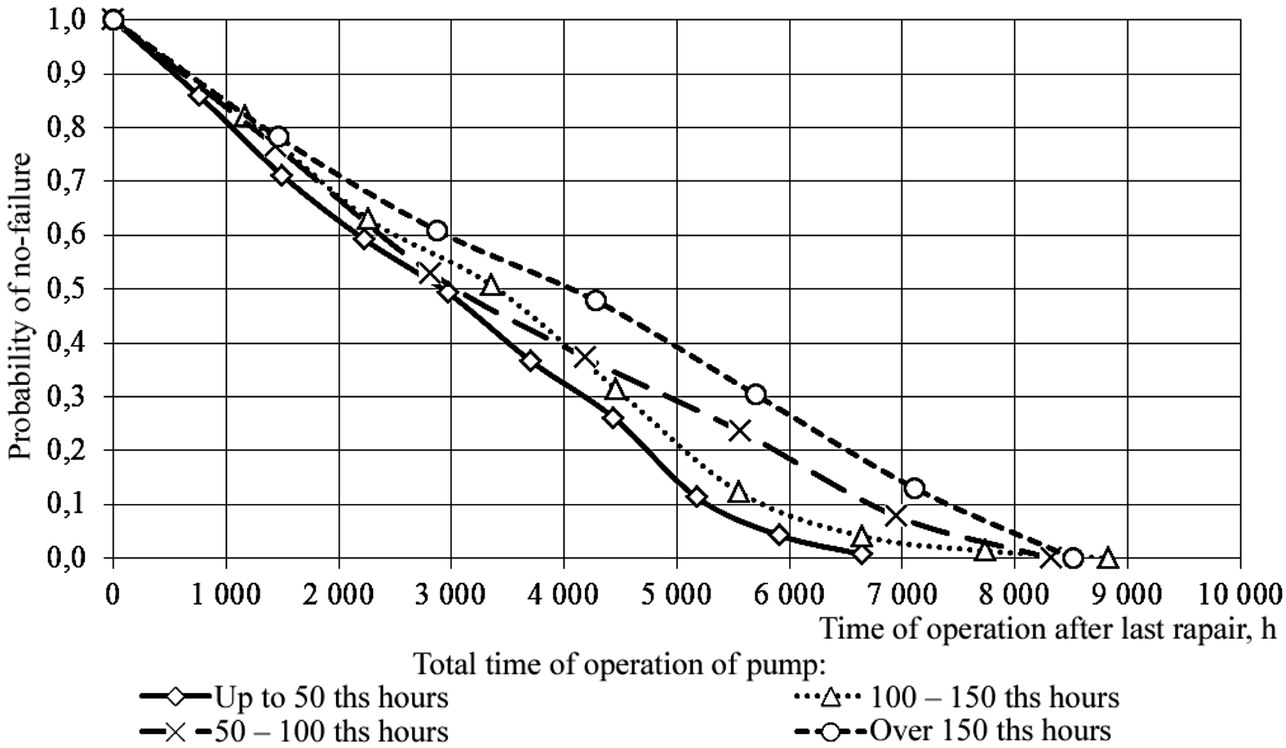

Figure 5. Probability of no-failure of NK type pumps

of this type. We can also identify the time of operation that is characterized by the beginning of abrupt growth of failure rate: 4 100 h for NK type pumps, 4 400 h for NKV type pumps and 5 400 h for NPS type pumps. The above abrupt growth characterizes the expected time to failure.

The probabilities of no-failure of pumps are presented in figure 4. NPS type pumps have a higher probability of no-failure.

The parent distribution of time to failure can be described with a Gomertz cumulative distribution factor. In this case the no-failure operation time is described with the following equation [8, 9]:

$$P(t) = \exp\left(-\int_0^t \lambda(t)dt\right),$$

where

$$\int_0^t \lambda(t)dt = K_1 t + K_2\left(\exp(K_3 t) - 1\right),$$

$$\lambda(t) = K_1 + K_2 K_3 \exp(K_3 t),$$

where K_1, K_2 and K_3 are positive constants that define the impact of environmental factors and system deterioration, h^{-1};

λ is the failure rate, h^{-1};

t is the time to failure, h.

The resulting distributions are presented in Table 2.

If the amount of analyzed data is sufficient, Gompertz-Makeham distribution allows analyzing the influence of time of operation on the probability of no-failure (Figure 5). For the purpose of the analysis, the sample was divided into 4 ranges.

Table 2. Resulting factors K_1, K_2, K_3

Parameter	NK type pumps	NKV type pumps	NPS type pumps
K_1, h^{-1}	0.00017	0.00017	0.00005
K_2, h^{-1}	0.024	0.100	0.015
K_3, h^{-1}	0.00070	0.00040	0.00065

Probability of no-failure and failure rate of NK type pumps under exponential distribution K_2 and linear distribution K_3 can be found according to the formulas:

$$P(t) = \exp\,[-(0{,}00017 \cdot t + 0{,}066 \cdot \exp\,(-2{,}733 \cdot 10^{-5} \cdot T) \cdot \cdot \exp\left((1{,}9 \cdot 10^{-5} \cdot T + 6{,}7 \cdot 10^{-4}) \cdot t - 1\right)],$$

$$\lambda(t) = 0{,}00017 + (0{,}125 \cdot 10^{-5} \cdot T + 0{,}440 \cdot 10^{-4}) \cdot \cdot \exp\left(-2{,}733 \cdot 10^{-5} \cdot T + (1{,}9 \cdot 10^{-5} \cdot T + 6{,}7 \cdot 10^{-4}) \cdot t\right),$$

where T is the total time of operation of piston compressor, h; t is the time to failure, h.

Figure 5 clearly shows the equipment «wearing in». Reliable prediction of ultimate time to failure requires regular updates of the statistical database.

Conclusion

The performed analysis has shown that the availability factor of pumps depends not only on the average time between maintenance (that in turn depends on the frequency of required maintenance), but also on the utilization factor of the pumps. The average time between maintenance can be extended by improving the quality of maintenance and quality control of spare parts. Optimal utilization factor can be obtained by mothballing excessive redundant pumps or evening the utilization of the pumps that operate in identical roles within the operational diagram (paired, standby operation, etc.).

The article set forth the dependences between failure rates and probabilities of no-failure for NK, NKV and NPS type pumps. Those characteristics did not depend on the installations they were fitted on which indicates similar operating conditions of the considered pumps of each type.

Expected time to failure without regard to total operation time is 4 100 h for NK type pumps, 4 400 h for NKV type pumps, 5 400 h for NPS type pumps. As soon as this time is reached, sudden failures become probable as components deterioration shows itself.

The identification of the ultimate time to failure for improved dependability and reliability of equipment operation must involve regular updates of input data in order to identify the beginning of the process of equipment “aging” for prevention of accidents caused by out-of-limit deterioration of equipment.

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