An analysis of reliability of electric submersible centrifugal pumps

M Ya Khabibullin and R I Suleimanov

Ufa State Petroleum Technological University, Branch of the University in the City of Oktyabrsky, 54а, Devonskaya St., Oktyabrsky, Republic of Bashkortostan, 452607, Russian Federation

E-mail: m-hab@mail.ru, info@of.ugntu.ru

Abstract. The average operating time before structural and technological failures of the submersible part of a typical ESP is 64.5–81.9% of the average operating time of new ESPs. Given that the set of typical ESPs includes a significant share of repaired and mixed (equipped with new and refurbished units) installations, this fact can be interpreted as evidence of poor quality of repair. The data obtained from Tatneft and Bashneft companies agree with this conclusion. The data provided by Nizhnevartovskneftegaz company do not contradict this conclusion. The high values of $T_{kt}$ obtained by Rosneft-Samaraneftegaz are a consequence of poor identification of the causes of ESP lifting during control operations, as a result of which some failures are treated as design and technological ones.

1. Introduction
A modern electric submersible pump (ESP) for oil production consists of a submersible part, including a centrifugal pump, an electric motor, a hydraulic protection (compensator and protector), a cable line, and a ground part, consisting of a control station and a transformer [1]. If any of the submersible units fails, it is necessary to perform underground repairs - silencing the well with process fluid, extracting the submersible part from the well, installing an arc submersible part, starting the installation, developing the well (removing process fluid from it) and putting the ESP into operation. The duration of underground repairs is several days, the cost is comparable to the cost of ESP, and losses from downtime significantly exceed it. Therefore, reliability of the submersible part of the ESP is crucial for consumers [2].

2. Materials and methods
After lifting, the failed submersible part is disassembled, and the units included in it are sent for inspection, and repair or write-off. The submersible part is never assembled from the units of which it consisted. Therefore, the level of reliability of the submersible part determined by the reliability of randomly selected units that have been repaired, does not depend on the level of reliability of the submersible part of the previous ESP. In this case, the failure rates can differ due to the different quality of repair, and the fact that each of them worked in different conditions and was audited in different states in previous operation periods [3].

Given the most important indicator of ESP failures, existing as a single assembly unit only during its descent into the well before the first failure, it is advisable to apply the average operating time before
failure of the ESP submersible part. The equivalent of this indicator is the so-called maintenance period (MP) of ESP. This indicator differs from the MCI of the well used by operators as it does not take into account failures.

The set of operating ESPs can be divided into two groups: with submersible parts, equipped before the descent into the well with new units, and with submerged parts, a certain share of which are already operated units [4].

The values of the average operating time before failures of the submersible parts of each group are different. The average operating time before failures of new ESPs characterizes the design and manufacture of the failure of submersible parts and can be determined by the results of their control operation, taking into account only failures caused by design and technological reasons. The average operating time before failures of the second group characterizes the quality of repair of components. The data received from consumers does not contain statistical data on the results of operation of ESP of the second group, which forces to judge the impact of repair quality on the failure of the average operating time before failures taking into account only failures caused by design and technological reasons. The influence of operational factors is assessed by calculating the average operating time before failures of the second group, taking into account only failures caused by different (including operational) reasons.

When determining the operating time before failure based on the results of control operation, there were methodological difficulties since almost every set of operating time of submersible ESPs is a repeatedly truncated (centered) sample, as its variation series consists of arbitrarily mixed operating time before failure and before suspension (suspension means the end of an operation without a refusal). In these calculations, the operating time of a ESP was defined as termination (interruption) of monitoring or lifting the working submersible part to take geological and technical measures. The operating time of an ESP before failure for operational reasons was taken into account as the operating time before failure (when determining the average operating time of the ESP before operational failure) and before suspension (when determining the operating time before structural failure) [5].

The average operating time before structural and technical failures of the submersible part of a new ESP was determined as follows. It was assumed that the operating time before failures of the submersible parts is subject to the Weibull distribution law [6].

$$ F = e^{-at^b} \quad (1) $$

where a, b are the distribution law’s scale and shape; t - operating time, hour.

The values were determined from the values of b using the expression by the method of maximum probability for a repeatedly truncated sample [7]

$$ a = \frac{G}{\sum_{i=1}^{G} t_i^b + \sum_{j=1}^{J} t_j^b} \quad (2) $$

where $t_i$ and $t_j$ - operating time of $i$ and $j$ of objects before failure and before suspension; G and J are the total number of objects.

For each pair of b and a, the Pearson criterion $\chi^2_p$ was determined, and the dependence $\chi^2_p = f(b)$, which determines the minimum value of $\chi^2_p$ min and the corresponding values of $a_m$ and $b_m$ was constructed. The value $\chi^2_p$ min was compared with the maximum tabular value of the Pearson criterion, determined at a confidence level of $\gamma = 0.9$. If $\chi^2_p$ min exceeded the limit value of the criterion, the distribution law was discarded; if it did not exceed, it was taken for further calculations with the values of $a_m$ and $b_m$.

The average operating time before structural and technical failures of the submersible part of a new ESP was determined by formula [8]
we obtain the average operating time before failure 

\[ T_n = a_m^{-b_m} I \left( \frac{1}{b_m} + 1 \right) \]  

(3) 

where \( I \left( \frac{1}{b_m} + 1 \right) \) is the value of the gamma function.

3. Results and Discussion

The analysis was conducted on 22 samples of nine most common ESPs used by Tatneft, Bashneft, Rosneft-Samaraneftegaz and Nizhnevartovskneftegaz companies. The samples consisted of 1–89 ESP units with a failure rate of 0–31. Six of them (two in Tatneft, three in Bashneft, one in Rosneft-Samaraneftegaz) had statistics sufficient to verify the compliance of the distribution law with the statistical one with acceptable reliability [9].

The analysis of these six samples showed that in all cases the calculated minimum value of the Pearson criterion was less than its limit value, which indicates a satisfactory approximation of the distributions of workflows before failures of the Weibull distribution law with a rather narrow range of shape values \((b_m = 0.9 \div 1.1)\); in all cases, the values of \(b_m\) for the distribution of these developments were: 1.1 - in Bashneft; 1 - in Tatneft; 0.9 - in Rosneft-Samaraneftegaz; this suggests that the values of \(b_m\) depend on the location of control operations, and, therefore, it is possible to extend the obtained values to the whole set of samples. Due to the lack of samples sufficient for calculations in Nizhnevartovskneftegaz, the distribution of operating time before failures in all samples in this association was subject to the Weibull distribution law with an average static value of \(b_m = 1\), i.e. to the exponential distribution law.

As a calculation result for each new ESPs sample, the average operating time values \(T_{NKT}\) before design and technological failures were determined. If the value of the average operating time before failures of the submersible part for four associations is 1, in Tatneft the average operating time is significantly higher (1.59-1.92), in Bashneft it is almost the same (0.89-1), in Rosneft-Samaraneftegaz it is 0.55–0.67, which indicates the influence of the location of a control operation.

The average operating time before the failure of the submersible part of a typical ESP (in days) is determined by formula [10]

\[ T_T = K_n \frac{N}{M} 365 \]  

(4)

where \(N\) is the average number of ESPs in operation; \(M\) is the annual failures number; \(K_n\) is the operation coefficient.

Substituting the number of total annual failures for design and technological reasons in this formula, we obtain the average operating time \(T_{d\text{d}}\) before design and technological failures of the submersible part of a typical ESP; substituting the total annual number of failures (including failures for operational reasons) in the formula, we obtain the average operating time \(T_{d\text{d}}\) before any failure requiring underground repairs [11,12].

Taking the values of \(T_{d\text{d}}\) in each of the associations equal to 100%, we obtain the following values of \(T_{d\text{d}}\) and \(T_{d\text{d}}\) (in % of \(T_{d\text{d}}\)). The data are presented in the table.

The set of units includes a significant share of repaired and mixed (equipped with new and refurbished units) installations, this fact can be interpreted as evidence of poor quality of repair. The data obtained from Tatneft and Bashneft fully agree with this conclusion. The data obtained from Nizhnevartovskneftegaz do not contradict this conclusion. The high values of \(T_{d\text{d}}\) in Rosneft-Samaraneftegaz are a consequence of poor identification of causes of ESP lifting during control operation, as a result of which some failures caused by operational reasons are treated as failures caused by design and technological reasons.
Table. Average operating time before any failure requiring an underground repair of wells by associations (per day)

| Average failure time | Tatneft       | Bashneft      | Rosneft-Samaraneftegaz | Nizhnevartovsk-Neftegaz |
|----------------------|---------------|---------------|------------------------|-------------------------|
| $T_{ak}$             | 66.2-69.5     | 68.3-77.2     | 108.5-112.7            | 9.3-130.5               |
| $T_{ad}$             | 35.4-37.2     | 53.9-61.1     | 73-75.8                | 7.6-106.2               |

4. Conclusion
On average, the share of $T_{ad}$ in the four associations was 45.8–58.1% of $T_{ak}$, in Tatneft it was a slightly lower ratio, and in Rosneft-Samaraneftegaz it was slightly higher. It follows that under the influence of repair poor quality and submersible parts maintenance of ESPs (more failures for operational reasons) and wrong practice of equipping them with new and repaired units, the operating time before failure of a typical ESP can be reduced by almost half compared to the initial operating time before the failure of new (factory-made) ESPs. These data indicate that due to the elimination of these shortcomings in all associations, there are significant reserves to increase the actual operating time before the failure of the submersible parts of typical ESPs.

References
[1] Khabibullin M Ya Managing the processes accompanying fluid motion inside oil field converging-diverging pipes *Journal of Physics: Conference Series. International Conference "Information Technologies in Business and Industry"*. 2019. C. 042012. DOI: 10.1088/1742-6596/1333/4/042012
[2] Khabibullin M Ya Managing the reliability of the tubing string in impulse non-stationary flooding *Journal of Physics: Conference Series. International Conference "Information Technologies in Business and Industry"*. 2019. C. 052012. DOI: 10.1088/1742-6596/1333/5/052012
[3] Polyakov V N, Chizhov A P, Kotenev Yu A and Mukhametshin V Sh 2019 Results of System Drilling Techniques and Completion of Oil and Gas Wells *IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering)* 378(1) 012119 1–7 DOI: 10.1088/1755-1315/378/1/012119
[4] Korn G A and Korn T M 1984 Mathematical Handbook for Scientists and Engineers: Definitions, Theorems, and Formulas for Reference and Review (Moscow: Nauka)
[5] Zaynagalina L Z On the determination of design and geometric parameters of a upper bit slurry grinder *IOP Conference Series: Materials Science and Engineering*. 2020. C. 012094. DOI: 10.1088/1757-899X/905/1/012094
[6] Barber A H, George C J, Stiles L H and Thompson B B 1983 Infill Drilling to Increase Reserves-Actual Experience in Nine Fields in Texas, Oklahoma and Illinois J. Pet. Tech pp. 1530-1538
[7] Kuleshova L S, Kadyrov R R, Mukhametshin V V, and Akhmetov R T 2019 Auxiliary equipment for downhole fittings of injection wells and water supply lines used to improve their performance in winter *IOP Conference Series: Materials Science and Engineering (MEACS 2018 – International Conference on Mechanical Engineering, Automation and Control Systems)* 560(1) 012071 1-6 DOI: 10.1088/1757-899X/560/1/012071
[8] Haoran Zh, Yongtu L and Xingyuan Zh 2017 Sensitivity analysis and optimal operation control for large-scale waterflooding pipeline network of oilfield *Journal of petroleum science and engineering* 154 pp. 38-48
[9] Sun W and Mun-Hong H 2017 Forecasting and uncertainty quantification for naturally fractured reservoirs using a new data-space inversion procedure European Assoc Geoscientists & Engineers Computational geosciences 15th Conference on the Mathematics of Oil Recovery (ECMOR) (Amsterdam, Netherlands) 21(5-6) pp.1443-1458

[10] Malyarenko A M, Bogdan V A, Kotenev Yu A, Mukhametshin V Sh, and Umetbaev V G 2019 Wettability and formation conditions of reservoirs IOP Conference Series: Earth and Environmental Science (IPDME 2019 – International Workshop on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 378(1) 012040 1–6 DOI: 10.1088/1755-1315/378/1/012040

[11] Zaynagalina L Z Dynamics of the oscillatory system of the near-bit slurry grinder IOP Conference Series: Materials Science and Engineering. 2020. C. 012092. DOI:10.1088/1757-899X/905/1/012092

[12] Zaynagalina L Z On the development of an experimental design and field test of an upper bit tool IOP Conference Series: Materials Science and Engineering. 2020. C. 012093. DOI:10.1088/1757-899X/905/1/012093