On determining the reliability of wells constructed on the shelf

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Abstract. Reliability is a desirable property of a completed well including offshore. On practice, the concept of "well reliability" is often connected with the reliability of its supporting structure - support. This is true if strength issues are considered, requiring the determination of the values of the loads that the main power element of the well can work on. And this is not true if the reliability of a well is understood as its long-term and safe operation, since in this case it is necessary to take into account the objects that form the system of well reliability. The algorithm for determining the reliability of completed wells is shown using the example of underground gas storage (UGS) wells. Determination of reliability has a significant economic component, since it establishes such indicators of wells as gamma-percentage service life and extended (within the residual service life) safe operation period. If these indicators are not defined as indicators of well reliability, then they are assigned. As a rule, the assigned dates are shorter than the actual ones and this leads to an increase in well maintenance costs, in particular, due to the number of industrial safety examinations that must be carried out at the end of the assigned period of time regardless of the technical condition of the wells.

Keywords: Well; Shelf; Reliability System; Reliability Indicators; Residual Service Life; Safety

1. About the possibility of applying the classical theory to assessing the reliability of wells

The reliability of objects is determined by the quantitative values of indicators characterizing its (considered) properties [1, 2]. Within the framework of the general theory of reliability, the values of indicators are determined using statistical data. Therefore, the scope of the general theory is limited. The subjects of her research are large-scale objects that are manufactured and operated under statistically homogeneous conditions. At the same time, complex objects are represented as a set of individual elements connected in a certain way (Figure 1).

In this case, the probability of failure-free operation of the system will be calculated using the appropriate formulas. For example, when sequential connecting of elements, according to the formula (1):

\[ P(t) = P_1 \cdot P_2 \cdot \ldots \cdot P_n = \prod_{i=1}^{n} P_i \]  

(1)
The complexity of determining well reliability indicators is as follows:
- wells are not mass-produced items;
- they cannot be represented as elements with a certain type of connections.
Therefore, the classical statistical theory of reliability is not applicable to wells.

A more general approach to the calculation assessment of the reliability of technical objects is that failures are considered as a result of the interaction of an object as a "physical system" with other objects and the environment.

The system of the object's reliability is specific one at the same time, as well as the methods of obtaining quantitative values of the parameters of its reliability, in particular, using qualimetry methods.

2. On methods for obtaining quantitative indicators of the reliability of an object
To determine the reliability of an object, information is needed about the failures of its parts, assemblies, and the object as a whole.

The main source of information on reliability is various tests, for example, life (factory) and operational in real operating conditions.

Note that the reliability indicator, the assessment of which is determined from the operation data, is called the operational reliability indicator.

As you can see, the reliability of wells can be established by the operational reliability indicator.

3. Example 1 - Definitions of operation reliability index (gamma-percent service life) of UGS wells
Underground gas storage facilities are usually constructed on the basis of depleted gas fields, therefore, in the oil-and-gas industry, UGS wells are “long-livers”. Moreover, these are wells, during the life of which the industrial safety examination (ISE) has been carried out more than once. In this case: the actual life of operation was established; technical condition and residual service life of the supporting structure (support) [3]; the life of operation of the wells was extended (or not) [4].

The results obtained with the ISE can be considered as data on the operational reliability of wells and used to determine their gamma-percent service life.

We should remind you that the gamma-percentage service life is the uptime of the facility provided with the required probability γ.

If we consider wells, then in order to obtain a gamma-percent service life, data on their actual service lives and the number of failures in the observed periods are required. The number of failures in this case will correspond to the number of wells, the life of which has not been extended.

The sample of wells in this case was eight hundred (800) items, and their service life ranged from 30 to 50 years or more.

Table 1 shows the ISE results used for 2007-2011 years of UGS wells [5].
Table 1. Distribution of the number of UGS wells by extension of safe operation.

| Extension period of operation | Wells number, % | Year of ISE realization |
|-------------------------------|-----------------|-------------------------|
|                               | 2007            | 2008 | 2009 | 2010 | 2011 |
| Full period of extension      | 57.8 %          | 55.2%| 90.3 %| 81.1 %| 91.1 %|
| Shortened period of extension | 38.4 %          | 41.0 %| 5.1 %  | 16.2 %| 5.5 % |
| Not extended                  | 3.8 %           | 3.8% | 4.6% | 2.7% | 3.4% |

From the data in Table 1, one can see that the percentage of the number of wells whose service life is not extended was stable and averaged 4%. It is significant that the reasons why it was not extended for the wells were different, for example:
- production casing leaks;
- intercasing pressures;
- cross-flows between layers.

Despite this, the wells were assigned to one group - the group of failed ones.

This is allowed in the practice of engineering reliability analysis. The used principle is called the principle of the same consequences and consists in the fact that random events (failures, damage, etc.) that lead to the same consequences can be included in the general classification group [6].

The life of operation of UGS wells, provided with a probability of no-failure operation $\gamma = 96\%$, was 42 years. This is the actual operational indicator of the reliability of UGS wells, in accordance with which the previously assigned life of their operation has been adjusted - 30 years.

We should conclude the next fact. Well reliability analysis allows you to adjust the assigned service life.

4. Example 2 - Extension of the safe operation life of UGS wells

Prediction of the reliability (prolongation of the safe operation period) of a well requires the creation of a system of its reliability. This takes into account the elements that can affect the reliability of the well during the predicted service life.

The extension of the safe operation life of UGS wells was carried out according to the following algorithm [7].

1) The residual service life of the $T_{\text{residual}}$ of the supporting structure is calculated (performed analytically [4]);

2) A reliability system is made and the well reliability coefficient $K$ is calculated (performed using qualimetry methods) (2):

$$ K = \frac{\sum_{i=1}^{4} (a_i \cdot \delta_i) - 1}{2}, $$

where, $a_i$ - quantitative assessment (code) of the element state (characterizing the degree of its reliability);

$\delta_i$ is the coefficient of significance (weighting coefficient) of the object included in the well reliability system.

The significance coefficient reflects the influence of the element on the well reliability. The values of the coefficients were obtained from the results of an expert survey of industry specialists using the methodology of normalized coefficients [8].

The elements included in the well reliability system and their weighting factors are shown in Table 2.
Table 2. UGS well reliability system and weighting coefficients of elements.

| Elements               | $\delta_i$ |
|------------------------|------------|
| Production casing      | 0.35       |
| Intercasing space      | 0.24       |
| Wellhead area          | 0.1        |
| Wellhead equipment     | 0.31       |

Table 3 shows an example of the description of the characteristics of the state of an element included in the well reliability system, the degree of its reliability and the corresponding code.

Table 3. Characteristics of the state of the intercasing space, the degree of its reliability and the corresponding code.

| Characteristics of state     | Degree of reliability | Code, $a_i$ |
|------------------------------|-----------------------|-------------|
| The intercasing (and behind-the-casing) pressures have permissible values. During the previous three years (the last three cycles of the well operation for injection - withdrawal), there has been a dynamics of an increase of intercasing pressures and a deterioration in the contact of the cement stone to the production casing. | Small | 1 |
| The intercasing (and behind-the-casing) pressures have permissible values. During the previous three years (the last three cycles of the well operation for injection - withdrawal), there has been no dynamics of an increase of intercasing (and behind-the-casing) pressures and deterioration of the contact of the cement stone with the production casing. There are no intercasing (and behind-the-casing) pressures. The intercasing spaces are equipped with intercasing pressure control devices. Access with the transmission of information in real time. | Average | 2 |
| 3) The coefficient of reduction of the residual service life of well C is determined. | Big | 3 |

Table 4 shows the values of the K coefficient, the reliability levels corresponding to its values, and the coefficients for reducing the residual service life of wells C.

Table 4. Coefficient of reliability and coefficient of reduction of residual well service life.

| Coefficient of reliability of well K | Well reliability level | Coefficient of reduction of residual well service life |
|-------------------------------------|------------------------|-----------------------------------------------------|
| 0.8 – 1.0                           | Very high              | 0.9                                                 |
| 0.64 – 0.8                          | High                   | 0.7                                                 |
| 0.37 – 0.64                         | Average                | 0.5                                                 |
| 0.2 – 0.37                          | Low                    | 0.3                                                 |
| 0.0 – 0.2                           | Very low               | 0                                                   |

5) Calculation of the extended life of safe operation $T_{\text{residual}}^{\text{Safe}}$ according to the formula (3):

$$T_{\text{residual}}^{\text{Safe}} = T_{\text{residual}} \cdot C$$ (3)

We emphasize that the prediction of the terms of safe operation is carried out taking into account the operating conditions, as well as the technical condition of the supporting structure, and the objects included in the well reliability system.
Reliability analysis is rational, since it helps to improve the efficiency of wells operation, and also allows the development of measures to improve their reliability and endurance.

5. Conclusion
In conclusion, we note that the forming of a system for the reliability of wells constructed on the shelf is the key point in the issue of their reliability. So, if the algorithm for forming a well reliability system can be considered universal, then the set of objects included in it will be individual and should take into account the specifics of the construction and subsea operation of wells, their design and wellhead connection, the used control systems, etc.

We also note that the proposed algorithm for determining the reliability is relatively simple, logical, allows taking into account the individual characteristics of wells and has been tested by practice. At the same time, statistical data, as the initial material for calculations, are used to determine the operational indicator of well reliability - the gamma-percentage service life.

For comparison, let us point out the work [9], which provides an assessment of the reliability of casing pipes (not wells) of ultra-deep oil and gas wells using statistical data and numerical modeling. This requires creating a theoretical model and determining its variables (including rocks, cement sheath and casing strength factors). To determine the parameters of the distribution of model variables (taking into account their random distribution), a lot of statistical data and analyzes results are required. As a result, to obtain the distribution of the residual strength and reliability of the casing pipes, numerical modeling is carried out using Monte Carlo method.

In our opinion, the complication of solving the problem to a greater extent demonstrates the authors' proficiency in the methods of probabilistic analysis and does not contribute to taking into account the individual operating conditions of the casing strings in specific wells.

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References
[1] Bolotin V V 1984 Prediction of the service life of machines and constructions (Moscow: Mashinostroenie) 321 p
[2] Cheboksarov A N 2012 Fundamentals of the theory of reliability and diagnostics: a course of lectures (Omsk: SibADI) 76 p
[3] Regulations on the industrial safety expertise of underground gas storage wells for various purposes and the appointment (extension) of their safe operation: STO Gazprom 2-3.2-056-2006 2006 (Moscow: OOO «Gazprom expo») 54 p
[4] Manual for calculating the endurance and the residual service life of wells: STO Gazprom 2-3.2-346-2009 2009 (Moscow: OOO «Gazprom expo») 36 p
[5] Shamshin V I, Fedorova N G, Dubenko V E 2014 About periods definition of the safe operation of oil-and-gas wells Design of oil-and-gas wells onshore and offshore (Moscow) vol 3 pp 30 - 32
[6] Efremov L V 1983 The principle of identical consequences and its application in the analysis of machine reliability Reliability and quality control vol 5 pp 33 – 36
[7] Methodology for calculating the terms of safe operation of underground gas storage wells STO Gazprom 2-3.5-770-2013 2015 (Moscow: JSC «Gazprom») № IV 12 p
[8] Methodical recommendations for assessing the risk of accidents in hydrotechnical structures of reservoirs and industrial waste storage 2001 (Moscow: FGUP NII VODGEO)
[9] Shangyu Y, Renren Zh, Jianjun W, Xinhong L, Heng F, Ming Y 2021 Reliability assessment of ultra-deep oil and gas wellbore casing using data statistics and numerical simulations Journal of Loss Prevention in the Process Industries vol 69 104369 ISSN 0950-4230
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