Influence of technical condition parameters on the period of safe operation of technological pipelines

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Abstract. The task is to assess the further period of the total operating time of pipeline systems after monitoring their technical condition, depending on the generalized impact of the technical parameters of oil and gas processing equipment. Nine signs of pipeline systems were identified, and the assessment was carried out using an indicator characterizing their residual life. The authors developed a mathematical model, using calculation methods obtained diagnostic coefficients and informativeness of the sign for each of the time periods, which are determined by experts. An algorithm for estimating the residual resource of technological pipelines is proposed. Conclusions are drawn about the possibility of using the proposed algorithm to implement tasks of this type.

1. Introduction

Systems of technological pipelines of oil and gas refining, petrochemical and chemical industries are an integral part in the production of commercial products and occupy the first place in terms of metal consumption among the technological equipment of technological plants. During operation, under the influence of various operational factors, the development of various mechanisms of damage to metal equipment takes place, of which the most common are various types of corrosion. Corrosion wear leads to a gradual decrease in the wall thickness of the equipment and the approximation of the thickness to the rejection values established by the current regulatory and technical documentation in the field of industrial safety. This, in turn, leads to a loss in the strength of equipment elements, which is fraught with the development of emergency situations associated with depressurization of equipment from the effects of increased pressure and temperature on the thinned walls.

To monitor the technical condition of pipeline systems susceptible to corrosion, at a certain time interval not exceeding ten years, an examination of industrial safety is carried out. The purpose of this event is, firstly, to assess the conformity of the object of examination to industrial safety requirements, and secondly, to determine the technical condition of the object of examination and to assess the possibility of its further safe operation.

The final and main stage of the industrial safety review is the assessment of the residual life of the pipeline system. In case of corrosion wear, the calculation of the resource of a process pipeline is carried out mainly by two methods:
• to determine the weakest element of the pipeline for corrosion wear and resource assessment for this element;
• by calculating the residual life by the method using mathematical statistics of the entire pipeline as one, by changing the wall thickness and failures of elements.

The information necessary for predicting the remaining life is provided by the values of technical parameters, which are measured during repairs and audits. Next, the necessary values of the technical parameters are extrapolated over time, and the ability to perform its functions for a period equal to the residual service life is analyzed.

The methods of mathematics that are used in expert calculations, as a rule, make it possible to estimate the upper limit of the residual resource. In certain cases, this boundary can be overestimated several times in relation to the assigned value of the resource by an expert in the conclusion of an expert examination of industrial safety [1].

Large amounts of technical data make it possible to analyze scenarios of possible results of examinations that will be carried out in the future, to build a mathematical model that most fully characterizes this type of equipment [1, 2, 10-14].

Currently, the influence of technical parameters of pipeline systems and the process itself [2, 4], modeling and forecasting the residual life of computer technology [2, 3], mathematics [4, 5, 6], and neural networks [11-14] are widely estimated. But even the availability of such extensive tools and techniques does not always provide the necessary and ease of use of systems of complex equations.

2. The experimental procedure and the obtained results

We have 12 features that affect the residual life of pipeline systems: commissioning date($\tau_1$), service life ($\tau_2$), pressure ($P$), temperature ($T$), hazard class ($k$), outer diameter ($d$), wall thickness rejected ($h_3$), wall thickness minimum measured ($h_2$), wall thickness design ($h_1$), corrosion rate ($v$), average relative thinning of the wall ($h_4$), Average permissible relative wear ($h_5$)

We have data on 47 expert opinions on technological pipelines with an expert opinion of 4 to 10 years (table 1). There are no data on pipelines in the sample for which the expert opinion would give a negative conclusion.

The influence of the listed parameters ($\tau_1$, $\tau_2$, $P$, $T$, $k$, $d$, $h_1$, $h_2$, $h_3$, $v$, $h_4$, $h_5$) on the residual resource of pipelines can be determined by calculating their information content [1].

Therefore, we will evaluate for several iterations: at the first iteration, we divide the pipelines into two groups — those with a residual resource of 5 years and not having such a resource.

There are thirteen signs ($\tau_1$, $\tau_2$, $P$, $T$, $k$, $d$, $h_1$, $h_2$, $h_3$, $v$, $h_4$, $h_5$), and the result is the residual resource for the first iteration - 5 years, or its absence. We will divide pipelines into two groups: “A” - having a residual life of 5 years or more; “B” - not having such a resource.

We find the information content of each of the thirteen signs.

As an example, the calculation of information content for the sign "Corrosion rate ", denoted as $v$

Corrosion rate is in the range from 0.021 to 0.188 mm. The range was divided into six equal intervals. Next, we determined the frequency of pipelines falling into one of the groups (“A” or “B”). The burst pressure interval from 0.021 to 0.051 mm has 7 pipelines in group “A” and 0 pipelines in group “B”; and, for example, the interval from 0.111 to 0.141 has 4 pipelines in group “A” and 2 pipeline in group “B”.

Table 1. Data on pipelines and features affecting the residual resource.

| No | $\tau_1$ | $\tau_2$ | $P$ | $T$ | $k$ | $d$ | $h_1$ | $h_2$ | $h_3$ | $e$ | $v$ | $h_4$ | $h_5$ | Resource |
|----|--------|--------|-----|-----|----|-----|-------|-------|-------|-----|-----|-------|-------|----------|
| 1  | 1976   | 34     | 0.07| 160 | 3  | 89  | 6.0   | 3.5   | 2     | 1.75| 0.074 | 0.32  | 0.61   | 6       |
| 2  | 1977   | 33     | 0.07| 160 | 3  | 219 | 10.00| 6.5   | 2.5   | 2.60| 0.106 | 0.25  | 0.70   | 5       |
| 3  | 1978   | 32     | -0.1| -55 | 3  | 159 | 7     | 5     | 2.5   | 2.00| 0.063 | 0.20  | 0.66   | 6       |
| 4  | 1978   | 32     | 0.07| 130 | 3  | 219 | 10    | 6.3   | 2.5   | 2.52| 0.116 | 0.27  | 0.99   | 10      |
| 5  | 1978   | 32     | 0.6  | 30  | 4  | 159 | 7     | 4.4   | 2.5   | 1.76| 0.081 | 0.24  | 0.94   | 10      |
| 6  | 1977   | 33     | 0.6  | 30  | 4  | 108 | 6     | 4.5   | 2     | 2.25| 0.045 | 0.29  | 0.96   | 10      |
We determine the relative frequency of falling into one or another group within the interval: if 7 pipelines from 32 pipelines of group “A” fall into group “A”, then for the first interval the relative frequency of falling into group “A” is = 21.9% (table 2).

**Table 2.** The definition of informativeness of the sign “Corrosion rate”.

| Interval | Change range $v$, % | The number of pipelines in the group | Relative frequency, % | Smoothed frequency, % | $\tilde{y}_{Ai}$ | $\tilde{y}_{Bi}$ | DC | $J_i$ |
|----------|---------------------|-------------------------------------|-----------------------|----------------------|-----------------|-----------------|-----|-------|
| 1        | 0,051               | 7                                   | 21,9                  | 0                    | 16,875          | 8               | 2,109 | 3,242 | 0,144 |
| 2        | 0,081               | 8                                   | 25                    | 20                   | 21,875          | 20              | 1,094 | 0,389 | 0,004 |
| 3        | 0,111               | 10                                  | 31,3                  | 40                   | 22,813          | 28              | 0,815 | -0,89 | 0,023 |
| 4        | 0,141               | 4                                   | 12,5                  | 40                   | 15,313          | 26              | 0,589 | -2,299 | 0,123 |
We use the Nadar-Watson formula for nuclear smoothing. The Parzen window was chosen to have a fixed width of 5 intervals. A piecewise linear function was used as the nuclear function \( \phi \).

Next, we find the relation of the smoothed frequencies of the groups “A” and “B” for each interval. For the first interval:

\[
\frac{\tilde{y}_{A1}}{\tilde{y}_{B1}} = \frac{8}{16.25} = 0.492.
\]

Next, we determine the diagnostic coefficient (DC) for the \( i \)-th interval according to the formula [7]:

\[
DC_i = 10 \cdot \lg \left( \frac{\tilde{y}_{A1}}{\tilde{y}_{B1}} \right).
\]

According to the Kullback formula, the coefficient of informativeness of a sign in the \( i \)-th interval [7]:

\[
J_i = 0.5 \cdot \left| \frac{\tilde{y}_{A1} - \tilde{y}_{B1}}{100} \right|.
\]

The sum of the informativeness coefficients at all intervals will determine the informativeness of the attribute.

The results of determining the information content of all nine signs are shown in table 3.

**Table 3.** The results of the diagnostic coefficient and the information content of the sign.

| Parameter   | Commissioning date | Value   |
|-------------|--------------------|---------|
| Range       | 1963 1970 1977 1984 1991 1998 2002 |         |
| DC          | 3.979 2.82 0.591 0.341 -1.072 -2.779 -3.802 |         |
| J           | 0.06 0.103 0.008 0.004 0.026 0.105 0.067 0.373 |         |
| Parameter   | Service life       |         |
| Range       | 8 15 22 36 43 51 |         |
| DC          | -5.051 -3.291 -2.469 -0.767 0.389 0.525 2.45 |         |
| J           | 0.035 0.052 0.086 0.014 0.005 0.006 0.074 0.272 |         |
| Parameter   | Pressure           |         |
| Range       | -0.1 0.6 1.3 2 3,4 4.1 |         |
| DC          | 1.283 1.283 0.689 -0.561 -2.833 -3.291 -1.53 |         |
| J           | 0.022 0.044 0.012 0.005 0.122 0.07 0.009 0.284 |         |
| Parameter   | Temperature        |         |
| Range       | -55 -4 47 98 149 200 251 |         |
| DC          | 3.979 4.369 0.969 0.477 -1.145 -1.16 -1.295 |         |
| J           | 0.06 0.152 0.015 0.004 0.032 0.027 0.027 0.317 |         |
| Parameter   | Hazard class       |         |
| Range       | 2 3 4 8           |         |
| DC          | -0.902 -0.694 0.231 0.445 |         |
| J           | 0.008 0.011 0.002 0.005 |         |
| Parameter   |                    |         |
| Range       | 57 110 163 216 325 |         |
| DC          | -1.411 -1.352 -1.072 0.115 4.113 |         |
| J           | 0.031 0.058 0.033 0 0.13 0.252 |         |
| Parameter   |                    |         |
| Range       | 4 5.3 6.6 7.9 9.2 10.5 |         |
| DC          | -0.045 -0.078 0.327 -0.28 -1.072 0.969 |         |
| J           | 0 0 0.003 0.002 0.026 0.012 0.051 |         |
Next, we found the sum of diagnostic coefficients for all signs for each pipeline system.

The distribution of the amounts of diagnostic features for pipelines that have and do not have a residual life of 5 years is shown in Figure 1.

We use the results to estimate the residual life for 10 pipelines that have the same parameters as the wells studied above.

The figure shows that with the sum of the diagnostic coefficients less than -14, the residual life of less than 5 years, with the sum of the diagnostic coefficients more than -12, the residual life of more than 5 years, the interval [-14, -12] is uncertainty.

![Figure 1](image-url)  
**Figure 1.** The distribution of pipelines by the sum of diagnostic coefficients for a residual life of 5 years.
Next, we apply this algorithm to assess the possible residual resource of pipelines equal to 6 years, 8 years, and 10 years. The greatest accuracy was obtained when analyzing a possible residual resource equal to 8 years. There is a clear separation and only 2 pipelines are in the zone of uncertainty. According to other calculations, 3–4 pipelines are knocked out.

Comparing the simulation results with the expert opinion, we see that there are 2 out of 47 pipelines showing erroneous results. According to technical specifications, the seventeenth pipeline may have a residual life of up to 10 years. Pipelines 15, 30 and 38 require a more detailed analysis to adjust the residual life.

An increase in the number of analyzed technological pipelines (100 or more) in the used mathematical model increases the necessary accuracy of forecasting, providing a more detailed analysis of the uncertainty interval. On the other hand, assessments of the technical condition by experts, regulatory and technical documents that do not allow conversion to numerical values, as well as previous conclusions of the industrial safety examination, have a significant impact. Also, the performance of some parameters, such as, for example, the transported process medium in the pipeline, is difficult to translate into numerical values.

3. Conclusion
The method of forecasting the residual life of pipeline systems can be used in individual cases when there is a significant error in the technical information that is necessary for an expert assessment. An advantage of the developed method is the potentiality of constructing a mathematical model for managing technical parameters that affect the numerical value of the residual life and determine the effect of each of the parameters on the entire process pipe. This method provides the necessary opportunity to assess the residual life with a maximum probability and allows you to bring the values closer to the values of the expert assessment in comparison with the regulated standard methods given in the current regulatory and technical documentation for predicting the residual life of technical devices and their elements.

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