Technical condition parameters affecting the period of safe operation of technological pipelines

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Abstract. The task is to estimate the period of technological pipelines safe operation depending on the total influence of oil refining equipment technical parameters. 9 feature properties of technological pipelines were singled out, and the estimation was made with the help of such indicator as the residual life of pipelines. The authors constructed a mathematical model, calculated the diagnostic coefficients and informative character of the characteristic for each period accepted by the expert. A mechanism for estimating the safe operational lifetime of pipeline systems is proposed. Conclusions were drawn about the advisability of applying the proposed method for solving this class of problems.

Technological pipelines transporting flammable gases, highly-flammable and combustible liquids, as well as toxic substances, belong to technical devices operating at a hazardous production facility. Under the influence of workloads and environments, as well as other operational factors, corrosion and erosion of pipeline components occur, which can lead to a loss of strength. Therefore, after expiration of the time established by the current regulatory and technical documentation, an industrial safety inspection is carried out, and the most important stage is to evaluate the period for further safe operation.

Nowadays, a probabilistic estimate of the residual life is the priority method for extending the period for further safety of pipeline systems.

The method of forecasting the residual life is based on the use of a priori and current statistical information. The latter is acquired when measuring the parameters of the technical condition of the pipeline during inspections and repairs. The task is to extrapolate the ability of the pipeline to perform its functions for a period equal to the residual life.

Basically, the mathematical methods used in expert calculations allow us to estimate the upper limit of the residual life (tab 1). Sometimes this border is overstated with respect to the actual value[1].

Large data sets allow analysis of possible outcomes of future examinations, build a model that most fully characterizes this type of equipment [1, 2, 10-14].

Technical parameters of pipeline systems provide an opportunity to judge about their condition, as well as about changing parameters in time, involving a variety of trajectories and forms of wear and probable destruction scenarios [6-9].

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At present, the influence of technical parameters of pipeline systems and the process itself is highly evaluated [2, 4], the residual life is modeled by computer technology [2, 3], mathematics [4, 5, 6], neural networks [11- 14]. However, even such an extensive arsenal does not always give the required accuracy of outcomes and the ease of complex equations applicability .

Table 1. Estimated residual life accepted by the expert.

Num ber	commissioning date, year	Residual life		Num ber	commissioning date, year	Residual life	
		by calcu-lations	by find-ings			by calcu-lations	by find-ings
1	1963	7.9	5	28	1955	11.5	6
2	1972	7	4	29	1976	5.4	5
3	1955	14.5	6	30	1977	5.2	5
4	1955	7.15	4	31	1976	6.5	6
5	1955	5.8	4	32	1976	6.2	6
6	1955	11.7	4	33	1985	9.9	8
7	1955	10.3	6	34	1990	30.4	8
8	1955	16.2	9	35	1990	7.1	6
9	1955	12.5	9	36	1965	6.2	4
10	1955	14.7	10	37	1965	6.1	4
11	1955	8.4	6	38	1965	6.3	4
12	1977	5.8	5	39	1955	8.2	5
13	1955	8.6	5	40	1955	8.6	6
14	1963	5	5	41	1976	8.6	6
15	1955	8.1	5	42	1977	6.2	6
16	1990	5.5	5	43	1955	11.5	5
17	1976	8	8	44	1964	6.8	6
18	1972	6.1	6	45	1955	7.4	4
19	1955	6	6	46	1990	11.7	8
20	1990	6.7	6	47	1955	8.7	6
21	1955	12.6	10	48	1977	5.6	5
22	1955	13.2	10	49	1978	5.7	5
23	1955	7.9	6	50	1976	6.8	6
24	1995	17.6	10	51	1964	6.8	6
25	1955	16.3	10	52	1955	7.6	5
26	1955	11.7	10	53	1955	11.0	6
27	1955	17.4	10	54	1972	5.9	5

We have 9 features that affect the residual life of the pipeline systems: commissioning date (τ_1), service life (τ_2), pressure (P), temperature (T), environment (α), hazard class (k), pipe diameter (*d*), thickness according to certificate (h_1), measured thickness (h_2), relative residual thickness (ε).

We have data on 43 expert opinions on technological pipelines with an expert conclusion of 4 to 10 years (tab 2). The sample does not contain data on pipelines for which expertise would give a negative conclusion.

The influence of the above parameters (τ_1, τ_2, P, T, α, k, d, h_1, h_2, ε) on the residual life of pipelines can be determined by calculating their informativeness [1].

The evaluation of informativeness is carried out using Kullback's measure [1]. Since the Kullback's measures make it possible to evaluate the informativeness of the discrepancy between two classes, there are difficulties if we take three classes. Therefore, we will evaluate for several iterations: at the first iteration, we divide the pipelines into two groups - having a residual life of 5 years and not having such a residual life, at the second iteration we will divide them by residual life of 6 years, at the third - 8 years and at the 4th iteration - 10 years.

There are nine features (τ_1, τ_2, P, T, α, k, d, h_1, h_2, ε), and also a result - the residual life for the first iteration - 5 years, or its absence. We divide the pipelines into two groups: "A" - having a residual life of 5 years or more; "B" - not having a residual life.

Table 2. Data on pipelines and features that affect the residual life.

№	Commissioning date, year	Service life	Pressure, MPa	Temperature, ˚C	Environment	Hazard class	Pipe diameter, mm	Thickness according to certificate, mm	Measured thickness, mm	Relative thickness, %	Residual life of the pipeline, years
1	1963	42	0.6	40	highly-flammable liquid	4	159	8.5	5.4	63	5
2	1972	33	0.1	30	flammable liquid	4	114	4.5	3.5	77	4
3	1955	48	0.2	160	flammable gas	4	219	8	6.3	78	6
4	1955	55	0.3	-30	flammable gas, flammable liquid	4	168	8	5.7	71	4
5	1955	48	2.5	-15	highly-flammable liquid	4	168	10	5.6	56	4
6	1955	55	3	60	highly-flammable liquid	4	159	5	3.4	68	4
7	1955	47	2.5	-10	highly-flammable liquid	4	108	6	3.2	53	6
8	1955	47	3	60	highly-flammable liquid	4	89	5	3.2	64	9
9	1955	47	0.5	-15	highly-flammable liquid	4	89	4.5	3.3	73	9
10	1955	47	0.1	150	fire resistant liquid	4	168	8	6.1	76	10
11	1955	47	2.5	-15	highly-flammable liquid	4	168	10	5.6	56	6
12	1977	27	0.6	50	flammable gas	2	57	5	3.2	64	5
13	1955	55	1.4	130	flammable gas	4	57	5	2.6	52	5
14	1963	42	0.6	40	highly-flammable liquid	4	159	7	5.4	77	5
15	1955	55	1.45	130	flammable gas	4	219	8	7	87	5
16	1990	20	2.5	150	flammable liquid	4	108	6	4.2	70	5

№	Commissioning date, year	Service life	Pressure, MPa	Temperature, ˚C	Environment	Hazard class	Pipe diameter, mm	Thickness according to certificate, mm	Measured thickness, mm	Relative thickness, %	Residual life of the pipeline, years
17	1976	28	0.09	100	flammable gas	2	57	3.5	2.9	82	8
18	1972	33	0.1	30	flammable liquid	4	114	4.5	3.5	77	6
19	1955	48	3	60	highly-flammable liquid	4	89	5	3.2	64	6
20	1990	20	2.5	100	highly-flammable liquid	3	89	6	3.1	51	6
21	1955	47	1	150	highly-flammable liquid	4	219	8	4.3	53	10
22	1955	47	2	70	highly-flammable liquid	4	60	4.5	3.5	77	10
23	1955	47	2.5	100	flammable liquid	4	168	10	5.8	58	6
24	1995	7	0.4	90	highly toxic substances	4	325	10	6.5	65	10
25	1955	47	0.3	-30	highly toxic substances	4	325	10	6	60	10
26	1955	47	1.4	130	highly toxic substances	4	89	5	4.1	82	10
27	1955	47	0.2	150	highly-flammable liquid	4	325	10	6.7	67	10
28	1955	48	1	-15	highly-flammable liquid	4	60	5	3.7	74	6
29	1955	55	2.5	100	flammable gas	4	159	8	3.8	48	4
30	1976	27	2.9	140	flammable gas	4	325	10	7.8	78	5
31	1977	26	0.05	50	highly-flammable liquid	2	325	10	7	70	5
32	1976	27	0.17	120	highly-flammable liquid	2	273	9	7.8	87	6
33	1976	27	0.17	140	flammable liquid	2	273	8	5.5	69	6
34	1985	25	2	130	highly-flammable liquid	4	114	8	3.1	39	8
35	1990	20	1.2	100	highly-flammable liquid	4	57	5	2.9	58	8
36	1990	20	0.5	40	flammable liquid	4	57	5	3.5	70	6
37	1965	45	1.8	40	non-combustible substance	4	108	4.5	3.4	76	4
38	1965	45	0.4	45	flammable liquid	2	159	6	5.9	98	4
39	1965	45	1.5	40	flammable liquid	2	76	4.5	3.3	73	4
40	1955	48	2.5	100	highly-flammable liquid	4	168	10	5.8	58	5
41	1955	48	1	150	flammable gas	4	114	6	1.8	30	6
42	1976	27	0.25	50	flammable gas	2	57	4	3	75	6
43	1977	26	0.17	140	highly-flammable liquid	2	530	9	8.4	93	6

We find the informativeness of each of the nine features.

As an example, the calculation of informativeness for the feature "Temperature", indicated as *T*.

The temperature is in the range from -30 to 160 °C. The range was divided into equal intervals: -30 to 10 °C; from 10 to 35 °C; from 35 to 60 °C; from 60 to 85 °C; from 85 to 110 °C; from 110 to 135 °C; higher than 135 °C. We got 7 intervals. Further, the hitting frequency of the pipelines into one of the groups ("A" or "B") was determined. The burst pressure interval from -30 to 10 ° C has 5 pipelines in the group "A" and 2 pipelines in the group "B", and, for example, the interval from 85 to 110% has 6 pipelines in the group "A" and 1 pipeline in the group "B".

We determine the relative frequency of hitting into this or that group within the interval: if the group "A" got 5 pipelines from 35 pipelines of the group "A", then for the first interval the relative frequency of hitting into group "A" equals y_A = 14,2% (tab. 3).

Table 3. Determination of the informativeness of the feature "Temperature".

Interval	Measuring range *T, %*	The amount of pipelines in the group		Relative frequency, 5		Smoothed frequency,%		$\frac{\tilde{y}_{Ai}}{\tilde{y}_{Bi}}$	DC	J_i
		A	B	y_A	y_B	$\tilde{y}_A$	$\tilde{y}_B$			
1	up to 10	5	2	14.29	25	8	16.25	0.492	-3.07	0.12
2	35	1	1	2.8	12.5	8.28	18.75	0.442	-3.54	0.18
3	60	6	3	17.1	37.5	12.28	23.75	0.517	-2.86	0.16
4	85	3	1	8.5	12.5	12	16.25	0.738	-1.31	0.02
5	110	6	1	17.1	12.5	15.71	11.25	1.397	1.45	0.03
6	135	5	0	14.2	0	15.14	3.75	4.038	6.06	0.34
7	more than 135	9	0	25.7	0	14.86	1.25	11.88	10.75	0.73
Sum		35	8	100	100	-	-	-	-	1.61

The weighted smoothed frequency is determined for levelling the influence of the distribution on the intervals. The frequency of the characteristic in the two preceding and in the two subsequent intervals is taken into account. Two intervals preceding the interval No. 1, - zero and minus one, have a zero frequency.

The weighted smoothed frequency is calculated by the formula [1]:

$$\tilde{y} = \frac{(y_1 + 2 \cdot y_2 + 4 \cdot y_3 + 2 \cdot y_4 + y_5)}{10} \tag{1}$$

where $y_1 \dots y_5$ - frequencies in the intervals.

For the group "A" in the first interval, the weighted smoothed frequency:

$$\tilde{y}_{A1} = \frac{(0 + 2 \cdot 0 + 4 \cdot 14.29 + 2 \cdot 2.8 + 17.1)}{10} = 8\% \tag{2}$$

For the group "B" in the first interval, the weighted smoothed frequency:

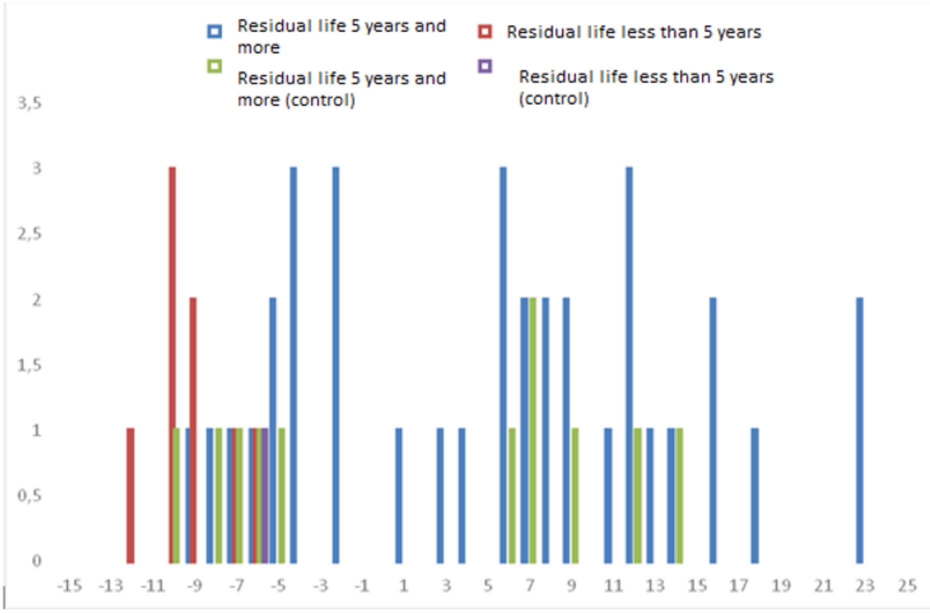

Fig. 1. Distribution of pipelines by the sum of diagnostic coefficients for the residual life of 5 years

Further, we apply this algorithm to estimate the possible pipeline residual life equal to 6 years, 8 years and 10 years. The results are shown in Figures 2, 3 and 4.

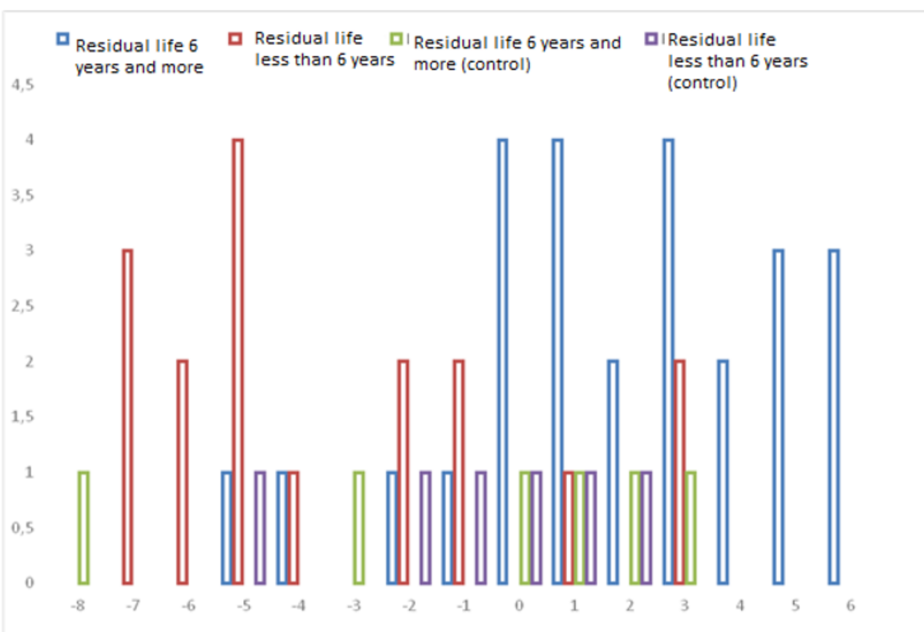

Fig. 2. Distribution of pipelines by the sum of diagnostic coefficients for the residual life of 6 years

https://doi.org/10.1051/matecconf/201822402090

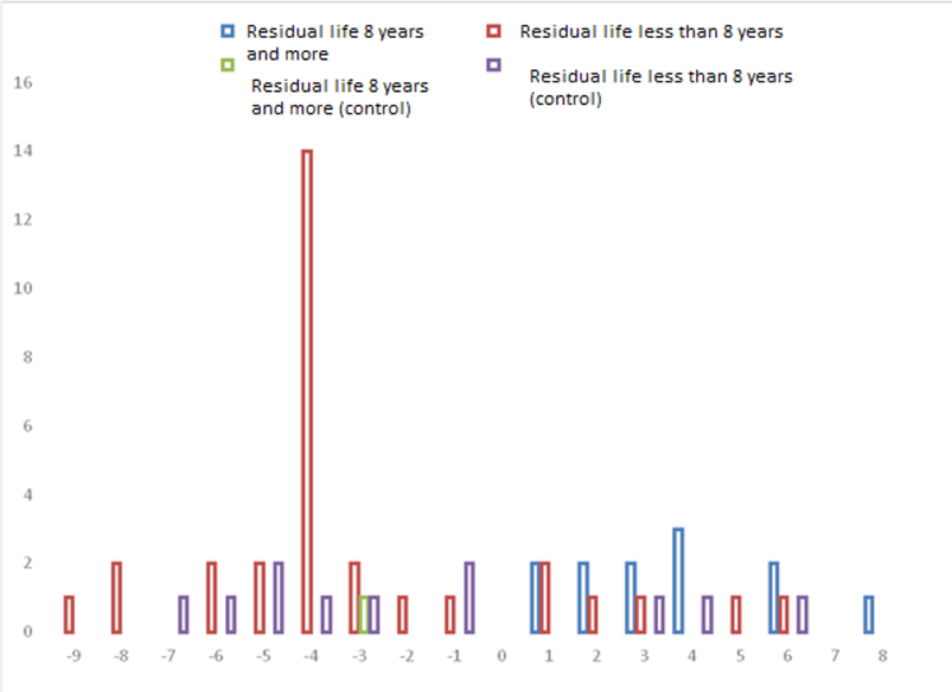

Fig. 3. Distribution of pipelines by the sum of diagnostic coefficients for the residual life of 8 years

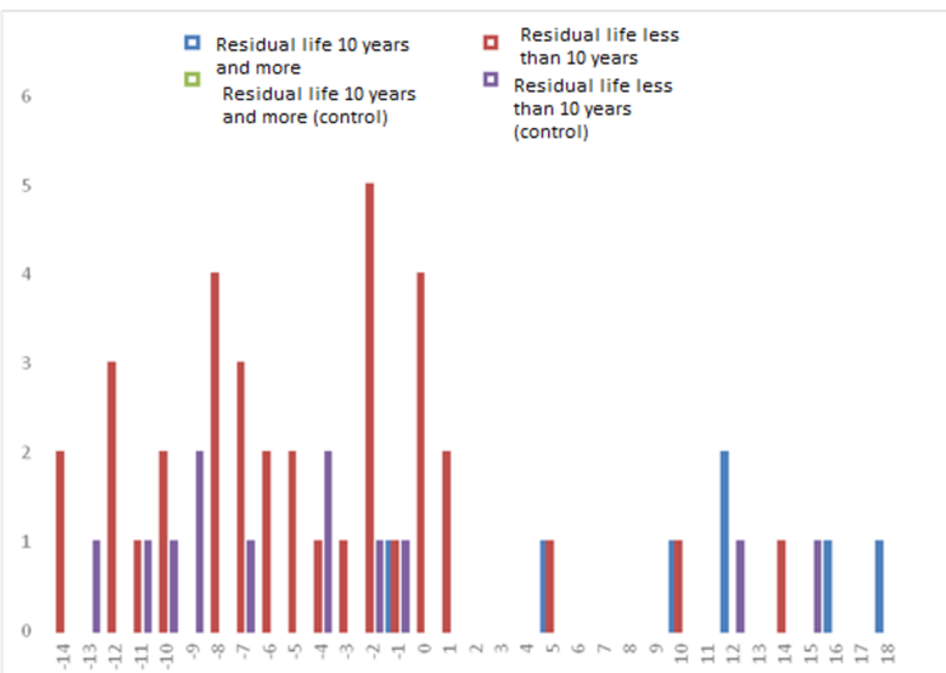

Fig. 4. Distribution of pipelines by the sum of diagnostic coefficients for the residual life of 10 years

Table 6. Evaluation of the method effectiveness.

№	Residual life of the pipeline, years	Residual life of 5 years evaluation	Residual life of 6 years evaluation	Residual life of 8 years evaluation	Residual life of 10 years evaluation
1	5	Agreement	Agreement	Agreement	Agreement
2	4	Agreement	Agreement	Agreement	Agreement
3	6	Agreement	Agreement	Wrong	Wrong
4	4	Agreement	Agreement	Agreement	Agreement
5	4	Not defined	Agreement	Agreement	Agreement
6	4	Agreement	Agreement	Agreement	Agreement
7	6	Not defined	Agreement	Agreement	Agreement
8	9	Agreement	Agreement	Not defined	Agreement
9	9	Agreement	Agreement	Not defined	Agreement
10	10	Agreement	Agreement	Agreement	Agreement
11	6	Not defined	Wrong	Agreement	Agreement
12	5	Agreement	Agreement	Agreement	Agreement
13	5	Agreement	Wrong	Wrong	Agreement
14	5	Agreement	Agreement	Agreement	Agreement
15	5	Agreement	Agreement	Agreement	Wrong
16	5	Agreement	Wrong	Agreement	Agreement
17	8	Agreement	Agreement	Agreement	Agreement
18	6	Agreement	Agreement	Agreement	Agreement
19	6	Agreement	Agreement	Not defined	Agreement
20	6	Agreement	Agreement	Agreement	Agreement
21	10	Agreement	Agreement	Agreement	Agreement
22	10	Not defined	Agreement	Agreement	Agreement
23	6	Agreement	Wrong	Agreement	Agreement
24	10	Agreement	Agreement	Agreement	Agreement
25	10	Agreement	Agreement	Agreement	Agreement
26	10	Agreement	Agreement	Agreement	Not defined
27	10	Agreement	Agreement	Agreement	Agreement
28	6	Agreement	Agreement	Not defined	Agreement
29	4	Not defined	Agreement	Agreement	Agreement
30	5	Agreement	Wrong	Agreement	Agreement
31	5	Agreement	Agreement	Agreement	Agreement
32	6	Agreement	Agreement	Agreement	Agreement
33	6	Agreement	Agreement	Agreement	Agreement
34	8	Agreement	Agreement	Agreement	Agreement
35	8	Agreement	Agreement	Agreement	Agreement
36	6	Agreement	Agreement	Agreement	Agreement
37	4	Agreement	Agreement	Agreement	Agreement
38	4	Agreement	Agreement	Agreement	Agreement
39	4	Agreement	Agreement	Agreement	Agreement
40	5	Agreement	Agreement	Agreement	Agreement
41	6	Agreement	Agreement	Wrong	Agreement
42	6	Agreement	Agreement	Agreement	Agreement
43	6	Agreement	Agreement	Agreement	Not defined
44	5	Not defined	Wrong	Wrong	Agreement

№	Residual life of the pipeline, years	Residual life of 5 years evaluation	Residual life of 6 years evaluation	Residual life of 8 years evaluation	Residual life of 10 years evaluation
45	6	Not defined	Agreement	Agreement	Agreement
46	4	Not defined	Agreement	Agreement	Agreement
47	8	Agreement	Agreement	Wrong	Agreement
48	6	Agreement	Agreement	Wrong	Agreement
49	5	Agreement	Wrong	Agreement	Agreement
50	5	Agreement	Agreement	Agreement	Agreement
51	6	Wrong	Agreement	Agreement	Agreement
52	6	Not defined	Wrong	Agreement	Agreement
53	5	Agreement	Agreement	Agreement	Agreement
54	6	Agreement	Agreement	Wrong	Wrong
55	5	Agreement	Wrong	Agreement	Agreement

Comparing the results of the simulation with the expert conclusion, we see that there are 8 pipelines (grayed) out of 55, showing erroneous results. The third pipeline, according to technical characteristics, can have a residual life up to 10 years. Pipelines 16, 30 and 49 require more detailed analysis in the direction of increasing the residual life, and pipelines 11, 44, 52, 54 - do not fit the model.

A greater number of pipelines (from 100 and more) in the model should improve the accuracy of the forecast, enabling a more detailed analysis of the indeterminacy interval. On the other hand, such factors as expert assessments, normative documentation as well as previous expert conclusions, have a great influence. In addition, a number of parameters, such as, for example, environment transported through a pipeline, is difficultly converted into numerical values.

Conclusions

The method for predicting the residual life of technological pipelines, given in this article, can be used in those cases when there is a large error in the initial information necessary for the expert evaluation. The advantage of the above method is the possibility of developing a mathematical model of operating with technical parameters that affect the numerical value of the residual life and determine the influence of each of the parameters on the entire pipeline system as a whole. This method allows to estimate the residual life with the utmost probability with the approximation of obtained results to results of the expert evaluation, rather than the calculation by standard methods given in the industrial safety regulatory documents.

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