Estimate Tank Quality Margin

E Sh Gaysin¹, Y A Frolov², O A Nasibullina³

¹Lecturer, Transport and Storage of Oil and Gas Chair, Ufa State Petroleum
Technological University, 8/3 Kosmonavtov str., Ufa 450062, Russian Federation
²Professor, Transport and Storage of Oil and Gas Chair, Ufa State Petroleum
Technological University, 8/3 Kosmonavtov str., Ufa 450062, Russian Federation
³Assistant Professor, Petroleum Technology Equipment Chair, Ufa State Petroleum
Technological University, 1 Kosmonavtov str., Ufa 450062, Russian Federation

E-mail: gaysin.emil@mail.ru

Abstract. The article addresses the issues of ensuring the reliability of tanks taking into
account their life cycle by assessing and maintaining an appropriate level of quality. The work
proposes: a structure that allows to assess the quality of such a complex technical system as a
tank; Methodology, algorithm and formulas for evaluation of integral quality index.

1. Introduction

To date, there are many works dedicated to ensuring the reliability of tanks in terms of extending their
residual life.

However, such work does not take into account many other significant indicators. Reliability is
only one of them for the whole population, referred to as product quality.

The indicators, in turn, are divided into four major categories: characterized properties and their
number, mode of expression and life cycle stages (Table 1).

Table 1. Product Quality Indicators.

| By characteristic properties | By the number of characterized properties | By expression method | By Lifecycle Stage |
|------------------------------|-------------------------------------------|----------------------|--------------------|
| Indicators of assignment     | Single                                    |                      | Predicted          |
| Indicators of economic use   | Complex                                   |                      | Design             |
| Reliability Indicators       | Integral (set of complex)                 |                      | Production         |
| Transportability indicators  |                                           |                      | Operational        |
| Standardization and unification indicators | In natural units |                      |                    |
| Ergonomic indicators         |                                           |                      |                    |
| Safety Indicators            |                                           |                      |                    |
| Patent and legal indicators  |                                           |                      |                    |
| Environmental indicators     |                                           |                      |                    |
| Esthetic                     |                                           |                      |                    |

Reliability as an indicator falls into the category of characteristic properties (Table 2).
Table 2. Quality indicators by characteristic properties.

| Destination indicators: | Ergonomic indicators: | Safety indicators: |
|------------------------|----------------------|-------------------|
| - classification (loading capacity, power, capacity); | - hygienic (illumination, temperature, humidity, dust content, radiation); | - chemical; |
| - functional and technical efficiency (productivity of technological process, faultlessness, accuracy of measurement of quality); | - anthropometrical; | - radiation; |
| - constructive (dimensions, existence of additional devices); | - physiological and psychophysiological; | - mechanical; |
| - structure | - psychological | - electric; |

| Indicators of economic use: | | Safety indicators: |
|----------------------------|-------------------|-------------------|
| - specific consumption of raw materials, materials; | | - chemical; |
| - efficiency; | | - radiation; |
| - total labor input of products at its operation | | - mechanical; |

| Patent and legal indicators: | | Safety indicators: |
|-----------------------------|-----------------|-------------------|
| - patent purity; | | - electric; |
| - patent protection | | - magnetic; |

| Environmental indicators: | | Safety indicators: |
|---------------------------|-----------------|-------------------|
| - interaction indicators with the surrounding nature and the habitat of live organisms | | - electromagnetic; |

| Reliability indicators: | Standardization and unification indicators: | Esthetic: |
|-------------------------|------------------------------------------|-----------|
| - non-failure operation; | - applicability coefficient; | - information expressiveness; |
| - durability; | - repeatability coefficient; | - rationality of a form; |
| - maintainability; | - unification factor for product group | - perfection of execution; |
| - storageability; | | - stability of trade dress; |
| - complexity | | - integrity |

| Transportability indicators: | Esthetic: |
|-----------------------------|-----------|
| - average duration of preparation of a product for transportation; | - information expressiveness; |
| - average labor input preparation of a product for transportation; | - rationality of a form; |
| - the average duration of loading of a product on the vehicle | - perfection of execution; |

Each of these indicators has an impact on the quality of the tank as a technical system as a whole, but it is difficult to take them all into account at the initial stage.

2. Tank quality assessment procedure
Today, the national standard of the Russian Federation GOST R ISO/TU 29001-2007, which presents a model of quality management system, is in force for organizations supplying products and providing services in the oil, petrochemical and gas industry. Taking into account the characteristics of the different stages of the life cycle, the adapted model may look as follows (Figure 1).
We propose a methodology for assessing the integrated VST (vertical steel tank) quality indicator as a weighted average geometric value, based on the cost of structural elements of the technical system, their quality and weight (depending on the importance and consequences as a result of failure or accident), the life cycle stage of the vehicle and a number of other parameters [1-3]. At the same time, the integral quality of each stage will take into account the quality of previous stages:

\[
K_i^{VST\text{ integr}} = \left( \prod_{j=1}^{i} K_j q_j \right)^{-1},
\]

where

- \( i \) – life cycle stage number for which the tank quality integral indicator is determined;
- \( j \) – stages with 1 on \( i \);
- \( K_j \) – tank quality at arbitrary \( j \)-stage of life cycle;
- \( q_j \) – weight of \( j \)-th stage of life cycle.

If all stages are equal (\( q_{VST}^{j} = 1 \); But if necessary, the sums of certain categories can also be reduced to 1) the integral indicator of tank quality at different stages will be:

\[
\begin{align*}
K_{\text{проект}}^{VST\text{ integr}} &= K_{\text{design}}, \\
K_{\text{изготов}}^{VST\text{ integr}} &= K_{\text{design}} \cdot K_{\text{production}}, \\
K_{\text{транспорт}}^{VST\text{ integr}} &= K_{\text{design}} \cdot K_{\text{production}} \cdot K_{\text{transportation}}, \\
K_{\text{монтаж}}^{VST\text{ integr}} &= K_{\text{design}} \cdot K_{\text{production}} \cdot K_{\text{transportation}} \cdot K_{\text{installation}}, \\
K_{\text{экспл}}^{VST\text{ integr}} &= K_{\text{design}} \cdot K_{\text{production}} \cdot K_{\text{transportation}} \cdot K_{\text{installation}} \cdot K_{\text{operation}},
\end{align*}
\]

where \( K_{\text{design}}, K_{\text{production}}, K_{\text{transportation}}, K_{\text{installation}}, K_{\text{operation}} \) – the quality of the reservoir estimated only by criteria of this stage (design, production, transportation, mounting, operation respectively), and not considering previous.

The presented formulas imply that the condition of the tank as a whole depends on errors or defects not only of the current but also of the previous stages.

It is proposed to use the following Table 3 to evaluate the quality of the tank. The table shows the stages and sub-stages of the VST life cycle, the criteria to be evaluated on each of them, as well as defects and other factors affecting the overall state of the technical system.

---

**Figure 1.** Mutual influence of life cycle stages (solid line - direct influence, dotted - reverse in the form of lessons learned in subsequent cycles).
### Table 3. Structure of VST quality assessment.

| Quality of the tank | Lack of fusion and lack of penetrations of a weld joint |
|---------------------|-------------------------------------------------------|
| Life cycle          | Violations of a form of a seam (undercuts, shrinkable grooves, exceeding of camber, exceeding of smelting rate, a deposit, removal [angularity/withdrawal], accumulate, burn-throughs, etc) |
| Design              | Other defects of a weld joint (local damage of metal because of accidental ignition of an arc, metal splashes, superficial edge fins, metal thinning, etc) |
| Quality of a stage  | Quality of materials                                  |
| Preparation of specification | Using low-quality electrodes                        |
| Development of the general plan | Quality of installation of equipment                  |
| Calculation of construction VST | Quality of weld joints                               |
| Development of the project metal constructions and construction metal detail | Quality of mounting of heat insulation               |
| Design of the basis / base | Quality control of installation and construction works |
| Examination passing | Operation                                              |
| Production          | Substage life cycle (operation): The period extra earnings; The Period of the settled operation; The Period of intensive wear |
| Quality of production of metal rolling | Quality of the base and basis                         |
| Declines            | Quality of the basis                                  |
| Captivities         | Slump                                                 |
| Flakes              | Gradual settlement                                    |
| Volosovina          | On the area of the basis                              |
| Stratifications     | On basis perimeter                                    |
| Microcracks         | Differential settlement                               |
| Uneven alloying     | Roll                                                  |
| Violation of geometry of rolling | In the form of "step"                               |
| Edge fins           | On the area of the basis                              |
| Quality of production of rolled preparations | On basis perimeter                                   |
| Quality of weld joints | Quality of the base. See also: Slump                |
| Quality of production of equipment | Quality of metalwork                                 |
| Transportation      | The main                                              |
| Quality of rolled preparations after transportation | Corrosion of metalwork                              |
| A uniform bend in the longitudinal direction | Continuous superficial corrosion                    |
| Local dents at edge of a roll | Through corrosion                                    |
| Crushing of a part of a roll | Focal corrosion                                      |
| Corrugations on a roll surface | Ulcer                                              |
| Mounting            | Pit corrosion                                         |
| Quality of mounting and preparation of the basis / base | Violations of a geometrical form                     |
| Quality of mounting of metalwork | Stability loss                                      |
| Mounting imperfections | The general                                           |
| Dents, bouges       | Local                                                 |
| Tough fixing of mine ladders orgas-leveling system with VST | Bucklings of a wall or bottom                        |
| Metal tear-outs from a panel at deployment | Angular movements or bend of edge                   |
| Through breakdowns of metal structures by installation equipment | Vibration                                           |
| Lack of the base under latches or a gas-leveling system system | Bottom. See also: Violations of a geometrical form, Corrosion of metalwork |
| Pulling up of a part of a bottom edge to a VST wall before welding | Corrosion of metalwork                              |
| Local plastic deformations of a wall, bottom, roof | Roof. See also: Violations of a geometrical form, Corrosion of metalwork |
| Quality of weld joints | The others                                           |
| Cracks of a weld joint | Ladder. See also: Corrosion of metalwork              |
| Cavities, a gas time, fistulas, shrinkable sinks, a rough ripple, craters in a weld joint | Platform. See also: Corrosion of metalwork           |
| Firm inclusions in a weld joint | Quality of the equipment                             |
| Quality of the equipments | Quality of weld joints                               |
| Quality of heat insulation | Quality of weld joints                               |

#### 3. Procedure for assessment of tank structural elements quality

On the basis of analysis of works on determination of technical systems quality, it is proposed to also use weighted average geometric value of quality for structural elements of VST.

\[
K = \prod_{i=1}^{n} \left( k_i^q_i \right)^{1/n}, 0 \leq q_i \leq 1; \quad (2)
\]
\[ k_i = q_{ij} \times \frac{P_{ij}}{P_{ij}^{\text{eff}}}, 0 \leq q_{ij} \leq 1, P_{ij}^{\text{min}} \leq P_{ij} \leq P_{ij}^{\text{max}} \leq P_{ij}^{\text{base}}; \]  

where $q_i$ and $k_i$ – weight and quantitative assessment of the quality of the $i$-th structural element, respectively;  
$q_{ij}$ – weight of the $j$-th property of the $i$-th structural element;  
$P_{ij}$ – current absolute value of the $j$-th property of the $i$-th element, respectively;  
$[P_{ij}^{\text{min}}, P_{ij}^{\text{max}}]$ – certificate (base) interval of values of index of $j$-th property of $i$-th element;  
$[P_{ij}^{\text{oper} \text{min}}, P_{ij}^{\text{oper} \text{max}}]$ – range of valid operating values of the $j$-th property of the $i$-th element;  
$P_{ij}^{\text{eff}}$ – most effective for operation value of index of $j$-th property of $i$-th element;  
when $P_{ij} > P_{ij}^{\text{eff}}$ the value $k_i = 1$.

| Item quality | Weight | Quality of a system | Item quality | Weight | Quality of a system | Fact difference with the forecast, % |
|--------------|--------|---------------------|--------------|--------|---------------------|----------------------------------|
| X            | 0,58   | 0,03                | AWM          | 0,35   | 0,03                | 33,22                            |
| Wᵢ           | 0,09   | 0,82                | GWM          | 0,06   | 0,82                | 40,86                            |
|              | 0      | 0,02                | HWM          | 0,56   | 0,02                | zero divide                      |
|              | 0      | 0,71                |              | 0,63   | 0,71                |                                  |
|              | 0,44   | 0,23                |              | 0,41   | 0,23                |                                  |
|              | 0,37   | 0,95                |              | 0,79   | 0,95                |                                  |
|              | 0,12   | 0,48                |              | 0,64   | 0,48                | 6094                            |
|              | 0,39   | 0,48                |              | 0,6094 | 0,4086              | 0,1184                           |
|              | 0,2772 | 0                   |              | 0,4086 | 0,1184              |                                  |
|              | 0      | 0,35                |              | 0,64   | 0,48                |                                  |
|              | 0      | 0,91                |              | 0,91   | 0,48                |                                  |
|              | 0,02   | 0,04                |              | 0,63   | 0,04                |                                  |
|              | 0,02   | 0,54                |              | 0,97   | 0,54                |                                  |
|              | 0,32   | 0,01                |              | 0,84   | 0,01                |                                  |
|              | 0,54   | 0,84                |              | 0,75   | 0,84                |                                  |
|              | 0,02   | 0,84                |              | 0,75   | 0,84                |                                  |
|              | 0,02   | 0,26                |              | 0,01   | 0,26                |                                  |

AWM – Arithmetic weighted mean, GWM – Geometric weighted mean, HWM – Harmonic weighted mean

Table 4. Assessment of tank quality margin.

For elements whose property indicators are difficult to determine from primary measurements, or additional calculations (for example, tank wall), the quality can be determined by the following formula

\[ k_i = \frac{T_{\text{resid} \text{act}}}{T_{\text{serv}}}, 0 \leq k_i \leq 1; \]  

when $T_{\text{resid} \text{act}}$ – actual residual service life (or life) determined in the course of calculations based on diagnostic results;  
$T_{\text{serv}}$ – service life (or service life) assigned to the object from the moment of its commissioning (specified in the design specification or in the certificate); when
Further, knowing the quality of each component of the technical system, it is possible to estimate the integral quality index of the tank according to formula (1) and the quality margin (Table 4).

The choice of weighted average geometric evaluation method is due to the following - when any of the tank elements fails (its quality is 0), then:
1) its further operation is unacceptable, and the quality of the entire system should fall to 0 (that is why the weighted arithmetic mean is not suitable);
2) the harmonic weighted mean cannot be determined due to the division by 0 operation (therefore this method is also not suitable).

Of the existing three weighted averages, only the weighted geometric average remains, which fully meets all requirements.

As can be seen from the example in the table above, the integral tank quality indicator at the moment is forecast (carried out, for example, at the time of the previous technical diagnosis) to be 0 (due to wear), however, since the calculation often uses safety margin factors, the actual current tank quality indicator is 0.4086 (40.86%). Thus, the VST has a quality margin of 40.86-0 = 40.86%, i.e. its wear was less than planned.

### 4. Tank quality assessment algorithm

Follow the following algorithm to estimate the integral tank quality.

1. Collect data on failures (repairs, accidents) and other information on structural elements of the tank from reports on technical diagnostics and certificates of tanks, and summarize them in the table (Table 5).

| The refused element | Model | Date of commissioning | Date of refusal | Total oper. time from the beginning of operation | Total oper. time from last recovery to current failure | Recovery time |
|---------------------|-------|-----------------------|-----------------|-----------------------------------------------|-------------------------------------------------|--------------|
| Emergency level announciator | V3C-107 | 05.07.2014 | 07.08.2015 | 398 (days) | 347 (days) | 2 (days) |

2. Perform data analysis and identify functional dependencies of reliability indicators with number and terms of failures (repairs, accidents) for each structural element: \( \omega(t), \lambda(t), P(t), Q(t) \).

3. Determine the weight of the structural elements of the tank (if necessary, use the program developed by the authors) [4].

4. In accordance with the Table 3, determine the current (actual) and predicted (at the moment from the moment of commissioning or the last repair taking into account the known parameters of tank wear, for example, corrosion rate, number of loading cycles, etc.) quality of the tank according to formula (1).

5. Calculate the tank quality margin as the difference between the actual quality and the predicted quality.

### 5. Appendices

Thus, the reserve of tank quality found according to the proposed method will allow to estimate the residual life of the whole system, adjust the time of preparation of preventive measures to prevent possible accidents, draw up an annual schedule of major repairs taking into account many significant factors in the aggregate, which were not previously taken into account.

### References

[1] Gaysin E Sh 2012 Methodical Approach to Evaluation of Quality of Technical Systems Taking
into Account their Life Cycle on the Example of Vertical Steel Tank *Oil and Gas Business* vol 3 pp 83-86

[2] Gaysin E Sh 2013 Ranking of elements of vertical steel tank by cost method *Oil and gas business* vol 11 3 pp 70-75

[3] Gaysin E Sh 2013 Comparative analysis of results of assessment of knots, details and tank vertical steel in general cost and expert by methods *Online scientific magazine "Neftegazovoye Delo"* 3 pp 132-141 http://www.ogbus.ru/authors/GaysinESh/GaysinESh_1.pdf

[4] Gaysin E Sh, Afanasiev I A, Frolov Yu A Certificate 2018613508 Federation Certificate of state registration of the program for the computer "Assessment of quality of vertical steel tank" Applicant and patent holder of the Ufa State Petroleum Technological University Request № 2017662954 from 12.12.2017 published 15.03.2018