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# COMPREHENSIVE CEMENTING QUALITY ASSESSMENT AND RISK MANAGEMENT SYSTEM

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**ABSTRACT**

Fastening the walls of wells is one of the most important stages that determines the quality of well construction in general, and the quality of fastening depends on several factors, primarily on the quality of the cement mortar. In this regard, the presented article is devoted to the problem of the quality of cementing well walls and assessing the risks of emergency situations due to poor-quality cementing. The article provides a methodology for assessment of the cementation quality of well walls and risk. Based on the results of processing acoustic logging data, cementometry and frequencies and the corresponding consequences in the form of qualitative and quantitative estimates of cementation, «constant risk» curves were constructed to determine the magnitude of the risk. Based on the data obtained, diagrams that made it possible to monitor the dynamics of risks over the past five years at the field under study, taken as an example were constructed. As a result of statistical analysis, the «probability-consequences» relationship (curves of constant risk of poor-quality cementing) was established for the field under consideration at different times, and their analytical approximations were obtained. The marked curves, being boundary ones, divide the coordinate plane into areas of acceptable and unacceptable risk. The area located below the constant risk curve is the area of acceptable risk. The area located above this curve is the area of unacceptable risk. The relationships between the state of contact between the column and the cement stone were established, expressed in the words «high», «good», «low», «unsatisfactory quality».

**Keywords:** Casing; cement quality; risk; acoustic logging of cement quality (ACL); probability and consequences.

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## 1. Introduction

One of the most important stages that determine the quality of well construction is the fastening of their walls. The quality of fastening depends on a number of factors, primarily on the quality of the cement mortar.

As a rule, after drilling is completed, casing strings are lowered into the well, and the annular space between the well wall and the outer surface is filled with cement. It is known that cementing the annulus is necessary to isolate individual layers in order to eliminate interlayer flows of various fluids. High-quality cementing of casing strings allows for effective control of the development of oil and gas fields. The following indicators indicate the high quality of casing cementation:

- compliance of the rise of cement in the annulus with the design height of its rise;
- the presence of cement in the annulus in a hardened state;
- uniform distribution of cement in the annulus;
- good adhesion of cement to the column and rocks.

Research shows that the quality of well cementing is influenced by many factors - from the type of cement used to the well design features and casing alignment. Successful resolution of issues related to assessment of the quality of cementing and risks associated with emergency situations determines the importance and relevance of implementing a systematic approach using modern methods of information analysis and decision-making, new technologies and techniques, and previously acquired experience of the integrated use of acoustic cementometry and ultrasonic logging methods of leading companies in the world, make it possible to take into account these factors as much as possible and carry out an accurate diagnosis of the well cementing quality and the casing condition when using cement of any type. Based on the above, this article is devoted to the problem of assessing the quality of cementing and analyzing the risk of emergency situations that arise when cementing well walls.

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## 2. Methodology and research methods

The quality of casing cementation is controlled by various methods, in particular thermometry and radioactive isotopes, the gamma-gamma method and the acoustic method. Currently, the main method for assessing the quality of casing cementation is acoustic logging of cement quality (ACL), which is widely used in oil production enterprises. Based on quantitative data on the values of the ACL indicator, the quality of cementing is characterized, expressing this in words. In this work, we processed data from acoustic quality control of well cementing at one of the fields and proposed, on this basis, a methodology for assessing the quality of cementing and analyzing the risk of emergency situations associated with poor-quality cementing.

The methodological basis of the study was mathematical methods for analyzing information, assessing the quality of cementing and the risk of complications associated with poor-quality cementing within a single integral system.

## 3. Analysis of the state of knowledge of the problem

The studies we analyzed in this section showed that the production and practical implementation of new economically and environmentally beneficial cementing materials, as well as various additives that improve the quality of cement mortars, were preceded by deep fundamental scientific theoretical and experimental studies of the properties of various compositions and compounds. These studies made a great contribution to the study of the mechanisms of many processes, as well as in establishing the best compositions [1-3].

A review of literature sources has shown that the research accumulated so far in many studies, devoted to the improvement and development of technology and technical means to improve the quality of wall fastening when drilling wells, covers areas related to the study of the influence of chemical reagents on the properties of cement mortars, as well as the influence of fibrous materials that are industrial waste.

Scientific and technical developments carried out in academic, industry institutes, universities, scientific and technical complexes, and at drilling sites have led to the creation of various compositions.

The variety of geological and physical conditions for drilling operations significantly complicates obtaining an unambiguous answer to the question of which composition is better, and does not allow the creation of a universal technology for the process of fastening the walls of wells. Therefore, the work performed can be divided into separate groups according to its focus.

One of them includes a set of measures aimed at changing the rate of filtration and water separation, rheological parameters, thickening time, setting time, and increasing sedimentation stability. This work, carried out mainly in the laboratories of companies and institutes, allows them to optimize the process and quality of well casing.

Another group combines work on studying the influence of fibers from various materials on the rheological characteristics of cement mortars. The work of this group investigated fibers from carpet weaving, fibers from unused fishing nets, hollow microspheres, etc.

The analysis of the results of studies carried out in this group of works on the effectiveness of recycled nylon fibers obtained from various waste materials as a reinforcing component for various types of binding materials, such as cement mortars, gypsum and concrete, indicates the serious attention of researchers to finding ways to improve the quality of various materials by adding environmentally and economically beneficial production waste fibers to their composition. At the same time, solutions with different weight fractions and aspect ratios of fibers were studied; in the process of research, a comparison was also made with the characteristics of unreinforced mortar and similar studies, the results of which are covered in the literature. A group of studies is devoted to solving the problem of assessing the cementing quality and the risk of complications associated with poor-quality cementing [4-7].

Studies, the results of which are presented in [6], have shown that damage to the casing and cement of oil and gas wells can lead to environmental consequences, in particular the migration of methane into the atmosphere and/or into underground sources of drinking water. To determine complete and accurate casing and cement failure statistics, the authors analyzed 75505 compliance reports from 41381 conventional and unconventional oil and gas wells in Pennsylvania drilled from January 1, 2000 to December 31, 2012. Statewide data shows that the incidence of cement and/or casing problems for shale gas wells is six times higher than for conventional wells. The Cox proportional hazards model was used to assess impairment risk based on existing data. The Cox model is recognized as a highly predictive model in healthcare. In this regard, it is interesting to apply the model in other industries. The work [8] presents the results and comparative analysis of calculations on the Cox model using three tools: the statistical package Statistical Package for the Social Sciences, the R programming language and Russian software - the Loginom ana-

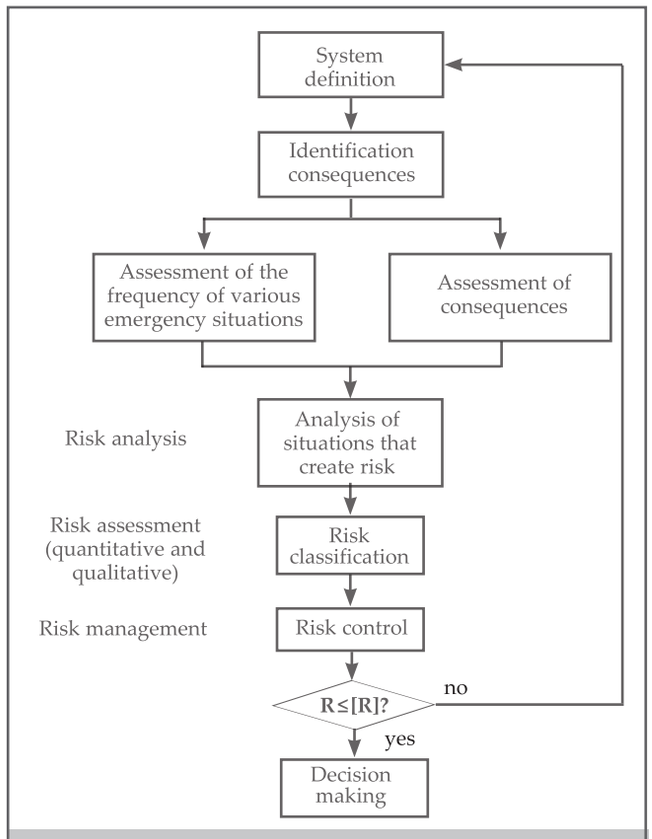


**Fig. 1. Diagram of the risk analysis and management system**

lytical platform. A distinctive feature of the developed probabilistic model is the determination of the risk of an event occurring in conditions of incomplete data, as well as the identification of indicators that have a significant impact on the degree of its manifestation. An analysis of the distribution of risks and their dynamics using this model was carried out, the results of which made it possible to establish differences in risk, both temporal and geographical.

The dynamics of well integrity violations shows the ambiguity of the results of comparing the performance of old and new wells. Assuming that the risk of cement/casing problems increases as the materials (cement/casing) age, the authors conclude that the risk of loss of structural integrity and the likelihood of government inspectors identifying a cement/casing problem will increase over time as more information about well inspection results becomes available. For example, a well drilled 3 years ago, which ideally would have a 3-year inspection record from which to draw conclusions, is more likely to experience loss of cement/casing integrity than a similar well drilled only 1 year ago. This raises an important question: Are wells drilled in 2012 more reliable than wells drilled in previous years, or is the apparent decline in government inspection reports causing under-inspection? The answer to this question will be provided by the results of observations and assessments using acoustic cementing logging data, which will allow establishing the quality of cementing with further risk assessment.

The general risk management system is shown in the diagram (fig. 1).

The focus of the review on risk management is that risk analysis and assessment serve as a subsystem within a given system structure. System definition, difficulties in identification problems [6, 7, 9-11], frequency and impact assessment [12-14] are widely discussed in the literature. Most of the risk assessment methodologies reviewed analyzed wellhead and downhole equipment.

The components present in a well vary depending on the type of well being evaluated and its condition.

In some cases, for example, according to Patroni J. M. [15], Harrison M. R. and Ellis P. F. [16] et al., assessments were made using studies carried out on wells drilled for underground gas storage; risk assessments in this case were associated with workover or well entry procedures.

Most studies analyzed the possibility of manifestations from the wellbore into the atmosphere. Blowout has been considered as a single failure mode (or emergency) in studies such as Worth D. J. et al. [9], Harrison M. R. and Ellis P. F. [16] and Abimbola M. et al. [10], Wickenhauser P. L. et al. [11] studies classified releases into small leaks, large leaks and ruptures, while Edmondson and Hyde [7] distinguished between small and large hydrocarbon releases.

Larkin P. M. [17] assesses risks in facilities as minor, significant and catastrophic leaks as possible failure scenarios.

Some researchers have assessed the probability of failure over a fixed period of time or per operation. Several works are devoted to environmental risk assessment, which was carried out primarily for wells producing liquids or undergoing hydraulic fracturing. Thus, in works of Liu R. et al. [18], Gerstenberger M. C. et al. [19], Worth D. J. et al. [9], the costs associated with multiple risk measures were often combined to form a risk measure, and the economic risk, expressed in dollars per year, of operating a well was calculated. This approach was used in Wickenhauser P. L. et al. [11], Abimbola M. et al. [10], Worth D. J. et al. [9], which allowed, using a combined risk measure reflecting all consequences, consistent comparisons between potential maintenance actions to be made.

Alvarenga T. V. presented separate estimates of frequency and consequences in the risk matrix in his work [20]. To compare degrees of risk at a high level, it is possible to create qualitative risk measures by establishing the boundaries of quantitative measures, as was done in [12-14].

In general, a brief review of the scientific and periodical literature indicates the intensive work of specialists from various companies and scientific and design organizations in the field of developing new and improving existing compositions of cementing materials, as well as well cementing technologies. Evidence of this is the results of the activities of various companies, in particular the companies MI Drilling Fluids Co. Ltd., Baroid, Weatherford, Schlumberger, Russian companies, etc., which even now remain one of the leaders in the development of the latest compositions of drilling and cementing fluids.

Modern cementing systems, as already noted, may contain elastic particles and fibers that ensure the resistance of hardened cement to high mechanical loads. The most modern cement systems contain so-called «smart» or «intelligent» materials, which, in the event of damage to the cement shell, swell upon contact with aqueous or formation fluids and restore the isolation of the formations. The ultimate goal of these cementing technologies is to provide resistance to various well drilling conditions and various geological disturbances that may occur over time and to provide reservoir isolation [21, 22].

A comparative analysis of research carried out in recent years shows that previous reagents and technologies are being replaced by increasingly more effective ones, both from an economic, technological and environmental point of view [23, 24]. Despite this, the problem of finding the best compositions that meet the requirements based on technological, economic, environmental and geographical considerations remains relevant, requiring the formulation and conduct of a number of complex theoretical, experimental, and field studies. Due to the variety of conducting and testing conditions, these studies require appropriate methodological elaboration.

First of all, this research should be aimed at developing and improving the scientific basis for regulating basic compositions, selecting environmentally friendly, cost-effective and geographically easily accessible materials for reinforcing cement mortars, as well as justifying the scope of their application. They should also provide for the need that arises in the process of research to understand new phenomena, mechanisms observed during research, to explain previously unknown patterns, to establish the reasons for the insufficiency of previously performed research, to fill to one degree or another the gaps in research on the problem under consideration, in this case, problems of high-quality fastening of well walls, etc.

As follows from the research results, different methods, means, techniques and principles are used at each level.

The analysis of literature sources, which reflect research on the problem under consideration, allowed us to monitor the results obtained at different times in different organizations and come to the appropriate conclusions.

Thus, the problem of improving the quality of well cementing, assessing the risk of emergency situations associated with poor-quality cementing is still on the agenda as important and relevant in the construction of oil and gas wells.

## 4. Materials and Methods

The starting material for the research was the results that made it possible to establish a connection between the quantitative assessment expressed by the readings of acoustic cementing logging and the quality of cementing, the assessment of which is expressed in words. The results of field observations formed the basis of the material for risk assessment. When using the noted material, modern methods of data processing and information analysis were used, based on the laws and rules of mathematical statistics and fuzzy logic.

## 5. Results and Discussion

Studies to determine the quality of cementation of the production casing are carried out in all newly drilled wells. In production wells, research is carried out as necessary or timed to coincide with geological and technical activities.

Based on the results of ACL (Acoustic cement logging) in newly drilled wells, table 1 presents general statistical data on the quality of fastening of production strings in the interval of productive formations of wells in one of the fields by year, which is also illustrated in figures 2 and 3.

As is known, risks arising in various situations are a general criterion consisting of the consequences of making a decision and the probabilities of their occurrence. The connection between these characteristics, usually expressed as a hyperbolic curve, is called a constant risk curve. It is built in the «probability-consequences» coordinate system. Using the data given in table 1, constant risk curves were constructed for various periods of the field under consideration. The constant risk curves are shown in figure 4.

The results shown in the graphs were processed by statistical methods, and analytical approximations of the graphical dependencies were found. As a result of processing, hyperbolic dependencies were obtained in the form of the expression:

$$p = R/K^b.$$

In this expression, $p$ means the frequency of a given event (probability estimate), $K$ – consequences (quality of cementing), $R$ – risk of poor-quality cementing.

In the graphs, the consequences expressed in words correspond to their quantitative values, meaning ACL readings (acoustic cement quality logging) and expressed as follows: with a value of 0-10, the quality is high, 10-20 corresponds to good quality, 20-30 means low quality, 30-150 cementation is of poor quality (absent). The parameters of the marked dependencies are given in table 2.

The risk curve discussed above divides the coordinate plane into two parts - an area of acceptable risk and an area of unacceptable risk, i.e. a dangerous area, as shown in figure 5. In this case, the «tolerance» zone expresses the willingness of the company, the decision maker, to generally accept a risk in order to obtain certain benefits, while maintaining confidence that the risk is worth taking the risk and is well controlled. In this regard, the experience accumulated by Weatherford specialists attracts attention. The company's downhole equipment specialists offer the necessary con-

**Table 1**
**Volume and results of ACL in the interval of productive formations by year**

| Year | Cementing quality | | | |
|---|---|---|---|---|
| | high | good | low | poor quality |
| 2015 | 43.6 | 35.9 | 18.6 | 1.9 |
| 2016 | 46.5 | 34.6 | 18.4 | 0.5 |
| 2017 | 51.3 | 34 | 14.7 | 0.1 |
| 2018 | 54.5 | 31.7 | 13.6 | 0.2 |
| 2019 | 77.5 | 17.9 | 4.4 | 0.2 |

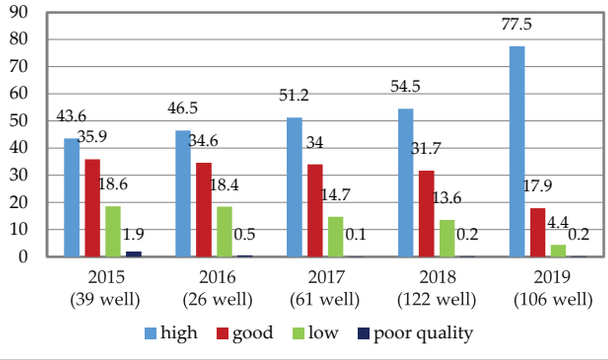


**Fig. 2. Dynamics of cementing quality for the period 2015-01.01.2020 (interval of cementing productive formations)**

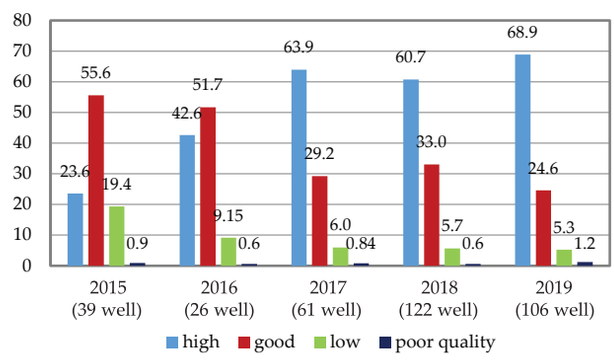


**Fig. 3. Dynamics of cementing quality for the period 2015-01.01.2020 (the entire cementing interval from the mouth to the bottom of the production string)**

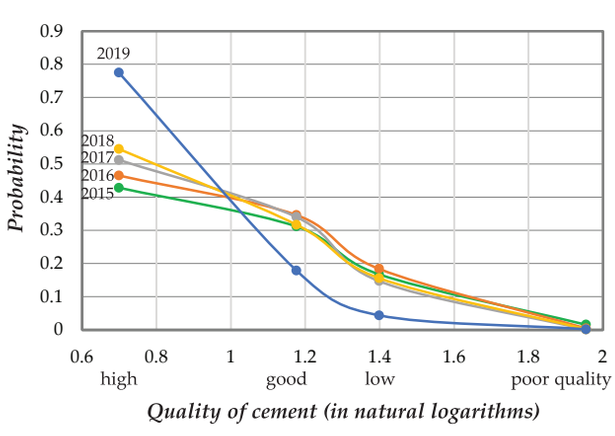


**Fig. 4. «Probability-consequence» relationship (constant risk curves of poor-quality cementing) of the field under consideration at different times**

Table 2

**Parameters of statistical expressions of the «probability-consequence» relationship**

| Year | $p=R/(\ln K)^b$ |
|---|---|
| 2015 | $R=0.2512;\ b=3.009$ |
| 2016 | $R=0.2477;\ b=4.131$ |
| 2017 | $R=0.2188;\ b=5.556$ |
| 2018 | $R=0.2362;\ b=5.013$ |
| 2019 | $R=0.1847;\ b=5.633$ |

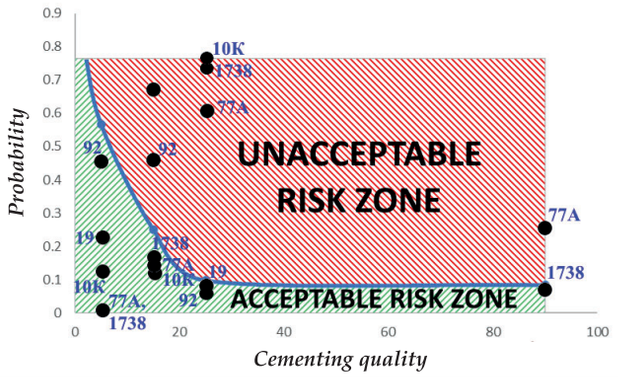


**Fig. 5. Constant risk curve and wells falling into different areas of acceptable and unacceptable risk of poor-quality cementing**

ditions and approaches for risk management, which can improve process safety and ensure trouble-free wellbore casing. As already noted, based on the results of a statistical analysis of the frequencies and consequences of complications, a relationship was obtained between the frequency and consequences, considering the quality of cementing in the form of the relationship shown in table 2.

In order to assess risk acceptability, the following data is required:

- ACL readings and qualitative assessment results;
- frequency values for occurrence of events related to cementing quality.

To recognize the marked areas, additional well data was collected. Their possible positions are established against the background of the constant risk curve, as is done in figure 5.

It should be noted that an important point in assessing risks is to ensure that the results of risk analysis can be used to develop recommendations on the advisability of taking the measures necessary to reduce this risk. The Risk Tolerance Framework, developed by the UK Health and Safety Executive and adopted by many countries, provides key tests for deciding what actions to take that are close to tests carried out in real-world conditions. In the conditions noted, there are risks that tend to be ignored and other risks that people are not prepared to accept. However, there are also risks that can be accepted by making a trade-off between the benefits and the precautions necessary to reduce undesirable effects.

## Conclusion

It is shown that an important point in assessing risks is risk analysis and ensuring the possibility of using its results in order to develop recommendations on the advisability of taking measures necessary to reduce this risk. The issues of metrological support and the relationship between the parameters of the cement stone and the state of contact of the column with the cement stone, expressed in the words «high», «good», «low», «poor quality», are considered. Intervals with different levels of cementing quality have been established. At the same time, the advantage of the ACL is taken into account, namely that its data reflects the condition and volumes of cement stone already formed in the annulus and its mechanical contacts with the casing and the well wall, including during the entire life of the well. Another advantage is also the possibility of assessing the quality of grouting of the annular and annulus spaces of multi-column structures. Thus, based on the results obtained, the following conclusions can be drawn.

1. An analysis of the dynamics of the quality of cementing wells in the field under consideration for the period 2015-01.01.2020 allowed us to establish that in one of the areas, compared to others, in new drilled wells there is an increase in the quality of good adhesion of cement to the column in the interval from the wellhead to the bottom from 24% to 69%.
2. As a result of statistical analysis, the «probability-consequences» relationship (curves of constant risk of poor-quality cementing) was established for the field under consideration at different times, and their analytical approximations were obtained.
3. A methodology for assessing the risk of poor-quality cementing is proposed and the dynamics of risks over the years is analyzed.
4. Wells were identified based on the quality of cementing and associated risks, based on their location in the zone of acceptable or unacceptable risk.

Comprehensive analysis of the chemical composition and particle sizes of impurities from the products of production wells in the fields of Kazakhstan and Azerbaijan was carried out, a comparison of the results of which showed the presence of deposits of various natures and particle sizes. The results of the analysis make it possible to substantiate and evaluate the causes of failures of deep-well pumping equipment, as well as to develop appropriate measures to combat wear of the working parts of pumps.

Thus, the proposed methodology allows for a comprehensive analysis of the composition and size of impurities and confirms the presence of deposits with various characteristics and particle sizes, which lead to corrosion and mechanical wear of components of deep-well pumping equipment.

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