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## Original article

# Evaluating Integrity of Storage Tank Bottoms based on Advanced MFL/ET Scanning: Use Case in Kazakhstan

Daniyar A. Ualiyev<sup>1</sup>, Abdugaffor Mirzoev<sup>2</sup>

<sup>1</sup>Kazakh-British Technical University, Almaty, Kazakhstan

<sup>2</sup>ROSEN Europe B.V., Almaty, Kazakhstan

## ABSTRACT

**Background:** Ensuring the structural integrity of aboveground storage tanks (ASTs), especially their bottoms, is critical for the safe and efficient operation of oil and gas facilities. Traditional inspection methods often fail to detect early-stage corrosion and defects.

**Aim:** This study aims to evaluate the effectiveness of advanced Magnetic Flux Leakage (MFL) and Eddy Current Testing (ET) techniques for assessing AST bottom integrity and optimizing predictive maintenance strategies in Kazakhstan.

**Materials and methods:** A dataset of 27 ASTs across different regions of Kazakhstan was analyzed using ROSEN TBIT Ultra technology and ROSOFT for Tanks software. Over 97000 anomalies were detected and categorized by type, location, and corrosion depth. Analytical comparisons were made across tank sizes, regions, service life, and presence of galvanic protection systems.

**Results:** The results indicate a strong correlation between anomaly density and tank service life, volume, and environmental conditions. MFL/ET scanning proved more effective than traditional ultrasonic methods in detecting internal and external corrosion. The application of galvanic protection showed only partial reduction in corrosion rates. Systematic scanning significantly enhanced defect localization and maintenance planning.

**Conclusion:** The integration of MFL and ET into RBI strategies allows for early detection of defects, optimized maintenance, reduced downtime, and enhanced safety. This approach is especially beneficial for aging infrastructure in Kazakhstan's oil and gas industry.

**Keywords:** Storage tanks; MFL; Eddy Current Testing; non-destructive testing; ROSEN TBIT Ultra; corrosion detection; predictive maintenance; risk-based inspection; tank integrity.

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## Оригинальное исследование

# Оценка целостности днищ резервуаров на основе продвинутого сканирования MFL/ET: пример применения в Казахстане

Д.А. Уалиев<sup>1</sup>, А. Мирзоев<sup>2</sup>

<sup>1</sup>Казахско-Британский технический университет, Алматы, Казахстан

<sup>2</sup>ROSEN Europe B.V., Алматы, Казахстан

## АННОТАЦИЯ

**Обоснование.** Обеспечение структурной целостности вертикальных резервуаров, особенно их днищ, имеет ключевое значение для безопасной и эффективной эксплуатации объектов нефтегазовой отрасли. Традиционные методы контроля зачастую не обеспечивают своевременного выявления коррозии и дефектов днищ резервуаров на начальных этапах их развития.

**Цель.** Оценить эффективность применения передовых технологий магнитного рассеяния потока (MFL) и вихретокового контроля (ET) для диагностики состояния днищ резервуаров и оптимизации стратегий прогнозного обслуживания в Казахстане.

**Материалы и методы.** Был проведён анализ данных обследования 27 резервуаров из разных регионов Казахстана с использованием оборудования ROSEN TBIT Ultra и программного обеспечения ROSOFT for Tanks. Обнаружено более 97 000 аномалий, классифицированных по типу, местоположению и глубине коррозии. Проведён сравнительный анализ по объёму, возрасту, региону и наличию гальванической защиты.

**Результаты.** Установлена чёткая зависимость плотности аномалий от срока службы резервуара, объёма и условий эксплуатации. Сканирование с применением MFL/ET оказалось значительно эффективнее традиционных методов ультразвукового контроля. Гальваническая защита показала лишь частичное снижение уровня коррозии. Комплексное сканирование повысило точность локализации дефектов и планирования ремонта.

**Заключение.** Интеграция технологий MFL/ET в стратегии RBI (инспекции на основе оценки риска) позволяет на раннем этапе выявлять дефекты, оптимизировать обслуживание, снижать время простоя и повышать безопасность. Данный подход особенно актуален для стареющей инфраструктуры нефтегазовой отрасли Казахстана.

**Ключевые слова:** резервуары, MFL, вихретоковый контроль, неразрушающий контроль, ROSEN TBIT Ultra, коррозия, прогнозное обслуживание, инспекция по рискам, целостность резервуара.

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## Түпнұсқа зерттеу

# MFL/ET жетілдірілген сканерлеу технологияларының негізінде резервуар түбінің тұтастығын бағалау: Қазақстанда қолдану мысалы

Д.А. Уәлиев<sup>1</sup>, А. Мирзоев<sup>2</sup>

<sup>1</sup>Қазақ-Британ техникалық университеті, Алматы қаласы, Қазақстан

<sup>2</sup>ROSEN Europe B.V., Алматы қаласы, Қазақстан

## АННОТАЦИЯ

**Негіздеу.** Тік резервуарлардың, әсіресе олардың түбінің құрылымдық тұтастығын қамтамасыз ету мұнай-газ саласының объектілерін қауіпсіз және тиімді пайдалану үшін маңызды болып табылады. Дәстүрлі бақылау әдістері жиі бақылаудың дәстүрлі әдістерін анықтауға мүмкіндік бермейді көбінесе олардың дамуының бастапқы кезеңдерінде резервуарлардың түбіндегі коррозия мен ақауларды уақтылы анықтауды қамтамасыз етпейді.

**Мақсаты.** Резервуарлар түбінің жай-күйіне диагностика жүргізу және Қазақстанда болжамды қызмет көрсету стратегияларын оңтайландыру үшін ағынның магниттік шашырауының (MFL) және құйынды тоқтық бақылаудың (ET) озық технологияларын қолданудың тиімділігін бағалау.

**Материалдар мен әдістер.** ROSEN TBIT Ultra жабдығы мен ROSOFT for Tanks бағдарламалық қамтамасыз етуін пайдалана отырып, Қазақстанның әртүрлі өңірлерінен 27 резервуарды зерттеу деректеріне талдау жүргізілді. Коррозияның түрі, орналасуы және тереңдігі бойынша жіктелген 97000-нан астам ауытқулар анықталды. Көлемі, жасы, аймағы және гальваникалық қорғаныстың болуы бойынша салыстырмалы талдау жүргізілді.

**Нәтижелері.** Аномалия тығыздығының резервуардың қызмет ету мерзіміне, көлеміне және жұмыс жағдайына нақты тәуелділігі анықталды. MFL/ET көмегімен сканерлеу дәстүрлі ультрадыбыстық бақылау әдістеріне қарағанда айтарлықтай тиімді болды. Гальваникалық қорғаныс коррозия деңгейінің ішінара төмендеуін ғана көрсетті. Толық сканерлеу ақауларды дәл анықтап, жөндеу жұмыстарын тиімді жоспарлауға мүмкіндік береді.

**Қорытынды.** MFL/ET технологияларын RBI стратегиясына біріктіру (тәуекелді бағалауға негізделген инспекциялар) ақауларды ерте анықтауға, техникалық қызмет көрсетуді оңтайландыруға, бос уақытты азайтуға және қауіпсіздікті жақсартуға мүмкіндік береді. Бұл тәсіл Қазақстанның мұнай газ саласының ескірген инфрақұрылымы үшін ерекше өзекті болып табылады.

**Негізгі сөздер:** резервуарлар, MFL, құйынды тоқтық бақылау, бұзбайтын бақылау, ROSEN TBIT Ultra, коррозия, болжамды қызмет көрсету, тәуекелге негізделген инспекция, түбінің тұтастығы.

## Дәйексөз келтіру үшін:

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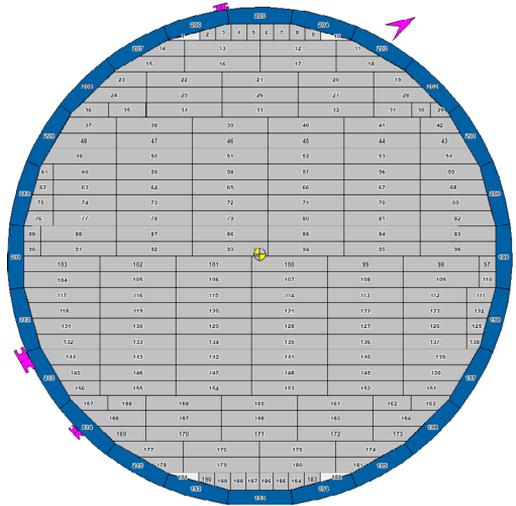
**Introduction**

Aboveground storage tanks (ASTs) are indispensable in industries such as oil and gas, chemicals, and agriculture. These tanks store essential resources and play a crucial role in supporting industrial processes and economic development. However, maintaining their structural integrity, particularly the condition of their bottoms, which support the full weight of thousands of tons of stored products (e.g., oil, chemicals, water), is a significant challenge.

The tank bottom is constructed from multiple steel plates arranged in a structured layout. It consists of bottom plates and annular plates as in Fig. 1, with the latter forming a reinforced ring along the perimeter. Annular plates are typically thicker than the central plates to handle increased stress near the shell-to-bottom joint.

To maintain structural integrity and prevent leaks, the plates are welded together using lap joints or butt joints. The welds follow a staggered pattern to distribute stress more evenly across the bottom. Additionally, corrosion protection measures, such as cathodic protection systems or protective coatings, are often incorporated to enhance durability and extend the service life of the tank. These design considerations ensure that the tank bottom can withstand operational loads while maintaining leak-tight performance and long-term reliability.

Corrosion, mechanical stress, and sediment accumulation contribute to material degradation, increasing the risk of leaks and failures. Such incidents can lead to catastrophic environmental contamination, safety hazards, and substantial financial losses, underscoring the importance of regular and thorough inspections. A strong reminder of the consequences of inadequate storage tank



**Figure 1. Tank bottom visualization in ROSOFT for Tanks 5.1.2 software**

integrity management is the Norilsk disaster of May 2020. As shown on Fig. 2 a fuel storage tank at a power plant collapsed, releasing over 21000 tonnes of diesel into nearby rivers, ultimately reaching the Arctic Ocean. The incident, attributed to structural failure caused by permafrost, resulted in severe environmental damage and costly remediation efforts. The cleanup efforts were extensive, and Nornickel, the company responsible, was fined approximately \$2 billion by the Russian government [1, 2]. This disaster highlighted the critical need for proactive inspection, predictive maintenance, and adaptation to evolving environmental risks to prevent similar failures.



a)



b)

**Figure 2. Environmental Impact of the Storage Tank Failure at the Norilsk Power Plant**  
a) Collapsed Storage Tank at Norilsk Power Plant; b) Aerial View of the Contaminated River

**Materials and methods**

Advanced scanning technologies play a key role in assessing the integrity of AST bottoms. Magnetic Flux Leakage (MFL) has proven more effective than localized ultrasonic testing for detecting corrosion and metal loss across large areas.

In Kazakhstan, regulatory requirements mandate periodic diagnostics and corrosion control. The application of MFL/ET technologies improves inspection reliability, supports compliance, and enhances maintenance planning.

**Types of Storage Tanks**

The study considers fixed-roof, external floating roof, and internal floating roof tanks. Fixed-roof tanks are the most common and cost-effective design. Floating roof tanks reduce vapor losses by moving with the liquid level. Internal floating roof tanks combine both designs, improving emission control and storage efficiency.

**Tank Bottom Inspection**

In accordance with Industrial Safety Regulation in Kazakhstan<sup>1</sup>, storage tanks that are in operation are subject to periodic inspection and non-destructive testing to determine their actual technical condition and to assess the potential duration of their continued safe operation. Based on the inspection results, the timeline for the next scheduled inspection must be established. As per Paragraph 2 of the Rules tank inspections are categorized into full (offstream) and partial (onstream) inspections.

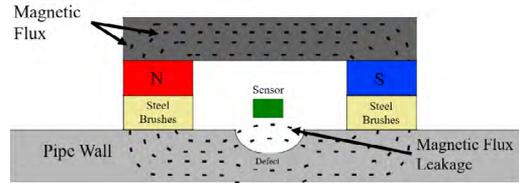
A partial inspection is performed without taking the tank out of service and focuses on external evaluations. It includes visual assessments, geometric checks, and localized thickness measurements to monitor structural integrity. Partial inspections are typically conducted every 5 years or in response to specific concerns, such as signs of corrosion or deformation detected during routine monitoring.

A full inspection requires the tank to be taken out of service, emptied, degassed, and cleaned to allow comprehensive access. This process includes visual inspection, geometric assessments, and NDT methods such as ultrasonic thickness measurements (UT), radiographic, and eddy-current testing to evaluate metal integrity and detect corrosion, cracks, and structural deformations. Full inspections are conducted at least once every 10 years, or more frequently based on regulatory requirements, operational history,

As part of full inspection, the Regulation on Industrial Safety Requirements for the Operation and Maintenance of Oil and Oil Product Storage Tanks<sup>2</sup> mandates tank bottom thickness measurements at a minimum of two points per sheet in two mutually perpendicular directions (refer to section 370). However, such spot UT measurements often fail to provide a comprehensive assessment of tank bottoms, leaving critical defects undetected. To address these limitations, advanced technologies like MFL in combination with ET have been increasingly adopted to enhance inspection accuracy and reliability. MFL technology enables a more thorough evaluation of metal loss patterns, offering valuable insights for predictive maintenance and risk mitigation. Meanwhile, ET is used to distinguish

features on the internal (product side) and external (soil side) surfaces of the bottom.

Studies on MFL have demonstrated its effectiveness in detecting metal loss features like corrosion. According to the sources [3–5], MFL technology (Fig. 3) provides several advantages: it enables rapid coverage of large areas, is non-intrusive with minimal surface preparation, and is highly effective in detecting corrosion and pitting.



**Figure 3. MFL Principle in Tank Bottom Inspection [6]**

The benefits of comprehensive scanning of tank bottoms are well-recognized across the global oil and gas industry and are witnessing increasing demand in Kazakhstan. For instance, full MFL scanning is mandated by the corporate standard of KazTransOil [4] and is also adopted by internationally operated companies such as TCO, NCOC, and KPO, all of which align with API best practices.

**Table 1. LoIE Example for Tank Bottoms**

Inspection Category	Inspection Effectiveness Category	Soil Side
A	Highly Effective	Floor scan >90%
B	Usually Effective	Floor scan >50%
C	Fairly Effective	Floor scan 5 to 10+% plates
D	Poorly Effective	Possible testing:
		– Spot UT – Flood test
E	Ineffective	Ineffective inspection technique/plan was utilized

Tab. 1 illustrates the effectiveness of various bottom scanning methods, as outlined in the API 580 guidelines. Notably, full MFL scanning is rated as providing the highest level of effectiveness, whereas spot ultrasonic testing (UT) measurements are categorized as poorly effective

**Case Study**

**Scope and Data Inputs**

In this study, a unique long-term MFL/ET tank bottom inspection dataset of 27 ASTs from various regions of Kazakhstan (Fig. 4) was analyzed. These tanks, primarily used for crude oil storage, have capacities

<sup>1</sup> GOST P 52630-2012. Steel welded vessels and apparatus. General specifications. [online.zakon.kz/Document/?doc\\_id=37870566](https://online.zakon.kz/Document/?doc_id=37870566).

<sup>2</sup> Приказ Министра по чрезвычайным ситуациям Республики Казахстан от 15 июня 2021 года № 286 «Об утверждении Правил обеспечения промышленной безопасности при эксплуатации и ремонте резервуаров для нефти и нефтепродуктов». [adilet.zan.kz/rus/docs/V2100023068](https://adilet.zan.kz/rus/docs/V2100023068).

ranging from 5000 to 20000 m<sup>3</sup> and service lives varying from 10 to 39 years. Inspection data revealed a total of 97,467 anomalies, with 39,546 external corrosion anomalies and 57,921 internal corrosion anomalies. The depth of metal loss features ranged from 19% to 100%, highlighting the urgent need for effective monitoring and maintenance strategies. Tab. 2 below provides an overview of the 27 tank parameters along with the number of anomalies detected during the inspections.

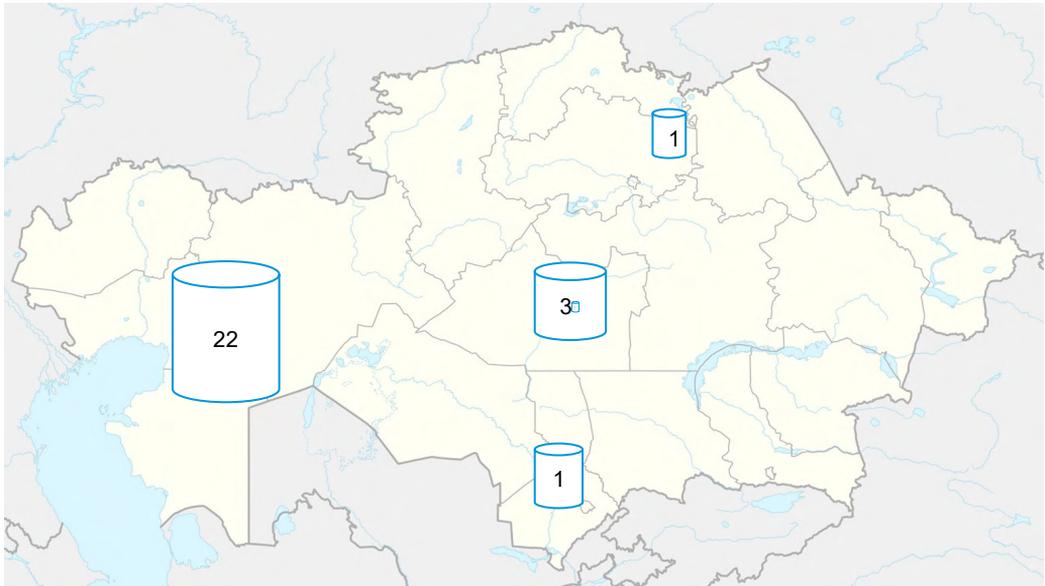
The objective of this study is to provide comprehensive analytical review of AST bottom integrity based on representative selection of MFL/ET inspection data in Kazakhstan. The study aims to:

- Assess the advantages of MFL/ET technologies over traditional inspection methods.

- Identify common trends in metal loss at AST bottoms.

**Table 2. Overview of the tank parameters and anomalies**

Item No.	Parameter	Absolute Value	Percentage from Total
1	Number of tanks	27	
2	Tank capacity	5000, 10000 and 20000 m <sup>3</sup>	
3	Average service life, years	20	
4	Total number of anomalies	97,467	
5	Bottom plates anomalies	93,79	96%
6	Annular plates anomalies	3,677	4%
7	External anomalies	39,546	41%
8	Internal anomalies	57,921	59%



**Figure 4. Geographical location of the storage tanks examined in this study**



**Figure 5. ROSEN Tank Bottom Inspection Tool (TBIT Ultra) [7]**

Data Analysis and Interpretation (TBIT Ultra tool and ROSOFT for Tanks)

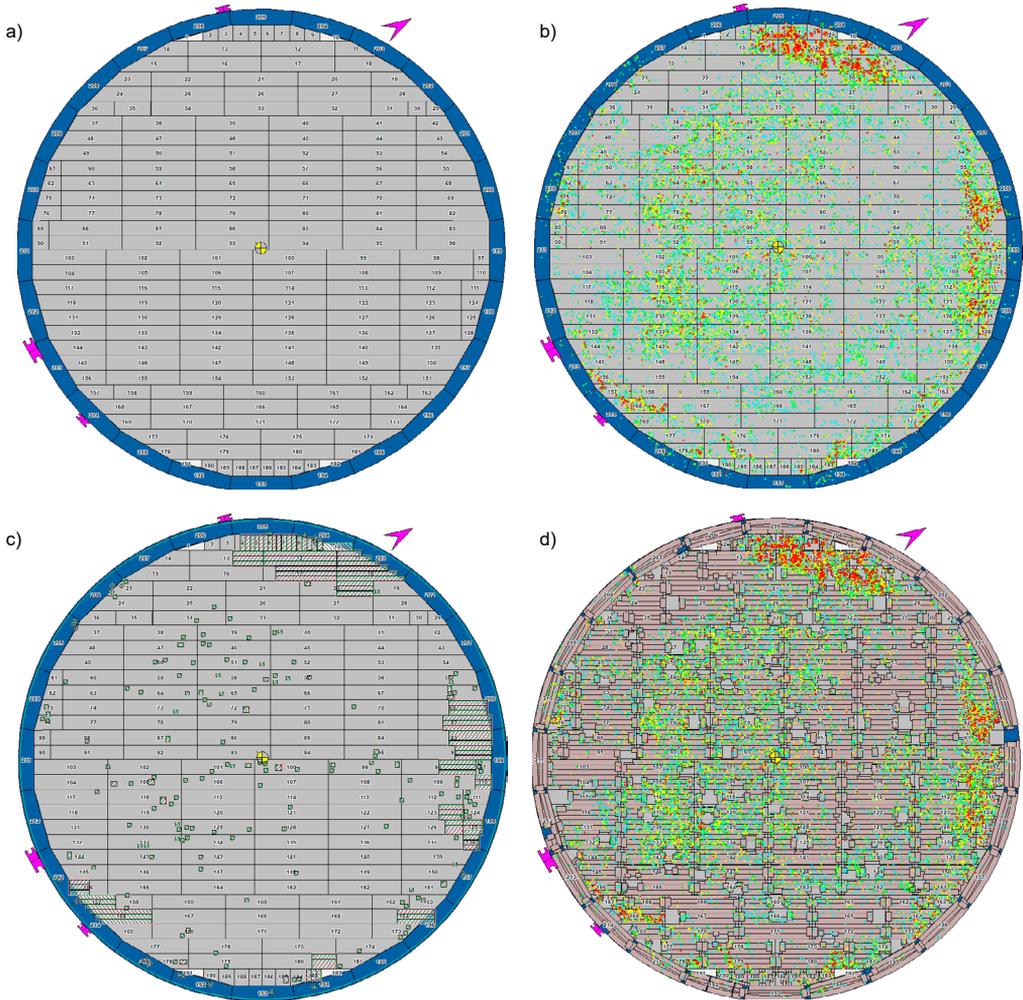
1. This study utilizes the results of tank bottom scanning performed with the ROSEN TBIT Ultra tool (Fig. 5). First introduced to the market in 1996, this tool is known for its exceptional data reliability and consistency.
2. The tank bottom inspection by ROSEN follows a structured approach to ensure accurate defect detection and assessment:
3. Pre-Inspection Activity – The technician assigns a numbering system to the tank bottom plates, marking them with unique reference points and a coordinate system. System setup and sensor functionality are tested before starting the inspection.
4. Tank Bottom Scanning – The process involves MFL/EC scanning with the ROSEN TBIT tool, UT for thickness verification, and visual inspection for blind zones. Safety measures, including proper

ventilation and intrinsically safe equipment, are strictly followed.

5. Data Evaluation and Reporting – Initial data is reviewed in real time, followed by a more detailed offline analysis using specialized software. The final report includes MFL and UT results, defect documentation, and repair recommendations. The ROSOFT for Tanks software was utilized to visualize inspection results, providing detailed insights into defect locations, depths, damage categorization, and repair tracking. Designed for TBIT, the software enables precise identification of tank bottom defects, accurate metal loss measurement, damage type classification, and monitoring of previously repaired areas. As shown on Fig. 6 ROSOFT also offers a range of flexible visualization tools – including scan line views, wall thickness mapping, and coordinate-based displays – to support comprehensive condition assessments and effective maintenance planning.

**Results**

In Fig. 7, the analysis reveals patterns in the relationship between tank volume, service life, and anomaly density. Smaller tanks (5000 m<sup>3</sup>) exhibit a significant variation in service life, reaching over 30 years in some cases, and are often characterized by high anomaly density, which may indicate material degradation or accumulated operational stress. Tanks with a volume of 10000 m<sup>3</sup> have relatively low anomaly density, suggesting better structural integrity at the time of inspection. However, the overall trend indicates that anomaly density increases with service life, confirming the cumulative effects of wear and aging. Larger tanks (20000 m<sup>3</sup>) demonstrate extended service lives, sometimes reaching up to 40 years, but also show the highest anomaly densities, emphasizing the correlation between longevity and structural degradation. These findings highlight the need for systematic monitoring and pre-



**Figure 6. Scanned bottom of the tank in the ROSOFT software**

- a) general scan visualization;
- b) identified corrosion defects;
- c) visualization of bottom plate repair/replacement;
- d) scanned bottom plates with detected anomalies

ventive measures, as an increase in operational time is accompanied by a rise in anomaly density, which may elevate the risk of failures and require additional safety measures.

The chart in the Fig. 8 shows the service life and corrosion rate of tanks with capacities of 5000 m<sup>3</sup>, 10000 m<sup>3</sup>, and 20000 m<sup>3</sup>. The orange bars represent service life, while the blue and purple bars indicate the average internal and external corrosion rates, respectively.

In the 5000 m<sup>3</sup> group, the service life ranges from 10 to 25 years, and the corrosion rate is distributed chaotically. In the 10000 m<sup>3</sup> category, the service life is generally lower, while the corrosion rate remains high regardless of the tank's age. The 20000 m<sup>3</sup> group shows a wider range of service life values, but young tanks often experience high corrosion rates. This data supports the conclusion that tank capacity directly influences corrosion behavior and maintenance strategies. Smaller tanks, such as those with

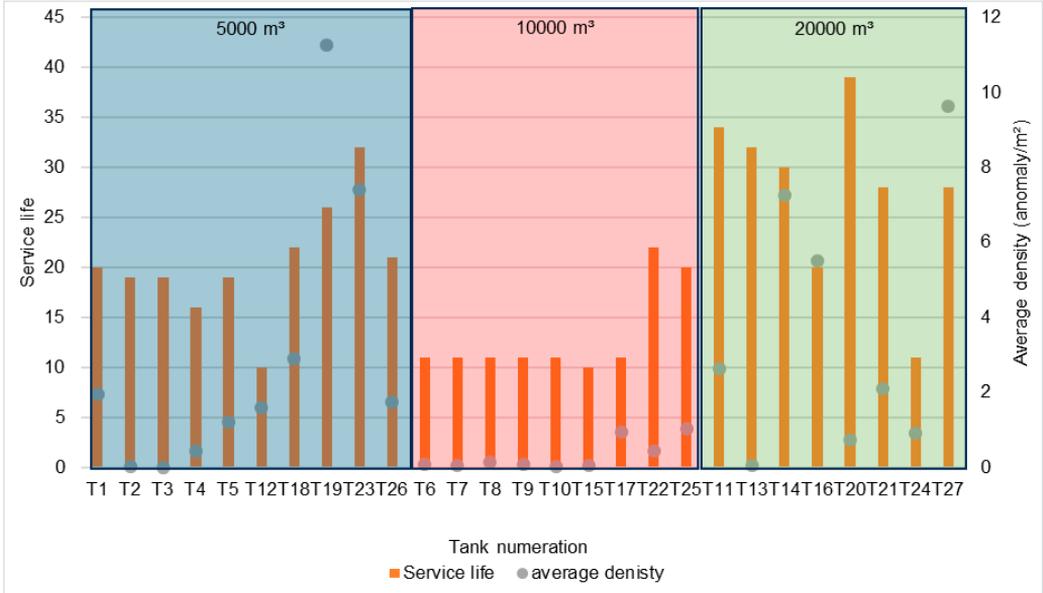


Figure 7. Analysis of service life and anomaly density in storage tanks of different capacities

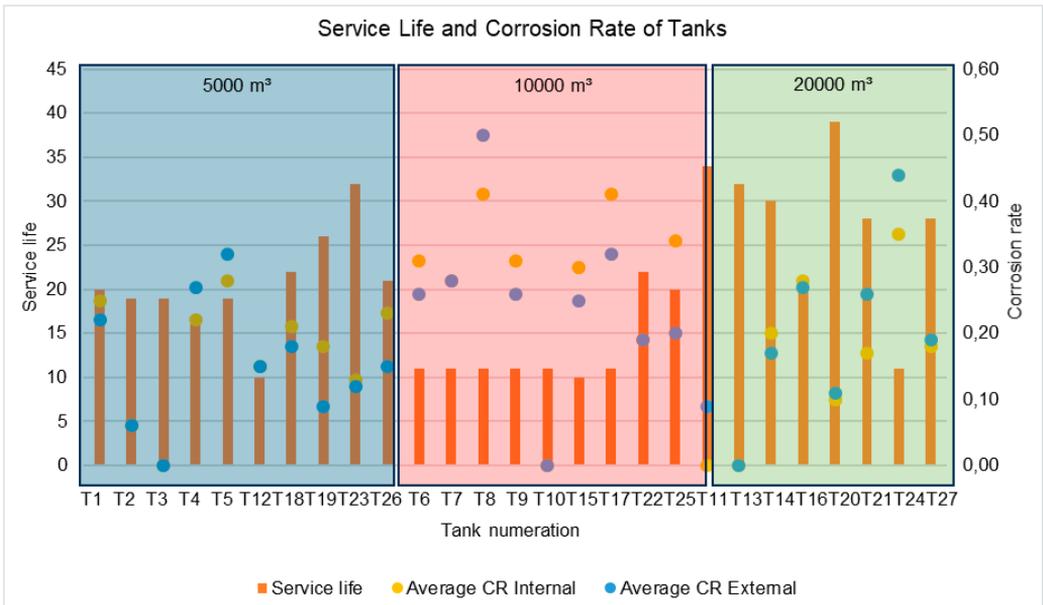


Figure 8. Service life and corrosion rate of tanks

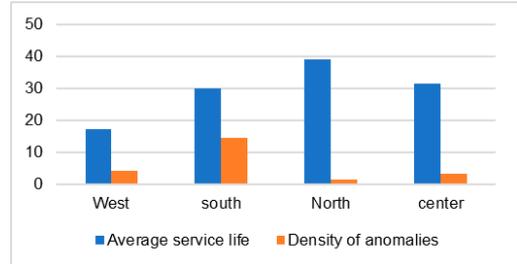
5000 m<sup>3</sup> capacity, experience more rapid and localized corrosion, indicating the need for frequent maintenance and more effective protective coatings. In contrast, larger tanks (10000 and 20000 m<sup>3</sup>) tend to accumulate damage more gradually over time, which makes long-term monitoring and cathodic protection systems essential. The correlation between anomaly density and the effectiveness of protective measures, particularly galvanic protection, highlights the importance of tailored maintenance strategies based on tank size and operational conditions [8, 9]. In addition, Fig. 9 shows the average service life and anomaly density across four regions: West, South, North, and Center. Higher anomaly density, as seen in the South, may contribute to faster wear. In contrast, the North region has the longest service life and the lowest anomaly density, which may indicate better operating conditions or higher-quality materials.

In addition, Fig. 10 presents a comparative analysis of tanks with and without galvanic protection, showing the number of internal anomalies and the corresponding service life. The tanks on the left side, shaded in blue, represent those without galvanic protection, while those on the right side, shaded in red, are equipped with galvanic protection.

From the visual distribution of the data, there does not appear to be a strong direct correlation between the presence of galvanic protection and the number of internal anomalies. Both groups exhibit varying levels of anomalies, and the mere presence of protection does not consistently result in lower anomaly counts across all tanks.

However, a general trend can be observed in both groups: the number of internal anomalies tends to increase with the age of the tank. Especially among tanks with galvanic protection, older tanks (with longer service life) tend to show higher anom-

aly counts, suggesting that time and operational wear still contribute to internal degradation, even in the presence of protective systems. In tanks without galvanic protection, the number of anomalies is already quite high across all ages, and while the relationship with age is less clearly defined, it is evident that the lack of protection contributes to consistently higher anomaly levels overall.



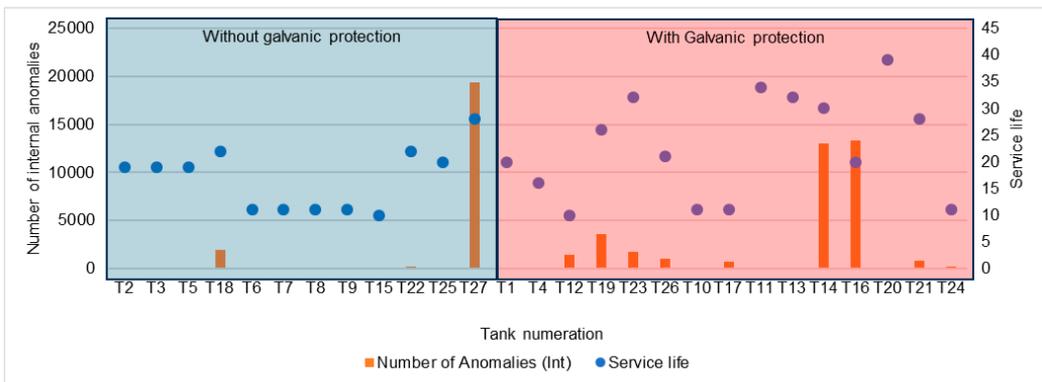
**Figure 9. Average service life and anomaly density by region**

This indicates that while galvanic protection may mitigate corrosion or degradation to some extent, it does not eliminate the long-term effects of aging, and the accumulation of anomalies over time is still significant factor regardless of protection status.

**Conclusion**

The study demonstrated the high efficiency of TBIT findings in assessing the integrity of storage tank bottoms. These techniques provided a detailed and accurate evaluation of corrosion and structural defects, surpassing the capabilities of traditional inspection methods.

The research confirmed that MFL and ET technologies enable the early detection of critical defects, allowing for timely maintenance interven-



**Figure 10. Assessment of Internal Corrosion in Tanks Based on Protection Status and Operational Time**

tions and reducing the risk of unexpected failures. The case study showed that the application of these advanced scanning methods significantly improved the accuracy of defect localization and classification. As a result, maintenance teams were able to prior-

itize repairs more effectively, optimizing resources and minimizing the downtime of storage facilities. A comprehensive analysis of all factors reveals a complex interrelation between tank age, volume, geographic location, protective measures, and ove-

rall technical condition. The key takeaways can be summarized as follows:

1. The risk of damage increases by 45% with both age and volume of the tanks.
2. Coating quality and the presence of galvanic protection are critical in reducing the rate of degradation (the case study shows 32% in corrosion rate reduction).
3. Smaller tanks exhibit a high susceptibility to corrosion (25% higher than average) even at an early stage of their operational life, highlighting the need for further investigation and analysis.
4. Regional operating conditions significantly impact on the service life and structural integrity of the tanks.
5. Systematic monitoring and preventive maintenance are essential, particularly for bottom plates and tanks without protective systems.

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**Authors' contribution.** All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. The greatest contribution is distributed as follows: Daniyar A. Ualiyev – collecting and processing the experimental data, conducting the research, performing a comprehensive analysis and interpretation of the results, and drafting the manuscript; Abdugaffor Mirzoev – revising the analytical content, reviewing the findings, and editing the manuscript.

Furthermore, the integration of TBIT data into a risk-based inspection (RBI) framework will enhance predictive maintenance strategies, making operations not only safer but also more cost-efficient. The findings also highlight the importance of continuous monitoring and data-driven decision-making in the oil and gas industry.

Overall, the study provides strong evidence that the adoption of advanced NDT techniques can significantly contribute to improving the reliability and sustainability of storage tank infrastructure. The results suggest that a wider implementation of MFL and ET technologies across the industry could lead to substantial long-term benefits, including enhanced operational efficiency and reduced environmental risks associated with tank failures.

### ДОПОЛНИТЕЛЬНО

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### AUTHORS' INFO

\*Daniyar A. Ualiyev

ORCID [0009-0001-3437-8795](https://orcid.org/0009-0001-3437-8795)

e-mail: [ualiiev03@gmail.com](mailto:ualiiev03@gmail.com).

Abdugaffor Mirzoev

ORCID [0009-0009-9416-8974](https://orcid.org/0009-0009-9416-8974)

e-mail: [gmirzoev@rosen-group.com](mailto:gmirzoev@rosen-group.com).

### ИНФОРМАЦИЯ ОБ АВТОРАХ

\*Уалиев Данияр Арманович

ORCID [0009-0001-3437-8795](https://orcid.org/0009-0001-3437-8795)

e-mail: [ualiiev03@gmail.com](mailto:ualiiev03@gmail.com).

Абдугаффор Мирзоев

ORCID [0009-0009-9416-8974](https://orcid.org/0009-0009-9416-8974)

e-mail: [gmirzoev@rosen-group.com](mailto:gmirzoev@rosen-group.com).

\*Автор, ответственный за переписку / Corresponding Author