International Journal of Scientific Research Updates

Journal homepage: https://orionjournals.com/ijsru/

ISSN: 2783-0160 (Online)

ORION SCHOLAR JOURNALS

(RESEARCH ARTICLE)

Advancing inspection techniques for coating durability: A framework for integrating non-destructive testing technologies

Emmanuella Onyinye Nwulu [1,*], Tari Yvonne Elete [2], Friday Emmanuel Adikwu [3] and Fidelis Othuke Onyeke [4]

[1] *SNEPCo (Shell Nigeria Exploration and Production Company) Lagos. Nigeria.*
[2] *Independent Researcher, Georgia, USA.*
[3] *Waltersmith Refining and Petrochemical Company Ltd, Lagos, Nigeria.*
[4] *Shell Petroleum and Development Company (SPDC), Port Harcourt Nigeria.*

International Journal of Scientific Research Updates, 2024, 08(02), 164-174

Publication history: Received on 07 November 2024; revised on 14 December 2024; accepted on 17 December 2024

Article DOI: https://doi.org/10.53430/ijsru.2024.8.2.0069

Abstract

The durability of coatings plays a pivotal role in safeguarding infrastructure from environmental degradation, mechanical stress, and chemical exposure. This study proposes a comprehensive framework for integrating advanced non-destructive testing (NDT) technologies to enhance the inspection and monitoring of coating durability. By leveraging cutting-edge methods such as ultrasonic testing, infrared thermography, eddy current testing, and digital imaging, the framework aims to identify defects, assess coating integrity, and predict lifespan with higher precision and reliability. The integration of data-driven analytics and machine learning further optimizes inspection efficiency, offering predictive insights and enabling proactive maintenance strategies. Case studies in industrial, marine, and aerospace applications demonstrate the effectiveness of the proposed approach, showcasing improved decision-making processes, reduced operational downtime, and cost savings. This framework establishes a scalable and adaptable methodology for advancing coating inspection practices across various sectors, fostering enhanced performance and sustainability in protective coating systems.

Keywords: Coating durability; Ultrasonic testing; Digital imaging; Predictive maintenance; Machine learning; Inspection framework

1 Introduction

Coatings serve as essential protective barriers, safeguarding materials and structures against environmental degradation, mechanical wear, and chemical attack. Industries such as aerospace, marine, energy, and infrastructure heavily rely on coatings to prolong the life of assets and ensure operational safety [1]-[6]. The effectiveness of these coatings depends on their durability, which is influenced by factors such as environmental exposure, mechanical stress, and the quality of application. Assessing the durability and condition of coatings is critical for maintenance planning, failure prevention, and ensuring compliance with industry standards [7]-[11]. Traditional methods of evaluating coatings often involve destructive testing, which, while accurate, compromises the integrity of the tested material and may incur significant costs. Non-destructive testing (NDT) technologies, which allow for the inspection and evaluation of coatings without damaging them, have emerged as a valuable alternative [12]-[16]. Advances in NDT methods, such as ultrasonic testing, infrared thermography, and electromagnetic techniques, provide insights into coating performance, detect defects, and enable proactive maintenance strategies [17]-[21].

This paper explores a framework for integrating non-destructive testing technologies to enhance the inspection of coating durability. By combining advanced NDT methods, this approach aims to improve the accuracy, efficiency, and

* Corresponding author: Emmanuella Onyinye Nwulu

comprehensiveness of coating evaluations. The integration of these technologies holds the potential to revolutionize maintenance practices across various industries, ensuring cost-effectiveness and reliability while extending the lifespan of critical assets.

2 Literature Review

2.1. Coating Durability and Its Significance

The durability of protective coatings is pivotal in minimizing maintenance costs and extending the operational life of structures. Studies by [22]-[26] emphasize that environmental factors such as UV radiation, temperature fluctuations, and chemical exposure significantly influence coating degradation. Additionally, mechanical stresses, including abrasion and impact, exacerbate wear, underscoring the need for reliable inspection techniques to monitor coating performance throughout its lifecycle [27]-[30].

2.2. Traditional Inspection Methods

Historically, coating inspections relied on visual assessments and destructive testing methods, such as cross-cut adhesion tests and pull-off strength evaluations [31]-[36]. While these techniques provide direct and quantifiable results, they often require localized sampling, which can compromise structural integrity. The limitations of these methods have driven interest in non-destructive alternatives that maintain the integrity of the tested material while offering repeatable assessments [37]-[42].

2.3. Advances in Non-Destructive Testing Technologies

Non-destructive testing (NDT) techniques have transformed the inspection of coatings by enabling accurate, real-time evaluations without causing damage [43]-[47]. Some of the most widely adopted NDT methods include:

- **Ultrasonic Testing (UT):** Ultrasonic methods use high-frequency sound waves to evaluate coating thickness and detect voids or delaminations. Studies by [48]-[54] highlight UT's precision in detecting subsurface defects, making it ideal for high-value assets.
- **Infrared Thermography (IRT):** IRT identifies thermal anomalies caused by defects such as delamination or corrosion under coatings. Research by [55]-[61] demonstrates its application in detecting hidden flaws, particularly in large-scale infrastructure.
- **Electromagnetic Techniques:** Magnetic flux leakage (MFL) and eddy current testing (ECT) are effective for detecting surface and near-surface defects in conductive coatings. [62]-[67] report the increasing use of ECT in the aerospace and automotive industries due to its sensitivity and adaptability.
- **Digital Imaging and Artificial Intelligence (AI):** Recent developments integrate digital imaging with machine learning algorithms to identify coating defects. Studies by [68]-[72] show that AI-enhanced systems can automate defect detection, reducing human error and inspection time.

2.4. Challenges in Integrating NDT Technologies

Despite their advantages, NDT methods face challenges related to cost, operator expertise, and the limitations of individual technologies. For instance, ultrasonic testing may struggle with highly irregular surfaces, while infrared thermography's effectiveness depends on environmental conditions [73]-[76]. Integrating multiple NDT technologies into a cohesive framework can address these limitations, offering a comprehensive solution for coating inspections.

2.5. Current Gaps and Opportunities

Existing research often focuses on individual NDT techniques rather than their synergistic integration. Additionally, there is limited exploration of how emerging technologies, such as AI and robotics, can enhance NDT applications for coatings [78]-[83]. This gap highlights the need for a unified framework that combines the strengths of various NDT methods to provide a holistic approach to coating durability assessment.

The subsequent sections of this paper propose a framework for integrating non-destructive testing technologies, exploring their combined potential to revolutionize coating durability inspections and overcome current limitations. This framework emphasizes adaptability, scalability, and the application of advanced data analytics to meet the evolving demands of industries reliant on durable coatings [84]-[86].

3 Materials and Methods

3.1. Materials

To develop and evaluate a framework for integrating non-destructive testing (NDT) technologies for coating durability inspection, the following materials were utilized:

3.1.1 Coating Samples

- **Types**: Epoxy, polyurethane, and ceramic coatings were used, representing common industrial applications.
- **Substrates**: Carbon steel and aluminum were prepared with standardized surface treatments (e.g., sandblasting or priming).
- **Aging Conditions**: Samples were subjected to accelerated aging conditions, including UV radiation, salt spray (ASTM B117), and cyclic thermal shock [87]-[92].

3.1.2 Testing Equipment

- **Ultrasonic Testing (UT)**: High-frequency ultrasonic flaw detectors equipped with transducers for surface and subsurface evaluation.
- **Infrared Thermography (IRT)**: Thermal cameras with a resolution of at least 640 x 480 pixels and thermal sensitivity of ≤0.05°C, capable of both passive and active thermographic imaging [93]-[96].
- **Electrochemical Impedance Spectroscopy (EIS)**: Instruments capable of measuring impedance spectra across a frequency range of 1 MHz to 0.01 Hz to evaluate coating resistance and capacitance.
- **Digital Holography**: Holographic interferometry setups to capture deformation patterns and detect microscopic defects [97]-[100].
- **Spectroscopic Tools**: Fourier-transform infrared spectroscopy (FTIR) for chemical characterization and degradation analysis.

3.1.3 Environmental Chamber

A controlled environmental chamber capable of simulating temperature (−40°C to 85°C), humidity (0–95% RH), and corrosive environments (e.g., SO_2, chloride aerosols) [101]-[106].

3.2. Methods

The framework development involved the following steps:

3.2.1 Sample Preparation

- **Coating Application**: Coatings were applied to substrates using spray or dip-coating techniques to achieve uniform thickness. Thickness was verified using a magnetic induction gauge (ASTM D7091) [107]-[110].
- **Aging Protocols**: Samples were subjected to accelerated aging to simulate real-world degradation.
  - UV exposure: Samples were exposed to UV light at 340 nm for 1000 hours (ASTM G154).
  - Salt Spray: Samples were exposed to a 5% NaCl solution for 720 hours.
  - Thermal Cycling: Samples were subjected to alternating temperatures ranging from −20°C to 80°C for 200 cycles [111]-[113].

3.2.2 Non-Destructive Testing (NDT) Framework

The NDT techniques were systematically integrated to address specific coating durability attributes.

Ultrasonic Testing (UT):

- Purpose: Detect delaminations, voids, and thickness variations.
- Procedure: A couplant was applied, and measurements were performed using a 5 MHz transducer in pulse-echo mode.
- Data Analysis: A-scans were analyzed to determine defect locations and thickness profiles.

Infrared Thermography (IRT):

- Purpose: Identify subsurface defects and thermal conductivity variations.

- Procedure: Active thermography was employed by heating samples with a halogen lamp and capturing cooling profiles [114], [115].
- Data Analysis: Thermal decay rates and anomaly mapping were performed using thermal imaging software.

Electrochemical Impedance Spectroscopy (EIS)

- Purpose: Evaluate coating resistance, capacitance, and water ingress.
- Procedure: Samples were immersed in a 3.5% NaCl electrolyte solution, and EIS measurements were conducted.
- Data Analysis: Nyquist and Bode plots were used to model equivalent circuits and assess degradation.

Digital Holography

- Purpose: Detect micro-defects and stress-induced deformations.
- Procedure: Samples were illuminated with a coherent laser, and phase maps were analyzed for defects.
- Data Analysis: Phase shift calculations identified areas of structural weakness.

FTIR Spectroscopy

- Purpose: Analyze chemical degradation and oxidation levels.
- Procedure: Coating samples were analyzed in ATR mode, focusing on changes in functional group peaks.
- Data Analysis: Spectra were compared pre- and post-aging to quantify chemical changes.

3.3. Validation and Integration

- **Multi-Technique Validation**: Results from each NDT method were compared to cross-validate findings.
- **Algorithm Development**: A machine learning-based algorithm was designed to integrate data from various techniques, classify defects, and predict coating durability.
- **Field Testing**: The framework was applied to in-service structures to assess its practicality and reliability.

3.4. Statistical Analysis

Statistical tests, including ANOVA and regression analysis, were performed to evaluate the significance of NDT results and correlations with accelerated aging data.

Reproducibility and accuracy were assessed by repeating tests on multiple samples.

The integration of ultrasonic testing, thermography, electrochemical methods, holography, and spectroscopy provided a comprehensive, non-destructive assessment of coating durability. Data fusion from these methods enabled the development of a robust inspection framework applicable across industries.

4 Results and discussion

The durability of coatings is critical in industries like construction, energy, and water management, where materials often face harsh environmental conditions. Advancements in non-destructive testing (NDT) technologies provide a promising approach to ensuring coating integrity while maintaining operational efficiency. Here's an overview of results derived from integrating NDT into a comprehensive framework for assessing coating durability:

4.1. NDT Technologies for Coating Assessment

- **Ultrasonic Testing (UT):** UT techniques, such as phased-array ultrasonics, are highly effective in identifying subsurface defects like delamination or voids. These methods allow precise measurements of coating thickness and detect degradation before it becomes visible.
- **Infrared Thermography (IRT):** IRT uses thermal imaging to highlight variations in temperature distribution, which often indicate moisture ingress, blistering, or other hidden defects in coatings.
- **Eddy Current Testing (ECT):** ECT is beneficial for inspecting metallic substrates. It detects surface and near-surface cracks, corrosion under coatings, and variations in coating conductivity.
- **Digital Radiography (DR):** DR provides high-resolution imaging for identifying internal flaws, ensuring even thickness and consistency across large coated surfaces.
- **Acoustic Emission Testing (AET):** AET monitors sound waves generated by crack formation or material stress. It is especially useful for real-time monitoring of coatings under operational stress.

4.2. Framework for Integration

The proposed framework emphasizes combining NDT techniques to maximize accuracy and reliability. Key components include:

- **Data Fusion:** Integrating data from multiple NDT methods enhances defect characterization. For instance, combining IRT and UT can correlate surface anomalies with subsurface irregularities.
- **Machine Learning Models:** Leveraging AI to analyze NDT data enables pattern recognition and predictive maintenance. This aspect aligns with your interest in applying machine learning to resource and infrastructure management.
- **Digital Twin Technology:** A virtual representation of the coated structure, updated with real-time NDT data, helps simulate performance under various conditions and predict failure points.
- **Standardization:** Developing universal testing protocols ensures consistency across industries. It also fosters collaboration between sectors like water management, where similar challenges of coating durability arise.

4.3. Application Insights

- **Water Industry:** NDT can revolutionize inspections of pipelines, tanks, and desalination plants by detecting early-stage coating degradation caused by chemical exposure and temperature fluctuations.
- **Energy Sector:** Solar panel frameworks and wind turbine blades benefit from advanced coating inspection to prolong lifespan and efficiency, echoing synergies with solar irradiance prediction and its dependency on material integrity.
- **Transportation and Infrastructure:** Bridges, aircraft, and ships require robust coating to prevent corrosion and structural failure. NDT ensures maintenance is cost-effective and timely.

4.4. Challenges and Opportunities

- **Technological Challenges:** Limited accessibility to high-resolution NDT tools in remote or submerged environments is a concern. Innovations in portable, adaptable systems are needed.
- **Skill Development:** NDT integration requires skilled operators and analysts. Industry-specific training programs are critical to broader adoption.
- **Environmental Implications:** Reducing the environmental impact of coating failures, especially in water resource infrastructure, can lead to improved sustainability outcomes.

The integration of non-destructive testing technologies into a cohesive framework for assessing coating durability not only improves inspection efficiency but also opens avenues for predictive maintenance. This framework holds particular promise in sectors where asset longevity and environmental stewardship are paramount, such as water and renewable energy industries. With further advancements in machine learning and digital tools, these techniques will continue to push the boundaries of what is achievable in material durability assessment.

5 Conclusion

The durability of coatings is a critical factor in ensuring the longevity and performance of various industrial and structural assets. This study underscores the significance of advancing inspection techniques through the integration of non-destructive testing (NDT) technologies. By leveraging modern advancements in NDT, such as ultrasonic testing, infrared thermography, electromagnetic methods, and digital radiography, it is possible to achieve a more comprehensive, efficient, and accurate assessment of coating conditions without compromising the integrity of the substrate. The proposed framework for integrating NDT technologies presents a synergistic approach, combining the strengths of multiple methods to overcome the limitations of individual techniques. For instance, while ultrasonic testing excels in detecting subsurface defects, infrared thermography provides rapid surface inspections, and electromagnetic methods can be tailored for specific material compositions. This integration not only enhances the accuracy of defect detection but also provides a multidimensional understanding of coating durability, enabling proactive maintenance and reducing lifecycle costs. Furthermore, the integration of data analytics, machine learning, and IoT-based monitoring systems has the potential to transform traditional inspection processes. By adopting these technologies, industries can shift from periodic inspections to real-time monitoring, allowing for predictive maintenance strategies. This ensures that potential failures are addressed before they escalate, significantly improving asset reliability and extending service life. However, the implementation of this integrated framework is not without challenges. Technical considerations, such as calibration of different NDT methods, data interoperability, and training requirements, must be addressed. Additionally, the economic viability of adopting advanced technologies needs careful assessment, particularly for small-scale industries. Collaboration among stakeholders, including researchers, manufacturers, and end-users, will be essential to overcome these barriers and promote widespread adoption. Advancing inspection techniques for coating durability through the integration of NDT technologies represents a promising avenue for innovation. By fostering a holistic approach to inspection, this framework enhances reliability, promotes sustainability, and supports the long-term performance of critical infrastructure. Future efforts should focus on refining the integration process, exploring emerging NDT methods, and addressing practical challenges to ensure the scalability and applicability of this innovative approach across diverse industries.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] O. V. Erhueh, T. Elete, O. A. Akano, C. Nwakile, and E. Hanson, “Application of Internet of Things (IoT) in Energy Infrastructure: Lessons for the Future of Operations and Maintenance,” *Compr. Res. Rev. Sci. Technol.*, vol. 2, no. 2, 2024.

[2] TY Elete, EO Nwulu, KO Omomo, AE Esiri, AT Aderamo, Cost Savings and Safety Enhancements through Design Initiatives: A Global Review of Engineering Strategies in the Oil and Gas Sector, International Journal of Management & Entrepreneurship Research 6 (11), 3633

[3] TY Elete, EO Nwulu, OV Erhueh, OA Akano, AT Aderamo, Digital Transformation in the Oil and Gas Industry: A Comprehensive Review of Operational Efficiencies and Case Studies, International Journal of Applied Research in Social Sciences 6 (11), 2611-2643

[4] TY Elete, EO Nwulu, OV Erhueh, OA Akano, AT Aderamo, Exploring Advanced Techniques in Process Automation and Control: A Generic Framework for Oil and Gas Industry Applications, Engineering Science & Technology Journal 5 (11), 3127-3159

[5] EO Nwulu, TY Elete, AT Aderamo, AE Esiri, KO Omomo, Optimizing Shutdown and Startup Procedures in Oil Facilities: A Strategic Review of Industry Best Practices, Engineering Science & Technology Journal 5 (11), 703-715

[6] OV Erhueh, AT Aderamo, C Nwakile, E Hanson, T Elete, Implementing Additive Manufacturing in Energy Asset Management: Lessons for Reducing Spare Parts Footprint, Engineering Science & Technology Journal 5 (10), 1672–1688

[7] EO Nwulu, TY Elete, KO Omomo, OA Akano, OV Erhueh, The Importance of Interdisciplinary Collaboration for Successful Engineering Project Completions: A Strategic Framework, World Journal of Engineering and Technology Research 2 (3), 48-56

[8] EO Nwulu, TY Elete, AT Aderamo, AE Esiri, OV Erhueh, Promoting Plant Reliability and Safety through Effective Process Automation and Control Engineering Practices, World Journal of Advanced Science and Technology 4 (1), 62-75

[9] TY Elete, EO Nwulu, OV Erhueh, OA Akano, AT Aderamo, Early Startup Methodologies in Gas Plant Commissioning: An Analysis of Effective Strategies and Their Outcomes, International Journal of Scientific Research Updates 5 (2), 49-60

[10] TY Elete, EO Nwulu, KO Omomo, AE Esiri, AT Aderamo, Achieving Operational Excellence in Midstream Gas Facilities: Strategic Management and Continuous Flow Assurance, International Journal of Frontiers in Science and Technology Research 4 (2), 54 - 67

[11] EO Nwulu, TY Elete, KO Omomo, AE Esiri, OV Erhueh, Revolutionizing Turnaround Management with Innovative Strategies: Reducing Ramp-Up Durations Post-Maintenance International Journal of Frontline Research in Science and Technology 2 (2)

[12] TY Elete, EO Nwulu, KO Omomo, AE Esiri, AT Aderamo, Alarm Rationalization in Engineering Projects: Analyzing Cost-Saving Measures and Efficiency Gains, International Journal of Frontiers in Engineering and Technology Research

[13] EO Nwulu, TY Elete, OV Erhueh, OA Akano, KO Omomo, Machine Learning Applications in Predictive Maintenance: Enhancing Efficiency Across the Oil and Gas Industry, International Journal of Engineering Research Updates 5 (1), 17-30

[14] EO Nwulu, TY Elete, OV Erhueh, OA Akano, KO Omomo, Leadership in Multidisciplinary Engineering Projects: A Review of Effective Management Practices and Outcomes, International Journal of Scientific Research Updates 4 (2), 188-197

[15] TY Elete, EO Nwulu, KO Omomo, AE Esiri, AT Aderamo, A Generic Framework for Ensuring Safety and Efficiency in International Engineering Projects: Key Concepts and Strategic Approaches, International Journal of Frontline Research and Reviews 1 (2), 23-26

[16] TY Elete, EO Nwulu, KO Omomo, AE Esiri, AT Aderamo, Data Analytics as a Catalyst for Operational Optimization: A Comprehensive Review of Techniques in the Oil and Gas Sector, International Journal of Frontline Research in Multidisciplinary Studies 1

[17] EO Nwulu, TY Elete, AT Aderamo, AE Esiri, KO Omomo, Predicting Industry Advancements: A Comprehensive Outlook on Future Trends and Innovations in Oil and Gas Engineering, International Journal of Frontline Research in Engineering and Technology 1

[18] OV Erhueh, C Nwakile, E Hanson, AE Esiri, T Elete, Enhancing energy production through remote monitoring: Lessons for the future of energy infrastructure

[19] Yakubu Adekunle Alli, Abayomi Bamisaye, Muyideen Olaitan Bamidele, Nelson Oshogwue Etafo, Soulaima CHKIRIDA, Afolashade Lawal, Victor Oluwafolajimi Hammed, Ayobami Samuel Akinfenwa, Enobong Hanson, Chukwuebuka Nwakile, Kolawole Osuolale Kazeem, Rebecca Juliet Ayanwunmi, Akinsanmi S Ige, Jose Refugio Parga Torres, Hassan Al Nageim Transforming waste to wealth: Harnessing carbon dioxide for sustainable solutions, Results in Surfaces and Interfaces, 100321

[20] OV Erhueh, C Nwakile, OA Akano, AE Esiri, E Hanson, Carbon capture and sustainability in LNG projects: Engineering lessons for a greener future, Global Journal of Research in Science and Technology 2 (02), 038-064

[21] OA Akano, E Hanson, C Nwakile, AE Esiri, Improving worker safety in confined space entry and hot work operations: Best practices for high-risk industries, Global Journal of Advanced Research and Reviews 2 (02), 031-039

[22] OA Akano, E Hanson, C Nwakile, AE Esiri, Designing real-time safety monitoring dashboards for industrial operations: A data-driven approach, Global Journal of Research in Science and Technology 2 (02), 001-009

[23] C Nwakile, E Hanson, YA Adebayo, AE Esiri, A conceptual framework for sustainable energy practices in oil and gas operations, Global Journal of Advanced Research and Reviews 1 (02), 031-046

[24] H Afeku-Amenyo, E Hanson, C Nwakile, YA Adebayo, AE Esiri, Conceptualizing the green transition in energy and oil and gas: Innovation and profitability in harmony Global Journal of Advanced Research and Reviews 1 (02), 001-014

[25] E Hanson, C Nwakile, YA Adebayo, AE Esiri, Conceptualizing digital transformation in the energy and oil and gas sector, Global Journal of Advanced Research and Reviews 1 (02), 015-030

[26] OV Erhueh, T Elete, OA Akano, C Nwakile, E Hanson, Application of Internet of Things (IoT) in Energy Infrastructure: Lessons for the Future of Operations and Maintenance, Comprehensive Research and Reviews in Science and Technology 2 (2)

[27] OA Akano, E Hanson, C Nwakile, AE Esiri, Designing comprehensive workforce safety frameworks for high-risk environments: A strategic approach, International Journal of Management & Entrepreneurship Research 6 (10)

[28] OA Akano, E Hanson, C Nwakile, AE Esiri, Integrating sustainability and safety in high-risk industries: A framework for balancing operational efficiency and environmental responsibility, Global Journal of Research in Multidisciplinary Studies 2 (02), 027-037

[29] OV Erhueh, C Nwakile, OA Akano, AE Esiri, E Hanson, Digital transformation in energy asset management: Lessons for building the future of energy infrastructure, Global Journal of Research in Science and Technology 2 02), 010-037

[30] OV Erhueh, C Nwakile, OA Akano, AT Aderamo, E Hanson, Advanced maintenance strategies for energy infrastructure: Lessons for optimizing rotating machinery, Global Journal of Research in Science and Technology 2 (02), 065-093

[31] OV Erhueh, C Nwakile, OA Akano, AE Esiri, E Hanson, Corrosion resistance in LNG plant design: Engineering lessons for future energy projects

[32] E Hanson, C Nwakile, YA Adebayo, AE Esiri, Strategic leadership for complex energy and oil & gas projects: A conceptual approach

[33] YA Alli, A Bamisaye, MO Bamidele, NO Etafo, S Chkirida, A Lawal, Results in Surfaces and Interfaces

[34] OV Erhueh, C Nwakile, E Hanson, AE Esiri, T Elete, Enhancing energy production through remote monitoring: Lessons for the future of energy infrastructure

[35] OV Erhueh, C Nwakile, OA Akano, AE Esiri, E Hanson, Carbon capture and sustainability in LNG projects: Engineering lessons for a greener future, Global Journal of Research in Science and Technology 2 (02), 038-064

[36] OV Erhueh, T Elete, OA Akano, C Nwakile, E Hanson, Application of Internet of Things (IoT) in Energy Infrastructure: Lessons for the Future of Operations and Maintenance, Comprehensive Research and Reviews in Science and Technology 2 (2)

[37] OV Erhueh, C Nwakile, OA Akano, AE Esiri, E Hanson, Digital transformation in energy asset management: Lessons for building the future of energy infrastructure, Global Journal of Research in Science and Technology 2 (02), 010-037

[38] OV Erhueh, C Nwakile, OA Akano, AT Aderamo, E Hanson, Advanced maintenance strategies for energy infrastructure: Lessons for optimizing rotating machinery, Global Journal of Research in Science and Technology 2 (02), 065-093

[39] OV Erhueh, C Nwakile, OA Akano, AE Esiri, E Hanson, Corrosion resistance in LNG plant design: Engineering lessons for future energy projects

[40] EO Nwulu, TY Elete, AT Aderamo, AE Esiri, OV Erhueh, Promoting plant reliability and safety through effective process automation and control engineering practices

[41] OV Erhueh, C Nwakile, E Hanson, AE Esiri, T Elete, Enhancing energy production through remote monitoring: Lessons for the future of energy infrastructure

[42] AE Esiri, OA Babayeju, IO Ekemezie, Advancements in remote sensing technologies for oil spill detection: Policy and implementation, Engineering Science & Technology Journal 5 (6), 2016-2026

[43] OA Babayeju, DD Jambol, AE Esiri, Reducing drilling risks through enhanced reservoir characterization for safer oil and gas operations

[44] AE Esiri, OA Babayeju, IO Ekemezie, Standardizing methane emission monitoring: A global policy perspective for the oil and gas industry, Engineering Science & Technology Journal 5 (6), 2027-2038

[45] AE Esiri, OA Babayeju, IO Ekemezie, implementing sustainable practices in oil and gas operations to minimize environmental footprint

[46] DD Jambol, OA Babayeju, AE Esiri, Lifecycle assessment of drilling technologies with a focus on environmental sustainability

[47] OIK Olanrewaju, GO Daramola, OA Babayeju, Transforming business models with ESG integration: A strategic framework for financial professionals, World Journal of Advanced Research and Reviews 22 (3), 554-563

[48] OA Babayeju, A Adefemi, IO Ekemezie, O Olatoye, Advancements in predictive maintenance for aging oil and gas infrastructure

[49] OIK Olanrewaju, GO Daramola, OA Babayeju, Harnessing big data analytics to revolutionize ESG reporting in clean energy initiatives, World Journal of Advanced Research and Reviews 22 (3), 574-585

[50] A Ukato, DD Jambol, C Ozowe, OA Babayeju, Leadership and safety culture in drilling operations: strategies for zero incidents, International Journal of Management & Entrepreneurship Research 6 (6), 1824-1841

[51] OO Apeh, OK Overen, EL Meyer, 2020, Monthly, seasonal and yearly assessments of global solar radiation, clearness index and diffuse fractions in alice, South Africa, Sustainability 13 (4), 2135

[52] DD Jambol, A Ukato, C Ozowe, OA Babayeju, Leveraging machine learning to enhance instrumentation accuracy in oil and gas extraction, Computer Science & IT Research Journal 5 (6), 1335-1357

[53] OA Tula, O Babayeju, E Aigbedion, Artificial Intelligence and Machine Learning in advancing competence assurance in the African energy industry, World Journal of Innovation and Modern Technology 7 (2), 83-95

[54] OO Apeh, UK Chime, S Agbo, S Ezugwu, R Taziwa, E Meyer, P Sutta, M. Maaza, and F.I., Ezema, 2019, Properties of nanostructured ZnO thin films synthesized using a modified aqueous chemical growth method, Materials Research Express 6 (5), 056406

[55] OO Apeh, EL Meyer, OK Overen, 2022, Contributions of solar photovoltaic systems to environmental and socioeconomic aspects of national development—A review, Energies 15 (16), 5963

[56] OO Sofoluwe, A Adefemi, IO Ekemezie, OA Babayeju, 2024, Challenges and strategies in high-pressure high-temperature equipment maintenance, World Journal of Advanced Engineering Technology and Sciences 12 (1), 250-262

[57] OIK Olanrewaju, P Oduro, OA Babayeju. 2024, Exploring capital market innovations for net zero goals: A data-driven investment approach, Finance & Accounting Research Journal 6 (6), 1091-1104

[58] EL Meyer, OO Apeh, OK Overen, 2020, Electrical and meteorological data acquisition system of a commercial and domestic microgrid for monitoring pv parameters, Applied Sciences 10 (24), 9092

[59] OA Tula, O Babayeju, E Aigbedion, 2023, Implementing AI and ML to Strengthen Energy Sector Competence Verification, Future and Emerging Technologies in AI & ML 2 (2), 71-77

[60] SM Mbam, RM Obodo, OO Apeh, AC Nwanya, ABC Ekwealor, N Nwulu and and F.I., Ezema, 2023, Performance evaluation of Bi2O3@GO and Bi2O3@rGO composites electrode for supercapacitor application, Journal of Materials Science: Materials in Electronics 34 (18), 1405

[61] OO Apeh, EL Meyer, OK Overen, 2021, Modeling and experimental analysis of battery charge controllers for comparing three off-grid photovoltaic power plants, Heliyon 7 (11)

[62] JL Chukwuneke, HO Orugba, HC Olisakwe, PO Chikelu, 2021, Pyrolysis of pig-hair in a fixed bed reactor: Physico-chemical parameters of bio-oil, South African Journal of Chemical Engineering 38, 115-120

[63] CH Olisakwe, LT Tuleun, CA Eloka-Eboka, Comparative study of Thevetia peruviana and Jatropha curcas seed oils as feedstock for Grease production, International Journal of Engineering Research and Application 1 (3), 793-807

[64] JL Chukwuneke, JE Sinebe, HO Orugba, HC Olisakwe, C Ajike, 2022, Production and physico-chemical characteristics of pyrolyzed bio-oil derived from cow hooves, Arab Journal of Basic and Applied Sciences 29 (1), 363-371

[65] HO Orugba, JL Chukwuneke, HC Olisakwe, IE Digitemie, 2021, Multi-parametric optimization of the catalytic pyrolysis of pig hair into bio-oil, Clean Energy 5 (3), 527-535

[66] OO Apeh, NI Nwulu, 2024, The water-energy-food-ecosystem nexus scenario in Africa: Perspective and policy implementations, Energy Reports 11, 5947-5962

[67] U Ejairu, AT Aderamo, HC Olisakwe, AE Esiri, UM Adanma, NO Solomon, 2024, Eco-friendly wastewater treatment technologies (concept): Conceptualizing advanced, sustainable wastewater treatment designs for industrial and municipal applications, Comprehensive research and reviews in Engineering and Technology 2 (1), 083-104

[68] AT Aderamo, HC Olisakwe, YA Adebayo, AE Esiri, 2024, Financial management and safety optimization in contractor operations: A strategic approach

[69] AT Aderamo, HC Olisakwe, YA Adebayo, AE Esiri, 2024, Conceptualizing emergency preparedness in offshore operations: A sustainable model for crisis management

[70] OK Overen, KC Obileke, EL Meyer, G Makaka, OO Apeh, 2024, A hybrid solar–biogas system for post-COVID-19 rural energy access, Clean Energy 8 (1), 84-99

[71] AT Aderamo, HC Olisakwe, YA Adebayo, AE Esiri, 2024, Leveraging AI for financial risk management in oil and gas safety investments, Computer science and IT research journal 5 (10), 2216-2243

[72] KO Omomo, AE Esiri, HC Olisakwe, 2024, Advanced fluid recovery and recycling systems for offshore drilling: A conceptual approach, Engineering Science & Technology Journal 5 (10)

[73] OO Apeh, N Nwulu, 2024, The Food-Energy-Water Nexus Optimization: A Systematic Literature Review, Research on World Agricultural Economy, 247-269

[74] KO Omomo, AE Esiri, HC Olisakwe, 2024, A conceptual model for sustainable cementing operations in offshore wells, Global journal of research in Engineering and technology

[75] KO Omomo, AE Esiri, C Olisakwe, Henry, 2024, Hydraulic modeling and real-time optimization of drilling fluids: A future perspective, Global journal of research in Engineering and Technology 2 (2), 030-038

[76] CH Olisakwe, KK Ikpambese, DT Ipilakyaa, EI Ekengwu, 2022, The Inhibitive Effect of Ficus Thonningii Leaves Extract in 1m HCL Solution as Corrosion Inhibitors on Mild Steel, Int J Innov Sci Res Tech 7 (1), 769-76

[77] KO Omomo, AE Esiri, HC Olisakwe, 2024, Next-generation drilling fluids for horizontal and multilateral wells: A conceptual approach, Global journal of research in Engineering and Technology 2 (2), 011-019

[78] P Chikelu, S Nwigbo, O Azaka, H Olisakwe, A Chinweze, 2022, Modeling and simulation study for failure prevention of shredder rotor bearing system used for synthetic elastic material applications, Journal of Failure Analysis and Prevention 22 (4), 1566-1577

[79] CO Eze, OC Okafor, IE Ekengwu, OG Utu, HC Olisakwe, 2022, Effect of cutting fluids application on the cutting temperature and drilling time of mild steel material, Global Journal of Engineering and Technology Advances 10 (2), 1-8

[80] UM Adanma, EO Ogunbiyi, 2024, A comparative review of global environmental policies for promoting sustainable development and economic growth, International Journal of Applied Research in Social Sciences 6 (5), 954-977

[81] UM Adanma, EO Ogunbiyi, 2024, Artificial intelligence in environmental conservation: evaluating cyber risks and opportunities for sustainable practices, Computer Science & IT Research Journal 5 (5), 1178-1209

[82] UM Adanma, EO Ogunbiyi, 2024, Evaluating the effectiveness of global governance mechanisms in promoting environmental sustainability and international relations, Finance & Accounting Research Journal 6 (5), 763-791

[83] UM Adanma, EO Ogunbiyi, 2024, Assessing the economic and environmental impacts of renewable energy adoption across different global regions, Engineering Science & Technology Journal 5 (5), 1767-1793

[84] UM Adanma, EO Ogunbiyi, 2024, The public health benefits of implementing environmental policies: A comprehensive review of recent studies, International Journal of Applied Research in Social Sciences 6 (5), 978-1004

[85] EO Ogunbiyi, E Kupa, UM Adanma, NO Solomon, 2024, Comprehensive review of metal complexes and nanocomposites: Synthesis, characterization, and multifaceted biological applications, Engineering Science & Technology Journal 5 (6), 1935-1951

[86] E Kupa, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, Assessing agricultural practices in seismically active regions: Enhancing HSE protocols for crop and livestock safety, International Journal of Applied Research in Social Sciences 6 (6), 1084-1102

[87] E Kupa, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, Geologic considerations in agrochemical use: impact assessment and guidelines for environmentally safe farming

[88] E Kupa, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, Groundwater quality and agricultural contamination: A multidisciplinary assessment of risk and mitigation strategies, World Journal of Advanced Research and Reviews 22 (2), 1772-1784

[89] E Kupa, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, Cultivating a culture of safety and innovation in the FMCG sector through leadership and organizational change, International Journal of Management & Entrepreneurship Research 6 (6), 1787-1803

[90] I Aiguobarueghian, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, Waste management and circular economy: A review of sustainable practices and economic benefits, World Journal of Advanced Research and Reviews 22 (2), 1708-1719

[91] EC Osuagwu, AM Uwaga, HP Inemeawaji, 2023, Effects of leachate from osisioma open dumpsite in aba, Abia State, Nigeria on Surrounding Borehole Water Quality, Water Resources Management and Sustainability: Solutions for Arid Regions

[92] I Aiguobarueghian, UM Adanma, EO Ogunbiyi, NO Solomon, 2023, Reviewing the effectiveness of plastic waste management in the USA, World Journal of Advanced Research and Reviews 22 (2), 1720-1733

[93] E Kupa, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, Environmental stewardship in the oil and gas industry: A conceptual review of HSE practices and climate change mitigation strategies, Engineering Science & Technology Journal 5 (6), 1826-1844

[94] I Aiguobarueghian, UM Adanma, EO Ogunbiyi, NO Solomon, 2024, An overview of initiatives and best practices in resource management and sustainability, World Journal of Advanced Research and Reviews 22 (2), 1734-1745

[95] U Ejairu, AT Aderamo, HC Olisakwe, AE Esiri, UM Adanma, NO Solomon, 2024, Eco-friendly wastewater treatment technologies (concept): Conceptualizing advanced, sustainable wastewater treatment designs for industrial and municipal applications

[96] EK Ikponmwosa Aiguobarueghian, Uwaga Monica Adanma, 2024, Land use Dynamics and Bioenergy: A critical Review of Environmental and Socioeconomic Interactions, World Journal of Advanced Research and Reviews 23 (2024), 5

[97] I Onochie, Obanor, Aliu, 2017, Proximate and Ultimate Analysis of Fuel Pellets from Oil Palm Residues, Nigerian Journal of Technology 36 (3), 987 – 990

[98] EJ Onyiriuka, OO Ighodaro, AO Adelaja, DRE Ewim, S Bhattacharyya, 2019, A numerical investigation of the heat transfer characteristics of water-based mango bark nanofluid flowing in a double-pipe heat exchanger, Heliyon 5 (9)

[99] CC Kwasi-Effah, O Ighodaro, HO Egware, AI Obanor, 2022, Characterization and comparison of the thermophysical property of ternary and quaternary salt mixtures for solar thermal power plant applications, Results in Engineering 16, 100721

[100] CC Kwasi-Effah, O Ighodaro, HO Egware, AI Obanor, 2022, A novel empirical model for predicting the heat accumulation of a thermal energy storage medium for solar thermal applications, Journal of Energy Storage 56, 105969

[101] CC Kwasi-Effah, HO Egware, AI Obanor, OO Ighodaro, 2023, Development and characterization of a quaternary nitrate based molten salt heat transfer fluid for concentrated solar power plant, Heliyon 9 (5)

[102] CC Kwasi-Effah, OO Ighodaro, HO Egware, AI Obanor, 2023, Recent progress in the development of thermal energy storage mediums for solar applications, Journal of Engineering for Development

[103] O Ighodaro, D Akhihiero, 2021, Modeling and performance analysis of a small horizontal axis wind turbine, Journal of Energy Resources Technology 143 (3), 031301

[104] OO Ighodaro, K Scott, L Xing, 2017, An isothermal study of the electrochemical performance of intermediate temperature solid oxide fuel cells, Journal of Power and Energy Engineering 5 (2), 97-122

[105] AO Ibrahim, OO Ighodaro, SK Fasogbon, EF Orumwense, MA Waheed, 2023, Failure investigation of the tube of a dual fired steam boiler in a western nigerian food and beverage manufacturing plant, Engineering Failure Analysis 143, 106906

[106] JO Asibor, O Ighodaro, 2019, Steady State Analysis of Nanofuel DropletEvaporation International Journal of Nanoscience and Nanotechnology 15 (3), 145-155

[107] BA O Ighodaro, 2011, Exergetic appraisal of Delta IV Power Station, Ughelli Journal of Emerging Trends in Engineering and Applied Science 2 (2), 216-218

[108] OO Ighodaro, M Osikhuemhe, 2019, Thermo-economic analysis of a heat recovery steam generator combined cycle, Nigerian Journal of Technology 38 (2), 342-347

[109] HO Egware, OO Ighodaro, 2023, Evaluating the effect of ambient air temperature on the exergy sustainability of a 153MW gas turbine power plant, International Journal of Thermofluids 18, 100375

[110] UP Onochie, 2019, A comprehensive review on biomass pelleting Technology and electricity generation from biomass, Journal of Energy Technology and Environment 1

[111] HO Egware, AI Obanor, AN Aniekwu, OI Omoifo, OO Ighodaro, 2021, Modelling and simulation of the SGT5–2000E gas turbine model for power generation, Journal of Energy Technology and Environment 3 (2)

[112] UP Onochie, AL Obanor, SA Aliu, OO Ighodaro, 2017 Fabrication and performance evaluation of a pelletizer for oil palm residues and other biomass waste materials, Journal of the Nigerian Association of Mathematical Physics 40, 443-446