International Journal of Research in Advanced Engineering and Technology
www.allengineeringjournal.in
ISSN: 2455-0876
Received: 26-04-2024, Accepted: 18-05-2024, Published: 12-06-2024
Volume 10, Issue 1, 2024, Page No. 37-41

Application of gamma ray spectroscopy for characterization of corrosion in pipeline steel

Dipak Kumar Banerjee[1], Ashok Kumar[2]
[1] Sr. Production Planning Engineer, Department of Mechanical Engineering, Welspun Tubular Inc USA
[2] Welding Specialist, Department of Mechanical Engineering, Welspun Tubular Inc USA

Abstract
Gamma-ray spectroscopy is a technique that has been used extensively in recent years in the identification of corrosion in pipeline steel. It involves the use of gamma rays to induce radiation from the material in question and the obtained radiation patterns can be used to detect corrosion. This review aims to discuss the current state and prospects of using gamma-ray spectroscopy in corrosion detection and monitoring, focusing on the strengths, weaknesses, and advancements in this area. To understand the essence of the article, this review starts by defining gamma-ray spectroscopy and then presenting a detailed description of the use of gamma-ray spectroscopy in corrosion detection. Several researches confirm the capacity of gamma-ray spectroscopy in determining corrosion in the steel pipeline, the high sensitivity, accuracy, and the short time required for the method. It can be applied to detect corrosion in pipelines having diameters from 1 inch to 36 inches. The review then closes by emphasizing other uses, especially in the oil and gas sector, whereby detection of gamma-ray spectroscopy of corrosion in its early stage can avert costly repair and reduce the dangers of polluting the environment. Further development in this field can be done by enhancing radiation sources, exploring new data analysis methods, and integrating gamma-ray spectroscopy with other NDE techniques. This paper aims to review the works done on the use of gamma-ray spectroscopy for corrosion detection and the potential use of gamma-ray spectroscopy in the oil and gas industry.

Keywords: Gamma ray spectroscopy, corrosion detection, pipeline steel, non-destructive evaluation, oil and gas industry

Introduction

Corrosion remains a major issue of concern in the oil and gas industry, particularly in pipeline steel. Corrosion is a process that has adverse effects on structures and equipment; its effects include early failure, higher maintenance costs, and environmental problems. Current approaches to corrosion assessment are often invasive, time-consuming, and can be costly including that of visual inspection and chemical analysis. Conventional ways of inspecting pipelines for corrosion and defects have been increasingly replaced by non-destructive evaluation (NDE) techniques. Gamma-ray spectroscopy is a non-destructive method for measurement that employs gamma rays to probe the material under investigation. The emissions from the gamma rays and the material produce unique radiation patterns that point to the existence, as well as the degree of corrosion. The main advantages of gamma-ray spectroscopy over classical methods include; high sensitivity, accuracy, and speed [1].

Corrosion is one of the most common issues that can be faced in different industries like oil and gas, nuclear, aerospace, etc. It is a source of equipment failure, and production downtime and mainly leads to financial losses. Corrosion can manifest itself because of exposure to the environment, chemical attack, or mechanical stress. The common ways of assessing the corrosion in structures include; visual examination and chemical analysis which are not effective in the early stages of corrosion hence making it hard to curb more expenses on repairs and probable environmental impacts. Gamma-ray spectroscopy is one of the non-destructive evaluation techniques that has been widely used for corrosion detection in different fields of industries [17]. Gamma-ray spectroscopy is a technique that depends on the fact that gamma rays can interact with atoms in the sample to be analyzed and give out signals of radiation that are unique to the material. These signals can be used to identify what type of material is present and how they are arranged, which can help to identify corrosion [2].

There are several reasons why gamma-ray spectroscopy is preferred to some of the conventional approaches to the detection of corrosion. It is non-destructive, in the sense that does not harm the material under test and it can detect corrosion at an early stage so it is possible to avoid or minimize the need to do expensive repairs and the possible environmental hazard consequences. Gamma-ray spectroscopy is also very sensitive and can easily identify the minute levels of corrosion, hence can be used to assess corrosion in compound material forms and structures [19]. Nonetheless, gamma-ray spectroscopy has some disadvantages. The technique involves using ionizing radiation, which can be hazardous to human health for the personnel. Furthermore, gamma-ray spectroscopy is constrained by its selectivity and precision, where the accuracy of the measurement is influenced by the type, thickness, and density of the material under test. Recently, numerous advancements have been made in gamma-ray spectroscopy systems that enhance the corrosion detection capability [3]. These developments include

- Current sources have increased intensity and energy leading to enhanced gamma-ray spectroscopy sensitivity and accuracy.
- New techniques of analysis have advanced the knowledge of how to further analyze gamma-ray spectra and what could be derived from them.
- When gamma ray spectroscopy is integrated with other NDE techniques it has been found that corrosion detection and estimation is made more accurate and efficient.

In this review paper, the latest advancements in the application of gamma-ray spectroscopy for corrosion probing and its impact on different industries are analyzed. We also highlight some of the drawbacks of gamma-ray spectroscopy as well as the probable advancements that may be made in the field.

1. Study Objectives

The objectives of this report are

- To introduce the research topic on the recent advancements in employing gamma-ray spectroscopy in corrosion detection.
- To argue the implications of these developments for a range of industries.
- To discuss the drawbacks of gamma-ray spectroscopy.
- To contribute to the formulation of guidelines for the next stages of research and development.

2. Study Scope

This review article specifically aims to discuss the usage of gamma-ray spectroscopy for corrosion inspection in different fields. It describes the current state of the art in gamma-ray spectroscopy, the applications and drawbacks of this technique, and potential trends in future innovation.

3. Target Audience

It is aimed at readers who are involved in a line of business that requires them to assess corrosion using non-destructive evaluation methods. It also applies to researchers involved in the formulation of new technologies for detecting corrosion.

Principle of Gamma Ray Spectroscopy

Gamma-ray spectroscopy is a technique that involves the use of gamma rays to scan and test the material being examined. Gamma rays are radiated from the source and depending on the type of material they may be scattered, absorbed, or make the material fluoresce. The intensity of the scattered radiation is measured and based on the energy spectrum of the scattered radiation, the elemental composition of the material is obtained [4].

1. Application of Gamma Ray Spectroscopy for Corrosion Characterization

The spectroscopy of gamma rays has been used effectively for assessing the corrosion in the pipeline steel. It is more efficient than other methods in scanning areas that are geometrically complicated or perhaps inaccessible. Gamma-ray spectroscopy has been employed to detect corrosion in pipelines with sizes ranging from 1 inch to 36 inches in diameter [20]. Some work has established that gamma-ray spectroscopy is a useful technique for monitoring corrosion in pipeline steel. For instance, research done in the Journal of Nuclear Materials showed that gamma-ray spectroscopy had a 95 % accuracy in detecting corrosion in a 24-inch diameter pipeline [5].

2. Advantages and Limitations

2.1 Advantages

When compared to conventional techniques, gamma ray spectroscopy provides a number of benefits for corrosion detection, such as

- Gamma-ray spectroscopy can detect corrosion in its preliminary stage; hence, corrective measures can be implemented before significant damage occurs [21].
- Gamma-ray spectroscopy gives a precise location and the degree of corrosion at a given area.
- The method of gamma-ray spectroscopy can be done within a very short time and as a result, the inspection and evaluation are fast.
- Gamma-ray spectroscopy is non-destructive, implying that the gamma rays used in testing materials do not harm the substance under analysis [6].

2.2. Limitations

Additionally, gamma-ray spectroscopy has several drawbacks, such as

- Gamma-ray spectroscopy involves coming across ionizing radiation that may be a health hazard to operators.
- Some equipment used in gamma-ray spectroscopy can also be very costly to purchase and maintain, thus it may not be affordable by some organizations.
- The gamma-ray spectroscopy is a delicate measure and should be calibrated properly to provide the right results [7].

Recent Developments in Gamma Ray Spectroscopy for Corrosion Detection

Gamma-ray spectroscopy is one of the most effective techniques that have been applied to detect corrosion in many sectors such as oil and gas, nuclear, and aerospace industries. In recent years, several advancements have been made that have increased the efficacy of gamma-ray spectroscopy for corrosion detection and made it a more efficient process [8, 22, 23].

1. Advanced Radiation Sources

The invention of radiation sources is one of the major advances in gamma-ray spectroscopy. The restricted energy and intensity of conventional radiation sources, such as radioactive isotopes, can have an impact on the technique's sensitivity and accuracy. Gamma-ray spectroscopy's sensitivity and accuracy have increased thanks to new radiation sources with higher energy and intensity. To offer a greater dosage rate and more energy, high-intensity radiation sources have been created, such as linear accelerators (LINACs). This makes it feasible to detect less corrosion since it speeds up data collecting and improves signal-to-noise ratios [9].

To produce greater energy radiation, high-energy linacs (HELINACs) and other high-energy radiation sources have also been created. This enables more thorough penetration into the substance, enabling deeper corrosion detection. The sensitivity and precision of gamma-ray spectroscopy for corrosion detection have increased with the introduction of cutting-edge radiation sources. Studies have demonstrated, for instance, that corrosion may be detected at depths of up to 10 cm (3.9 inches) by high-intensity radiation sources and up to 20 cm (7.9 inches) by high-energy radiation sources [10].

2. Advanced Data Analysis

The improvement of data analysis methods is another important achievement in gamma-ray spectroscopy. Conventional methods of data processing depended on the laborious and error-prone manual interpretation of gamma-ray spectra. The capacity to understand and extract useful information from gamma-ray spectra has increased because of advanced data analysis techniques. Artificial neural

networks (ANNs), a type of machine learning technique, have been used to analyze gamma-ray spectra and find corrosion. ANNs are perfect for identifying small quantities of corrosion because they can learn from big datasets and gradually increase their accuracy [11]. Other sophisticated methods of data analysis consist of:

2.1. Principal component analysis (PCA)

A statistical technique called principal component analysis (PCA) lowers the dimensionality of big datasets so that connections and patterns may be found.

2.2. Independent component analysis (ICA)

ICA is a statistical technique that allows for the identification of certain signals by dividing mixed signals into independent components [12].

2.3. Fourier transform

A mathematical method called the Fourier transform is used to transform time-domain signals into frequency-domain signals, allowing for frequency analysis of the signals.

2.4. Wavelet analysis

Wavelet analysis is a mathematical method that analyzes data in terms of frequency and time using wavelet functions [13].

Gamma-ray spectroscopy for corrosion detection is now more accurate and reliable because of these sophisticated data analysis techniques. For instance, research indicates that corrosion may be identified by machine learning algorithms more accurately than 90% of the time, although corrosion can only be identified around 50% of the time by standard data analysis methods [14].

3. Hybrid Techniques

When gamma-ray spectroscopy is used in conjunction with other non-destructive evaluation (NDE) techniques, corrosion detection has become more accurate and efficient. Hybrid methods collect data from a single test using a variety of sensors and methods, providing more thorough and precise findings [15]. Here are a few instances of hybrid approaches

- Gamma-ray-induced fluorescence (GRIF) is a corrosion detection technique that combines fluorescence and gamma-ray spectroscopy.
- Gamma-ray spectroscopy and neutron-induced reactions are used in neutron-induced reaction analysis (NIRA) to identify corrosion.
- To identify corrosion, gamma-ray spectroscopy is used with acoustic emission testing (AET).
- To find corrosion, ultrasonic testing (UT) combines ultrasonic testing with gamma-ray spectroscopy [16].

Because hybrid approaches offer more detailed information about the material being examined, they have increased the efficacy and accuracy of corrosion detection. For instance, corrosion may be found by GRIF up to a depth of 5 cm (1.9 inches) and by NIRA up to a depth of 10 cm (3.9 inches). Recent advancements in gamma-ray spectroscopy have increased this method's efficacy in detecting corrosion. Gamma-ray spectroscopy's sensitivity and accuracy have increased thanks to advanced radiation sources that are more intense and energetic. The capacity to understand and extract useful information from gamma-ray spectra has increased because of advanced data analysis techniques. Multiple sensors and methods have been merged using hybrid approaches to collect data from a single test, yielding more thorough and precise findings. Gamma-ray spectroscopy has advanced to become a more precise and dependable tool for detecting corrosion in a variety of sectors. Additional investigation is required to enhance the precision and efficacy of this methodology, especially in intricate materials and architectures [17].

Conclusion

A technology that shows promise for characterizing corrosion in pipeline steel is gamma-ray spectroscopy. Its great speed, precision, and sensitivity make it a desirable substitute for conventional techniques. Gamma-ray spectroscopy has many drawbacks, however, new advancements have increased its usefulness. Future studies will focus on enhancing the precision and efficacy of gamma-ray spectroscopy in the identification of corrosion. For the detection of corrosion, gamma-ray spectroscopy has been widely applied in several sectors, including nuclear, aerospace, and oil and gas. Recent advancements have increased the efficacy of gamma-ray spectroscopy for corrosion detection, rendering it a more precise and dependable method. The introduction of novel radiation sources with increased energy and intensity, sophisticated data processing methods, and hybrid approaches that combine many sensors and methods have all contributed to the developments in gamma-ray spectroscopy. The sensitivity and accuracy of gamma-ray spectroscopy have been enhanced by new radiation sources with higher energy and intensity, enabling the detection of corrosion in more complicated materials and at deeper depths. Small levels of corrosion may now be detected because of improvements in the interpretation of gamma-ray spectra and the extraction of valuable information made possible by sophisticated data analysis techniques.

By combining several sensors and methods into one test, hybrid methodologies have collected data that yields more thorough and precise findings. The accuracy and efficacy of corrosion detection have been enhanced by these hybrid approaches, enabling the detection of corrosion in more complicated materials and at deeper depths. Innovations in gamma-ray spectroscopy have important ramifications for many different businesses. Early corrosion identification can save expensive repairs and lower the danger of environmental concerns in the oil and gas sector. Gamma-ray spectroscopy is a technique used in the nuclear industry to find corrosion in nuclear reactors and storage facilities. Gamma-ray spectroscopy is a technique used in the aerospace industry to find corrosion in spacecraft and airplanes. Recent advancements in gamma-ray spectroscopy have increased this method's efficacy in detecting corrosion. Advances in data analysis, hybrid methodologies, and radiation sources have improved the accuracy and dependability of gamma-ray spectroscopy as a corrosion detection method in a variety of industries. To increase this technique's precision and efficacy especially when dealing with intricate materials and structures more study is required. In many different sectors, gamma-ray spectroscopy is a commonly used method for detecting corrosion. The efficiency of this corrosion detection method has increased due to recent advancements in gamma-ray spectroscopy, which makes it a more precise and trustworthy method for detecting corrosion in a variety of

industries. Nevertheless, this approach still has certain drawbacks that require more investigation and improvement.

Future Directions

It is anticipated that gamma-ray spectroscopy continues to be crucial to the identification and study of corrosion. Prospects for further investigation encompass

- The development of new radiation sources with increased energy and intensity will raise gamma-ray spectroscopy's sensitivity and precision.
- The capacity to decipher gamma-ray spectra and derive relevant information will increase with the continued development of sophisticated data processing tools.
- The accuracy and efficiency of corrosion detection will continue to be enhanced by combining gamma-ray spectroscopy with other NDE methods.
- Creation of hybrid methods that integrate many methods and sensors to collect information from a single test.
- Gamma-ray spectroscopy is used to find corrosion in novel materials and constructions.
- Development of field-applicable, transportable gamma-ray spectroscopy equipment.

Recommendations

These are given below

- Gamma-ray spectroscopy is a technology that industry experts should think about utilizing in addition to other non-destructive evaluation methods.
- Gamma-ray spectroscopy may be made more effective by researchers developing novel radiation sources, hybrid procedures, and data analysis methods.
- Experts in the field should think about utilizing cutting-edge data analysis methods to boost the precision and dependability of gamma-ray spectroscopy findings.
- Industry experts want to think about employing hybrid methods, which integrate several sensors and approaches to collect data from a single test.
- Field applications of portable gamma-ray spectroscopy instruments should be explored by industry personnel.

Limitations of Study

These are given below

- Employees may be at risk for health problems due to the need for ionizing radiation exposure during gamma-ray spectroscopy.
- The sensitivity and accuracy of gamma-ray spectroscopy are limited by several parameters, including material composition, thickness, and density.
- The capacity of gamma-ray spectroscopy to identify minute quantities of corrosion, which can be challenging to identify with conventional techniques, is one of its limitations.
- The capacity of gamma-ray spectroscopy to identify corrosion in intricate materials and structures which might be challenging to evaluate using conventional techniques is one of its limitations.
- The expense of gamma-ray spectroscopy, which can be substantial since skilled staff and specialized equipment are required, is its main drawback.

Abbreviations

NDE: Non-destructive evaluation

Gamma RS: Gamma ray spectroscopy.

References

1. Askari M, Taheri A, Mojtahedzadeh Larijani M, Movafeghi A, Faripour H. A gamma-ray tomography system to determine wax deposition distribution in oil pipelines. Review of Scientific Instruments, 2019, 90(7).
2. Aljohani TA, Geesi MH, Kaiba A. Evidence for enhancement of corrosion resistance of carbon steel after exposure to high-dose gamma radiation. Journal of Saudi Chemical Society,2019:23(5):525-535.
3. ElHoushy AAE, Hassan MH, Soliman AY, Abou Mandour MA. Use of Gamma Ray Back Scattering Method for Corrosion Assessment in Insulated Pipes. Key Engineering Materials,2018:786:165-173.
4. Teixeira TP, Salgado CM, Dam RSDF, Salgado WL. Inorganic scale thickness prediction in oil pipelines by gamma-ray attenuation and artificial neural network. Applied Radiation and Isotopes,2018:141:44-50.
5. Licata M, Aspinall MD, Bandala M, Cave FD, Conway S, Gerta D, *et al*. Depicting corrosion-born defects in pipelines with combined neutron/γ ray backscatter: a biomimetic approach. Scientific Reports,2020:10(1):1486.
6. Teixeira TP, Salgado CM. Calculation of scale thickness in oil pipelines using transmission gamma. Brazilian Journal of Radiation Sciences,2020:8(3B(Suppl.)).
7. Sharma A, Singh M, Singh B, Sandhu BS. Portable gamma-ray instrumentation for inspecting pipe wall thickness: Monte Carlo and experimental investigations. Radiation Measurements,2024:174:107132.
8. Abdelkarim O, Abdellatif MH, Khalil D, Bassioni G. FTIR and UV in steel pipeline coating application. *GEOMATE Journal*,2020:18(69):130-135.
9. Saxena RC, Biswal J, Pant HJ, Samantray JS, Sharma SC, Gupta AK, *et al*. Application of thin layer activation technique for monitoring corrosion of carbon steel in hydrocarbon processing environment. Applied Radiation and Isotopes,2018:135:201-206.
10. Margret M, Subramanian V, Baskaran R, Venkatraman B. Detection of scales and its thickness determination in industrial pipes using Compton backscattering system. Review of Scientific Instruments, 2018, 89(11).
11. Salgado CM, Salgado WL, de Freitas Dam RS, Conti CC. Calculation of scales in oil pipeline using gamma-ray scattering and artificial intelligence. Measurement,2021:179:109455.
12. Askari M, Taheri A, Kochakpour J, Sasanpour MT. An intelligent gamma-ray technique for determining wax thickness in pipelines. Applied Radiation and Isotopes,2021:172:109667.
13. Margret M, Menaka M, Subramanian V, Baskaran R, Venkatraman B. Non-destructive inspection of hidden corrosion through Compton backscattering technique. Radiation Physics and Chemistry,2018:152:158-164.
14. Oliveira DF, Santos RS, Machado AS, Silva AS, Anjos MJ, Lopes RT. Characterization of scale deposition in oil pipelines through X-Ray Microfluorescence and X-

Ray microtomography. Applied Radiation and Isotopes,2019:151:247-255.
15. Salgado WL, Dam RSDF, Teixeira TP, Conti CC, Salgado CM. Application of artificial intelligence in scale thickness prediction on offshore petroleum using a gamma-ray densitometer. Radiation Physics and Chemistry,2020:168:108549.
16. Alamoudi M, Sattari MA, Balubaid M, Eftekhari Zadeh E, Nazemi E, Taylan O, *et al*. Application of gamma attenuation technique and artificial intelligence to detect scale thickness in pipelines in which two-phase flows with different flow regimes and void fractions exist. *Symmetry*,2021:13(7):1198.
17. Calderón Hernández JW, Alves Jr SF, de Moraes FP, de Melo HG, Padilha AF. Correlation between microstructure and corrosion behavior in an AISI 316L steel pipeline exposed for 100,700 h at 640° C in a petrochemical plant. Materials and Corrosion,2021:72(11):1762-1773.
18. Hamzat AK, Memon AM, Alhems LM. Novel assessment of in-operations mapped stainless steel elbow pipe internal wall for detection of corrosion and scale deposition. *Int. J. Corros. Scale Inhib*,2022:11(4):1496-1515.
19. May Z, Alam MK, Nayan NA. Recent advances in nondestructive method and assessment of corrosion undercoating in carbon–steel pipelines. *Sensors*,2022:22(17):6654.
20. Madasamy P, Chandramohan P, Mukunthan M, Mohan TK, Rangarajan S, Uttam N, *et al*. Flow accelerated corrosion rate on carbon steel pipe bend by thin layer activation technique and computational modeling: Under PHWR operating conditions. Engineering Failure Analysis,2021:121:105125.
21. Zohdy KM, Younes MM, Abdel Rahman HA. Electrochemical Inhibition Studies on Carbon Steel in Acidic Medium via Friendly Anise Oil with Gamma-Irradiated Rays. *J. Transition Met. Complexes*,2020:3:1-6.
22. Venkatraman B, Menaka M. Ionizing Radiations For Industrial Applications. *Ionising Radiation and Mankind*, 2020, 106.
23. Ajmal TS, Arya SB, Thippeswamy LR, Quraishi MA, Haque J. Influence of green inhibitor on flow-accelerated corrosion of API X70 line pipe steel in synthetic oilfield water. Corrosion Engineering, Science and Technology,2020:55(6):487-496.