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COMPARATIVE ANALYSIS OF RADIOGRAPHIC INSPECTION TECHNIQUES IN OIL AND GAS PIPELINE

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Abstract: The oil and gas industry continually faces challenges in maintaining the integrity and safety of its extensive pipeline networks. Traditional reactive maintenance strategies have often resulted in catastrophic failures, environmental damage, and significant production disruptions. This study advocates for a proactive safety management framework inspired by the Total Production System. Central to this framework is the comparative analysis of advanced radiographic inspection technologies. Various radiographic techniques are employed to detect critical defects such as corrosion and weld inconsistencies, enabling preventive measures before failures occur. This approach aims to enhance safety, environmental protection, and operational efficiency while minimizing costs. Research indicates that proactive maintenance, including radiographic inspection, can reduce pipeline failure rates by up to 70%, yielding substantial cost savings. This paper explores the current state of pipeline safety, critiques traditional practices, and provides a detailed comparative analysis of different radiographic inspection techniques, evaluating their effectiveness, cost-efficiency, and practical applications. By embracing innovation and prioritizing risk mitigation, the oil and gas industry can ensure the secure and sustainable delivery of energy resources.

Keywords: Radiographic inspection, non-destructive testing, pipeline integrity, weld defects, oil and gas, X-rays, gamma rays, Fe^{2+} carbon steel, environmental impact.

I. Introduction

The oil and gas industry relies heavily on an extensive network of pipelines for the transportation of vital resources. Ensuring the integrity and safety of these pipelines is a persistent challenge. Traditional maintenance strategies, characterized by a reactive "fix-it-when-broken" approach, have proven inadequate in preventing catastrophic failures, as evidenced by incidents like the 2014 GAIL pipeline explosion in Andhra Pradesh. This report proposes a shift towards a proactive safety management framework, inspired by successful models like the Total Production System. Emphasizing risk assessment, preventive measures, and the integration of advanced inspection technologies, particularly radiographic inspection techniques augmented by sophisticated image analysis algorithms, this approach aims to identify and address critical defects such as corrosion and weld inconsistencies early, thus mitigating risks and enhancing operational efficiency. This paper delves into the comparative analysis of various radiographic inspection techniques, evaluating their effectiveness and limitations within the context of pipeline safety.

II. Comparative Analysis of Radiographic and Non-Destructive Testing Methods in Pipeline Inspection

II 1. Summary of Relevant Studies

Defect Detection in Magnetic Flux Leakage Images

Jackson Daniel's study, "Defect Detection and Characterization in Magnetic Flux Leakage Images of Steam Generator Tubes,"[1] focuses on improving defect detection precision. Utilizing COMSOL modeling and Daubechies 4 wavelet filtering, the study constructs databases for circular and rectangular defects. Tsallis entropy-based segmentation is identified as optimal, demonstrating superior performance. The defect classification algorithm achieves high accuracy rates, and for defect sizing, Gray Level Co-occurrence matrix features are most effective. The methodologies proposed show exceptional accuracy in characterizing minimal-sized defects in magnetic flux leakage images of steam generator tubes.

In Situ Monitoring of Pipelines

Sugin Elankavi R's research, "In Situ Monitoring of Pipelines Using Semi-Autonomous Inspection Robots," [2] explores the use of semi-autonomous inspection robots for pipeline monitoring. The study finds that these robots enable real-time monitoring, efficient data collection, and inspection without disrupting operations. The technology is promising for enhancing pipeline safety and integrity, offering a viable solution for in situ monitoring.

Sub-Sea Gas Pipeline Leak Detection

P. C. Sridher's study, "Validating Sub-Sea Gas Pipeline Leaks Discharge Model for Arabian Sea Conditions," [3] successfully validates a model for predicting gas pipeline leaks. The research shows the model's accuracy in estimating leak discharges, contributing to better understanding and management of sub-sea gas pipeline behavior under specific environmental conditions.

Radiographic Testing Overview

Anup Kumar Dey's article, "Radiographic Testing: Principle, Procedure, Standards, Advantages, and Disadvantages," [4] provides a comprehensive overview of radiographic testing in non-destructive evaluation. It highlights the high sensitivity of radiographic testing, its principles, procedures, and standards, while also noting limitations such as radiation exposure and equipment costs.

Failure Analysis of Gas Pipelines

M. Bakhtiar Azim et al.'s research, "Failure Analysis of a Gas Pipeline," [5] investigates gas pipeline failure causes. The study emphasizes understanding failure mechanisms and proactive maintenance strategies to prevent catastrophic incidents, ultimately contributing to enhanced pipeline integrity and safety.

Subsea Pipeline Inspection Systems

The review paper by Ho, Michael; El-Borgi, Sami; Patil, Devendra; Song, Gangbing, "Inspection and Monitoring Systems for Subsea Pipelines," [6] surveys various technologies for subsea pipeline inspection and monitoring. It highlights the importance of advanced systems in ensuring subsea pipeline integrity and reliability.

Radiography Inspection for Pipeline Failures

Vusumuzi Samuel Mbizani Manny Mathuthu's research, "Reduction of Gas and Oil Pipeline Failures Using Radiography Inspection Technique," [7] stresses the effectiveness of radiography inspection in reducing pipeline failure rates. It provides a promising approach for enhancing safety and reliability in gas and oil pipelines through proactive inspection measures

In-Line Pipeline Inspection Methods

The article by Ma, Q.; Tian, G.; Zeng, Y.; Li, R.; Song, H.; Wang, Z.; Gao, B.; Zeng, K., "Pipeline In-Line Inspection Method, Instrumentation and Data Management,"[8] explores in-line inspection methods, instrumentation, and data management for pipelines. It underscores integrating advanced inspection methods with efficient data management to optimize pipeline inspection processes.

Non-Destructive Testing in Oil and Gas Industries

Batta Mahesh's research, "Application of Non-Destructive Testing in Oil and Gas Industries,"[9] highlights the broad applications of NDT techniques. The study emphasizes the role of NDT methods in ensuring the structural integrity of assets in the oil and gas industries, contributing to enhanced safety and reliability.

III. Radiographic Inspection Techniques

Radiographic Testing (RT) is a non-destructive testing method widely used in the oil and gas industry to inspect the internal structure of materials, particularly welds in pipelines. This technique employs X-rays or gamma rays to produce images of the internal features of a component, allowing for the detection of any defects or irregularities that may compromise the integrity of the structure.

III 1. RT Techniques in Pipeline Inspection

X-ray Radiography operates on the principle that X-rays, produced by an X-ray tube, are directed through the material and captured on a detector or film on the opposite side. This method is particularly effective for inspecting thinner materials and components due to the lower penetration power of X-rays compared to gamma rays. The main advantages of X-ray radiography include high image quality and resolution, although it is limited by its penetration depth and requires substantial shielding to ensure safety.

Gamma Radiography, on the other hand, uses gamma rays emitted from radioactive isotopes such as Iridium-192 or Cobalt-60. These rays pass through the material and are captured on a photographic film or digital detector. Gamma radiography is ideal for inspecting thicker materials and large pipelines due to its greater penetration depth. However, this technique requires strict safety protocols because of the use of radioactive materials.

III 2. Process of Radiographic Inspection

The process of radiographic inspection begins with the preparation of the pipeline surface, ensuring it is clean and free from any contaminants that could affect the image quality. The source of radiation and the detector or film are then positioned appropriately around the pipeline.

During the exposure phase, the X-ray tube is energized to emit radiation in X-ray radiography, or the radioactive source is positioned to emit gamma rays in gamma radiography. This radiation passes through the pipeline material and exposes the detector or film placed on the opposite side. If film is used, it is developed using chemical processing to reveal the image, while digital detectors process the image electronically.

The resulting radiographic image is then analyzed by a qualified inspector to identify any defects such as cracks, voids, or inclusions within the pipeline. Common types of defects detected include cracks, which are linear discontinuities that can significantly weaken the pipeline, and porosity, which refers to gas pockets trapped within the weld or material that reduce its strength. Inclusions, or foreign materials embedded in the weld, incomplete fusion, where the weld metal has not properly fused with the base metal, and corrosion, which erodes the material surface and is detected as changes in thickness, are also commonly identified.

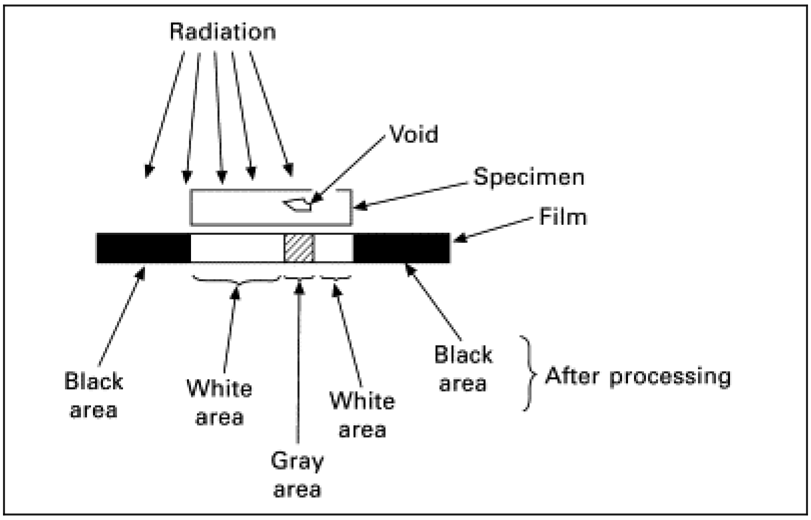


Figure 1 Radiographic Testing

III 3. Safety Considerations

Radiographic inspection involves exposure to ionizing radiation, which necessitates strict adherence to safety protocols. These include the use of shielding materials such as lead aprons and walls to protect personnel, maintaining a safe distance from the radiation source, minimizing the time spent near the radiation source, and monitoring radiation exposure with dosimeters.

IV. Methodology & Testing Setup

To conduct a comparative analysis of radiographic inspection techniques using Gamma ray inspection on 10-inch carbon steel pipelines, the following methodology is followed:

IV 1. Research Location and Resources

The study is conducted in an operational area in Maharashtra, focusing on selected 10-inch diameter carbon steel pipelines used for natural gas transportation.

IV 2. Instruments and Equipment

The inspection utilizes NABL-certified gamma ray inspection tools, with Iridium-192 as the radiation source. Film processing equipment includes developer tanks, rinse tanks, fixer tanks, and drying equipment.

IV 3. Personnel

Qualified personnel certified according to ASNT SNT TC-1A standards conduct the inspections.

IV 4. Pipeline Sample Selection

The sample selection focuses on 10-inch diameter carbon steel pipelines, chosen at random intervals to ensure representative data. Pipelines are marked with white spray for future reference, and films are marked according to guidelines.

IV 5. Experiment Setup

The setup involves using a portable gamma ray source projector with Iridium-192. The radiographic film, such as Kodak D4 and AGFA D7, is placed at the far end of the pipeline. Image Quality Indicators (IQIs) are used to verify the quality of the radiographic technique according to API 1104 guidelines.

IV 6. IQI Calculation and Placement

For a nominal wall thickness of 6.4 mm (0.252 inches), the appropriate IQI is selected from the API 1104 table. The IQI is placed adjacent to the weld, ensuring visibility on the radiograph without obscuring critical areas.

IV 7. Film Processing:

The exposed film is processed in a darkroom with appropriate chemical solutions. The processing includes developing, rinsing, fixing, washing, and drying the film at controlled temperatures.

IV 8. Safety Equipment

Safety measures include using personal dosimeters, lead aprons, gloves, and radiation survey meters to monitor radiation levels and ensure personnel safety.

IV 9. Ancillary Tools

Additional tools include densitometers to measure film density, white spray paint for marking, and measuring devices to ensure accurate positioning and documentation.

IV 10. Setup and Procedure

- Preparation: All equipment is calibrated and functioning properly. The inspection area is marked on the pipeline with white spray paint, and the radiographic film holder is positioned around the marked area.
- Exposure: The gamma ray projector with Iridium-192 is set up, and the source is maneuvered into position using winding gear and connector cables. The exposure time is calculated and adjusted for the actual Source-to-Film Distance (SFD).
- Processing: The film is developed, rinsed, fixed, washed, and dried in a controlled darkroom environment.
- Analysis: The processed film's density is measured, and the quality of the radiographs is verified using IQIs. The radiographic images are analyzed for defects, and the findings are documented.
- Safety: Radiation levels are monitored, and protective measures are enforced throughout the inspection process.

IV 11. Testing Techniques

The inspection uses the double wall single image technique, with film placed outside and the source outside.

IV 12. Assessment Criteria

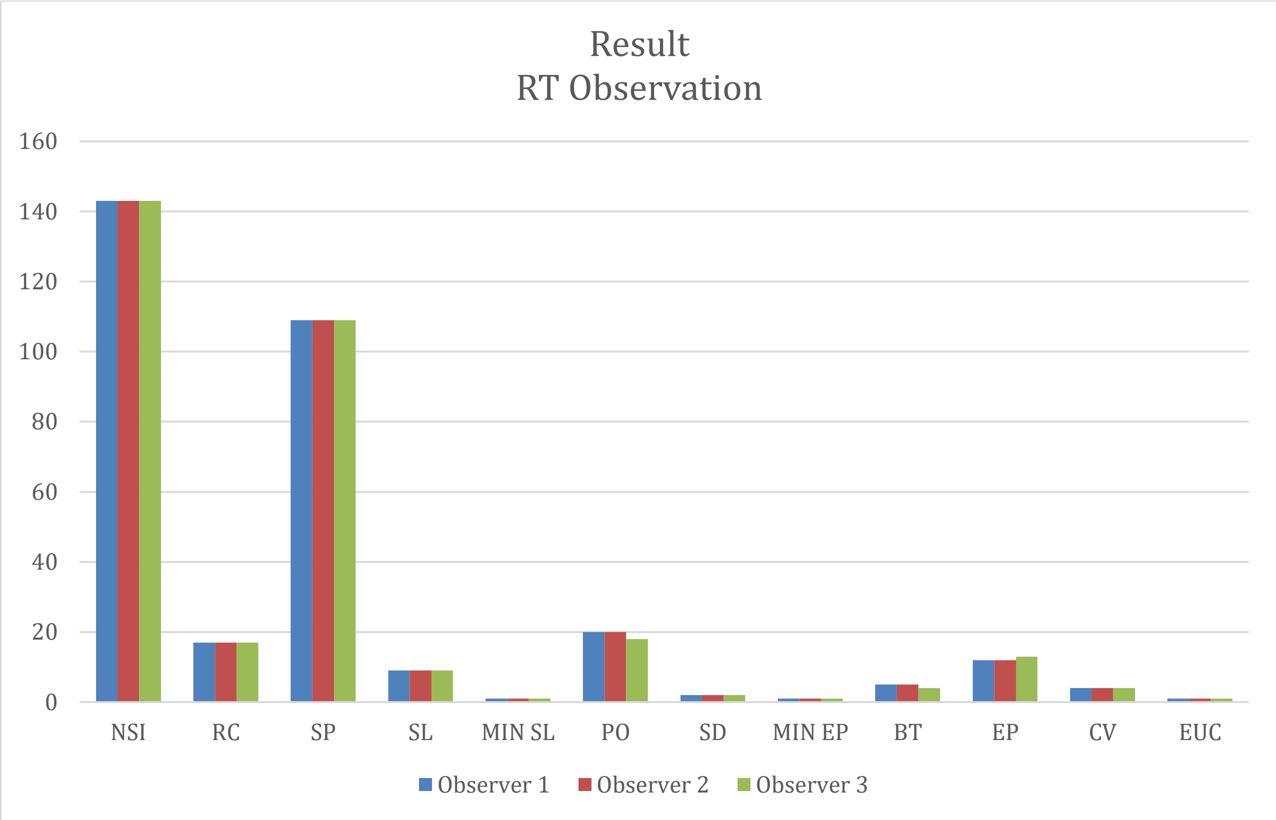
The analysis considers pipe size, material thickness, test location, type of discontinuity, and critical areas prone to failure, ensuring high-quality radiographs.

V. Result & Discussions

V 1. Result

Table 1 Observers Qualification and Experience

Sr No	Educational Qualification	Other Qualification	Experience (In NDT)
Observer 1	BE (Mech)	NDT Level II	9 Year
Observer 2	BE (Mech)	NDT Level II	6 Year
Observer 3	BE (Mech)	NDT Level II	2 Year



V 1 1. Overview

The comprehensive analysis of 99 weld joints, each comprising three sections, resulted in a total of 297 section observations. The inspection data from three observers were compared, focusing on the types and frequencies of defects identified, as well as any discrepancies among the observers.

Table 2 Summarized Table for RT Inspection Result

Observation	Observer 1	Observer 2	Observer 3	Discrepancies in Observation
NSI	143	143	143	0
RC	17	17	17	0
SP	109	109	109	0
SL	9	9	9	0
MIN SL	1	1	1	0
PO	20	20	18	2
SD	2	2	2	0
MIN EP	1	1	1	0
BT	5	5	4	1
EP	12	12	13	1
CV	4	4	4	0
EUC	1	1	1	0

V 1 2. Key Findings

- **Consistent Observations**
  The majority of defect types, including NSI (No Significant Indications), RC (Root Cracks), SP (Spatter), SL (Slag), MIN SL (Minimum Slag), SD (Surface Defects), MIN EP (Minimum Edge Porosity), CV (Cavities), and EUC (External Undercut), showed no discrepancies among the three observers. This indicates a high level of agreement and reliability in identifying these defects.
- **Discrepancies**
  The discrepancies were observed in the following defect types:

- PO (Porosity): Observer 3 identified 2 fewer instances of porosity compared to Observers 1 and 2.
- BT (Burn Through): Observer 3 identified 1 fewer instance of burn through compared to Observers 1 and 2.
- EP (Excess Penetration): Observer 3 identified 1 additional instance of excess penetration compared to Observers 1 and 2.

V 2. Discussion

Discrepancies in radiographic film interpretation, particularly in pipeline inspections, require prompt attention. Our analysis highlighted significant differences among the three observers, especially with Observer-3, the least experienced. Observer-3's interpretations diverged from those of Observer-1 and Observer-2, notably in identifying similar-looking defects such as slag inclusions (SL), porosity (PO), and incomplete penetration (EP). These minor differences in defect identification can have substantial safety implications, potentially leading to overlooked defects or unnecessary repairs.

To address these discrepancies, it is essential to provide additional training and mentoring for Observer-3, focusing on improving interpretation skills and understanding inspection standards. Emphasis should be placed on distinguishing similar-looking defects. Implementing robust quality assurance measures, including regular reviews, cross-training, and calibration exercises, is crucial for aligning interpretations and minimizing errors. Transparent documentation of discrepancies and the actions taken to address them ensures accountability and enables informed decision-making.

Furthermore, continuous improvement should be a primary focus, using feedback from discrepancies to refine protocols, enhance training, and optimize quality control measures. By addressing interpretation differences, particularly through focused training for Observer-3 and implementing quality assurance measures, the integrity and safety of pipeline systems can be better ensured. Special emphasis on recognizing and correctly identifying similar-looking defects will enhance inspection accuracy and reliability.

VI. Conclusion

In this experimental study, we investigated the critical aspects of non-destructive testing (NDT) radiography (RT), focusing on training, interpretation variability, and challenges associated with multiple defects.

The findings are summarized as follows:

VI 1. Significance of Training

- Rigorous training in non-destructive testing (NDT) radiography (RT) is crucial for accurate defect detection.
- Well-trained professionals contribute to reliable inspection results, ensuring safety and compliance.

VI 2. Interpretation Variability

- Interpretation of radiographic images varies among individuals based on their experience in the field.
- Seasoned practitioners recognize subtle indications that less experienced personnel might miss.

VI 3. Challenges with Multiple Defects

- Identifying multiple defects within the same weld can be challenging, especially for less experienced engineers.
- Overlapping patterns make differentiation difficult.

In summary, comprehensive training, collaboration, and ongoing skill development enhance NDT RT testing outcomes.

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