Examination of corrosion under insulation using gamma ray computed tomography

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Abstract. In this paper, we propose a screening and scanning approach using gamma ray transmission measurements and computed tomography (CT) to detect and locate corrosion areas in a pipeline. Screening obtains interval measurements of collimated gamma ray along the length of pipe, while scanning gives cross sectional images at the investigated area. The CT scanner consists of a clamped on mechanical gantry, a 1” x 1” NaI(Tl) scintillation detector, 11mCi Ba-133 source, 15mm x 5mm lead collimators and Ludlum scaler ratemeter. This technique was shown to be an effective way to determine the wall loss and erosion areas of at 2.5mm thickness. Several locations of an insulated pipe were screened and scanned. Using a portable gamma ray CT scanner we present the results, where the cross sectional image can indicate the occurrence of corrosion under insulator.

1. Introduction
Corrosion is deterioration of metal that weakens its structure and form. It can happen when the metal is exposed to oxygen and water. This condition allows rust to form through electrochemical reaction/oxidation. Corrosion in pipelines can be difficult to detect especially when the pipes are insulated and its surface appears to be in good condition. Abdullah et. al. suggested that the CT technique can also be used to determine the extent of corrosion under insulation (CUI), to detect blockages and to measure the thickness of deposit/materials built-up on the walls [1]. X-ray CT was used to trace cracks in a ceramic pot, and differentiate ceramic and metal material through the contrasting shades of black and white [2]. Corrosion detection through micro tomography and limited angle tomography has also been suggested by Van Steen and Ewert [2][3]. Recent works show that CT is also used in dimensional metrology and engineering inspection [4][5].

This paper discusses about a two-step process, i.e. screening and scanning of pipes for corrosion detection using gamma ray transmission technique. The first-step is to narrow down the location of suspected corroded area along the length of pipe via interval gamma ray measurements along the investigated pipe. The second-step is to perform a localized computed tomography (CT) scan of that pipe section where structural anomalies are suspected to occur. CT image reveals the pipe’s inner structure and enables the analysis of wall loss and erosion without opening the pipe’s insulation.
1.1. Computed tomography
Gamma ray computed tomography is an imaging technique that uses the penetrative gamma rays to obtain a two-dimensional view (2-D) cross sectional view of an object. When a beam of gamma ray penetrates a material, the intensity of the beam will be reduced through photoelectric effect and Compton scattering. Material of different densities and composition attenuates the incident beam, and this interaction is described in Equation (1).

\[ I = I_o e^{\mu x} \]  

where,
- \( I_o \) = intensity of incident beam
- \( I \) = intensity of transmitted beam
- \( \mu \) = linear attenuation coefficient
- \( x \) = sample thickness.

Figure 1 illustrates gamma ray beam going through an inhomogeneous material and Equation 2 gives the relation of the measured transmission ratio. The ratio corresponds to the sum of the attenuation coefficients multiplied by the corresponding path length of all the elements where the ray traverses. The linear attenuation coefficient, \( \mu \) for gamma rays is dependent on the given energy, material density and its atomic number. These transmission data are essentially a density distribution map of the object. Information along the known paths is reconstructed from a series of projections and is transformed into a cross sectional image. This cross sectional view allows the viewing of the objects internal non-destructively.

\[ \ln \left( \frac{I_o}{I} \right) = \mu (x-x') + \mu' x' \]  

\[ \text{Figure 1. } \gamma \text{-ray transmission through material.} \]

2. Gamma ray pipe inspection
A portable gamma ray CT scanner was developed at the Malaysian Nuclear Agency to inspect industrial pipeline for pipe diameters not more than 50cm [2]. It is a clamp-on system where its mechanical gantry can be fixed onto a vertical or horizontal pipe. The CT scanner consists of a clamped on mechanical gantry, a 1” x 1” NaI(Tl) scintillation detector, 11mCi Ba-133 source, 15mm x 5mm lead collimators and Ludlum scaler ratemeter. The scanner is equipped with a dedicated data acquisition and image reconstruction software that uses filtered back projection algorithm. The pipe sample was placed in the gantry, where the pipe is in the CT systems’ field of view. Scan parameters were set according to the sample sizes. Gamma ray pipe inspection involves positioning a gamma ray
source and a radiation detector on opposite sides of the medium of interest and relating changes in the transmitted intensity to changes in the mass per unit area of the material.

2.1. **Step 1: screening**
The insulated 4” pipe was inspected along its length at every 5 cm using 11 mCi Ba-133. The collimated ray passes through the insulation and pipe section and the transmitted ray is recorded by the 1” x 1” NaI(Tl) detector (Figure 2).

![Figure 2. Screening: pipe is inspected along the pipe’s length to locate suspected corroded section.](image)

2.2 **Step 2: scanning**
CT scan was performed at the pipe section (20cm from the top) where suspected wall loss has occurred using a portable gamma ray computed tomography machine. Figure 2 shows the scanning in progress using 11mCi Ba-133. Pipe thickness is 5mm and the insulation thickness is 4cm. At the circumference of the pipe, we added a 1mm copper plate (Plate 1), 2mm (Plate 2) and 3mm (Plate 3) steel so that the rays ‘slice’ through the plates, insulation and pipe.

![Figure 3. CT scanning setup at pipe location 20cm from the top. Three metal plates were added on the insulation surface.](image)
3. Screening and scanning results

Screening is an interval checking of the pipe for possible locations of suspected wall loss or pipe structure anomalies. In a pipe with intact structure, the density of pipe along its length should remain the same. Figure 4 shows three points (in red) where higher transmitted gamma rays were detected, which indicates the thinning of pipe wall. Figure 5 shows the area around the pipe circumference where there is wall thinning at locations 20cm and 35cm from the top of the pipe, and further narrows down the suspected CUI location. Figure 6 shows the image taken at 20cm position.

![Graph showing screening data](image1)

**Figure 4.** Screening Data: Suspected points of corrosion.

![Graph showing measurements](image2)

**Figure 5.** Screening Data: Measurements around the pipe section at 20cm and 35cm from the top.
Figure 6. Scanning: Cross sectional CT image at suspected wall loss section. (a) Image shows the 3 plates, insulation area and the pipe. (b) Zoom in to the pipe. Its wall loss is indicated by the deterioration of image pixels and analysis of the projection data.

In Figure 6, the dark shades represent air and the white/grey shade represent the metal pipe. Plate 1 is a faint shade of grey whereas Plate 2 is greyer and thicker, and Plate 3 is white. Although copper (8.86 g cm$^{-3}$) is more dense compared to steel (8.05 g cm$^{-3}$), however its thickness is 1mm compared to 2mm and 3mm steel respectively and therefore absorbs lesser gamma rays. Some artifacts are present in the image as well and it is due to data averaging and effects from the 3 metal plates. Further analysis of the projection data can estimate the thickness of pipe that is lost.

4. Summary
This project proposed the use of gamma ray transmission technique to detect and locate corrosion areas in a pipeline as a two-step process. Step 1 of the ‘Screening-Scanning’ process obtains measurements along the pipe’s length to narrow down suspected areas of pipe anomaly. Step 2 scans the pipe section to reveal the wall loss through CT images. This technique was shown to be an effective way to determine the wall loss and can be used to identify corroded sections.

5. References
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