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INVESTIGATION OF MULTIPHASE CONDITION IN PIPELINE USING GAMMA COMPUTED TOMOGRAPHY

INVESTIGASI KONDISI MULTIFASE DI DALAM PIPA MENGGUNAKAN TOMOGRAFI GAMMA TERKOMPUTERISASI

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ABSTRACT

INVESTIGATION OF MULTIPHASE CONDITION IN PIPELINE USING GAMMA COMPUTED TOMOGRAPHY. *The deposition of sand particles in pipeline is a problem that often occurs in the production and distribution of oil and gas. It could cause increased pressure, equipment failure, pipeline erosion, and production decline. It is very necessary to investigate internal condition of the pipeline without interrupting the operation. Gamma computed tomography (CT) is a technique that can image the internal structure of an object without interrupting or damaging the object (non-destructive testing). This paper presents a preliminary experimental study of multiphase (solid, liquid, and gaseous) conditions inside a horizontal pipe using gamma CT technique. A collimated ^{137}Cs source with 3.7 GBq activity emitted gamma photons to penetrate a 14 inches diameter horizontal pipe containing sand, water, and gasoline. The photons that penetrated object were detected using a scintillation detector at the other side of object. The scanner system performed translation and rotation scans to get 64 projection data, which will then be reconstructed into an image. The reconstructed images were able to show the pipe wall and the condition of the inside of pipe which was filled with sand, water, and gasoline. The pixel value is linear to material density with R^2= 0.9543. The result indicated the potential of gamma CT as a suitable technique to be used to investigate the multiphase conditions in the pipeline.*

Keywords*: Gamma CT, industry, multihpase, non-destructive testing, pipeline.*

ABSTRAK

INVESTIGASI KONDISI MULTIFASE DI DALAM PIPA MENGGUNAKAN TOMOGRAFI GAMMA TERKOMPUTERISASI. *Endapan partikel pasir pada jalur pipa merupakan masalah yang sering terjadi pada proses produksi dan distribusi dari minyak dan gas. Endapan tersebut dapat menyebabkan peningkatan tekanan, kegagalan peralatan, erosi pipa, dan penurunan produksi. Sangat penting untuk menginvestigasi kondisi di dalam jalur pipa tanpa mengganggu operasi. Gamma computed tomography (CT) merupakan sebuah teknik yang dapat mencitrakan struktur internal dari sebuah obyek tanpa mengganggu atau merusak obyek tersebut (uji tak merusak). Makalah ini menyajikan percobaan pendahuluan pada kondisi multifase (padat, cair, dan gas) di dalam pipa horizontal menggunakan teknik gamma CT. Sumber ^{137}Cs yang terkolimasi dengan aktivitas 3,7 GBq memancarkann foton gamma menembus pipa dengan diameter 14 inci yang berisi pasir, air, dan bensin. Foton yang menembus obyek dideteksi menggunakan sebuah detektor sintilasi pada bagian lain dari obyek. Sistem melakukan pemindaian translasi dan rotasi untuk mendapatkan data 64 proyeksi yang mana akan dibangun menjadi sebuah citra. Citra hasil rekonstruksi mampu menunjukkan dinding pipa dan kondisi bagian dalam dari pipa yang mana berisi pasir, air, dan bensin. Nilai piksel linier terhadap nilai densitas material dengan R^2= 0,9543. Hasilnya mengindikasikan potensi gamma CT sebagai teknik yang sesuai untuk menginvestigasi kondisi multifase di dalam jalur pipa.*

Kata kunci*: Gamma CT, industri, multifase, pipa, uji tak merusak.*

INTRODUCTION

Products from oil reservoir are sometimes accompanied by small quantities of solid such as sand or fracturing materials [1]. Sand is frequently produced along with production fluids from an unconsolidated oil reservoir with low formation strength [2]. The sand deposits can lead to flow impediment, erosion, enhanced pipe bottom corrosion, trapping of pigs, and other flow assurance issues [3]. These failures can cause unexpected downtime and risk to equipment as well as personnel and environment [4]. Therefore, it is important to investigate inside condition of pipelines in order to ensure production and distribution sustainability. Besides, the investigation process must not interfere with the production or distribution process.

CT is an advanced technique that has been continuously developed and used for diagnostic purposes not only in medical but also in industry, biology and civil engineering. Tomography started with the theoretical justification of the possibility of reconstructing the distribution of a certain parameter across a planar section of an object from its projections [5]. In tomography, there are several kinds of transmission can be used based on the measurement requirement such as laser, electron, ultrasonic, neutron, X-ray, gamma-ray, and so on. For industrial purposes, gamma-ray has two main advantages over other transmission: 1) high detection efficiency of high density or thick materials and 2) the use of a radioisotope that does not require a high-voltage power supply system [6]. However, the use of gamma radiation sources has disadvantages such as the ionizing radiation hazard, potential lost sources, leakage of source capsules, and so on.

While for medical tomography, a patient goes to the computed tomography system (CT), for industrial applications, the CT system should be transported up to the object and, mechanically adapted to the object setting [7]. It is important to design a portable and mechanically adapted to the object. The first generation of tomography is the most effective method to be applied in the industry. It uses single source and detector makes it more simple to adapt to objects in industrial plant. While the existing gamma CT systems use a turntable to place the test objects, our system can perform measurement without contact to objects that allow it to be applied in industrial plant.

In this paper, a horizontal pipe with diameter of 14 inches (355.6 mm) containing sand, water, and gasoline was scanned using parallel beam gamma tomography system. The system consisted of mechanical part, a gamma-ray source, a NaI(Tl) scintillation detector, computerized controlled module, data acquisition, and computer. The data were built into image using filtered back projection (FBP) algorithm. The results can be used for the further development of gamma tomography scanning system for investigating the multiphase condition inside the industrial process units.

METHODOLOGY

Object

A steel pipe with diameter of 355.6 mm and thickness of 12.7 mm was used as the object that contains multiphase material such as sand, water, gasoline, and air (solid, liquid, and gaseous phases) as shown in Figure 1. Based on its density, sand is at the bottom followed by water, gasoline, and air. In order to get a good visual of the condition inside the pipe, a transparent lid was provided.

Tomographic System

The experiment was performed using parallel beam gamma tomography. The mechanical part consisted of gantry and a couple of collimators for gamma-ray source and detector as shown in Figure 2. The collimator is made from lead and its slit has a diameter of 5 mm. The scan was started with a set of translational scans that covered all of the object dimension. After a set of translational scans is completed then the gantry conducted rotational scan with determined angle to perform the next set of translational scans until the gantry is rotated to 180^0. The parallel beam transmission tomography only requires a half circle (180^0) scan, the 180^0 scan data is just the same as the 0^0 data and so on.

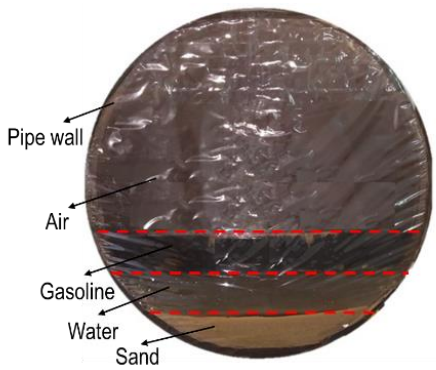

Figure 1. Object: steel pipe filled by sand,water, and gasoline.

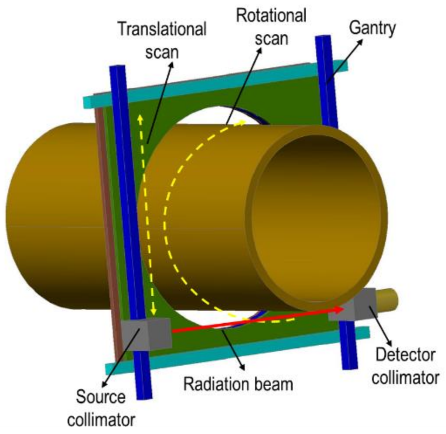

Figure 2. Mechanical part of gamma CT parallel beam.

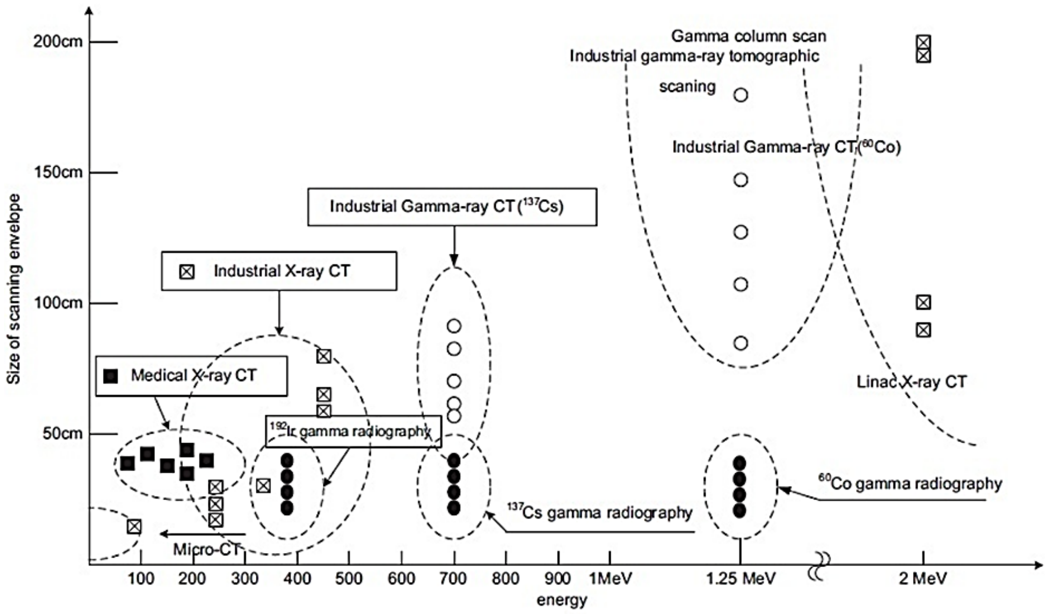

Figure 3. Computed tomography category [10].

The system is able to conduct translational and rotational scan automatically which is controlled by programmed microcontroller module [8]. Based on the mechanical part, the maximum sample size that can be scanned by this system is 600 mm in diameter. The mechanical part must be modified to be able to scan larger sized object as long as it still measurable by this method. Figure 3 shows CT and radiography techniques with energy and ranges of object sizes that can be measured. Tomography system have its own challenges to be applied in industrial fields because it must fits to the objects, adjusts to the conditions around it and is also easy to relocate (portable) [9].

The ^{137}Cs with an activity of 3.7 GBq was used in this experiment. It is commonly used in nuclear gauging applications in industries including tomography because it has a long half-life, it does not scatter interfere of photons of other energies and emits single clear photo peak [10]. It has a half-life of 30.23 years and decays by pure β-decay that produces ^{137}Ba, which creates all the γ-ray emissions with energy peak of 662 keV [11]. Scintillation detectors, such as, NaI(Tl), BGO, LYSO, LSO, and GSO are widely used in tomography applications [12–14]. In this experiment, NaI(Tl) detector (Ludlum model 44-2) was used as the receiver. Ludlum model 44-2 detector has relatively small diameter (1 inchi), its typical sensitivity to ^{137}Cs is 175 cpm per μR/hr, and its operational temperature range is -40 to 65 ^{0}C. Ludlum model 2200 was used to count the gamma photons. The high voltage setup was at 1000 V. The data were sent and strored to computer using LabVIEW program as the graphical user interface (GUI).

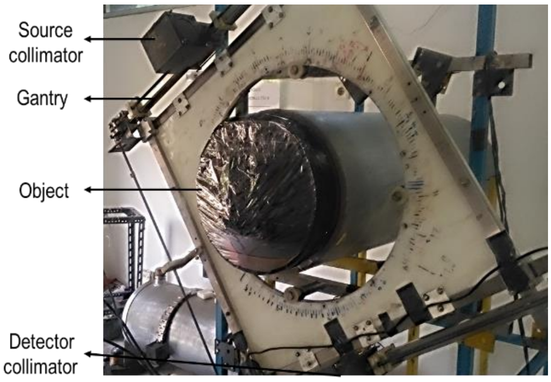

Figure 4. Experiment setup.

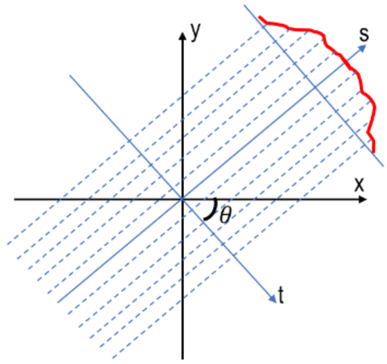

Figure 5. Parallel beam geometry [16].

Experiment Setup

The pipe was set at the center of the gantry as shown in Figure 4. A translational scan was conducted every 5 mm which made the pixel size of reconstructed image represents 5 mm × 5 mm. The counting time was 2 seconds and the radiation intensity beyond the object (air) was about 30,000 count/2 seconds. A number of projections in the experiment were 64 in 180^0 (every 2.8125^0). The pipe was scanned twice. The first was when the pipe is empty and the second was when the pipe contained multiphase material. The data collection duration of each scan is about 300 minutes (5 hours). It is become the limitation of the single detector method.

Image Reconstruction

Filtered back projection (FBP) algorithm was used to reconstruct the images. The FBP method is the best known technique in image reconstruction because its simplicity, low computational cost combined with good accuracy [15]. If the fast Fourier algorithm is used then the data should be obtained in 2n parallel rays and using the Radon transformation. The radon transform is defined as [16]:

$$\mathrm{P}(\mathrm{s},\theta) = \mathrm{R}(\mathrm{f}) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x\cos\theta + y\sin\theta - t)dxdy \quad (1)$$

the line integral is along a line (gamma ray beam) at an angle θ from the x-axis and at a distance $|t|$ from the origin. By rotating the coordinate system as shown in Figure 5:

$$t = x\cos\theta + y\sin\theta \quad (2)$$

$$s = x\sin\theta + y\cos\theta \quad (3)$$

$$x = t\cos\theta - s\sin\theta \quad (4)$$

$$y = t\sin\theta + s\cos\theta \quad (5)$$

An image is obtained by restoring the value of radon to the x,y-axis by using the inverse radon:

$$\mu(x,y) = \int_0^{\pi} P_\theta(t)\int_{-\infty}^{\infty}\delta(x\cos\theta + y\sin\theta - t)dtd\theta \quad (6)$$

RESULTS AND DISCUSSION

The results show that ^{137}Cs as the gamma source is able to distinguish the multiphase inside the pipe. By using 3.7 GBq of ^{137}Cs and collimators (for gamma source and gamma detector) with diameter of 5 mm, the radiation intensity at air position is 30,000 count/2 seconds. The scan profile at 90^0 position (vertical scan) shows that the interfaces between sand, water, and gasoline were recognized as shown in Figure 6. It means that energy of ^{137}Cs (662 keV) is effective in distinguishing materials that have adjacent densities (water and gasoline). The red curve represents the interfaces between the materials inside the pipe. The higher energy makes it less sensitive in terms of distinguishing adjacent material density. On the contrary, lower energy makes it unable to penetrate materials that have high density such as metals commonly found in industrial units.

The scan profile shows that it is possible to distinguish multiphase condition inside the pipe without intrusive or invasive action. This is the advantage of this technique. The ability of gamma radiation to penetrate and carry informations inside the objects can help to solve problems that exist in the industry.

It took about 4.8 minutes to get a set of projection data. It is the limitation of parallel beam scan method. Using single detector makes the scanning time longer. One way to reduce scanning time is to use a multi-detectors method. The more number of detectors used, the less time it takes to scan. Another way to reduce the scanning duration is by increasing the the activity of gamma radiation source.

All of 64 projections data were built into image using filtered back projection algorithm (FBP) built in matlab. The reconstructed image is shown in Figure 7. The results show that gamma CT has successfully mapped multiphase condition inside the pipe. Based on the image, the highest density value (pipe wall) is represented by dark red color, while the lowest density value (air) is represented by blue color.

The wet sand is the most clearest part in the scan profile of the pipe because it has the highest density compared to the others. In the image, the color is dark yellow. The interface between sand and water is observed clearly. The intersections between water, gasoline, and air are able to be recognized too. Based on the image, it can be easily concluded that there are 4 different materials in the pipe.

The pixels color were also observed to study the relationship with the value of material density. The pixel region is shown in Figure 8. The first row are the RGB (red green blue) scale image pixel value and the second row are the 8 bit gray scale pixel value. The average pixel values of materials is shown in Table 1. Based on the gray scale value, the 8 bit pixel values are directly proportional to the material density values.

Figure 9 shows that the relationship between material density to pixel value is linear with $y = 27.846x+33.481$ and $R^2 = 0.9543$. Based on this results, the system can be further developed in order to predict the material density inside industrial units based on pixel value of the tomographic image. Further research is needed to develop the methods and determine the standards for application of gamma tomography in the industrial field.

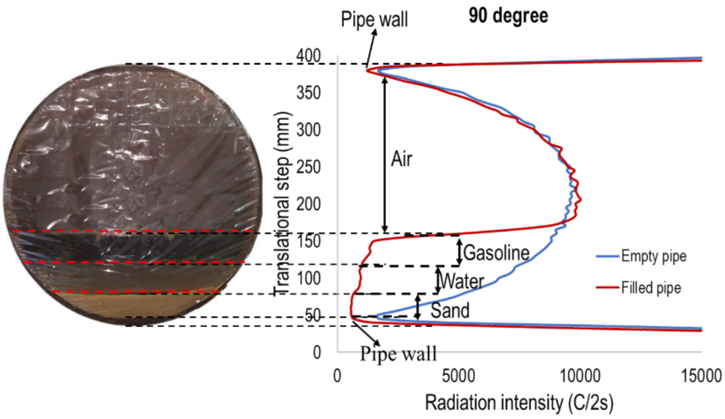

Figure 6. Vertical scan profile compared to object.

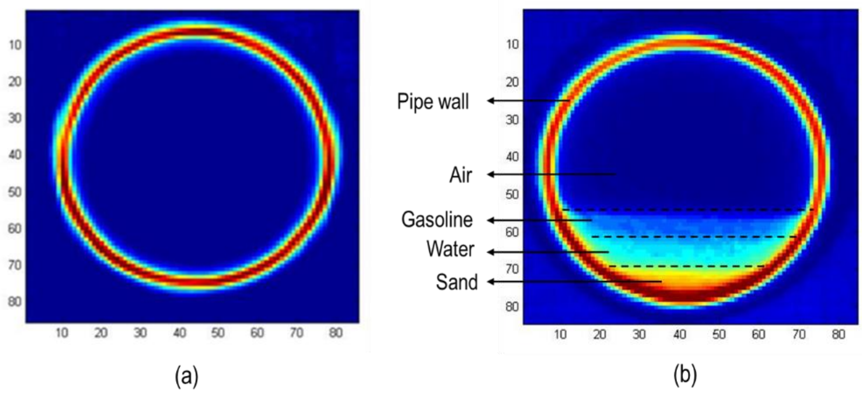

Figure 7. Reconstructed images, (a) empty steel pipe, (b) steel pipe filled by sand, water, and gasoline.

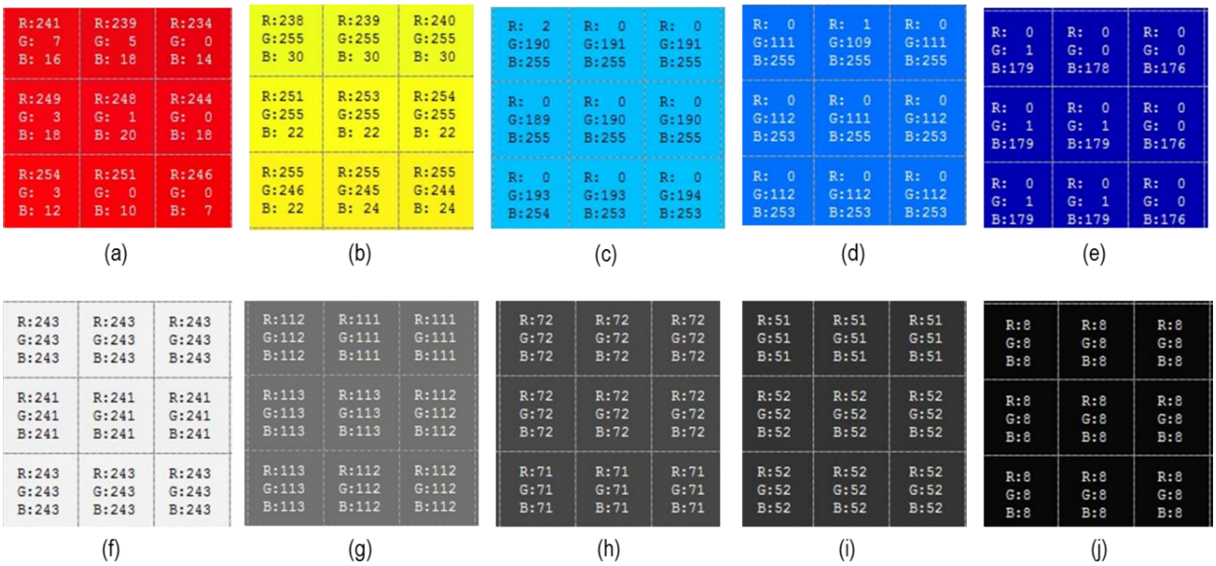

Figure 8. Pixel region of steel pipe filled by sand, water, and gasoline, (a) RGB pixels value of pipe wall, (b) RGB pixels value of sand, (c) RGB pixels value of water, (d) RGB pixels value of gasoline, (e) RGB pixels value of air, (f) gray scale pixels value of pipe wall, (g) gray scale pixels value of sand, (h) gray scale pixels value of water, (i) gray scale pixels value of gasoline, (j) gray scale pixels value of air.

Table 1. Average pixel value of materials.

Material	Density (g/cm^3)	RGB pixels value	Gray scale pixels value
Pipe wall (steel)	7.75	R= 245; G= 2; B= 15	242
Wet sand	1.92	R= 248; G= 251; B= 25	112
Water	1.00	R= 0; G= 191; B= 254	72
Gasoline	0.77	R= 0; G= 111; B= 253	52
Air	1.2×10^{-3}	R= 0; G= 0; B= 178	8

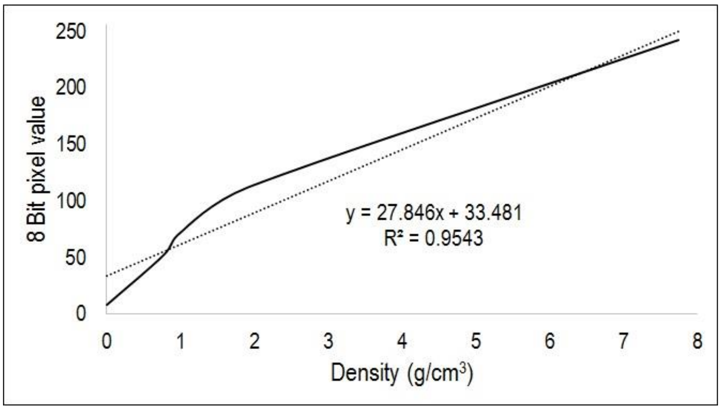

Figure 9. The relationship between material density to 8 bit pixel value.

CONCLUSION

The gamma computed tomography (CT) technique has been conducted to investigate density distribution inside a steel pipe. It was successfully identified multiphase conditions inside the pipe. Gamma source ^{137}Cs with energy of 662 keV is effective to be applied in the industrial field. It was able to distinguish material with adjacent densities value. The activity of ^{137}Cs was 3.7 GBq and it needed 2 seconds to get 30,000 counts at air position (not hitted the object). The pixel value is linear to material density with R^2= 0.9543. With further development, gamma tomography is not only able to image the internal structure of industrial units but potentially able to predict the value of the material density in it. The parallel beam scan method has limitation which is long duration of scanning process. The duration of data collection of each scan is about 300 minutes (5 hours). It can be solved using multi-detectors technique that is able significantly reduce the scanning time.

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