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Numerical Analysis of Backscatter Radiography for Prediction of Pipelines Situation: Their Bursting and Casing Failure Consideration from inside

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ABSTRACT

Backscatter radiography as a technique can successfully be applied for predicting the pipeline bursting and casing failure. A valid numerical technique will allow predicting these issues without needing to access the outside of the pipelines. Furthermore, this technique has the ability to estimate the shape and depth of damages. It is normally preferred to apply non-destructive testing (NDT) methods which can monitor the status of a pipeline from the internal surface of it without needing to access both sides of it depending on various locations of pipe such as underground or submarine. In the current study, backscatter radiography as an applicable and NDT method to detect locations with potential for pipeline bursting or casing failure was carefully investigated using the Monte Carlo simulation tool. The data obtained by the simulation process showed that backscatter radiography could detect deformations, corroded areas, depositions, creation of load on the casing, lacking proper cementation, excessive pressure inside the pipelines, and other factors which may increase the risk of pipelines bursting or casing failure (in-situ and online) with an acceptable accuracy.

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1. INTRODUCTION

Casings are steel alloys pipes that are inserted into a drilled borehole for prevention from wall collapse, control of formation pressures, and separation of low-pressure and high-pressure zones. After the installation of the casing in the borehole, a special mixture of concrete is injected behind it [1, 2]. Several factors such as corrosion, creation of load on the casing due to lacking proper cementation, reservoir subsidence, and casing material may lead to casing collapse [2-4]. The maximum resistance to in-situ horizontal stresses in casing can be generated by applying special alloys and the implementation of efficient concrete operations [5]. The other event which threatens the integrity of oil and gas transmission is pipelines bursting. High internal pressure and temperature can damage steel alloy pipes with different wall thicknesses and create deformations in radial directions [6, 7]. Excessive pressure inside the pipeline and some other factors such as aging, corrosion, deposition, and deformation can also increase the risk of bursting in the pipelines [8, 9].

In petroleum industries, in the case of damage to deeply buried casings, it is problematic, costly, or, in some cases, impossible to repair. Therefore, continuous monitoring of casing and pipelines is a necessary factor for safe operation and avoiding adverse consequences [3]. Casings and pipelines can be inspected by various methods such as acoustic technology, magnetic tools, eddy currents, thermal imaging, multi-arms caliper pigs, or determining fluid pressure at different points. There is information in the literature about the strengths and weaknesses of inspection methods and comparison between them [10-12].

Compton scattering, and inspection methods based upon it, have good potential for use in the field of monitoring pipelines. Backscatter radiography is a technique that previously has been proposed by Jamshidi et al. [13] for detecting corrosion and deposition inside pipelines without the need to access

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the back of them. In the current study, the possibility of applying this method in a tool or equipment for detecting locations with the potential of pipeline bursting or casing failure was investigated by a simulation tool.

2. METHODOLOGY

In conventional radiography configuration, the source of radiation is fixed on one side of a material, and a detector or film is installed on the other side [14]. The backscatter radiography is encouraged for some objects which both sides of them are not accessible such as buried pipelines underground. For inspection of a pipeline by backscatter radiography, radiation source and detectors are located inside it. Then, its internal will be irradiated and monitored [15, 16]. While transmitting oil and gas by pipelines, the internal fluid pressure can damage and deform the pipe body. Chemical reactions such as corrosion can reduce pipe resistance against the internal pressure, as well [7]. Bursting in the corroded areas in a pipeline is more probable than the other ones. Corrosion detection inside pipes by backscatter radiography technique was already investigated [11]. Deformation as a bulge on the outside surface of the pipe is a result of excessive pressure on the internal surface. For the simulation process, changes in the internal pressure are equivalent to changes in the density of the fluid flowing in the pipelines [17].

Casing failure may be caused by corrosion, change in internal fluid density, or change in internal or external pressure on the casing [18]. In some cases, when the pipe is almost empty, the external load may collapse the casing. The other factor that should be considered is the existence of small empty spaces as voids between the concrete and the casing. These voids may be filled by a high-pressure fluid [4, 17]. Most of the time, the overpressure on the concrete and consequently on the casing may lead to collapse. Some relationships between the density of concrete and its compressive strength based on the experiments have been developed [19, 20]. However, the concrete density increases with increasing the pressure but, there would be a high potential for collapse after achieving the maximum compressive strength of concrete [18]. To apply backscatter radiography technique for detecting areas with potential of bursting or collapse in pipelines, the assembly of source and detectors that is justified in the middle of the casing or pipeline, monitors 360 degrees of the pipe at the same time, and moves along it. The installed detectors count the number of backscattered photons or neutrons using a ring-shaped source with a mono-energetic sharp pencil beam. Change in the number of photons shows abnormalities along the pipeline.

The speed of inspection by this method will depend on several factors. Source strength or exposure rate of sources is the most crucial parameter. Considering photon or neutron energies, the efficiency of the detectors and electronics used in the setup can also have an essential role in the inspection speed.

In this research, simulation of backscatter radiography for monitoring factors that increase the possibility of casing collapse or pipeline bursting was performed by the Monte Carlo simulation tool. Figure 1 shows the simulated geometry used in the MCNP code, which is internationally recognized for analyzing the transport of neutrons and photons [21]. Although, backscattered photons or neutrons are counted in all detector cells considered in the design section (as shown in Figure 1) but, the results obtained by the cell that produces sharpest peaks during the inspection are presented in the results and discussion section.

The speed of inspection by backscatter radiography in the experiment depends on several factors. The most important parameter is the source strength or exposure rate of photon sources. The efficiency of the detectors and electronics used in the setup can have an essential role in the inspection speed, as well.

3. RESULTS AND DISCUSSION

The energy of photon and neutron sources, irradiation angle, beam type, and atomic densities of materials required for the simulation were obtained from the literature, considering the ALARA principle [4, 13, 22-28].

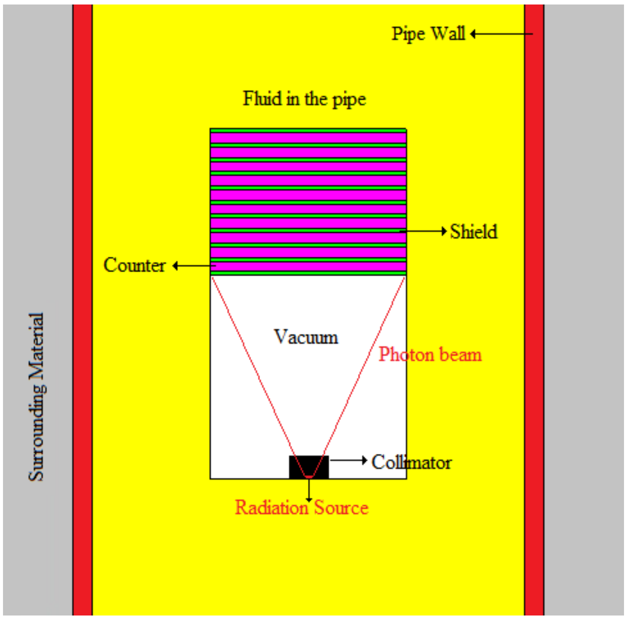

Figure 1. The geometry used in the simulation

Figure 2 shows two types of deformations that were simulated in this study for pipeline bursting. The peak of these deformations was less than 20% of the inside diameter of the pipe. The thickness of the pipeline and casing in all of the simulations was at 1 cm. To prevent photons from entering other areas and affecting the counts, shields (made of lead) were used.

Figures 3 and 4 show photon logs (based on Figure 2) by 75, 200, and 660 keV photon sources. The results clearly showed that high-energy photons could produce logs with sharper peaks in comparison with low-energy ones. These deformations can start the bursting in transmission pipelines.

Figure 5 shows the backscatter radiography data by 660 keV photons when a pipe is surrounded by various materials such as concrete, water, air, and soil. Since in this energy range, few photons may pass through the thickness of the pipe wall and reach behind it, the backscatter photons will then be returned to the pipe. Figure 6 shows detecting deformations when the pipe is filled with oil, gas, or brine.

According to this figure, log peaks are more distinctive when gas (with low density) flows inside the pipe. Figure 7 shows backscatter radiography data for deformations with different sizes. In this simulation, the

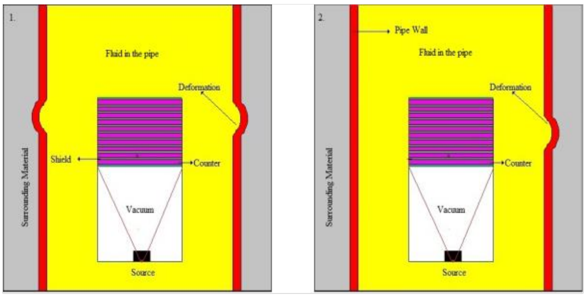

Figure 2. Two types of deformations investigated in pipeline bursting

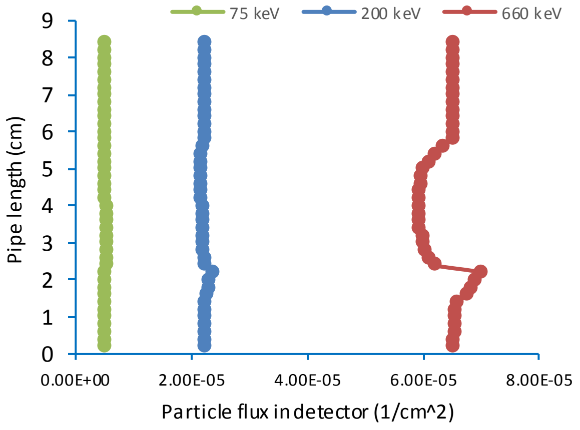

Figure 3. Photon log by various photon energies for detection of deformation shown in Figure 2 (left)

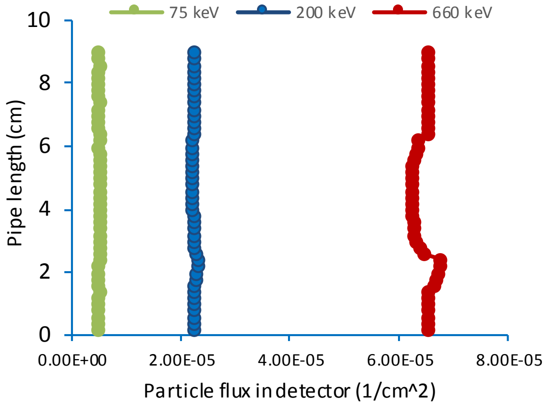

Figure 4. Photon log by various photon energies for detection of deformation shown in Figure 2 (right)

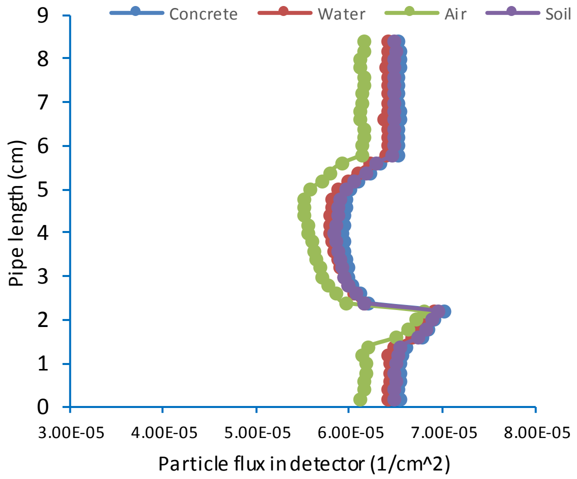

Figure 5. Photon log for detection of deformation in a pipe considering different surrounding materials (photon energy=660 keV)

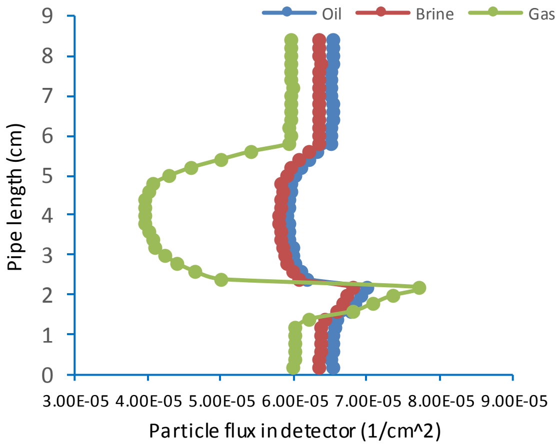

Figure 6. Photon log for detection of deformation in a pipe considering different fluids in the pipe (photon energy=660 keV)

depth of deformation was assumed to be around 5, 10, and 15% of internal pipe diameter. The results showed that this method could detect small deformations (even 5%). Figures 8 and 9 show backscatter photon radiography data by 660 keV photons and 4.2 MeV, respectively neutrons (neutron source of Am-Be with an average energy of 4.2 MeV) inside a pipe when the crude oil is under compression. The oil density can vary from 0.75 to 0.95 g/cm^3 with pressure change. The results show that the neutron log is more distinctive for detecting fluid density change in a pipeline compared with the photon log. Considering deformation shown in Figure 2. (left) is more frequent than Figure 2 (right), the results in Figures 5 to 9 are based on the deformation shown in this figure.

Several phenomena that may lead to casing collapse were also considered in the simulation process. Figure 10 shows two different geometries used for the detection of deformations in the casing. In these geometries, the size of deformation at the peak was less than 20% of the inside diameter of the casing.

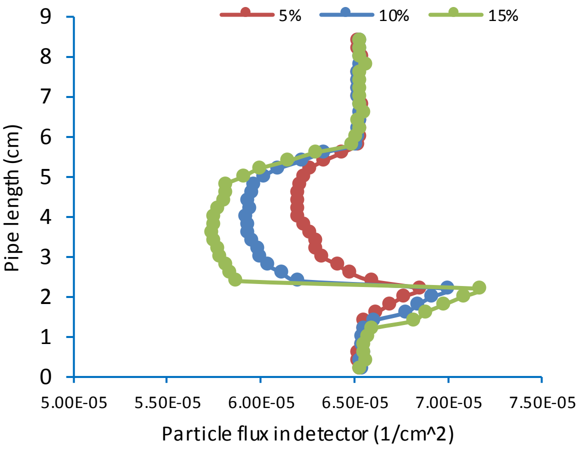

Figure 7. Photon log for detection of deformations in a pipe in terms of percentage of internal diameter by 660 keV photons

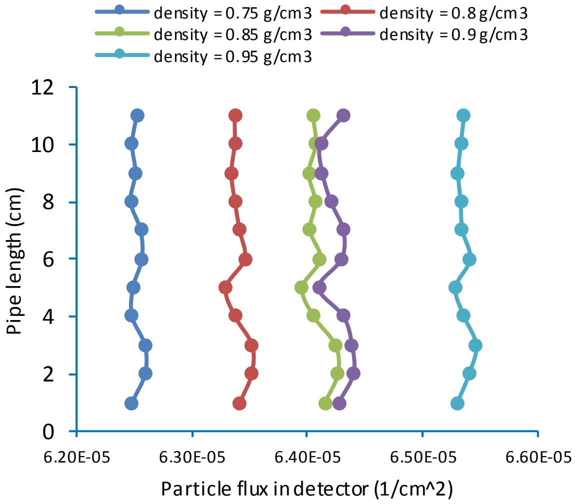

Figure 8. Photon log for different densities of crude oil in the pipeline (photon energy=660 keV)

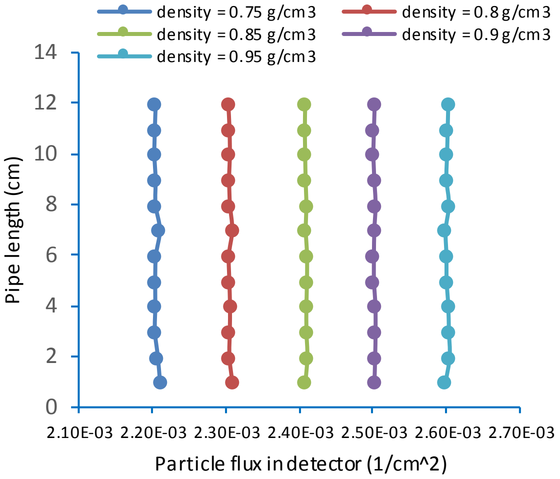

Figure 9. Neutron log for different densities of crude oil in the pipeline (neutron energy=4.2 MeV)

Figures 11 and 12 show deformation detection by 75, 200, and 660 keV photon sources. According to these figures, sharper peaks in the obtained logs are observed by applying photon sources with higher energies compared with the other sources.

Figure 13 shows results of radiography by 660 keV photons when the crude oil inside the casing was diluted in comparison with the standard conditions. As shown in this figure, there might be no fluid in a part of the casing in some cases. Empty casing or decreasing the fluid density inside the casing provides enough potential for collapse. Changes in the density of the fluid in the casing could accurately be monitored by backscatter photon radiography.

Figure 14 shows the results of backscatter radiography for monitoring spaces between the casing and concrete where filled by gas, brine, or oil. This simulation was repeated by applying an average 4.2 MeV neutron source, as well.

Results of counting produced photons during neutron-gamma interactions were presented in Figure

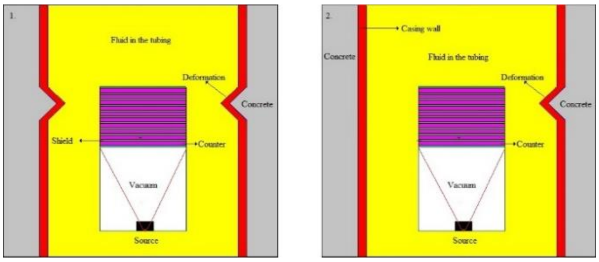

Figure 10. Two types of deformations investigated in casing collapse

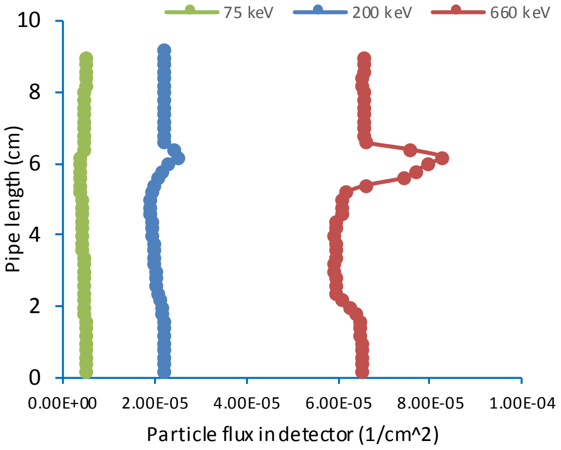

Figure 11. Photon log by various photon energies for detection of deformation shown in Figure 10.1

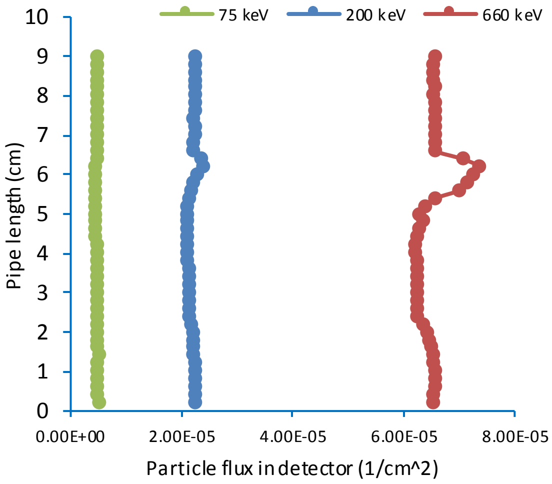

Figure 12. Photon log by various photon energies for detection of deformation shown in Figure 10 (right)

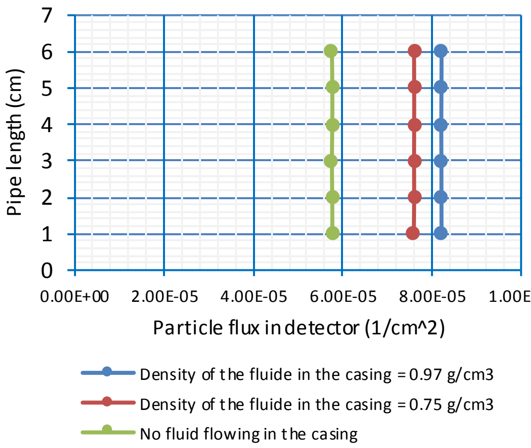

Figure 13. Photon log for different densities of fluid flowing in the casing (photon energy=660 keV)

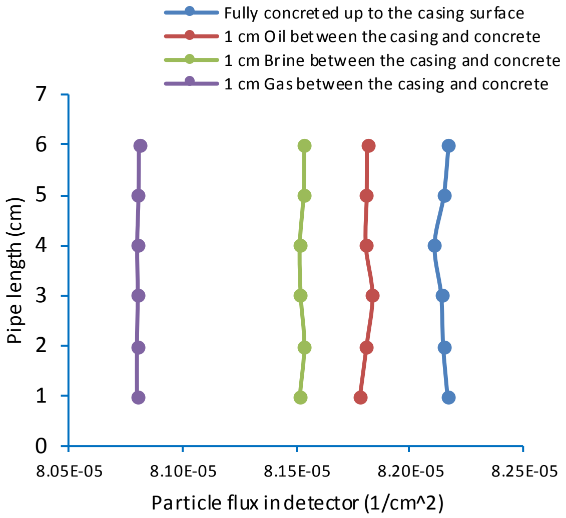

Figure 14. Photon log for detection of space between the casing and concrete filled by oil, gas, and brine (photon energy=660 keV)

15. As shown in this figure, there is a good distinction between the state fully concreted and the state with the presence of voids where filled by oil or gas. Figure 16 shows the radiography data with a neutron source and counting produced photons.

Results in Figures 13 to 16 are based on the deformation shown in Figure 10. The primary purpose of the simulation was to realize the pressure increment on the outer surface of the casing. The mentioned parameter was detected via its consequence in the density of concrete. A change in the density of concrete could be identified by applying a neutron source.

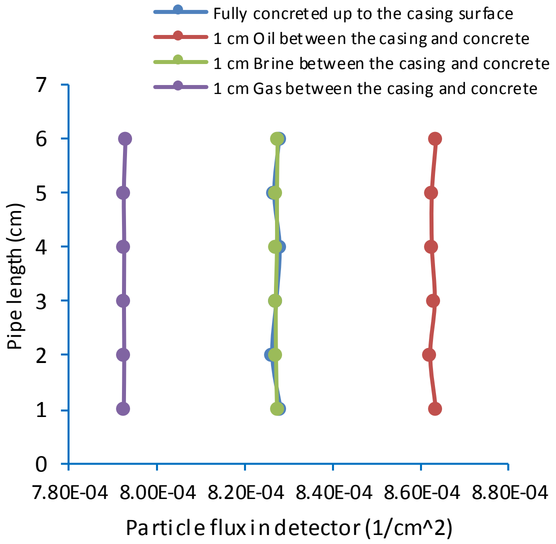

Figure 15. Photon log for detection of space between the casing and concrete filled by oil, gas, and brine by applying neutron source (source average energy=4.2 MeV)

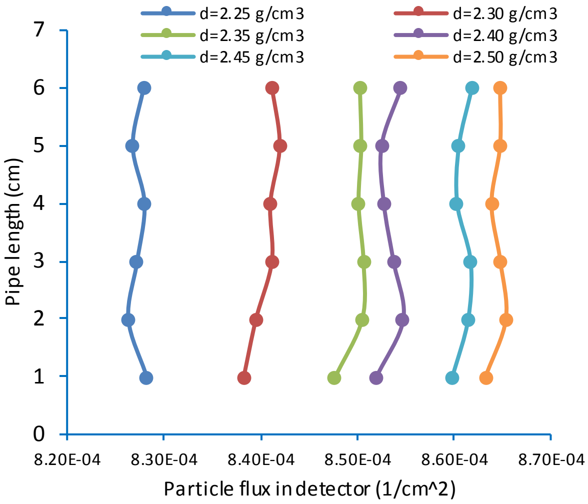

Figure 16. Photon log obtained by neutron source considering various concrete densities behind the casing (source of Am-Be, average energy = 4.2 MeV)

Neutrons could pass through the steel body of the casing and enter the concrete material. In the concrete, photons with different energies might be produced and scattered in the medium due to interacting neutron-gamma. A number of these photons might backscatter to the detectors placed in the middle of the casing. The pressure on the outside surface of the casing can be obtained by counting the photons and comparison with typical situations. In fact, the concrete density will change with changes in photons count. This may be a potential for casing collapse. Based on the results obtained by the simulations, creating an initial prototype for more extensive research and applying it to identify and correct issues in the design can be recommended as a future direction.

4. CONCLUSIONS

Casing failures and pipeline bursting are significant problems in upstream oil industries, and every year, a lot of resources are spent on repairing, rehabilitating, and re-drilling due to the consequences of this phenomenon. In this research, Monte Carlo method was fully applied to investigate probable pipeline bursting and casing failure. The backscatter radiography technique in the early detection of destructive factors was successfully used. The results showed that backscatter radiography by the source of photon or neutron as a fast, in-situ, and non-destructive testing method could monitor inside pipeline or casing and detect abnormalities which may cause bursting or collapse. This method, along with the other inspection techniques, can be applied for the pipeline inspection.

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Persian Abstract

چکیده

در صنایع نفت و گاز، رادیوگرافی پس پراکنده به عنوان یک تکنیک موفق می تواند در تشخیص تغییر حالت و فروشکست خطوط لوله جداری به کار گرفته شود. یک تکنیک عددی معتبر اجازه پیشگویی درخصوص این موضوعات بدون نیاز به دسترسی به پشت خطوط لوله را میسر می سازد. علاوه بر این، این تکنیک قابلیت تخمین شکل و عمق آسیب ها را نیز دارد. بسته به موقعیت مکانی این خطوط که ممکن است در زیر زمین یا دریا باشند، معمولا ترجیح داده می شود از روش های آزمون غیر مخرب (NDT) که می توانند وضعیت خطوط را از داخل آنها و بدون نیاز به دسترسی به پشت آنها پایش کنند استفاده شود. در این مطالعه، رادیوگرافی پس پراکنده به عنوان یک روش کاربردی و غیرمخرب برای شناسایی نقاط با قابلیت تغییر حالت تورمی و یا فروشکست به کمک ابزار شبیه سازی مونت کارلو به کار گرفته شده است. نتایج حاصل از شبیه سازی ها نشان می دهد این روش می تواند به خوبی تغییر حالات، نواحی خورده شده، رسوبات، فشارات وارده بر جدار، سیمان کاری نامناسب، فشار بیش از حد داخلی و یا سایر عواملی که ممکن است ریسک احتمال وقوع این دو پدیده را افزایش دهند (به صورت درجا و زنده) و با دقت قابل قبولی آشکار سازد.