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Simulation of Deposition Detection inside Wellbore by Photon Backscatter Radiography

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P A P E R I N F O

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A B S T R A C T

In the process of extracting oil and gas from hydrocarbon reservoirs, the formation of depositions inside pipes, fittings, and storage tanks, not only accelerates corrosion but also reduces a significant volume of operating capacities. The most critical step in solving the problem of deposition formation is their early and timely detection. In industries, internal surfaces of the pipeline are usually inspected by nondestructive testing (NDT) methods. The detection of depositions should operationally be difficult if there were special conditions for accessing the back of pipelines. Therefore, a suitable method is encouraged to detect deposition in the pipes and tubes when one side or a small part of them is accessible. In this paper, the Monte Carlo simulation tool was applied to use backscatter radiography (as an NDT inspection technique) for in-situ detection of depositions inside the metallic pipelines. In fact, the simulation process shows the correctness and efficiency of the backscatter radiography technique. It would determine some significant factors such as photon energy, angle of irradiation, or location of detectors which affect the design before experiment. The results showed that backscatter radiography as a viable technique could properly detect the location of depositions inside the pipes.

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1. INTRODUCTION

In the field of oil and gas industries, monitoring of depositions is a significant subject for preventing harmful consequences and costly damages due to flow restriction through transmission pipelines [1]. Some changes in pressure and temperature cause some physical and chemical phenomena for deposition formation when the fluids approach the earth's surface from underground in the extraction process of hydrocarbon reservoirs [2]. Organic and inorganic (such as asphaltene, wax, hydrate, and mineral compounds) depositions commonly formed in the pipelines and equipment [3]. Asphaltene has a complex molecular structure and is the most polar composition in oil [4]. Waxes are high molecular weight and complex compounds which generally are in the solid phase at ambient temperature. Wax depositions (with normal chains of alkanes) stick on the internal pipes at low temperatures and make longer chains [5, 6]. Hydrate depositions are typically formed in gas transmission pipelines, as well. In the cold seasons, gas molecules in pipes are imprisoned and frozen in cages made from water. Plugs will block the flow path and stop gas processing during hydrate crystals formation [7].

Petroleum industries often suffer from inorganic depositions, including carbonates and sulfates [8]. These deposits are generally associated with water formed in calcium carbonate, calcium sulfate, and barium sulfate. Some deposits, such as iron sulfide and iron carbonate, may also be produced as corrosion agents [9].

Caliper Pipeline Inspection Gauge (Caliper PIG) with mechanical arms is a device that is used in fluids (such as water, oil, and gas) transfer pipes for measuring holes geometry [10].

Some methods for monitoring deposition formation or narrowing in the pipelines and equipment are radiography, ultrasonic, determination of fluid pressure in various points, thermal imaging, and the other inspection techniques [11-14]. However, there is some information about the strengths and weaknesses of

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various inspection methods [15, 16] but, a predictable technique based on the Monte Carlo simulation tool is widely encouraged for the depositions formation location detection and their contents determination. In this research, the mentioned technique was carefully studied in detail and validated.

2. METHODOLOGY

According to the radiography applications, X and γ-rays penetrate through materials structure to find their quality [17]. The radiography tool advantage compared with the other methods (such as Caliper PIG) is the observation of the visual image of pipe cross-section without demanding mechanical arms and sticking on the internal surface of the tube [10]. The conventional radiography is feasible for pipes and tubes, which both sides of them are available. The positions of radiation source on one side and detector or film on the other side are important. Compton scattering shows good potential for use in the field of NDT monitoring. The backscatter radiography based on Compton scattering has been proposed for single-sided radiography under inspection. This type of radiography can be applied for in-situ detection of faults inside pipelines without demanding the back of them [15, 18]. Figure 1 illustrates the principle of the backscatter radiography method for the detection of depositions inside a pipeline [19].

Figure 2 shows the simulated geometry used in the Monte Carlo N-Particle (MCNP) code. Specifications of materials used in the simulation were extracted from literature [5, 8, 20-25]. A mono-energetic source of photon produced a ring-shaped sharp beam and irradiated the inner side of the pipeline. Deposition in one area of the pipe was defined as the thickness of wax, asphaltene, salt, or hydrate over the internal surface of it. Simulations were carried out several times by different photon energies and depositions with various thicknesses, lengths, and materials. The best results were obtained in the counter cell with about 11 cm far from the radiation source for the design investigated in this research.

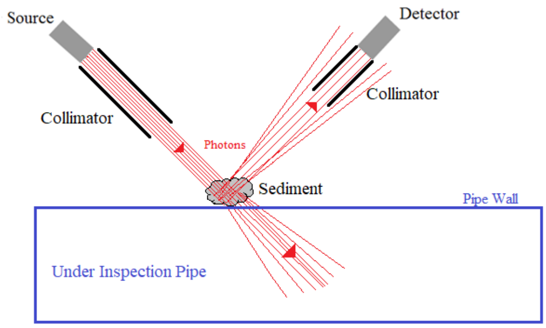

Figure 1. Principle of photon backscatter radiography for detection of deposition on a pipe wall

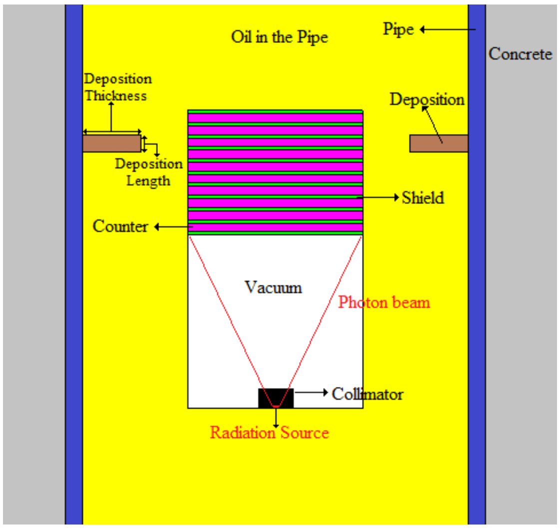

Figure 2. The geometry used for input of MCNP code

As shown in Figure 3, the depositions can be monitored by moving the inspection device through the pipeline. Some scattered photons entered the detector were counted after photons emission from source and their interactions consideration with fluid, pipe, deposition, and concrete behind the tube. Then, the results were drawn as a graph versus the traveled distance. A change in the number of photons in the log can indicate the deposition occurrence along the pipeline.

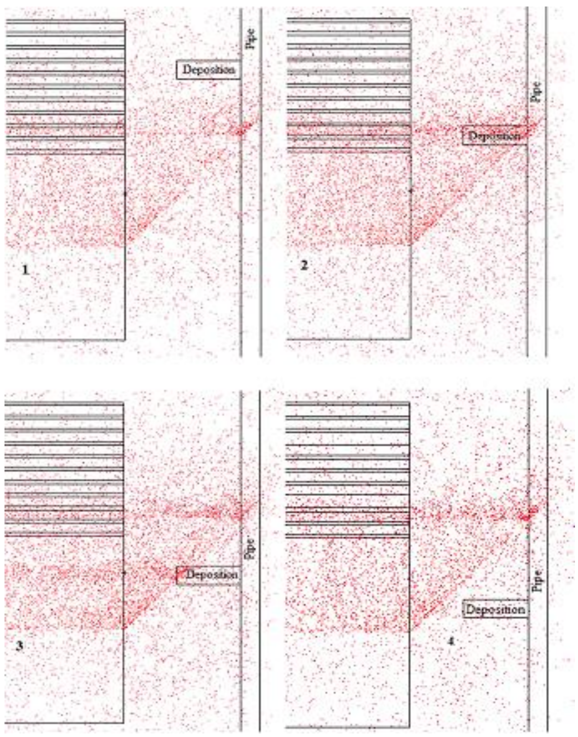

Figure 3. Moving the inspection device in front of the deposition through the pipe (dots show traced photons)

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

Since there only are theoretical data on this type of research and still, no practical setup is tested, the necessary data (such as the energy of photons, angle of irradiation, and kind of photon beam) were obtained from the literature considering ALARA principle [15, 26]. The deposition should be significant when it occupies at least 20% of the pipe diameter. Figure 4 shows the results of this method for detection of $CaCO_3$ deposition inside a pipe with 1 cm length and 2.2 cm thickness of internal pipe diameter using 75, 200, and 660 keV photon sources. The results showed that low-energy photons could not produce good results due to passing photons through the fluid, penetration into the deposition, re-entry through the fluid, and finally, into the detector. Figures 5 and 6 show detecting asphaltene, $CaCl_2$, $CaCO_3$, $CaSO_4$, and wax depositions inside a pipe using 200 and 660 keV photons. All depositions had 1 cm length and 20% of internal pipeline diameter in thickness. The peaks shown in Figures 5 and 6 indicate the presence of deposition on the pipe surface. Furthermore, these figures clearly show that scattering will be increased, and more scattered photons may be detected (by a detector) when a high energy photon source is applied. The location of the deposition on the internal surface of the pipe can be found by counting backscattered photons in the detector versus distance. The difference in the number of backscattered photons in the area of deposition in comparison with the other parts of the pipeline led to some peaks. The material of the deposition area, density, and photon scattering property in the location of deposition may be different from the other internal areas of a pipeline. Figure 7 shows

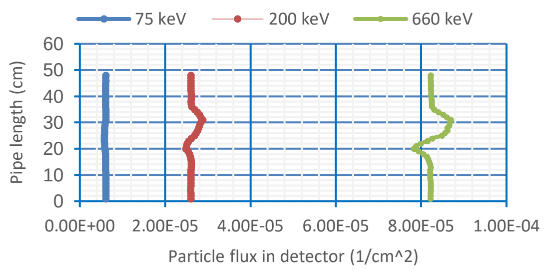

Figure 4. Photon log for various photon energies along the pipe with CaCO3 deposition (deposition thickness is equal to 20% of internal pipe diameter and deposition length is equal to 1 cm)

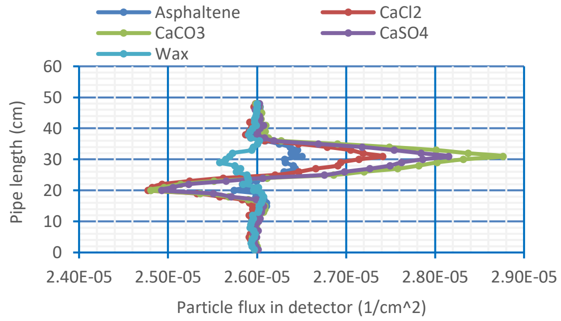

Figure 5. Photon log for various deposition materials (deposition thickness is equal to 20% of internal pipe diameter, deposition length is equal to 1 cm, and photon energy is equal to 200 keV)

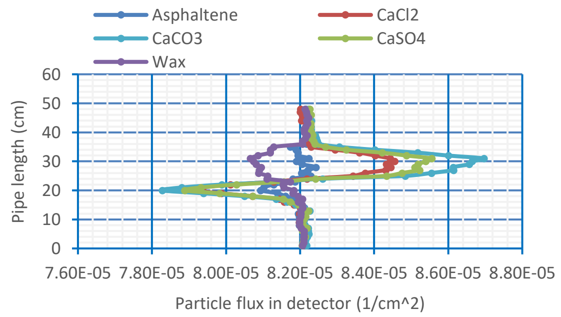

Figure 6. Photon log for various deposition materials (deposition thickness is equal to 20% of internal pipe diameter, deposition length is equal to 1 cm, and photon energy is equal to 660 keV)

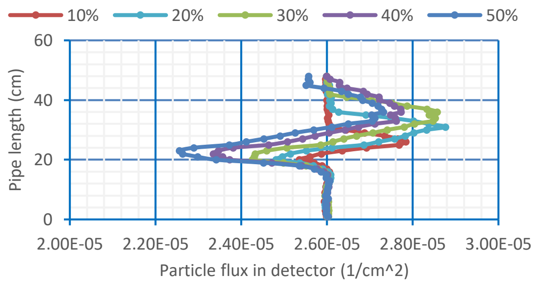

Figure 7. Photon log for various deposition thicknesses of $CaCO_3$ (deposition thickness=10, 20, 30, 40, and 50% of internal pipe diameter, deposition length=1 cm, photon energy=200 keV)

the results of backscatter radiography by 200 keV photons for detecting $CaCO_3$ depositions with various thicknesses. The deposition thickness range is 10 to 50% of the internal diameter of the pipe. The results showed that this method can detect thin depositions to prevent further problems. Figure 7 indicates the better results for thicker depositions (which are closer to the source and detector), as well.

Since hydrate depositions may be formed in gas pipelines, their depositions can also be studied. For hydrate deposition detection, the fluid inside the pipeline was assumed as natural gas. Figure 8 shows the results of hydrate deposition detection simulation inside the pipe with 1 cm length and thickness of 2.2 cm (20% of the internal diameter of the pipe) of internal pipe diameter using 200 keV and 660 keV photon sources. Figure 9 shows the results of deposition detection with a thickness range of 10 to 40% of the internal diameter of the pipe. Simulations were repeated for depositions with the same thicknesses but with different lengths. Figure 10 shows the hydrate deposition detection with a length range of 1-2.5 cm. The results showed that dimensions of peaks in photon logs were in good compatibility with depositions inside pipelines.

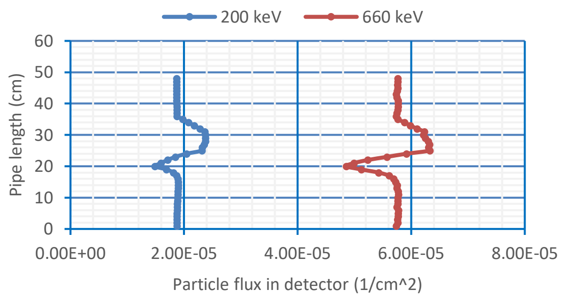

Figure 8. Photon log for various photon energies along the pipe with hydrate deposition (deposition thickness=20% of internal pipe diameter and deposition length=1 cm)

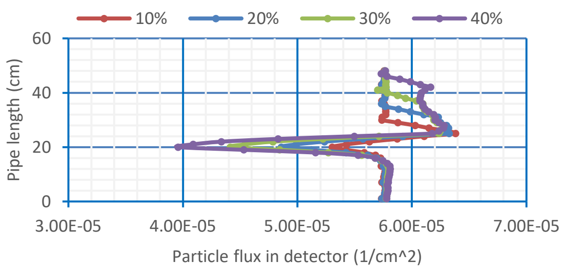

Figure 9. Photon log for various deposition thicknesses of hydrate deposition (deposition thickness=10, 20, 30, and 40% of internal pipe diameter, deposition length=1 cm, and photon energy=660 keV)

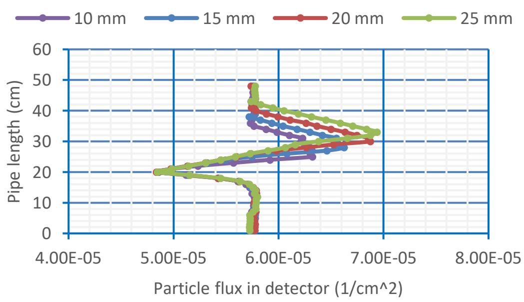

Figure 10. Photon log for various deposition lengths of hydrate (deposition thickness=20% of internal pipe diameter and photon energy=660 keV)

4. CONCLUSIONS

In the field of oil and gas production, various factors can prevent from the maximum operational volumes. One of these factors which has a remarkable effect on these industries is the formation of depositions inside the pipelines. Backscattered photon radiography can be applied as a practical and viable method for the detection of depositions inside the pipes where located in the wellbores without enough access to them or in the other positions where both sides of pipes cannot be accessible. In the current research, the Monte-Carlo tool was properly applied to simulate various depositions such as organic, inorganic, and hydrates detection (with various thicknesses, lengths, materials, and photon energies) inside the pipelines by backscattered photon radiography. Since counting scattered photons in detectors is easy, this technique can detect depositions in the early stages of their formation with reasonable accuracy. Furthermore, no mechanical movable part is requested in the structure of backscattered photon radiography, which is used for detecting depositions where are not accessible.

5. REFERENCES

1. Ragunathan, T., Husin, H., Wood, C.D., "Wax Formation Mechanism, Wax Chemical Inhibitators and Factors Affecting Chemical Inhibition", ***Applied Sciences***, Vol. 10, No. 2, (2020), 1-18. DOI: 10.3390/app10020479
2. Civan, F., "Reservoir Formation Damage, Gulf Professional Publishing", (2015), 23rd September. eBook ISBN: 9780128019108
3. Mousavi-Dehghani, S., Riazi, M., Vafaie-Sefti, M., Mansoori, G., "An analysis of methods for determination of onsets of asphaltene phase separations", ***Journal of Petroleum Science and Engineering***, Vol. 42, No. 2-4, (2004), 145-156. DOI: 10.1016/j.petrol.2003.12.007
4. Fakher, S., Ahdaya, M., Eltukl, M., Imqam, A., Critical review of asphaltene properties and factors impacting its stability in crude oil. ***Journal of Petroleum Exploration and Production Technology***, Vol. 10, (2019), 1183-1200. DOI: 10.1007/s13202-019-00811-5
5. Ganeeva, Y.M., Yusupova, T.N., Romanov, G.V., "Waxes in asphaltenes of crude oils and wax deposits", ***Journal of Petroleum Science***, Vol. 13, No. 4, (2016) 737-745. DOI: 10.1007/s12182-016-0111-8
6. Martyushev, D., Modeling and Forecasting of Paraffin Settings on an Existing Extractive Fund of Oil Deposits, ***International Journal of Engineering, Transactions C: Aspects***, Vol. 32, No. 12, (2019), 1704-1709. DOI: 10.5829/IJE.2019.32.12C.02
7. Makwashi, N., Zhao, D., Ismaila T.A., Paiko, I., "Pipeline Gas Hydrate Formation and Treatment: A Review", 3rd National Engineering Conference on Building the Gap between Academia and Industry, Faculty of Engineering, Bayero University, Kano. (2018), https://www.researchgate.net/publication/330262173

8. Vazirian, M. M., Charpentier, T. V. J., de Oliveira Penna, M., & Neville, A. "Surface inorganic scale formation in oil and gas industry: As adhesion and deposition processes", ***Journal of Petroleum Science and Engineering***, Vol. 137, (2016), 22-32. DOI: 10.1016/j.petrol.2015.11.005
9. Al Rawahi, Y.M., Shaik, F., Rao, L.N., Studies on scale deposition in oil industries & their control, ***International Journal for Innovative Research in Science & Technology***, Vol. 3, (2017), 152-167. http://www.ijirst.org/articles/IJIRSTV3I12056.pdf
10. Darling. T. "Well Logging and Formation Evaluation", Elsevier Inc. (2005). https://www.sciencedirect.com/book/9780750678834/well-logging-and-formation-evaluation
11. Ellinger, M., "A history of in-line inspection tools", ***Inspectioneering Journal***, (2017). https://inspectioneering.com/journal/2017-04-27/6416/a-history-of-in-line-inspection-tools
12. Serra, O., Fundamentals of Well-logging Interpretation: The Interpretation of Logging Data, ***Developments in Petroleum Science,*** Vol. 15, (1986) https://www.academia.edu/10053890/Fundamentals_of_Well_Log_Interpretation_OSerra
13. Liu, E., Peng, S., Zhang, H., Huang, L., "Blockages detection technology for oil pipeline", ***Journal of the Balkan Tribological Association***, Vol. 22, (2016), 1045–1057. https://www.researchgate.net/publication/330845379
14. Díaz-Sánchez, H., Rojas-Trigos, J.B., Leyva, C., Trejo-Zárraga, F., "An approach for determination of asphaltene crystallite by X-ray diffraction analysis: A case of study", ***Petroleum Science and Technology***, Vol. 35, No. 13, (2017), 1415-1420. DOI: 10.1080/10916466.2017.1336771
15. Jamshidi.V., Davarnejad, R., "Simulation of corrosion detection inside wellbore by X-ray backscatter radiography", ***Applied Radiation and Isotopes***, Vol. 145, (2019), 116-119. DOI: 10.1016/j.apradiso.2018.12.026
16. Saxena, H., Majhi, A., Behera, B., "Prediction of wax content in crude oil and petroleum fraction by proton NMR", ***Petroleum Science and Technology***, Vol. 37, No. 2, (2019), 226-233. DOI: 10.1080/10916466.2018.1536713
17. Gawdzinska, K., Grabian, J., Przetakiewicz, W., "Use of X-ray radiography in finding defects in metal-matrix composite casts", ***Metalurgija***, Vol. 47, (2008), 199-201. https://hrcak.srce.hr/file/35671
18. Xiong, X., Yantao, L., Daquan, C., Wei, Z., Xiaoming, W., Yingjie, W., Zhiming, Z., "A compact, high signal-to-noise ratio line-detector array Compton scatter imaging system based on silicon photomultipliers", ***Applied Radiation and Isotopes***, Vol. 154, (2019), 108845. DOI: 10.1016/j.apradiso.2019.108845
19. Tsoulfanidis, N., Landsberger, S., Measurement and Detection of Radiation. Taylor & Francis: USA. (2015), DOI: 10.1201/b18203
20. Jowett, F., Petroleum waxes. In: Hobson G.D., editor. ***Petroleum Technology***. New York: Wiley. (1984)
21. Diallo, M.S., Cagin, T., Faulon, J.L., Goddard III. W.A. "Thermodynamic properties of asphaltenes through computer assisted structure elucidation and atomistic simulations", ***Development in Petroleum Science***, Vol. 40, (2007), 103-127. DOI: 10.1081/LFT-120040254
22. Max, M.D. "Natural Gas Hydrate in Oceanic and Permafrost Environments". Springer Netehrlands Publishers. (2003) https://www.springer.com/gp/book/9781402013621
23. Chong, Z. R., Yang, S.H.B., Babu, P., Linga, P., Li, X.-S., 2016. Review of natural gas hydrates as an energy resource: Prospects and challenges, ***Applied Energy***, Vol. 162, 1633-1652. DOI: 10.1016/j.apenergy.2014.12.061
24. Hosseinipour, A., Japper-Jaafar, A., Yusup, S., Ismail, L., "Application of the Avrami Theory for Wax Crystallization of Synthetic Crude Oil", ***International Journal of Engineering, Transactions A: Basics***, Vol. 32, No. 1, (2019), 18-27. DOI: 10.5829/IJE.2019.32.01A.03
25. Speight, J.G. "Handbook of petroleum analysis", John Wiley & Sons, US. ISBN: 0-471-36167-4. (2001)
26. "NRC's Regulations, Title 10, Code of Federal Regulations", Standards for protection against radiation, Section 20.1003. (2016), https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/

Persian Abstract

چکیده

در استخراج نفت و گاز از مخازن هیدروکربوری، تشکیل رسوبات مختلف داخل لوله‌های انتقال، اتصالات و در نهایت مخازن ذخیره، نه تنها باعث تشدید فرآیند خوردگی این تجهیزات می‌گردد بلکه حجم قابل توجهی از ظرفیت‌های عملیاتی را نیز کاهش می‌دهد. مهمترین گام در حل معضل تشکیل رسوبات داخل تجهیزات، تشخیص زود هنگام و به موقع آنهاست. در صنایع، سطوح داخلی خطوط لوله معمولاً با روش‌هایآزمون غیر مخرب (NDT) بررسی می‌شود. در شرایط عملیاتی چنانچهدسترسی به پشت خطوط لوله امکان‌پذیر نباشد، تشخیص رسوبات با استفاده از آزمون‌های غیر مخربمرسوم دشوار می‌گردد. به همین دلیلامروزه روش‌های مناسب تشخیص رسوب داخل لوله‌ها، بدون لزوم دسترسی به هر دو سمت آنها در حال توسعه می‌باشد. در این مقاله،به کمک شبیه سازی مونت کارلو، رادیوگرافیبا فوتون‌های پس‌پراکنده شده (در قالبیک روش بازرسیغیر مخرب) به عنوان روشی برای تشخیص درجای رسوبات داخل خطوط لوله فلزیمعرفیشده و صحت و کارآیی آن مورد ارزیابی قرار گرفته است.به کمک شبیه‌سازی می‌توان برخی عوامل تاثیرگذار مانند انرژی فوتون، زاویه تابش، یا محل قرارگیریشمارنده‌ها را قبل از آزمایشتجربی تعیین نمود. نتایجبه دست آمده از این مطالعه نشان داد که رادیوگرافیبا فوتون‌های پس‌پراکنده شدهمی‌تواند بدون نیاز به دسترسی به هر دو سمت لوله، به طور صحیح محل تشکیل رسوبات درون آنها را تشخیص دهد.