Gamma Rays Transmission Densitometry of Distillation Columns and Development of a Computerized Expert System for Faulty Analysis

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Abstract: Gamma rays transmission densitometry scanning of distillation columns is used to inspect non-invasively the internal structure and components distribution in columns. The transmission gamma counting patterns are thereafter interpreted into a diagnosis of possible malfunctions, breakdowns, or even anomalies of the column's performance. This research is aimed to develop a computerized expert system to assist in interpretation and diagnosis. The developed system incorporates several modules, namely, Patterns Recognition Kernel, Updateable Patterns/Statuses Database, Graphical User Interface (GUI), and an Application Mode Module (User) to process input gamma scanner measurement patterns for diagnosis. The system can diagnose the statuses of single as well as multiple stages of the distillation column being inspected, and provide justification and confidence level indicators. A generic distillation column design was modeled and the gamma scanner counting patterns were simulated using the Monte Carlo radiation transport code MCNP. Monte Carlo simulated column scanner measurements were generated for a total of six virtual stage statuses testing and evaluation of the developed diagnosis system showed good levels of reliability, accuracy, flexibility, and a reasonably short processing time. Moreover, this system can be applied for other distillation column designs and fault analysis.

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Keywords: distillation columns, transmission densitometry, pattern recognition, Monte Carlo radiation transport, fault analysis

1. Introduction

Radioisotope non destructive techniques (NDT) are very competitive and are largely applied for inspection, characterization, and troubleshooting complex industrial processes. The success of these applications is attributed to their unique ability to provide information which otherwise cannot be obtained by alternate techniques. One of the widly used radiological diagnosing tools of industrial processes such as distillation columns is the Transmission Gamma Ray Scanning (TGRS) [1]. In such measurements, Gamma Densitometry measurements are carried out along the column producing a counting pattern that can be compared, usually visually, to the same pattern of measurements for a normally operating column as outlined in Figure 1. TGRS reveals areas of internal breakdowns or abnormalities by outlining the differences and distortions in the obtained patterns which can be interpreted into a diagnosis of possible problems and breakdowns in the column's internal structure. Thus, diagnosis of distillation columns can be made pursuant to the detection of possible mechanical damage of trays inside the unit, as well as, certain anormalities in the column, such as flooding, blockages, weeping, etc.

The technique is based on the fundamental gamma ray transmission, represented by the well known relationship of gamma attenuation in matter:

$$I = I_0 e^{-\mu \rho x} \quad (1)$$

Where I is the intensity of a beam of uncollided gamma photons behind the object, I_o is the initial intensity of the gamma-rays beam incident on an object or a target material, μ is the mass attenuation coefficient of the target material, ρ is the density of the target, and x is the thickness of the object or the target (i.e. this would be the diameter of distillation column that the radiation is transmitted through it in the gamma-ray densitometry column scanning system) [12].

By analyzing the scanning results, a number of common malfunctions in trayed or packed columns can readily be determined, some of which are summarized in the following Table 1.

This research is meant to investigate the possibility and potential of automating the column's diagnosis process through gamma scans using a computerized Pattern Recognition techniques. This study is meant to provide an important contribution in pertaining technical fields in terms of high quality, high speed, accurate, reliable, cheap, and intuitive automated diagnosis tool that is much needed in petrochemical industries.

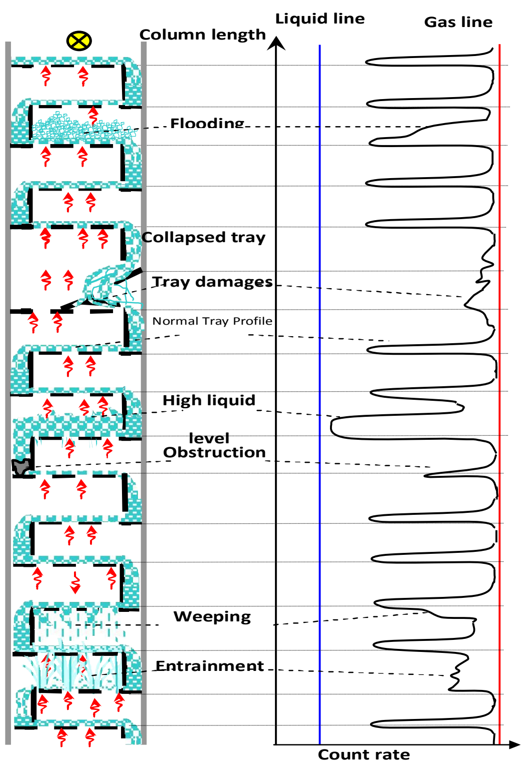


Figure 1: Sample diagnosis patterns obtained by gamma column scanner

Table 1 Typical Columns Malfunctions which can be Identified Using Gamma scanning

Problem Category	Columns Malfunctions
Mechanical related Problems	• Displaced or damaged trays, demister pads and packing • Corrosion resulting in partial tray damage • Missing, collapsed or buckled trays or manways • Out-of-place liquid or vapour distributors • Level control problems on chimney trays or base liquid level
Rate related problems	• Entrainment (slight, moderate, severe, jet flooding) • Weeping or dumping trays • Dry or flooded trays due to loading conditions • Unequal liquid levels on trays and in parting boxes, troughs and collectors
Process related problems	• Foaming on trays or in reboilers, condensers and accumulators • Maldistribution of vapour and liquid in packing • Liquid hold-up due to plugging and fouling • Superheated or subcooled feed or reflux

2. MATERIALS AND METHODS

MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. Specific areas of application include, but are not limited to, radiation protection and dosimetry, radiation shielding, radiography, medical physics, nuclear criticality safety, Detector Design and analysis, nuclear oil well logging, Accelerator target design, Fission and fusion reactor design, decontamination and decommissioning. The code treats an arbitrary three-dimensional configuration of materials in geometric cells bounded by first- and second-degree surfaces and fourth-degree elliptical tori.

The first step of this study was to construct an MCNP model of a generic design of distillation column. Monte Carlo modeling was used to explore the potential and the feasibility of the concept. A total of six MCNP models were constructed in the present study, five of which represent selected abnormal statuses of a single stage of the generic distillation column design. The sixth model obviously represented the normal status of the stage. This set of models provides a sort of a database of patterns corresponding to the normal, as well as, to some virtual breakdown cases.

The second step was to establish a pattern recognition system to be used for anaylizing input gamma scanner patterns and compare it to the set of reference data library or statuses database or ***Training Samples***. This module would act in a fashion similar to an automated ***"Expert System"***, that will obtain a suggested diagnosis deduced from the pattern recognition process. As the computerized pattern recognition results are normally associated with inherent uncertainty, therefore, it is essential to provide a confidence level indicator. From the system analysis and software design efforts a selected algorithm pattern recognition program was developed in MATLAB and it was incorporated with a simple intuitive graphical user interface for the code [4].

The gamma scan can either be conducted across the tray deck or the downcomer. Our work of Monte Carlo Simulation for the generation of ***Training Samples*** data and ***Test Samples*** data are based on gamma scans across the downcomer in order to gain down comer profile in addition to a reasonably informative side view of the tray deck. The column scanning system is shown in Figure 2.

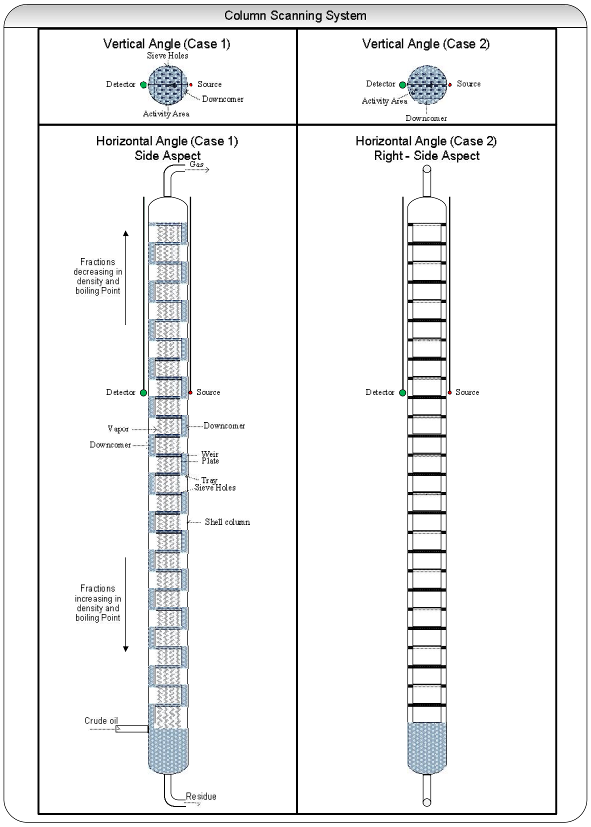


Figure 2 Sample of Column Scanning System

The third step was to examine the developed system against some case studys of virtual stage anomalties, herefrom is to be called ***"Test Samples"***. The data was generated by Monte Carlo simulations similar to Training Samples data with a deliberately added relative distortion to test the system's reliability and flexibility for diagnosis. Finally, the developed system components were refined and integrated under an intuitive Graphical User Interface ***"GUI"***, that was designed to include as much as possible visualization capabilities. Table 2 below summarizes the basic functions of the developed system along with the specific part of the system that would be responsible of executing those functions

Table 2 System Functions

Function	Component
Generation of Training and Test Samples	MCNP simulation of Gamma Ray Column Scanning System
System control	Expert System (GUI)
Diagnose status for Test Cases	Expert System (Knowledge Base Rules)
View results of diagnosis	Expert System (GUI)
Check of diagnosis reasons	Expert System (GUI)

In real, Gamma Column Scanning Systems are affected by some factors and components such as: Dimensions of the distillation column, Distillation column Design, Densities of the material that are measured, activity of the radioactive source, energy of the gamma photons from the radioactive source, type of the detector, time of the measurements, number of measurement points, and limits of radiation exposure. A standard generic design of tray type Distillation Column is obtained from the literature for the purpose of performing Monte Carlo simulation of gamma rays transport and detection in a gamma scanner as applied to such specific column design. In general, actual gamma scanner measurements can be carried out in two different orientations. The gamma scan can either be conducted across the tray deck or the downcomer. However, our Monte Carlo modeling and simulation of the measurements are based on gamma scans across the downcomer in order to gain a downcomer profile in addition to a reasonably informative side view of the tray deck. The source used in the simulation was ^{137}Cs emitting gamma particles of energy of 0.664 MeV [4]. Moreover, the detector simulated is a 2”×2” NaI(Tl). The detector is collimated by a lead shield to limit as possible the detected radiation to full energy unscattered photons travelling in a straight line from the source to the detector. A plot of the stage-scanner model simulated is shown in Figure 3.

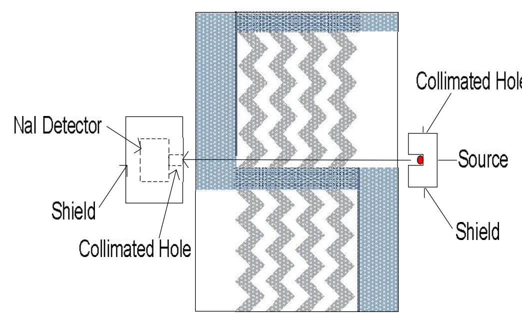


Figure 3 Stage-Scanner Simulation Model

RESULTS AND CONCLUSIONS

The evaluation of the system is based on some factors such as: reliability, speed, flexibility and accuracy of the system. Measurements of the references statuses in this work can be differed relatively by changing some factors such as: distribution and positions of the materials (liquid and vapor) inside column, and density of the materials. Test Cases will be produced to be similar to reference statuses but with some differences in measurements. The classification in the present system is carried out using the Pattern Matching concept. The concept is based on a mathematical model that calculates the absolute differences in scanner responses at each respective scanning point between the reference status (represented by training samples stored in the database) and test pattern (representing test samples). Test pattern is classified into one of the reference statuses that is corresponding to the least total sum of those differences. On top of the system's functions described above, the developed system comprises a Graphical User Interface (GUI) that gives complete accessibility and control of the system by the user. GUI is implemented using MATLAB. It is shown in Figure 4.

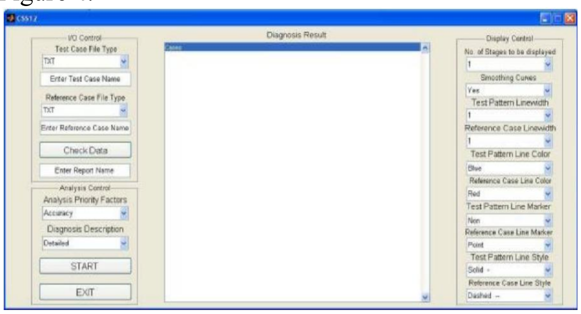
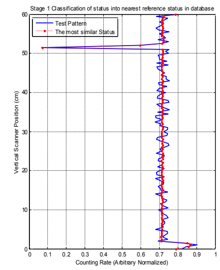


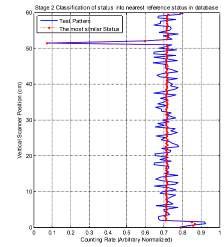
Figure 4 The Graphical User Interface of the developed computerized diagnosis System.

To evaluate the reliability and accuracy of this system, Test Cases must be represents the cases that are probable in the practical conditions. In this system, if reference statuses are used as Test Cases, each case will be classified into the reference status that is identical from database. Measurements of the references statuses in this work can be differed relatively by changing some factors such as: distribution and positions of the materials (liquid and vapor) inside column, and density of the materials. Test Cases are produced to be similar to reference statuses but with some differences in measurements. There are two methods to create different measurements for these reference statuses. First: if changing these factors include an entire stage. These test Cases are called Fluctuation Test Cases. Second: if changing these factors do not include an entire stage. It devotes on specific area in a stage. These Test Cases are called Shift Test Cases. Diagnosis evaluation is 3 levels: **Accurate** if test case is classified into its status, **Wrong** if test case of abnormal status is classified into another malfunction status, and **Critical Wrong** if test case of abnormal status is classified into Normal Stage Status [5,6]

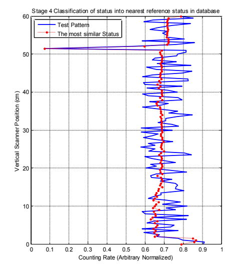
Each reference Test Case is fluctuated with an increasing Percentage Deviation to test the efficiency and the performance of the system in predicting the diagnosis of perturbed test data. Those Test Cases will help determine the maximum deviations.



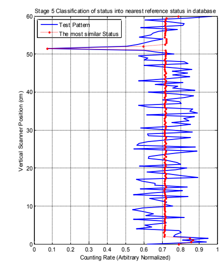
(a) %deviation= 1.9342



(b) % deviation = 3.3546



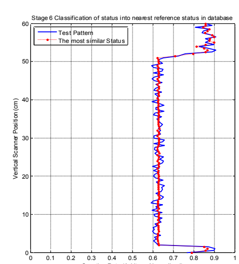
% Deviation= 7.0846



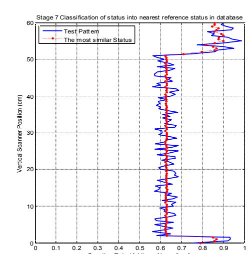
% deviation= 3.3546

Figure 5 Diagnosis evaluation of Normal operating Stage with reference to percentage deviation

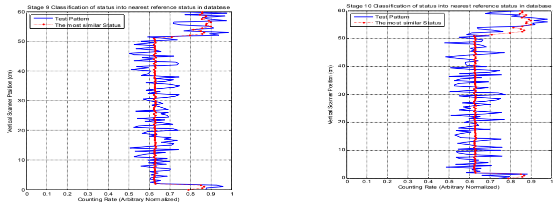
Percentage deviation corresponding to an accurate diagnosis of such perturbed cases. This test will illustrate our methodology of estimating the range of deviation of a Test Sample from a stored Training Sample of a certain reference status if an accurate diagnosis. This test was conducted for four different data sets for each status. Figure 5 summarizes the results of those tests with a focuses on the evaluation of the reliability and the accuracy of the system in light of the presented test results Now the diagnosis to be Malfunctioning Stage is done like Collapsed Tray with Percentage Deviation from Reference of Collapsed Tray status. Diagnosis results for different conditions are shown in Figure 6.



% deviation = 1.7311



% deviation = 3.3682

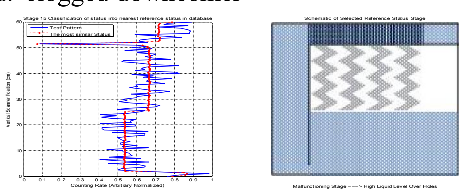


% Deviation = 6.3166 % Deviation = 7.0309

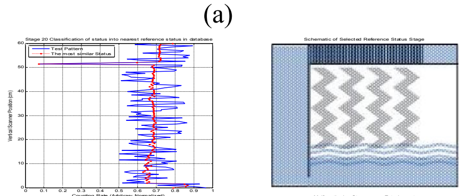
Figure 6 Diagnosis evaluation of Malfunction operating Stage like collapsed tray with reference to percentage deviation

Similarly other malfunctions like high liquid level over holes, entrainment, weeping and clogged down comer were also analyzed. Figure 7 below shows the Test Samples vs. Training Samples of the gamma scanner patterns as presented by the GUI of the developed system for the six stage statuses, namely;

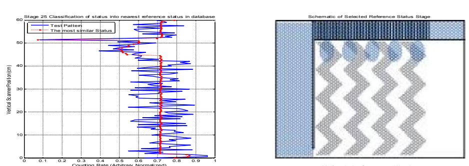
a. high liquid level over holes (at Weir Range),
b. entrainment,
c. weeping, and
d. clogged downcomer



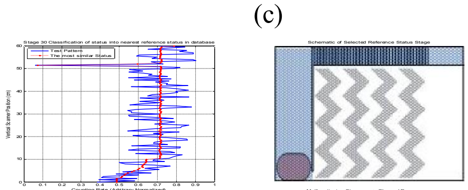
(a)



(b)



(c)



(d)

Figure 7 Representation of simulated Training Samples vs. Simulated Test Samples for (a) high liquid level over holes, (b) entrainment stage, (c) weeping stage, (d) clogged downcomer

Evaluation of the developed system showed that it has an acceptable level of reliability, accuracy, flexibility and a reasonably short processing time. Accuracy deduced in different test cases is more than 90%. Flexibility in diagnosing test samples that are not 100% compatible with training samples was also tested. In this context, test samples of measurements data at different incremental scanner positions per stage were given to the system for analysis and classification. The results of the flexibility evaluation showed a remarkable ability of the system to ignore the mismatched number of scanner positions (number of data points) between test samples and reference training samples. Evaluation of the speed performance of the system showed that the processing time consumed in diagnosing distillation column comprising 70 stages do not exceed some seconds [8,9,10].

Although this system has been applied for a specific design and dimensions of distillation column, it is believed that it can be extended for use for other distillation columns' designs and dimensions. The only adaptation necessary is reentering the training samples to rebuild the reference cases database [11, 12].

It is found that there is a great lack of application of artificial intelligence technology, in particular, application of expert systems to diagnose distillation columns' malfunctions [13] This would suggest a relative advantage of our system in support of applying it in more realistic situations in oil refining industry.

CONCLUSIONS

Gamma Ray Densitometry Column Scanning System generates measurements for diagnosis of distillation columns. This expert system incorporates several modules, namely, Pattern Recognition kernel, Database (Stored Training Samples of Diagnosis Statuses), and Graphical User Interface (GUI). Evaluation of the developed system showed that it has an acceptable level of reliability, accuracy, flexibility and a reasonably short processing time. Accuracy deduced in different test cases is more than 90%. Flexibility in diagnosing test samples that are not 100% compatible with training samples was also tested. Responding to lack of application of artificial intelligence technology,in particular, application of expert systems to diagnose distillation columns' malfunctions. This would suggest a relative advantage of our system in support of applying it in more realistic situations in oil refining industry. It would be remarkable contribution if one can add the capability of controlling the system remotely via internet for example, so that eliminate the need for the operator to be present at the same location where the measurements took place.

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References

[1] Johansen, G. A. and Jackson P. (2004) Radioisotope Gauges for Industrial Process Measurements, : John Wiley & Sons, Ltd. Abdel-Aal H. K., Aggour M. and Fahim M. A. (2003) Petroleum and Gas Field Processing, New York: Marcel Dekker.
[2] Shafiee MI, Boyce AN, Khandaker MM, Saad JM, Aziz TA, Mispan MS, Anuar MSM and Bakar BH. Pilot Studies on Rice.Yield Enhancement with Foliar Application of SBAJA in Sungai Besar, Selangor, Malaysia. Life Sci J 2013;10(1):329-335].(ISSN:1097-8135). http://www.lifesciencesite.com. 54
[3] Seader, J.D. and Henley E.J. (2006) Separation Processes and Principles, Chapter 7: "Distillation of Binary Mixtures". New Jersey: John Wiley & Sons.
[4] Urbanski N. F., Resetarits M. R., Shakur M. S. M. and Monkelbaan D. R. (1999) Gamma Scanning a Column Containing Closely Spaced Trays, Dallas: UOP LLC and Synetix.
[5] Abdullah, J. (2005) Gamma-ray scanning for troubleshooting, optimization and predictive maintenance of distillation columns, Hydrocarbon Asia, 01/02-02: pp.62-65.
[6] Mackworth, Alan K., Poole, david and Goebel, randy G., (1998) Computational Intelligence, Oxford Univ Pr.
[7] Reza Ahmadi. Survey of Image Denoising Techniques. Life Sci J 2013;10(1):753-755]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 118
[8] Badiru A. B., Cheung J. Y. (2002) Fuzzy engineering expert systems with neural network applications, New York: John Wiley & Sons.
[9] Syed Ahsan, Faisal Hayat, Muhammad Afzal, Tauqir Ahmad, Khadim H. Asif, H.M. Shahzad Asif, Yasir Saleem. Object Oriented Metrics for Prototype based Languages. Life Sci J 2012;9(4):63-66](ISSN:1097-8135). http://www.lifesciencesite.com. 10
[10] Theodoridis S. and Koutroumbas K. (2008), Pattern Recognition, Athena: Harcourt Brace & Company Ltd.
[11] Jain, Anil K., Duin, Robert P.W. and Mao, Jianchang, (2000) Statistical Pattern Recognition: A Review, IEEE.
[12] Hoon C. Y. and Ling Ai L. (2008) Distillation Column Selection and Sizing, KLM Technology Group.
[13] Kamal Mirzaie and Mehdi N. Fesharaki. A Methodology for Developing C2 Complex Systems Simulator. Life Sci J 2012;9(4):377-386] (ISSN:1097-8135). http://www.lifesciencesite.com. 58

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