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ANALYSIS OF A MULTIPHASE PHANTOM USING INDUSTRIAL COMPUTERIZED TOMOGRAPHIC SYSTEM DEVELOPED AT IPEN

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ABSTRACT

In this work, a multiphase phantom capable to be setting with solid, liquid and gas was testing using the third -generation industrial computed tomography developed at CTR/PEN. The phantom is cylindrical piece of 170 mm diameter and 240 mm height built in polymethylmethacrylate, iron, aluminum with a empty hole. Gamma ray tomography experiments were carried with the empty hole phantom and with the water filled hole phantom to measure the capability to distinguish the phases, especially the air and the water. In this work the scanner was setting for 90 views and 19 projections for each detector totalizing 11970 projections. The results were reconstructed using the Alternative Minimization algorithm in 60x60 pixels images. Experiments to determine the linear attenuation coefficients of the phantom were carried applying the Lambert-Beer principle. Results shown that was possible to distinguish between the phases even the polymethylmethacrylate and the water have very similar density and linear attenuation coefficients. It was established that the newly developed third-generation fan-beam arrangement gamma scanner unit has a good spatial resolution acceptable given the size of the phantom used in this study.

INTRODUCTION

Unlike the standard aspect of the computed tomography (CT) for medical application, tomography systems for the industrial applications should be adapted to the different size and geometry objects usually placed in a aggressive environment, which contains flammable superheated or corrosive materials, and may be, eventually, subject to high internal pressure: all these factors bring in many difficulties for setting CT devices around the objects (Fig 1) [1,2]. Therefore, the development of special CTs is required, inhibiting its production in large scale. In addition, the industrial systems involve dynamic processes and contain solids, liquids and gases mixtures when CT is an excellent option to see the phases distribution inside the vessels [3,4,5,6,7]. In other words, it is necessary to develop a tomographic system suitable for each purpose in industry [2, 6].

Figure 1 – Typical industrial process columns.

The CT systems based on the transmission use an array of encapsulated radioactive sources and detectors placed in opposite sides of the targeted object. [7,8,9,10]. First generation tomography systems consist of a source emitting a collimated radiation linear beam and a radiation detector (Figure 2 (a)). The source-detector system moves in opposite sides of the object, measuring the attenuation of radiation at each position.

In the second generation CT systems, a set of detectors is placed opposite to a set of radioactive sources, moving (source and detector) around the object under study, providing a number of projections equal to the number of detectors (Figure 2 (b)). Sometimes, these second generation systems, also, use multiple radioactive sources in order to reduce the analysis time of the system.

In the tomography of third generation, the source is collimated so that the path crossed by beams is similar to a fan (Figure 2(c)). The system moves around the targeted object, obtaining a particular view for an "x" position of the source-detector array. In this type of system, several sources and arrays of multiple detectors may be used.

Finally, the so-called fourth-generation CT systems use a fixed array of detectors (a large number of detectors mounted on a fixed ring) and a radioactive source that moves around the object (Figure 2 (d)). Inside, the fan-shaped beam is detected in 10.03 seconds. Records of any measure are from the detector, representing a view of the object. However, all CTs are constituted, basically, of same parts: radioactive sources; radiation detectors; a data acquisition system and a suitable computer.

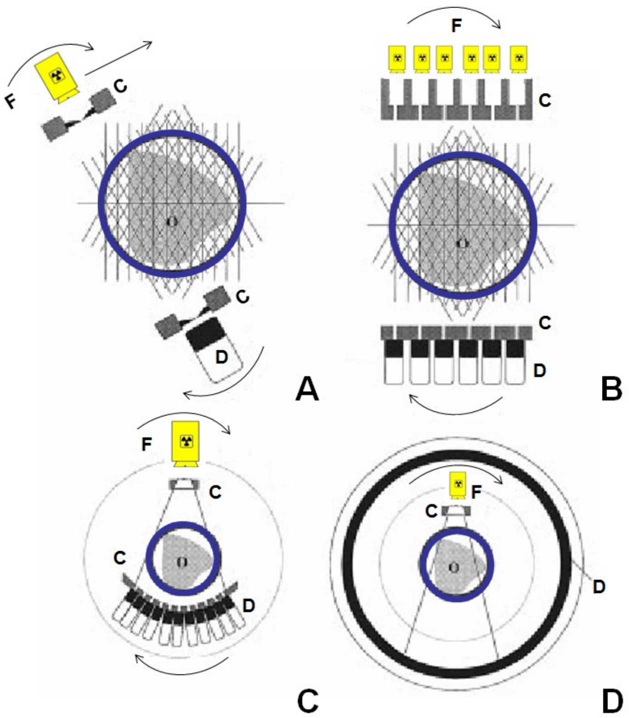


Figure 2 - (A) translation - rotation of a beam in parallel (first generation), (B) translation - rotation of multiple sources in parallel (second generation), (C) rotation of a fan-beam (third generation), (D) detector fixed - rotation source (fourth generation). D: detectors; F: source C: collimator, O: object of study .

A third generation computed tomography was developed for analysis of industrial multiphase systems at IPEN [2,11]. In its configuration, an array of seven 2” NaI(Tl) detectors is located in an arc concentric to the center of the ^{137}Cs gamma source. In order to increase the number of projections measurements in one view of the studied system, the number of detectors in the arc was effectively increased by using a collimator that moves across the detector arc. The whole assembly of the detectors and the radiation source are mounted on a gantry capable of being rotated round the test section axis through a stepper motor interfaced with a host computer. For testing the developed CT, a multiphase phantom was prepared in our laboratory and tomographic experiments were evaluated.

EXPERIMENTAL PROCEDURE

Tomography measurements were performed using the third generation CT developed at the CTR/IPEN [2,11]. Each of the seven 2” NaI(Tl) detectors has an individual collimator made in lead, so that the detectors are completely shielded by the collimator. Each collimator has a hole of 5 mm diameter for sampling beams. These dimensions for the collimator holes were optimized based on considerations of providing adequate area for detecting photons with good statistic into the chosen sampling period. The radioactive sealed ^{137}Cs (662 keV) source is 3.7 GBq placed inside a lead collimated shield system providing a 45° fan beam arc Fig. 3.

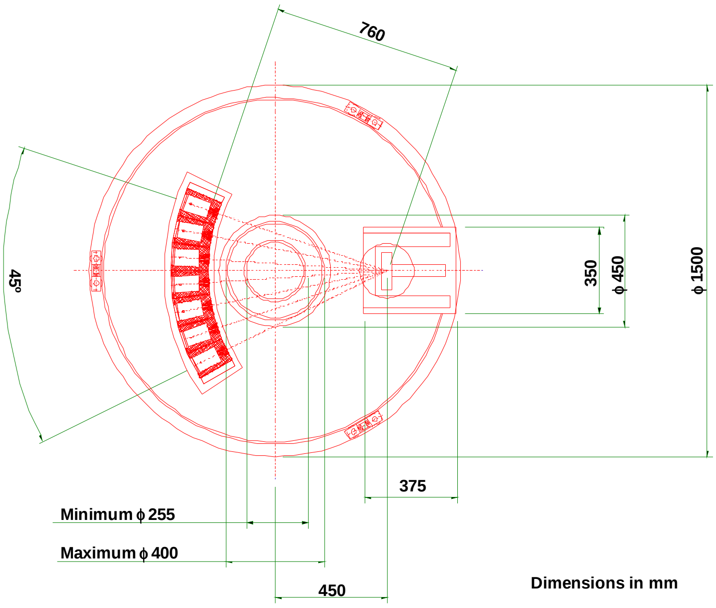


Figure 3. Top view drawing of the iCT used.

A multiphase phantom capable was designed and prepared in order to be able of varying the proportions of the phases (gas, liquid or solid) to validate the third generation tomography developed at CTR/IPEN. The 15 cm diameter phantom consists of polymethylmethacrylate solid containing three holes one filled with a steel plug another with an aluminum plug and the third one empty, as illustrated in Figure 4. The idea was to switch the gas and liquid phases, while maintaining the solids fixed.

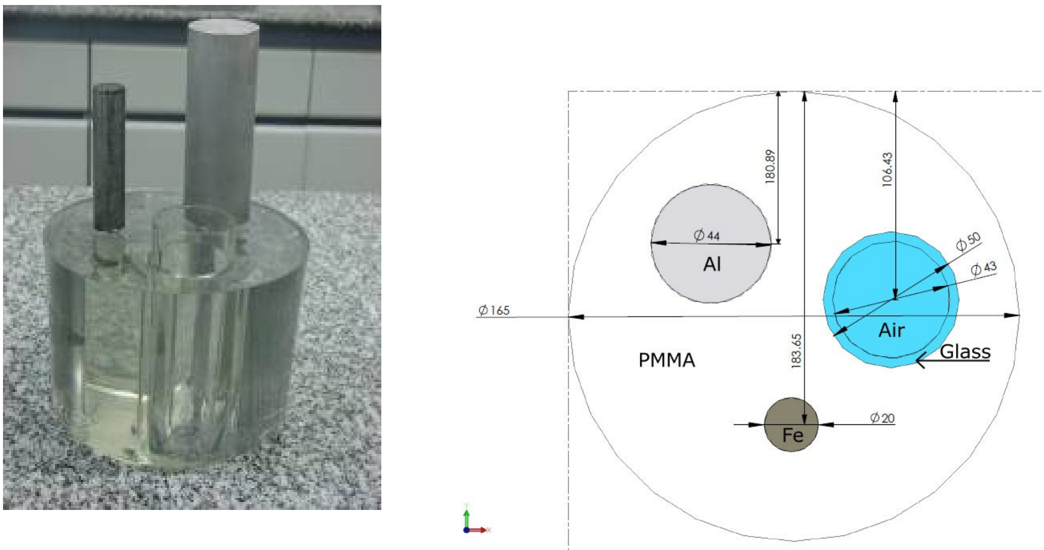


Figure 4. Picture of the multiphase phantom

The array of seven NaI(Tl) detectors and the ^{137}Cs source were placed on the rotatable gantry and the phantom was installed in the center between the array of detectors and the source. The gantry can be rotated around the axis of the phantom by a stepping motor that is controlled through a microprocessor. The size of the array of detectors is sufficiently large so that the entire phantom was within the field of view of the detectors all the time. Moreover, the whole assembly can be moved in the axial direction along the phantom to perform a scan at different axial levels of the phantom. Fig. 5 shows an illustration of the third generation CT with the phantom in the center of the gantry. The data acquisition board and the mechanical control used were developed at CTR/IPEN also [2,11].

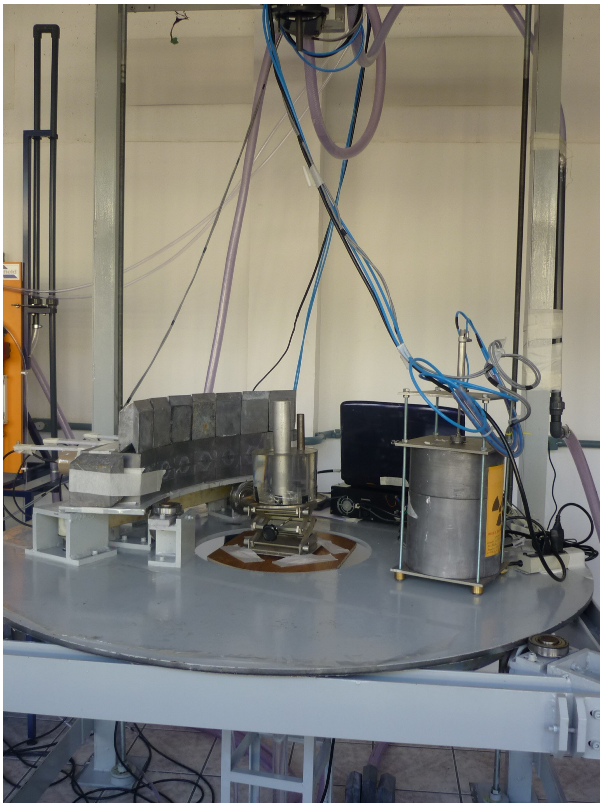


Figure 5. Set-up of the third generation CT.

The tomographic measurements were carried out using the multiphase phantom prepared at IPEN (Fig. 4). To obtain statistically significant results, and to reduce the effect of the position the CT scans were obtained rotating around the phantom the plate with the source and detectors 360° in 90 views, each view provided 4°. The movement of the detector–collimator assembly was controlled by another steeper motor, in each movement, this assembly rotated by 0.39° generating 19 projection per detector or 133 (19x7) projections per view totalizing 11970 projections per image. Previously, each NaI(Tl) detector was evaluated by gamma spectrometry techniques using a associated multichannel electronics and data acquisition board developed by CTR/IPEN.

The reconstruction algorithm used was the Alternative Minimization (AM) technique [8,12] and was implemented in MATLAB and VB platforms. This reconstruction algorithm is used, since, it has the following advantages: (1) it accounts for statistical variations associated with the radiation decay measurements; (2) it readily incorporates non-uniform beam effects; and (3) it ensures that the final reconstruction contains only positive values. The results were reconstructed in 60x60 pixels images. [8,12].

To compare the results of the linear attenuation coefficients of the phantom components is necessary to know the value these coefficients for pure materials (pure phase). Hubell & Seltzer (1996) created a database called NIST [13], where figures are available for the attenuation coefficients as a function of energy for a specific compound or material. In these experiments, the effective linear attenuation values were determined using densitometry, a procedure consists of the direct application of the Lambert-Beer equation (4) using in only one detector, where the material to be measured is placed in the path of the radiation.

RESULTS AND DISCUSSION

Fig. 6 shows the results of the transmittance lines obtained from the tomographic measurements for the phantom for the empty hole (gas) (6a) and for the hole filled with water (6b). It can be seen from this figure, well defined transmittance lines were found for different phases. The lower transmittance value was found for a phantom hole filled with water compared to that the hollow hole (air). In the air region (around the outside of the phantom) the transmittance values were near one.

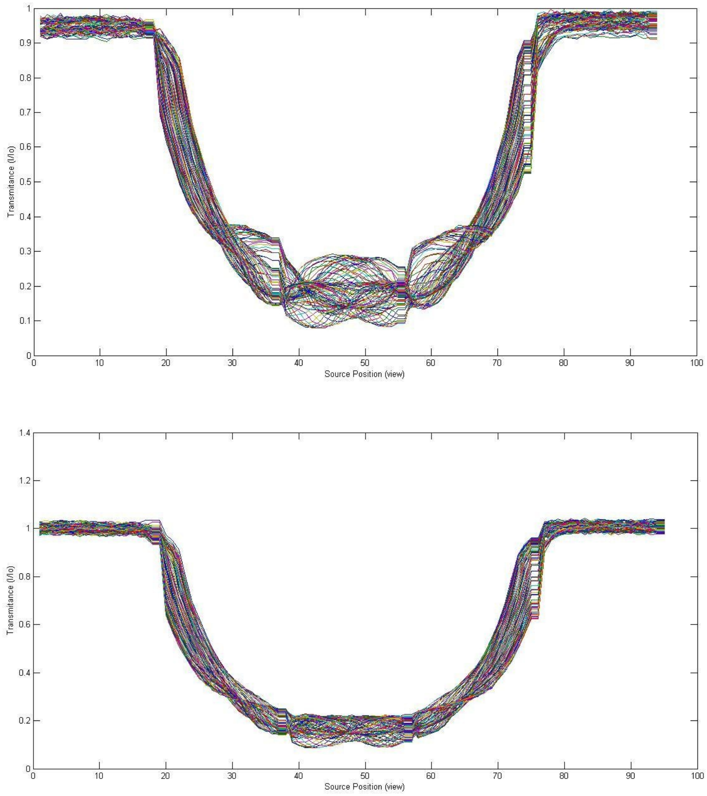
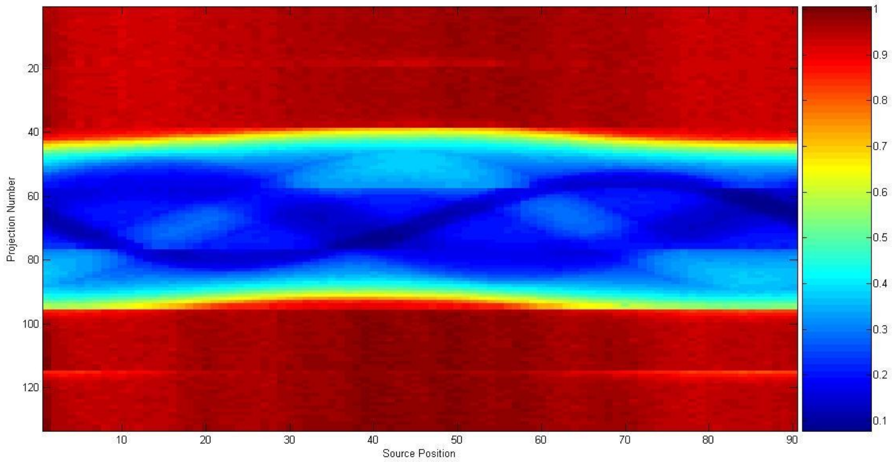
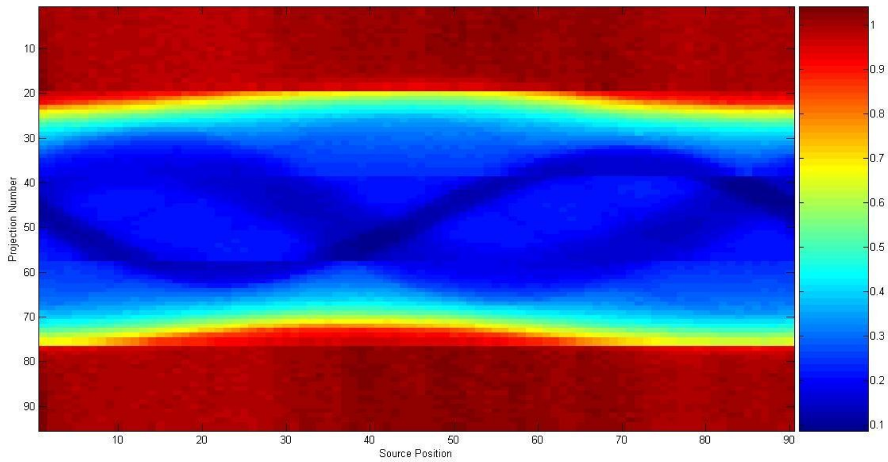


Figure 6 – Transmittance lines obtained for phantom with a empty hole (gas) (a) and water filled hole (b)

Figure 7 shows the sinogram obtained for phantom with a empty hole (7a) and water filled hole (7b). Each pixel from the sinograms represents the transmission value (I/Io) corresponding to a given projection and position of the source (view) or rotation angle. The sinograms showed dark blue shades to the objects of greater density. A sinogram allows checking the measurements quality obtained in the tomography sampling process. The absence of parallel bands or spots that could be attributed to malfunctioning detectors ensured the end result.



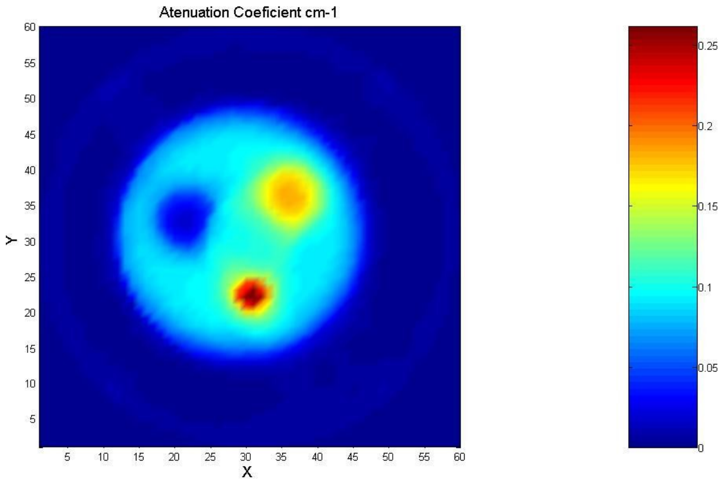
(a)



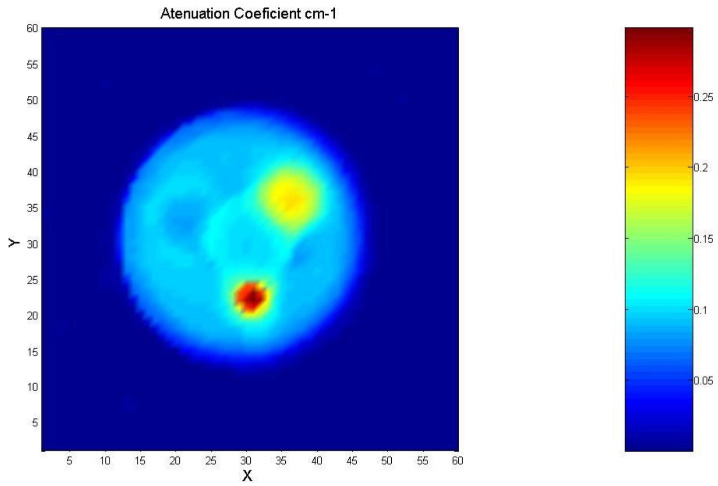
(b)

Figure 7 – Sinogram of phantom with a hole hollow (gas) (a) and filled with water (b)

Fig. 8 presents the reconstruction image of the empty hole phantom (8a) and water filled hole phantom (8b). A reasonable resolution was observed for both images. As it can be seen from this figure, the different densities of the phantom constituent materials can be clearly identified. The theoretical attenuation coefficients of each phantom constituent material are summarized in Table 1.



(a)



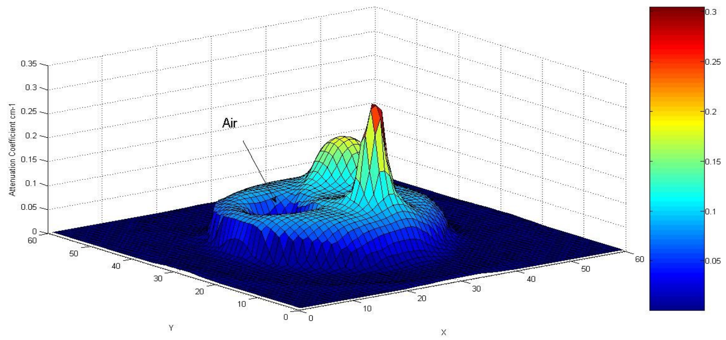
(b)

Figure 5 – Reconstruction images (60x60 pixels) from the empty hole phantom (gas) (a) and the water filled phantom (b) cases.

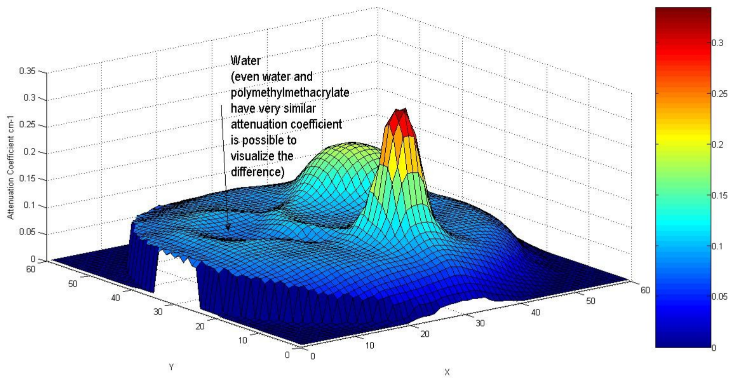
Table I: Material Mean Densities

Material	**Density (g/cm^3)**
Polymethylmethacrylate	1,2
Aluminum	2,7
Iron	7,9
Air	1,2 x 10^{-3}
Water	1,0

Analyzing Fig. 5(b), little differences can be observed between the images of the solid material (polymethylmethacrylate) and the water filled hole is due to the close density values of the two materials (Table 1) and ,consequently, of the attenuation coefficients, 0.09 cm^{-1} for plastic and 0.08 cm^{-1} for water. Another way to plot the Fig.5 results is shown in Fig.6 when can be distinguish very easy the empty hole in Fig.6(a) and the water filled hole in Fig.6(b). Actually it's so possible to obtain and process very rich data sets from the images. In future works more numerical analyses will be studied to demonstrate the powerful of the CT techniques.



(a)



(b)

Figure 5 – Attenuation coefficients difference between the phantom with the empty hole (a) and the phantom with the water filled hole (b).

1. CONCLUSIONS

It was established that the newly developed third-generation fan-beam arrangement gamma scanner unit has a good spatial resolution acceptable given the size of the multiphase phantom used in this study. The CT is capable of providing phase (liquid or gas) composition information in two phase systems. Although the system is only capable of providing time-average data, it can provide unique information concerning the structure of multiphase systems. The main advantage of the CT include it's a non-invasive nature, capability for providing local as well as global information and adaptability for automating the entire data acquisition process. However, more experiments need to be done to optimize spatial and time resolution testing many parameters as collimators width, number of views, sampling number, accounting time, etc. In future works the numerical image analyze and processing will be introduced and improved.

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