FLOW REGIME IDENTIFICATION METHODOLOGY WITH COMPUTERIZED TOMOGRAPHY

Alberto Ramon Ferreira Teixeira, ateixeira@con.ufrj.br
Nilson Costa Roberty, nilson@nuclear.ufrj.br
Nuclear Engineering Program – COPPE/UFRJ

Abstract. *This* work *presents* a flow *identification methodology in multiphase system in stratified oil-water-gas regime. The principle is based on detecting the amount of x-rays attenuated by passing through the duct containing the flow. The radiation interacts with the material and the composite duct fluid, causing the intensity of X ray declines. In this study, was used divergent bean into two and three dimensions. In this case we need to know the source position in order to back project the rays accordingly in a divergent way. In three dimensions, the projections discontinuity determination problem is substituted by the projections images contour determination. Each ray generates one algebraic equation. The system may be solved by the least square method or by some algebraic reconstruction technique such as the ART, MART or q-ART algorithms. The experiment shows that with a single view (a source-detector pair) it is possible to obtain information of a flow inside a duct (the attenuation of the radiation beam). However, it is not possible to make the reconstruction of the flow. Then, we use two views, so getting enough information to reconstruct the flow. The results presented show that the technique may be applied in the successfully flow regime identification.*

Keywords*: multiphase flow, computerized tomography, X ray transform, stratified oil-water-gas.*

1. INTRODUCTION

Many industrial and medical applications involves the reconstruction of functions from a small number of views given by many function projections related with its Radon, fan bean and cone beam associated with the X ray propagation. These functions in the reconstruction process that represents the radiation absorption coefficients estimation are frequently associated with characteristic sub-domains inside the whole function domain. These homogeneous parts may results from the manufacture process, or from some natural stratification or segregation of components inside the body. By collecting a-prior information about the support and the value of these characteristics parts, the number of constant parameters needed to resolves the uniqueness problem of reconstruction may be reduced. In the case of parallel two dimensional X ray bean, where the projection may gives us this additional information. The procedure consists in inspect its discontinuities and back projection it accordingly. The support of the possibles parts are located inside the convex polygonal domains that results from these lines intersection. The same method may be applied for divergent bean in two or three dimensions. In this case we need to know the source position in order to back project the rays accordingly in a divergent way. Note that in three dimensions, the projections discontinuity determination problem is substituted by the projections images contour determination. The kind of software appropriated to implement “shape from shadow” X ray based support determination are based on decomposed solid geometry. The second part of this constant by part reconstruction method is based on ray tracing. By determining the length of the intersection of a ray starting at the source and ending in the detector, we may weight the contribution of each characteristic part of the function to the detector intensity measurement. Each ray generates one algebraic equation that will compose the system with the unknown source intensity. The system may be solved by the least square method or by some algebraic reconstruction technique such as the ART, MART or q-ART algorithms will infer the appropriated intensities in the support of each part of the function. The technique of x-ray attenuation is often used in the petroleum industry because of its robustness and noninvasive nature, and can perform these measurements without changing the operational conditions. The two views are arranged at an of 90 degrees to each other, the intention is to measure the attenuation of the beam that is influenced by changes in the composition of the flow. This meter is highly dependent on the flow regime. The information flows in the water-oil-gas system are usually obtained by subject interpretation from visual observations which may lead to misinterpretations. Therefore, a noninvasive system that identifies the flow regime without subjective evaluation is very important. The data set required for training was obtained by mathematical model of stratified homogeneous regime.

2. MODEL PHYSICAL CONCEPT

Along a ray, the radiation can be absorbed by various known processes, depending on its nature and energy and also on the characteristics of the medium through which it propagates. There are situations in which the scattering process gives an important contribution to detectors measurements. In this case the appropriated modeling of the radiation propagation is done through the radiative transport equation. Since we are supposing ray, collimation, we will neglected the scattering process and consider only the extinction process. In this spatial case, the problem simplifies considerably, and the attenuation "Eq. (1)" of the ray along its trajectory is exponential, and we may identify the X ray transform with the algorithm of the ray attenuation in the

$$P[\sigma](\xi,\theta) = -\ln\left(\frac{I(E,\xi,\theta)}{I_0(E,\xi,\theta)}\right) = b(\xi,\theta) \tag{1}$$

$I_0(E,\xi,\theta)$ is the initial bean intensity for an specific energy E that decreases along the ray trajectory to I(E, ξ,θ). The "Figure 1" presents a logarithm-logarithm typical energy variation of the extinction cross section of for important materials utilized in the oil-gas industry [Hubbell and Seltzer].

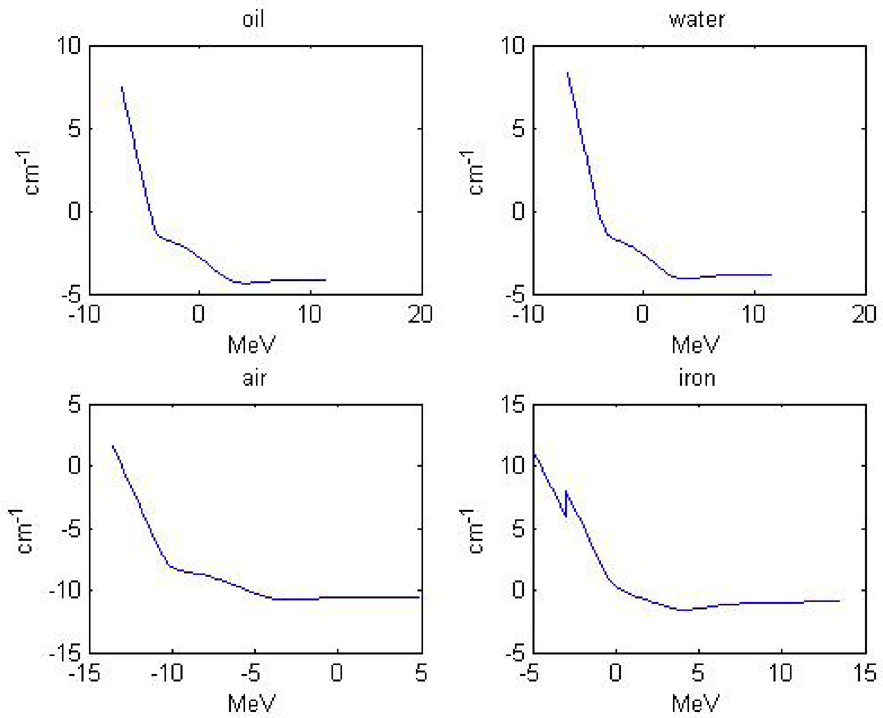

Figure 1. Log-Log extinction cross section energy dependency

When d = 2, the X ray transform is equivalent to the Radon transform used in the tomography. In general, we may have the parallel ray or divergence ray geometry. In our model, we are consider only a small number of views, and collecting each ray as an algebraic equation to form a system to be solved in order to reconstruction the constant by parts function representing the unknown material.

2.1. Posing the problem

For a radiation energy E fixed, let us consider the following problem: Giving some set of data $\{b(\xi,\theta)\}$, ξ *and* θ associated with a set of rays, to find the constant by part function σ.

Since we are supposing to know only a small amount of projections, such as only one or two views, we must give more information about the support of the function. The first possibility is derive it from the analysis of the projections. Projections are X ray shadows of the cross section and characteristics parts of the constant by parts functions representing the extinction coefficient of the material may be identified by analyzing the contours inside these radiographies. Contours in the two dimension projection of the three dimensional object and derivatives in one dimensional projection of the two dimensional object section.

The "Figure 2" and "Figure 3" exemplifies the two dimensional situation. The source of the parallel bean rays used to form the projection must be consider at the infinity.

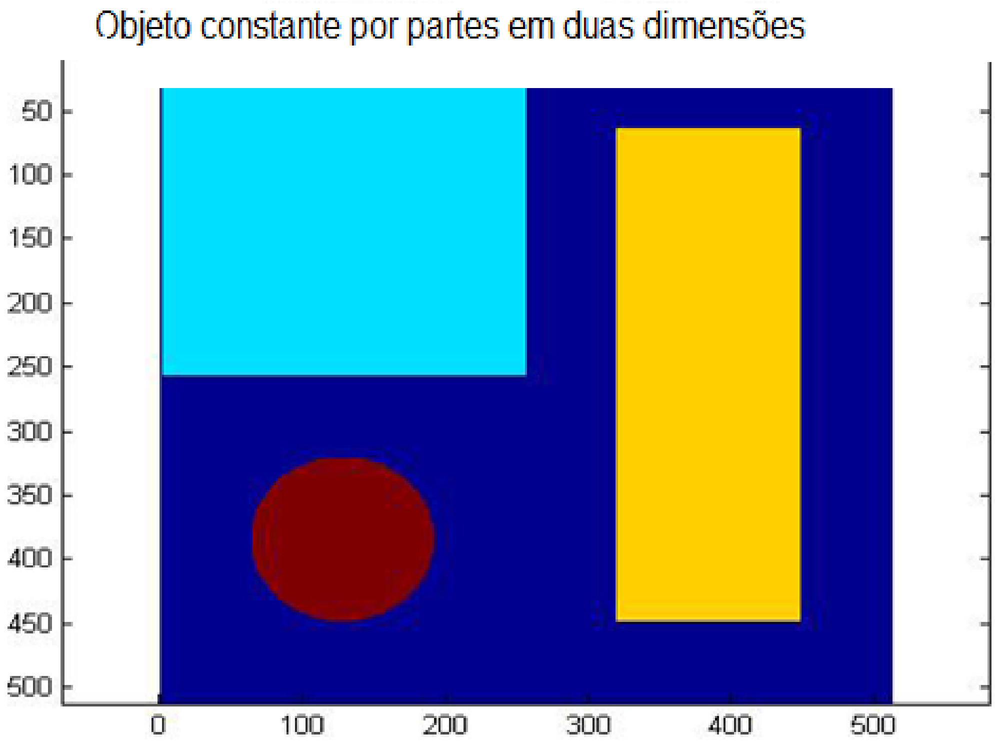

Figure 2. An constant by parts object to be projected

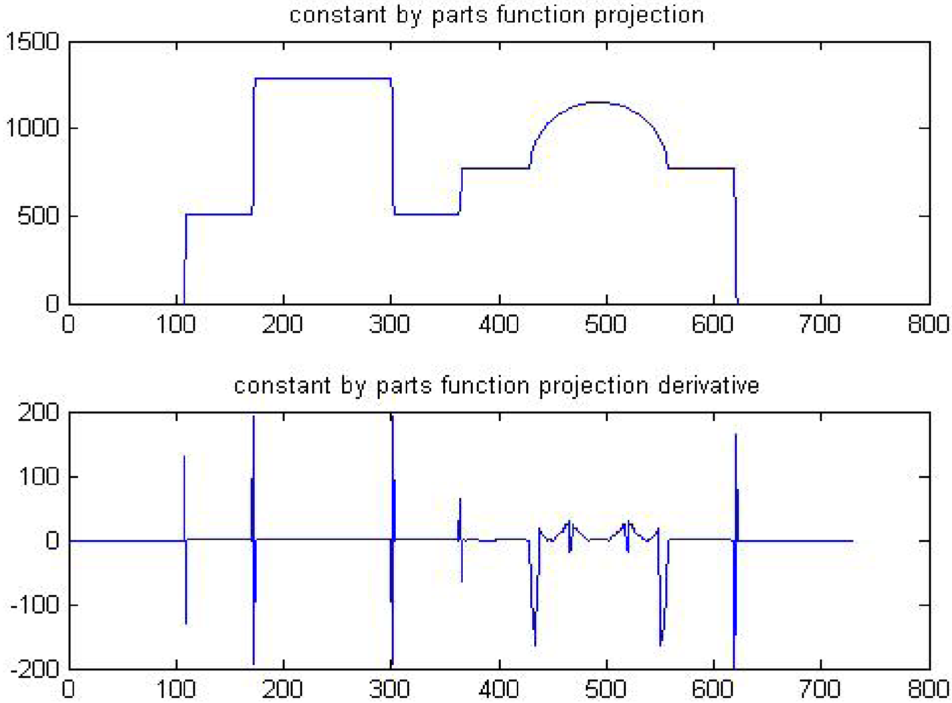

Figure 3. Projection and its derivative

We may note that the back projection of the derivative location will determines variables sized strips in which the values of the function are changing. Two or more views will make possible the determination of the convex envelop of the constant parts elements of the functions. If in addition we has some a-priori information that is independent of the projections, such as that the function represents as stratified medium as in the main application of this work, it will be easier the function support characterization. So, we will make the things very easy and assume that we have this kind of information about the source support and our problem becomes the following linear algebraic system problem.

2.2. Problem 1 (Algebraic linear System)

For a set of rays associated with c given $\{b(\xi,\theta),\ \delta_{n,i(\xi,\theta)}\ e\ \delta_{i(\xi,\theta)}, i = 1, \dots, I(\xi,\theta)\}$, to find σ_n such that:

$$\sum_{n=1}^{N} \sum_{i=1}^{I(\xi,\theta)} \sigma_n \delta_{n,i(\xi,\theta)} \left(\gamma_{i(\xi,\theta)} - \gamma_{i(\xi,\theta)-1}\right) = b(\xi,\theta) \tag{2}$$

2.3. Linear system inversion

Let us give a matrix representation to the problem by:

$$A^n_{(\xi,\theta)} = \sum_{i=1}^{I(\xi,\theta)} \delta_{n,i(\xi,\theta)} (\gamma_{i(\xi,\theta)} - \gamma_{i(\xi,\theta)-1}) \tag{3}$$

and writing the problem as: fixed the photon energy E, for a set of rays associated with (ξ,θ), given "Eq. (1)", to find σ_n that:

$$\sum_{n=1}^{N} A^n_{(\xi,\theta)} \sigma_n = b(\xi,\theta) \tag{4}$$

Classical methods based on algebraic reconstruction techniques such as ART, MART and others [Kak and Slaney] may be implemented for solutions of the problem. Other technique baased on singular values truncation may be adopted when the system is not so big. We also may adopted the Tikhonov regularization method, which is based on the following optimization problem:

Fixed the photon energy E, for a set of rays associated with (ξ,θ), to find the extinction coefficient x which is solution of the following minimization problem:

$$min\{ \;||\, Ax\text{-}b \,||\, + \epsilon \;||\, x \,||\; \} \tag{5}$$

The parameter ϵ is the Tikhonov regularization parameter (noise to signal ratio) and is choose in a such way that the error due to modification of the original problem does not compromises the stabilities benefits introduced by the improvement of the numerical condition number of the algebraic matrices problem.

3. METHOD APPLICATION AND RESULTS

We consider as an application of one or two beans X ray to identification of a multiphase flow with gas, oil and water inside a metallic duct. Due to the difference in the densities of the mixtures components, the flows stratifies, which gives an important a-priori information about the constant by part cross section that will be reconstructed. We have used this information to model the weight matrix a used with the reconstruction algorithm.

Numerical data has been produced with the simulated direct problem in two situations. In the first we consider only one view and collect the data in a direction parallel to the level of the flow stratification. These optical thickness are shown in "Fig.4" for one energy of 180 keV.

Based on the experimental three dimensional divergent bean whose geometry is showed in "Fig.5", we computed the set of data with photon energy 180 keV showed in "Fig. 6" for the first source position 1 and in "Fig. 7" for the source position 2.

3.1. Analysis of the single parallel view

When working with a single view, the image can not be rebuilt, but some information can be obtained, such as verification of different materials, discontinuities and derivative. The function utilized distinguishes the components of the experiment through the attenuation of the X ray beam.

Since the parallel rays are positioned in accordance with the flow stratification, the derivative of the projection data "Fig. 8" for the data in "Fig. 4" shows the approximated position of the boundaries inside the duct distinguishing the three phases, that is, the water oil and the oil gas boundaries.

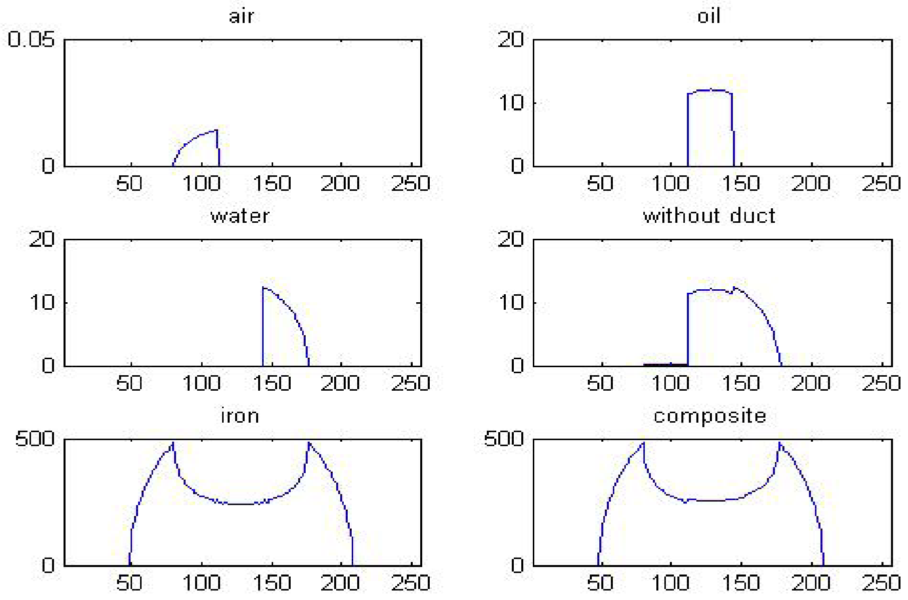

Figure 4. Optical thickness parallel bean with one view – 180 keV

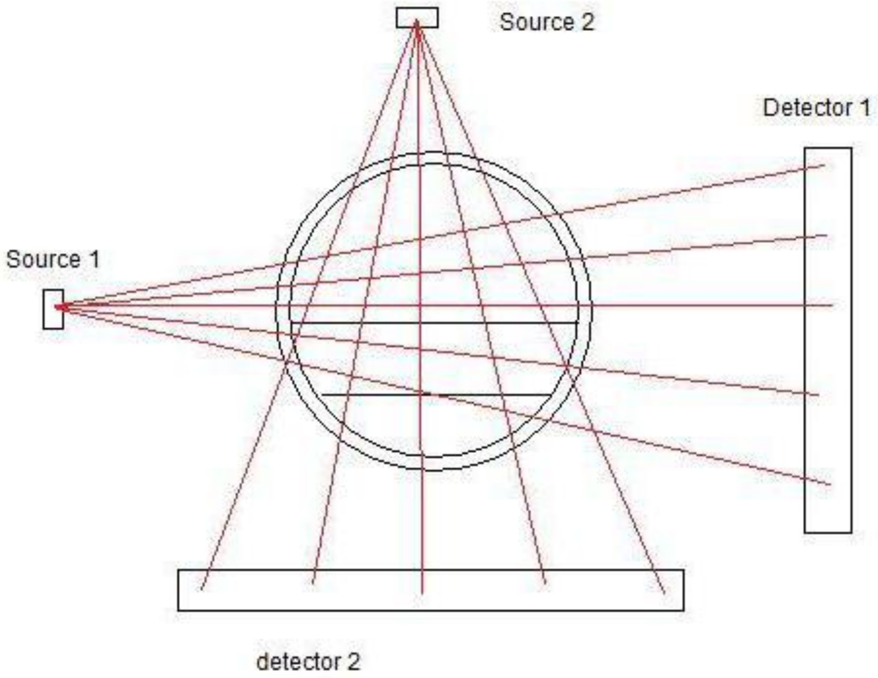

Figure 5. Divergent bean experimental set

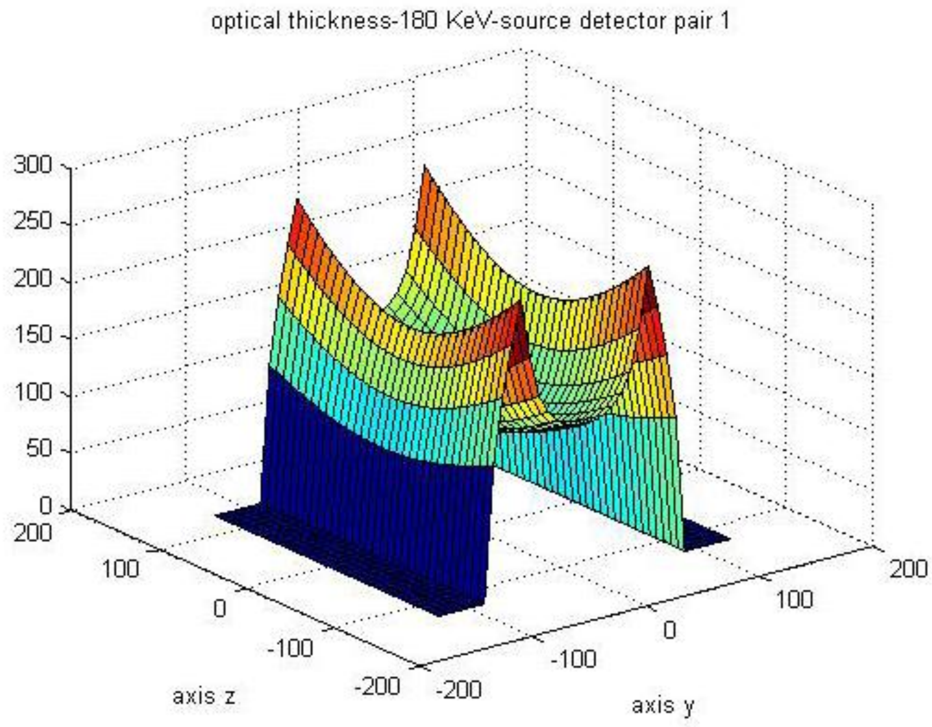

Figure 6. Optical thickness for the source position 1 – energy 180 keV

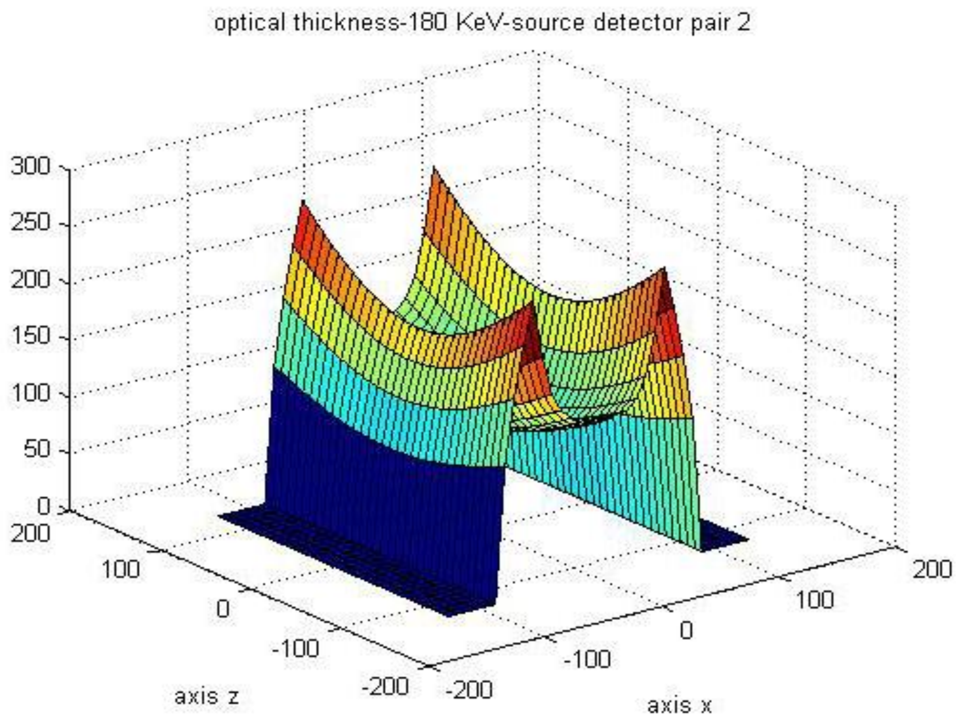

Figure 7. Optical thickness for the source position 2 – energy 180 keV

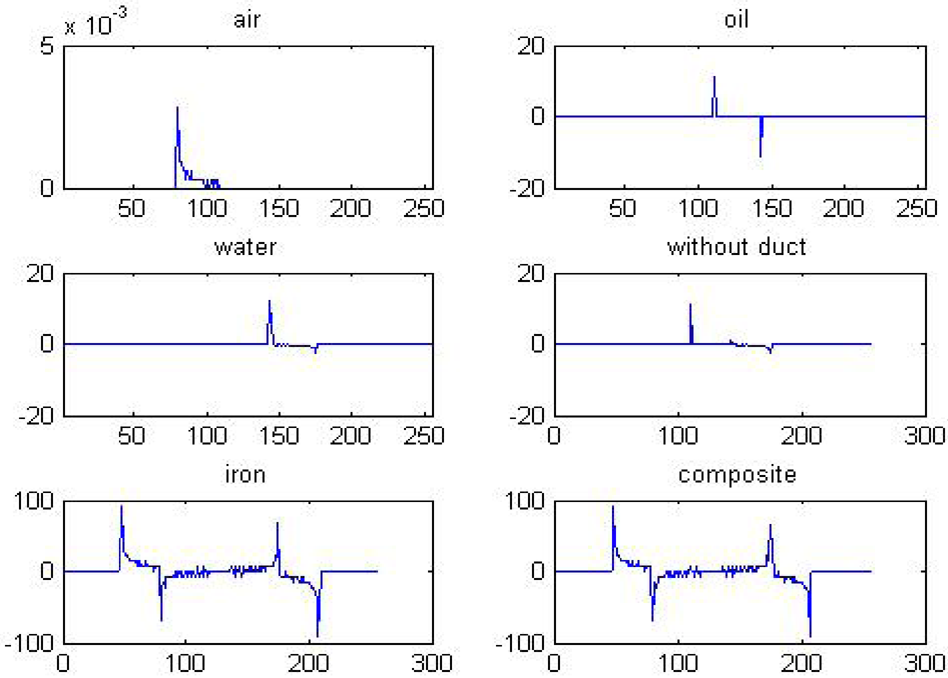

Figure 8. Derivative parallel bean optical thickness – energy 180 keV

3.2. Analysis for three dimensional problems with two views

In this case we build one algebraic system as postulated in Problem 1. In order to make possible the computation of the associated weight matrix A parameters, that is, calculates the $\gamma_{i(\xi,\theta)}$, we supposes a generic stratification as given by "Fig. 9".

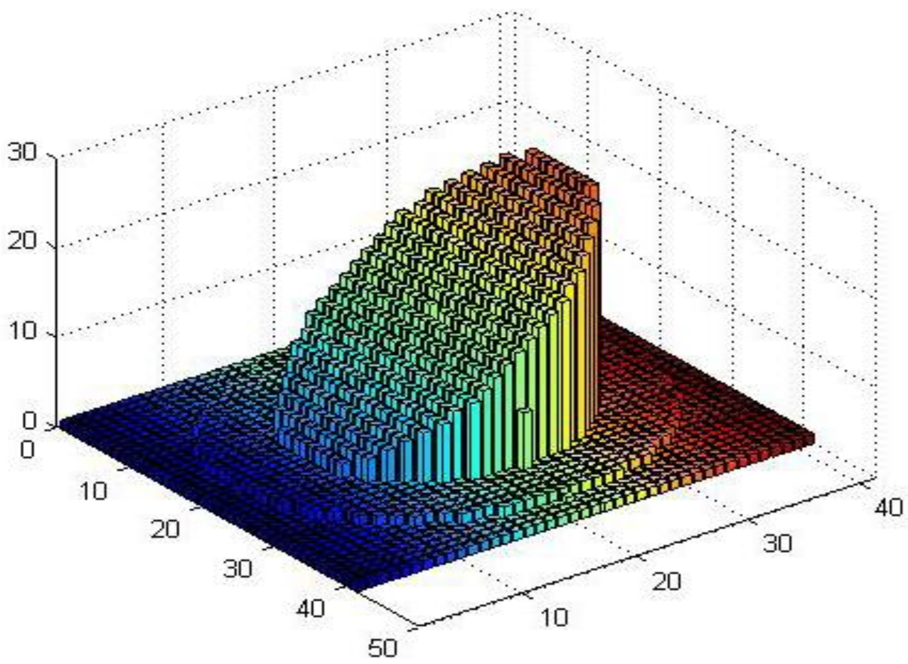

Figure 9. Weight determination

We may refine the distinction of the levels by considering more layers. Obviously, the stratification directions are represented in the layers definition. For the present study we have consider only 22 layers. Since the algebraic systems used in the reconstruction is ill-conditioned, we have used the Tikhonov regularization technique to obtain a stable solution for the absorption coefficients in the three reconstruction stratified layers of the multiphase flow. Experimental minimum regularization parameters of order 10^{-10} has been found. The "Fig. 10" shows the exact attenuation coefficient in blue reconstructed with Tikhonov regularization in red. The green curve is the instable results that ones obtain if solves the problem without regularization.

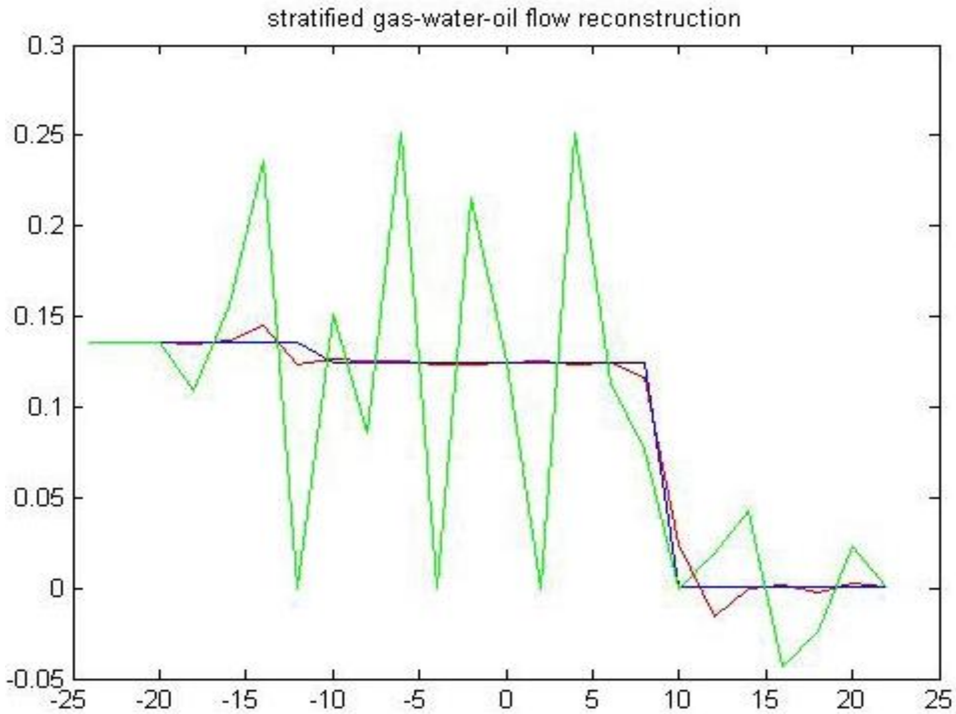

Figure 10. Reconstruction of water-oil-gas-air inside the duct – energy 180 keV

Results shows the adequacy of the present methodology.

4. CONCLUSIONS

For one view, the image can not be rebuild, but we can observe the existence of different materials through the attenuation of the beam X ray showing the discontinuities. The derivative of the optical thickness show the approximate location of borders within the duct, allowing to distinguish the phases.

For two views, the algebraic system used in the reconstruct process is ill-conditioned, then, we use the Tikhonov regularization and we obtain stable solution for the absorption coefficients of the three layers, them the image can be reconstructed.

4. REFERENCES

Hubbell, J.H. and Seltzer, S.M., 1996, "Tables of X ray Mass Attenuation Coefficients and Mass Energy-Absorption Coefficients from 1 keV to 20 MeV for Elements Z=1 to 92 and 48 Additional Substances of Dosimetric Interest", <http://www.nist.gov/physlab/data/xraycoef/index.cfm.>

Hu, B. et.al., 2005, "Development of an X ray Computerized Tomography (CT) System with Sparse Sources: Application to Three-phase pipe Flow Visualization", Experiments in fluids, Vol.39, pp.667-678.

Salgado, C. M., Schirru, R., Brando, L.E.B. and Pereira, M.N.A., 2009, "Flow Regime Identification with MNCP-X Code and Artificial neural Network", Proceedings of the 2009 International Nuclear Atlantic Conference-INAC 2009, ABEN, Rio de Janeiro, Brazil, ISBN: 978-85-99141-03-8.

Kak, A.C. and Slaney, M., 1987, "Principles of Computerized Tomography Imaging", IEEE Press, New York, Editorial Board.

Hussein, E.M.A. and Han, P., 1995, "Phase Volume-Fraction Measurement in oil-water-gas Flow Using Fast Neutrons", Nuclear Geophysis, Vol.9, pp.229-234.

Hansen, P.C., 1998, "Rank-Deficient and Discrete I11-Posed Problem", ISBN 0-89871-403-6.

Kaper, G.H., Leaf, G.K. and Linderman, A.J., 1995, "Formulation of a Ritz-Garlekin Type Procedure for the Approximate Solution of the Neutron Transport Equation", Vol. 50, pp.42-65.

Salgado, C.M., Brando, L.E.B., Pereira, M.N.A., Ramos, R., Silva, A.X. and Schirru, R., 2009, "Prediction of volume fractions in Three-Phase Flows Using Nuclear technique and Artificial Neural Network", Applied Radiation and Isotopes, doi:10.1016/j.apradiso.2009.02.093-Rference ARI4470(2009).