This work presents methodology based on the use of nuclear technique and artificial intelligence for attainment of volume fractions in stratified and annular multiphase flow regime, oil-water-gas, very frequent in the offshore industry petroliferous. Using the principles of absorption and scattering of gamma-rays and an adequate geometry scheme of detection with two detectors and two energies measurement are gotten and they vary as changes in the volume fractions of flow regime occur. The MCNP-X code was used in order to provide the data training for artificial neural network that matched such information with the respective actual volume fractions of each material.
2. GENERAL

2.1. MCNP-X Code

The MC technique is a very used tool of simulation in the area of radiation transport by means of computational codes, spread out in situations where measured physical are inconvenient or impossible. It consists of following many “particles”, one to one, since the source, where its “birth” occurs, throughout its “life”, until its “death” (escape, cut-off energy, absorption, etc.). The probability distributions are randomly showed using transport data to calculate the result in each step of its “life”. In this work MCNP-X code was used in the elaboration of mathematical models.

2.1. Artificial Neural Networks

The RNA’s are inspired mathematical models in the human brain that possess the capacity “to learn”, from a finite set of information, and to generalize the knowledge. A network multilayer perceptron was used with supervised learning whose construction possesses multiple layers and distinct activation functions. The training algorithm is the back-propagation [20] and the stop criterion is cross-validation which uses part of the data, so called test set, to decide the breakpoint of the training of the network avoiding, therefore, in such a way, a super training and consequence of loss in the generalization.

2.1. Flow Regime Models

The models of stratified and annular regime presented in Fig. 1 had been used to get a data in order to train the RNA. As a result, the values of the thicknesses (x_g, x_a and x_o) of each material had varied, in the simulation, getting different combinations of FVM. For each one of these combinations relative counts to transmission and scattered beams had been gotten. The used phases are: oil, gas and salty water (4% of salt (NaCl): weight fraction) average condition of salinity in the seawater [17]. The gaseous phase was substituted by air and the oil was assumed to consist simply of a hydrocarbon of the chemical form (C_5H_{10}) with a mass density of 0.896 g.cm^{-3} [3].

![Figure 1. Flow regimes: a) annular; b) stratified.](image-url)
3. METHODOLOGY

Combining transmission and scattered radiation of the measures principles, so called dual-mode, with a fan-beam it is possible to increase the area of the geometric measure on the cross section of the pipe, making the calculation of MFV less dependent of the regime, since the phases distribution out of the geometric volume defined by the source and detector 1, to see Fig. 2, also affects the result of the measure [15]. The model considers the extra contribution in the measures of transmission of scattered radiation [14].

3.1. Mathematical Modeling

The mathematical modeling considered sodium iodide homogeneous detectors activated with thallium (NaI (Tl)) [15] in the form of equilateral cylinder 1” x 1” and radioactive source point and collimate gamma-rays with emitting angular opening of 6.7° whose dual energies are 356 keV (\(^{133}\text{Ba}\)) and 121 keV (\(^{152}\text{Eu}\)). The test section of a steel tube ANSI316 with thickness of 1 cm and 18 cm of internal diameter was used. Geometry proposal uses fan-beam with two detectors of NaI (Tl), the one located 180° aligned to the source and the other to 90°, as shown in Fig. 2.

![Diagram](image)

Figure 2. System modeling of MVF calculation.

The simulated data had been used to train a RNA aiming to match them with the values for each MVF pre established. The third material (oil) was gotten by complement. The detectors had supplied the measures of transmission (I) and scattered (C) beams whose Pulses Height Distributions (PHD) are presented in Fig. 3. The input data of the RNA had been the relative counts of the photoelectric effect to the energy of 356 keV (I\(_{356}\)) and the relative counts to the energies of 20 to 300 keV (C\(_{20}, C_{30}, \ldots, C_{300}\)) and the output data had been air and water materials. The training parameters that had presented the lesser relative error in the production set are presented in Table 1. Important to mention, that the same training parameters for both regimes had been used.
Figure 3. PHDs gotten by the MCNP-X for beam: a) Transmitted; b) Scattered.

Table 1. Parameters of the network that presented better outputs set.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>Rate Learning $\eta = 0.01$ e Momentum = 0.1</th>
</tr>
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<tbody>
<tr>
<td>Activation Function</td>
<td>Layer</td>
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<tr>
<td>Linear [-1,1]</td>
<td>Input</td>
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<tr>
<td>Gaussian tanh</td>
<td>Hidden</td>
</tr>
<tr>
<td>Gaussian Complement</td>
<td>Out</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

The simulated 32 data set had fed the input layer of the RNA. Of those, 20 data had been used as training set, 6 data as test set and 6 data as production set, all data had been chosen randomly and can be seen in Fig. 4. The test set was used to evaluate the generalization of the network and the production set was used to evaluate the possibility of prediction of the RNA and therefore, it is not used in the training.

Figure 4. Training, Test and Production sets (1 to 6 data).
4.1. Stratified Regime

In Fig. 5 the input data are presented the FVM gotten for the RNA for all and in 6 Fig. the prediction for the production set of the stratified regime. The average relative errors for the air and water corresponding output data to each specific set of all the data used in the RNA are presented in Table 2(a).

![Figure 5. MVF gotten for all the used data: a) air; b) water.](image)

![Figure 6. Results gotten for the production set: a) air, b) water.](image)

4.2. Annular Regime

In Fig. 7 of input data are presented the MVF gotten for the RNA for all and in Fig. 8 the prediction for the production set of the annular regime. The average relative errors for the air
and water of the corresponding output data to each specific set of all the data used in the RNA
are presented in Table 2 (b).

![Graphs showing predicted versus actual volume fractions for air and water.](image)

**Figura 7.** MVF gotten for all the used data: a) air; b) water.

![Graphs showing predicted versus actual volume fractions for production set.](image)

**Figura 8.** Results gotten for the production set: a) air, b) water.

**Table 2.** The average relative errors of outputs RNA: Stratified; b) Annular.

<table>
<thead>
<tr>
<th>Set</th>
<th>Relative Error (%)</th>
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<tr>
<td></td>
<td>air</td>
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<tr>
<td>Production</td>
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</table>

<table>
<thead>
<tr>
<th>Set</th>
<th>Relative Error (%)</th>
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<tbody>
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<td></td>
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<td>water</td>
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<tr>
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<tr>
<td>Production</td>
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5. CONCLUSIONS

The use of MCNP-X code was important in the pertinent attainment of information to each material fraction in regimes studied, eliminating problems associated with availability of radioactive sources and detectors in the initial phase of the work. The RNA was capable to match the simulated data with the volume fractions of each present material in the system. The presented results had been gotten only from a RNA trained with the data of the stratified regime and that later it received the data from the annular regime. The RNA did not receive patterns from information on the flow regime and satisfactorily supplied to predictions of the volume fractions both regimes. The proposal methodology allied to the use of dual-energy gamma-ray two detectors, as well as the combination of dual-mode beam indicates to be possible to determine the volume fractions in three-phase systems: oil, water, gas, independent on the particular regime, however needs to evaluate others flow regimes.

REFERENCES

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