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# ARTIFICIAL NEURAL NETWORK AND NEUTRON APLICATION IN A VOLUME FRACTION CALCULATION IN ANNULAR AND STRATIFIED MULTIPHASE SYSTEM

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## ABSTRACT

Multiphase flows, type oil–water-gas are very common among different industrial activities, such as chemical industries and petroleum extraction, and its measurements show some difficulties to be taken. Precisely determining the volume fraction of each one of the elements that composes a multiphase flow is very important in chemical plants and petroleum industries. This work presents a methodology able to determine volume fraction on Annular and Stratified multiphase flow system with the use of neutrons and artificial intelligence, using the principles of transmission/scattering of fast neutrons from a $^{241}$Am-Be source and measurements of point flow that are influenced by variations of volume fractions. The proposed geometries used on the mathematical model was used to obtain a data set where the thicknesses referred of each material had been changed in order to obtain volume fraction of each phase providing 119 compositions that were used in the simulation with MCNP-X –computer code based on Monte Carlo Method that simulates the radiation transport. An artificial neural network (ANN) was trained with data obtained using the MCNP-X, and used to correlate such measurements with the respective real fractions. The ANN was able to correlate the data obtained on the simulation with MCNP-X with the volume fractions of the multiphase flows (oil-water-gas), both in the pattern of annular flow as stratified, resulting in a average relative error (%) for each production set of: annular (air= 3.85; water = 4.31; oil=1.08); stratified (air=3.10, water 2.01, oil = 1.45). The method demonstrated good efficiency in the determination of each material that composes the phases, thus demonstrating the feasibility of the technique.

## 1. INTRODUCTION

The occurrence of multiphase flow is very common in different industrial activities, including the chemical industry, electric power generation and oil, and to obtaining the volume fraction of each phase that composed the system flow presents difficulties for the engineering process. The search of the most accurate of their values is so important that is notorious that the number of researchs published has been increasing with the most different techniques and settings [1], [2], [3], [4] e [5]. This is a positive factor, since it is of interest to the industries of regarding the constant improvement of measures of volume fractions in multiphase systems, like oil-gas-water. Therefore, it is very important to have the measurement compact system, noninvasive and able to determine each material that composes the phases accurately and in real time without the need for separation and measurement of each phase separately.

Han and Hussein [6] achieved satisfactory results using fast neutrons in the implementation of volume fractions measures of two-phase flow (water-gas). Continuing the search, Russein and Han, [7], employed the transmission/scattering method of fast neutrons coming from a source of $^{241}$Am-Be and $^{3}$He detectors, along with simulations using a code itself [8] based on the Monte Carlo method. They measured volume fraction in a homogeneous three-phase flow containing air-water-oil and obtained satisfactory results, showing in their research that the method of measurement of volume fraction using fast neutrons is quite promising.

The absorption of thermal neutrons per nucleus of atoms may result in gamma rays characteristic that can be used to distinguish water of oil. This method requires nuclear activation, however, neutrons of low-energy, called thermal neutrons, which can not be produced in the field without the use of a moderator material involving the source of fast neutrons. Neutrons loss (escape and absorption) during the moderation process and the usually low values of the activation cross section necessitate the use of a source high neutron output. This has practical difficulties in terms of providing an adequate radiation shielding and produce a portable mobile device. Moreover, the capture of thermal neutrons can lead to activation of the material and other neighbors to the source material. Therefore, the direct use of a neutrons source, of low activity not moderate is more attractive for this purpose, since fast neutrons lose large amounts of energy when they collide with the most number of elements of low mass.

This work aims to study the neutrons (scattering/transmission) technique and artificial intelligence to determine the volume fractions in an annular and stratified multiphase system, like oil-water-gas. The technique is based on the principle of fast neutrons transmission/scattering in matter and arrangement used is composed of a of $^{241}$Am-Be source and point measures estimated which get results that are influenced by both the composition of the phase and the flow profile, as well as by the pipe characteristics. Mathematical models based on Monte Carlo method was developed in the MCNP-X code [9] to provide data for training ANN.

## 2. METHODOLOGY

The two main processes governing the interactions of neutrons with matter are scattering and absorption [10]. In the first, the neutrons are scattered when they collide with the atoms nuclei that constitute the matter, and second, the neutrons are absorbed by nuclei, which are an excited state and back to ground state emitting secondary radiation [11].

The fast neutrons lose energy when they collide with some elements of low mass, such as those present in crude oil which is a natural mixture of hydrocarbons (hydrogen and carbon) and water. After their interaction with a system containing such elements, there are new groups of neutrons energy, being used in this work, the same classified by Gibson and Piesch [12], i.e.: Thermal < 0.4 eV; Epithermicos 0.4 eV – 100 eV and Fast 100 keV.

The neutrons beam attenuation of a material is given by the type of Eq (1).

$$I = I_0 \times e^{-\Sigma_{tot}.X} \quad (1)$$

Were:
- I: intensity of the beam after passing through the material thickness;
- $I_0$: initial intensity of the beam;
- $\Sigma_{tot}$: Cross section macroscopic total for neutrons with E energy, for a particular material.

The mathematical models proposed in this work uses an energy spectrum from $^{241}$Am-Be neutrons source [13] and punctual measures (at 180º transmitted, and 90º scattering), where are recorded the flux of neutrons thermal, epithermal and fast, after their interactions with the system. For predicting the volume fraction was used an ANN where data for their training, the neutrons flow in the three energy groups mentioned, were obtained by mathematical simulation using the code MCNP-X.

## 2.1. Mathematical Modeling

In Figure 1 are presented proposals geometries used, which was considered an energy spectrum coming from $^{241}$Am-Be source and two point detectors. Among them an iron pipe with its internal and external diameters respectively measuring 18 cm and 20 cm, containing the three phases studied, salt water-oil-gas, whose volume fractions were obtained at the varying thicknesses of each material.

The air represented the gas and the oil used is a simple hydrocarbon, which has its molecular composition undefined (as is the case with the majority of crude oil), whose chemical formula and density are respectively $C_5H_{10}$ and 0.896 g.cm$^{-3}$ [7]. In the simulation of the fast neutrons interaction emitted by $^{241}$Am-Be source of the phases materials, were obtained point flows of thermal, epithermal and fast neutrons, depending on the compositions of the arrangements used as some shown in Tab. 1.

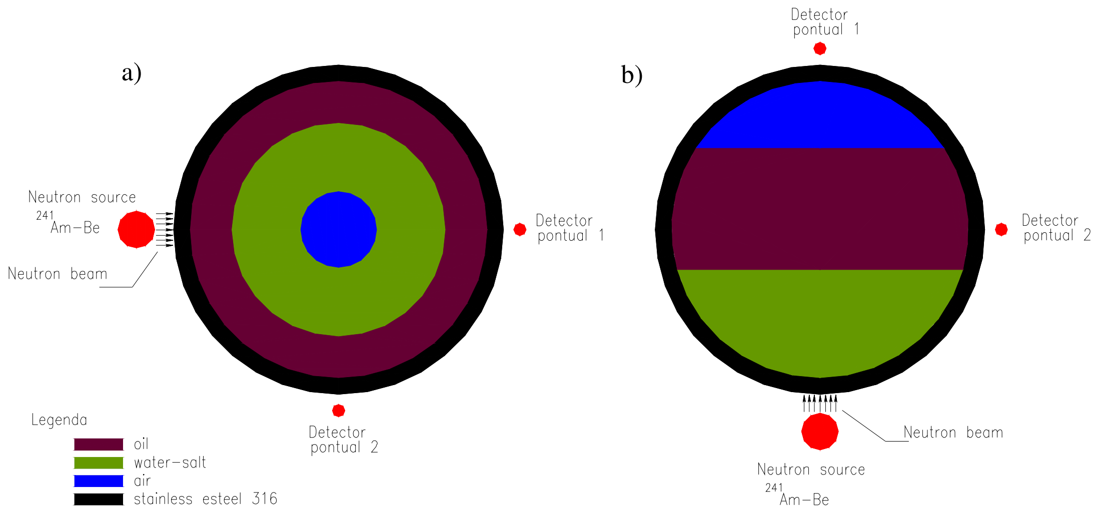


**Figure 1. Geometries simulated with three-phase flow pattern. (a) annular; (b) stratified.**

**Table 1 – Thermal, Epithermal and Fast Neutron Flows obtained in a simulation with the MCNP-X according to the arrangements.**

| | **Neutron flows ($cm^2.s^{-1}$)** | | | | | |
|---|---|---|---|---|---|---|
| ***Arrange ment*** | ***Transmitted*** | | | ***Escattered*** | | |
| | Thermal | Epithermal | Fast | Thermal | Epithermal | Fast |
| 1 | 1.5171E-05 | 1.3881E-05 | 8.7138E-05 | 1.1208E-05 | 1.7105E-05 | 2.1292E-04 |
| 2 | 6.7718E-06 | 1.4240E-05 | 1.1495E-04 | 3.9590E-06 | 1.28190E-05 | 2.1871E-04 |
| ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 118 | 1.1950E-06 | 8.5954E-06 | 1.2221E-04 | 4.2522E-07 | 6.6035E-06 | 2.2651E-04 |
| 119 | 1.6135E-05 | 1.3072E-05 | 7.8766E-05 | 1.1862E-05 | 1.6792E-05 | 2.1313E-04 |

## 2.2. Volume Fractions Prediction

The proposal geometry used in the mathematical model, shown in Fig. 1, was used to obtain a data set where the thickness for each material, were varied to obtain volume fractions of 119 compositions who provided the arrangements, as shown in the ternary[1] of Fig. 2, which were used in the simulation with the MCNP-X.

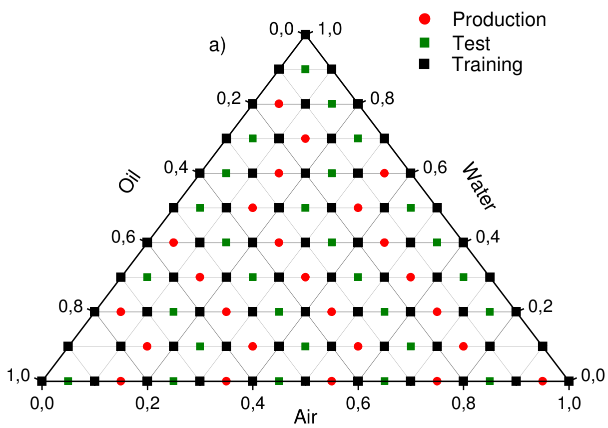


**Figure 2. Ternary diagram containing the 119 arrangements Compositions used in the simulation.**

Each material was varied from 0% to 100%, resulting in the point counts (transmitted/scattered) flow of neutrons thermal, epithermal and fast, some as shown in Tab.

[1] A ternary graphically depicts the ratios of the three variables as positions in an equilateral triangle. It is used in petrology and other physical sciences to show the proportions of systems composed of three species. In a ternary plot, the proportions of the three variables gas, water and oil must sum to some constant which is represented as 100%

1, for each configuration, which were the input data used to train the ANN to correlate them with the pre-set values for each material fraction.

## 3. RESULTS AND DISCUSSIONS

### 3.1. Volume Fraction with ANN

The data obtained by the MCNP-X code for the various materials fractions represented a set of 119 patterns used in the input layer for ANN training, from which 66 patterns were applied as training set, 28 as test set and 25 as production set of network, see Fig.2.

### 3.1.1. Annular Flow Pattern

The response of the ANN for the production set is shown in Fig. 3, and the average relative errors for air, water and oil data output corresponding to each specific set Standards (training, testing and production) is used in ANN is presented in Tab. 2.

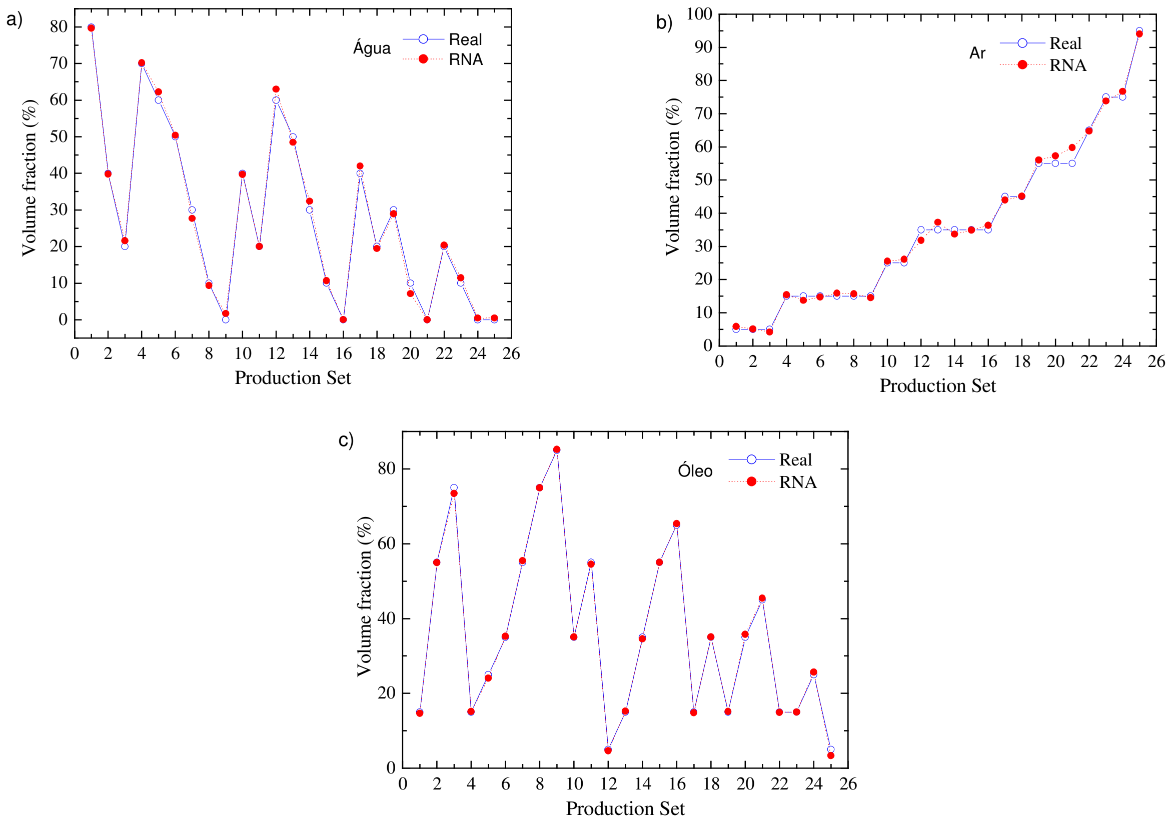


**Figure 3. Production set used by the neural network with their results for: a) water; b) air; c) oil.**

**Table 2. Average relative error for the training, test and production sets.**

| Set | Average relative error (%) | | |
|---|---|---|---|
| | air | water | oil |
| Training | 1.53 | 2.39 | 0.80 |
| Test | 3.82 | 4.00 | 3.22 |
| Production | 3.85 | 4.31 | 1.08 |

### 3.1.2. Stratified Flow Pattern

Similarly to annular the response of the ANN for the production set is shown in Fig. 4, and the average relative errors for air, water and oil data output corresponding to each specific set standards (training, testing and production) are used in ANN presented in Tab. 3.

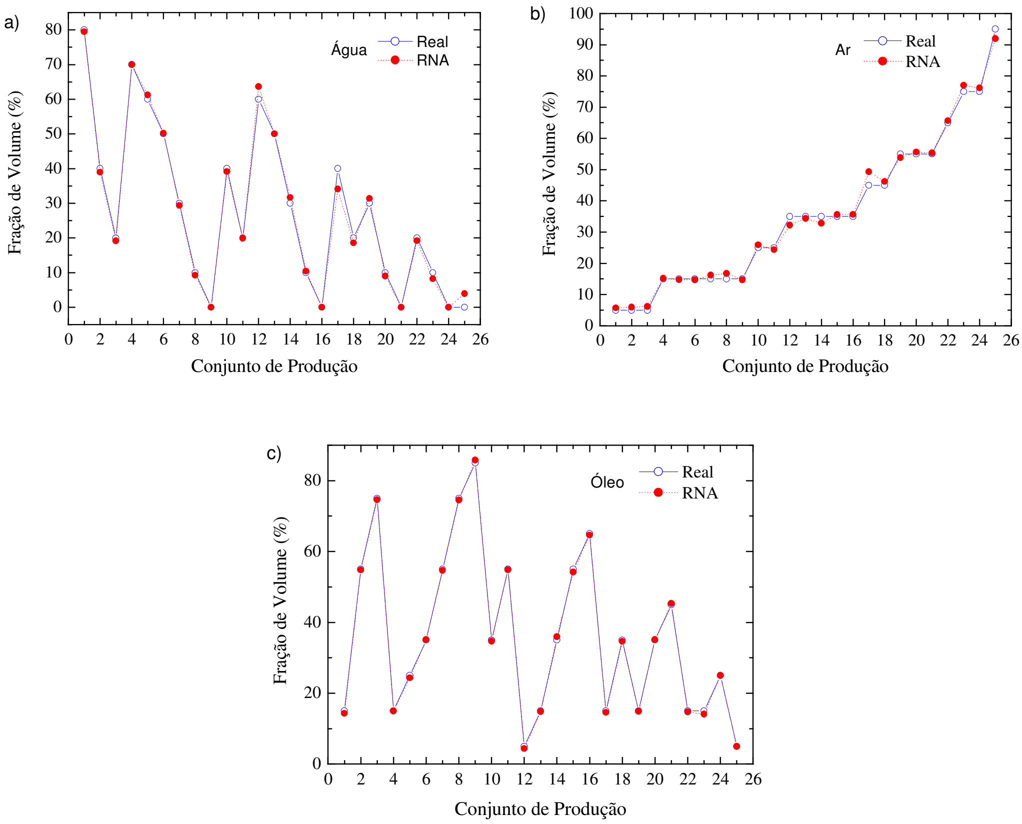


**Figure 4. Production set used by the neural network with their results for: a) water; b) air; c) oil.**

**Table 3. Average relative error for the training, test and production sets.**

| Set | Average relative error (%) | | |
|---|---|---|---|
| | air | water | oil |
| Training | 0.36 | 1.34 | 0.95 |
| Test | 2.69 | 2.40 | 6.38 |
| Production | 3.10 | 2.01 | 1.45 |

## 5. CONCLUSIONS

The MCNP-X code proved to be a very efficient tool, because its use was possible to obtain the flows of neutrons thermal, epithermal and fast for each volume fraction of the phases of flow regimes (stratified and annular) studied, air-water-oil. Such results would be difficult to obtain for the purpose of this work, therefore, problems of neutron source types availability, detectors and geometry of the system were eliminated with the use of the code.

As the MCNP-X, the ANN was a very efficient tool, being able to correlate the data obtained in the simulation with the MCNP-X with the volume fractions of the phases that composes the models systems (annular and stratified) flow phase, who used the energy spectrum coming from a $^{241}$Am-Be source and point measures, enabling predict with good accuracy the volume fraction of the air, water and oil.

The non-invasive method for predicting the volume fraction of the systems (stratified and annular) phase studied by using nuclear technique as the interaction of neutrons with the matter and ANN, showed good efficiency in determining the percentage of each material that compose the phases of the three-phase system studied. The method demonstrated good efficiency in the determination of each material that composes the phases, thus demonstrating the feasibility of the technique.

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