Study of geometry to obtain the volume fraction of multiphase flows using the MCNP-X code

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ABSTRACT

The gamma ray attenuation technique is used in many works to obtaining volume fraction of multiphase flows in the oil industry, because it is a noninvasive technique with good precision. In these studies are simulated various geometries with different flow regime, compositions of materials, source-detector positions and types of collimation for sources. This work aim evaluate the interference in the results of the geometry changes and obtaining the best measuring geometry to provide the volume fractions accurately by evaluating different geometries simulations (ranging the source-detector position, flow schemes and homogeneity Makeup) in the MCNP-X code. The study was performed for two types of biphasic compositions of materials (oil-water and oil-air), two flow regimes (annular and smooth stratified) and was varied the position of each material in relative to source and detector positions. Another study to evaluate the interference of homogeneity of the compositions in the results was also conducted in order to verify the possibility of removing part of the composition and make a homogeneous blend using a mixer equipment. All these variations were simulated with two different types of beam, divergent beam and pencil beam. From the simulated geometries, it was possible to compare the differences between the areas of the spectra generated for each model. The results indicate that the flow regime and the differences in the material’s densities interfere in the results being necessary to establish a specific simulation geometry for each flows regime. However, the simulations indicate that changing the type of collimation of sources do not affect the results, but improving the counts statistics, increasing the accurate.

Key words: MCNP; Multiphase flows; volume fraction; MCNP-X code; gamma ray; gamma ray attenuation

1. INTRODUCTION

In the oil industry, the multiphase flow is found frequently on production column of wells and pipelines, where occurs the transporting of multiphase fluids in liquid form (water, oil) with gas.

The off-shore oil exploration causes the multiphase fluid scroll long distances before reaching the separation unit. In the last years, with the discovery of pre-salt layer, the production is expanding at ever greater depths which makes the associated costs even higher. In these conditions, the equipment works in conditions more severe, and becomes essential make detailed researches to the feasibility and improvement of equipment as well as related processes for the transport of multiphase fluids.

In addition to the production pipelines project, it is important to determine some characteristics of fluids (such as volume fraction, composition of fluids, density and viscosity) at different
flow regimes, because its can help to have a suitable project of the separation unit which is on the production platform.

One tool for simulation of radiation transport widely used for the determination of these characteristics, is the Monte Carlo N-particle eXtended (MCNP-X) computer code [4], which is based on Monte Carlo method. This code simulates electrons and/or photons and is capable of representing complex three-dimensional geometries with a wide variety of entry data options more quickly, conveniently and with good accuracy when compared to practical experiments.

Many works that aim to calculate the volume fraction of multiphase flows in the oil industry, use gamma ray attenuation techniques [1][2][3][6][9], because it is a noninvasive technique with good precision and low cost [6]. In these works various geometries are performed, changing the types of flow, material compositions, source-detector positions and types of collimation for radioactive sources. When a detector and a source are used, the more conventional geometry is the source positioned at 180° of the detector.

Therefore this work aim evaluate the interference of the geometry changes and obtaining the best measuring geometry to provide accurately volume fractions by evaluating different source-detector position, types of flow regimes and homogeneity of composition using the MCNP-X code.

2. METHODOLOGY

A NaI(Tl) scintillation detector 1"x1", a punctual source of cesium, $^{137}$Cs, and a tube acrylic 10 cm external radius 5 mm thick, as shown in Fig. 1, were simulated in MCNP-X code to reach the proposed objective.

Figure 1: Model of geometry used in the simulations.
The model of detector’s simulation was based on information obtained from the gammagrapy technique [5][6][7][8]. Both dimensions and materials were used for the calculation with the MCNP-X code. This model is represented in Fig. 2.

The study was performed for the annular and smooth stratified flow regimes. Two types of biphasic composition are used, the first one with 50% water (density 1.0 g.cm\(^{-3}\)) and 50% oil (density 0.896 g.cm\(^{-3}\)) and other one with 50% air (density 0.001225 g.cm\(^{-3}\)) and 50% oil. In the smooth stratified flow regime the position of the source relative to the detector was changed, while in the annular regime the position of the material inside the pipe was changed.

A study to evaluate if the homogeneity of the compositions (oil-water and oil-air) affects the results was also performed. In this case two hypothetical homogeneous compositions with the same percentage of the biphasic compositions previously used, so, 50% of each material was used.

These studies, were also simulated with two different types of beam, divergent and pencil beam. A total of 24 different geometries was simulated in the MCNPX-X code.

3. ANALYSIS AND RESULTS

From the results of simulations in MCNP-X code were mounted 8 graphs comparing the spectra generated, making possible note the differences between the simulated geometries.
3.1. Geometries Used

3.1.1. Composition water-oil in smooth stratified regime and divergent beam

The spectrum of geometries with oil and water, homogeneous and heterogeneous, changing the source-detector position and the homogeneity of the composition were compared, as shown in Fig. 3.

![Geometries used in regime smooth stratified](image)

**Figure 3**: Geometries used in regime smooth stratified: a) Water-oil-source; b) Oil-water-source; c) Homogeneous oil-water composition; d) Geometry using divergent beam.

Analyzing the Fig. 4, can be noted that the code processes similar results across all the spectrum to the variation of source-detector position, but behaves differently to the homogeneous composition (Fig. 3c) having a lower attenuation, which is evident on the photopeak, however, there is a difference in the total area of the spectrum of 7% higher as compared with the geometry of a water-oil heterogeneous composition (Fig. 3a), and 5% for the oil-water composition (Fig. 3b).
3.1.2. Composition oil-air in the smooth stratified regime and divergent beam

In Fig. 5, the geometries with oil and air, homogeneous and heterogeneous, were compared and can be noted that the code processes similar results in photopeak region with a little difference during the whole spectrum for the exchange of source-detector position, with a 10% difference in the total area of the spectrum. For the homogeneity of composition, the photopeak is more distinct region of the spectrum but the remainder is similar to the geometries with heterogeneous compositions presenting a 17% difference in the total area of the spectrum compared to the heterogeneous composition of the oil-air and 5% to the heterogeneous composition air-oil. In homogeneous composition it is observed that there was a greater attenuation of the photopeak compared with the heterogeneous composition, contrary to what was noted in the previous situation in Fig. 4.

Figure 4: Comparison of the spectra of geometries using the water-oil composition in the smooth stratified regime and divergent beam.
3.1.3. Compositions oil-air and oil-water in the smooth stratified regime and pencil beam

With the geometries using a pencil beam, Fig. 6, in a smooth stratified flow, the spectrum remained similar when compared to Fig. 4 and Fig. 5, showing only an increase in the number of recorded counts.

3.1.4. Composition water-oil in the annular regime with divergent beam

Were compared the simulation results of the geometries with oil and water with homogeneous and heterogeneous flow and divergent beam according to the illustrated in Fig. 7.
Figure 7: Geometries used in regime annular: a) Water-oil-source; b) Oil-water-source; c) Homogeneous oil-water composition; d) Geometry using divergent beam.

The Fig. 8 shows that the code processes different results compared to smooth stratified regime. However it is noted a difference in the whole spectrum when comparing the variations of the material position, the total area of the spectrum of heterogeneous composition of water-oil (Fig. 7a) is 12% higher when compared with the oil-water (Fig. 7b) composition. However, with the homogeneous composition (Fig. 7c) it is observed a similarity to the heterogeneous composition of water-oil, both being less attenuated than when compared to the oil-water geometry, with a difference of 1% in the all area of the spectrum.

Figure 8: Comparison of the spectra of geometries using the water-oil composition in the annular regime and divergent beam.
3.1.5. Composition with oil and air in the annular regime and with divergent beam

The Fig. 9 shows the simulation results of geometries with oil and air in the annular regime with a divergent beam and can be noted that the code processes very different results to the position of materials with the total spectrum area of the heterogeneous composition of oil-air 43% bigger than the air-oil composition.

To the homogenous composition is observed that the result is not similar to any heterogeneous composition and the total area of the spectrum 16% larger than the air-oil composition and 46% less than the oil-air composition.

![Figure 9: Comparison of the spectra of geometries using the air-oil composition in the annular regime and divergent beam.](image)

3.1.6. Compositions oil-air and oil-water in the annular regime and pencil beam

The results for the geometries of water-oil and oil-air with pencil beam, shows that the differences to the position of materials and the homogeneity remain the same when change the beam type, realizing only a larger number of counts, as well as the case with the models smooth stratified regime under the same conditions.

3.2. Percentage Differences in the Total Area of the Spectra

Based on the results obtained and calculating the total areas of the spectra, were calculated the tables below with the percentage differences in the variations of materials position (annular regime), source-detector position (smooth stratified regime), regime change and between homogeneous and heterogeneous compositions.
In Table 1, is made the percentage difference between the two geometries of the same composition with the same types of regime and beam. Thus, it is possible to analyze the interference on the study results to the exchange position of the material (annular regime) and the source-detector position (smooth stratified regime).

<table>
<thead>
<tr>
<th>Composição com 50% óleo e 50% água</th>
<th>Composição com 50% óleo e 50% ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regime Smooth Stratified and Divergent Beam</td>
<td>3%</td>
</tr>
<tr>
<td>Regime Smooth Stratified and Pencil Beam</td>
<td>2%</td>
</tr>
<tr>
<td>Regime Annular and Divergent Beam</td>
<td>12%</td>
</tr>
<tr>
<td>Regime Annular and Pencil Beam</td>
<td>12%</td>
</tr>
</tbody>
</table>

Analyzing the data in Table 1, the percentage differences, in relation to the exchange position of each material, have a slightly different in the smooth stratified regime, independently of density, indicating that there will be no influence on the outcome of the study. Already in the annular regime, the differences are greater when there is a bigger gap between the densities of the materials, indicating a possible interference in the results of the study.

In the Table 2 is performed a comparison between the hypothetical homogeneous in their composition and variations of regime and beam, with the two possible geometries of heterogeneous composition.
Table 2: Percentage differences of the total area of the spectrum between homogeneous compositions and each heterogeneous composition.

<table>
<thead>
<tr>
<th>Homogeneous composition</th>
<th>Composition with 50% oil and 50% water</th>
<th>Composition with 50% oil and 50% air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector-oil-water-source</td>
<td>7%</td>
<td>5%</td>
</tr>
<tr>
<td>Detector-water-oil-source</td>
<td>5%</td>
<td>17%</td>
</tr>
<tr>
<td>Detector-oil-air-source</td>
<td>17%</td>
<td>5%</td>
</tr>
<tr>
<td>Detector-air-oil-source</td>
<td>5%</td>
<td>17%</td>
</tr>
<tr>
<td>Regime Smooth Stratified and Divergent Beam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regime Smooth Stratified and Pencil Beam</td>
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<tr>
<td>Regime Annular and Divergent Beam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regime Annular and Pencil Beam</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyzing the Table 2 it is possible concluded that when the differences between the densities of materials are lower, compared to densities of the compositions studied, the divergence between homogeneous and heterogeneous composition are small in both regimes. However, when the density difference is larger, the homogeneity of the composition significantly alter the results of the study.

In Table 3 we can observe the percentage difference between the two types of beam used, for the exchange material (annular regime), an exchange source-detector position (smooth stratified) and the homogeneity of the composition.

Table 3: Percentage differences between the types of beam in each geometry.

<table>
<thead>
<tr>
<th>Position of Material/Source-detector Position</th>
<th>Regime Smooth Stratified</th>
<th>Regime Annular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition with 50% oil and 50% water</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Composition with 50% oil and 50% air</td>
<td>3%</td>
<td>0%</td>
</tr>
<tr>
<td>Composition with 50% oil and 50% water</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Composition with 50% oil and 50% air</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Homogeneity of the composition</td>
<td>0%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Through these percentage differences it is possible state that in any regime studied, with any position of materials and being homogeneous or not the composition, the total areas of the
spectra with divergent beams and "pencil beam" have insignificant differences, indicating that these variations do not affect the result.

In relation to the type of beam emission, analyzing and comparing the graphs in the same condition, it is possible to note that despite having no differences in the areas of the spectra, the number of counts is much larger with the pencil beam "beam" than with the beam divergent. This is explained by the increased collimation of the source, which causes more events reach the detector.

4. CONCLUSIONS

With the results obtained by simulations in MCNP-X code, it can be concluded that the change of the source-detector position on the smooth stratified regime does not influence on the results of studies, however, when the position of the material in the annular regime is changed, this difference in geometry indicates that there is interference in the results, increasing its influence when the gap between the density is greater, with reference to the densities studied.

When were analyzed the results for the geometry variations between homogeneous and heterogeneous compositions, it was found that there is no interference in the resulting when similar densities are used, but the results indicate a possible influence in the study where the difference between the densities is bigger.

The change of the kind of collimation of the source, does not influence the result of the study, however, it improves the counting statistics, providing greater accuracy the data collected.

Using the technique developed in this study and compare these results, it is possible identify the flow regime of two-phase flow through the spectrums.

Based on the results can be defined the geometry that present less influence with the variation of the position source-detector, will be with the smooth stratified regime with heterogeneous compositions. To conduct studies with the annular or homogeneous compositions, it becomes necessary to make a study analyzing the density, the position of the materials and the interference of these factors in the results. In order to improve the technique developed and developing new procedures, studies of interference from the material density in the regime annular and homogeneous compositions, and analysis of geometries with different percentages of the materials of the composition, will be studied in the future.

REFERENCES