VOLUME FRACTIONS CALCULATION ON MULTIPHASE STRATIFIED REGIME ON CYLINDRIC PIPE USING GAMMA RAY AND MCNP6 CODE

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INTRODUCTION

- Due to the high demand for oil and its derivatives.
  - Extraction, refining and distribution are activities of great importance for a country's economy.

- Need for devices to allow precise flow measurements.
  - flow regime
  - flow rate
  - volumetric fractions

- Advantage:
  - real time analysis
  - noninvasive techniques
  - reliability in the results

OBJECTIVE

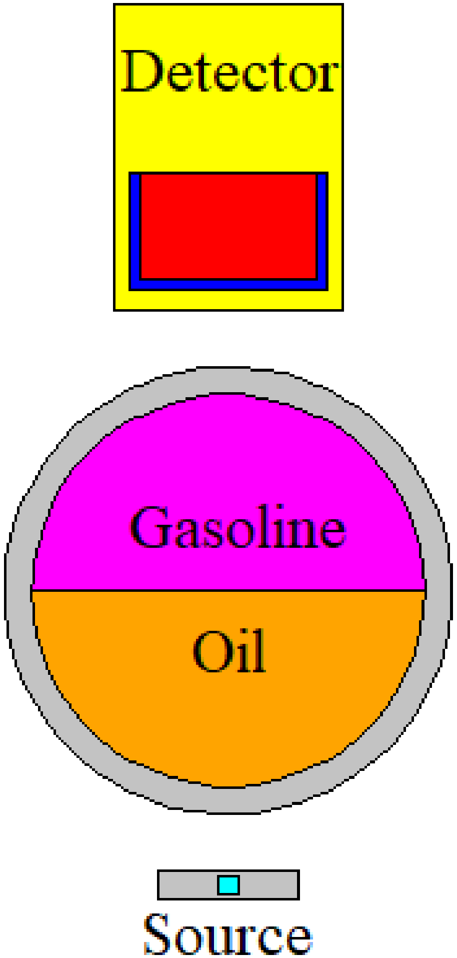
The objective of this study is to develop a mathematical equation for calculate the volume fractions of different fluids (oil-gasoline-gas) using gamma densitometry and the MCNP6 computational code based on the Monte Carlo method.

METHODOLOGY

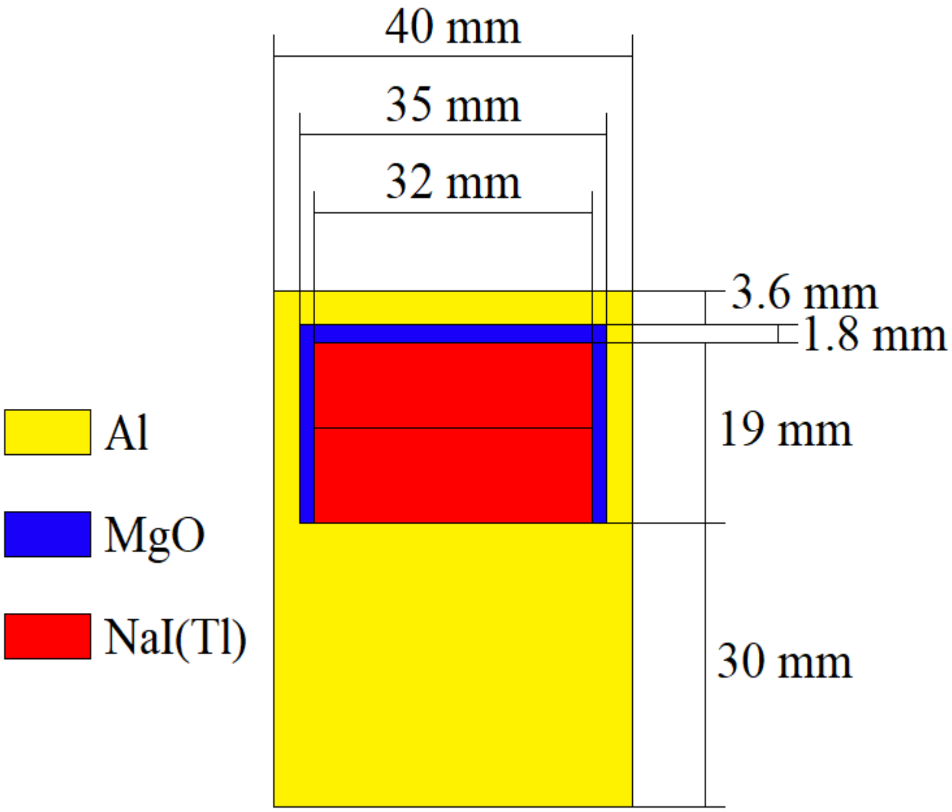
- The method is based on attenuation of a gamma transmitted beam through a pipe using code MCNP6.
- The measuring system was simulated in an acrylic pipe and fluids:
  - gasoline (C_8H_{18} - ρ=0.721 $g.cm^{-3}$)
  - oil ($C_{10}H_{18}O$ - ρ=0.955 $g.cm^{-3}$)
  - gas (air - ρ=1.205E-3 $g.cm^{-3}$)
- The study consisted in simulating a source of Cs-137 positioned diametrically opposite the 1¼ x ¾ " NaI(Tl) detector.
- Considering a simplified model with:
  - Biphasic fluid containing flow (0%, 25%, 50%, 75% and 100%)
  - Stratified flow regime
  - Pencil beam

SIMULATED GEOMETRY

2D visualization of measurement geometry.



Schematic representation of the detector considered in the simulation.



Volume Fraction

- The transmitted beam intensity is given by:

$$I(E) = I_0(E).exp\left(-\sum_{1}^{n} \alpha_i \mu_i(E).x\right)$$

$$\sum_{1}^{n} \alpha_i = 1$$

Where:

I – transmitted intensity;
I_0 – initial incident intensity;
x – fluid thickness;
α – volume fraction of fluid i;
E – incident radiation energy;
μ_i – total fluid attenuation coefficient i.

- For pencil beam geometry in pipes with square cross section, the calculation of the volume fraction of the fluids is given by:

$$\alpha_1 = \frac{\ln (I/I_2)}{(I_1/I_2)}$$

$$\alpha_2 = 1 - \alpha_1$$

ABOUELWAFA EQUATIONS

Where:

$\alpha_{1,2}$ – volume fraction of fluid 1 or 2;
I – gamma ray intensity transmitted with a pipe containing fluids 1 and 2;
$I_{1,2}$ – intensity containing only 1 or 2 fluid.

New Mathematical Equation

- For a pipe with a straight cylindrical section, the procedure was to calculate the height of each material inside the pipe using these equations:

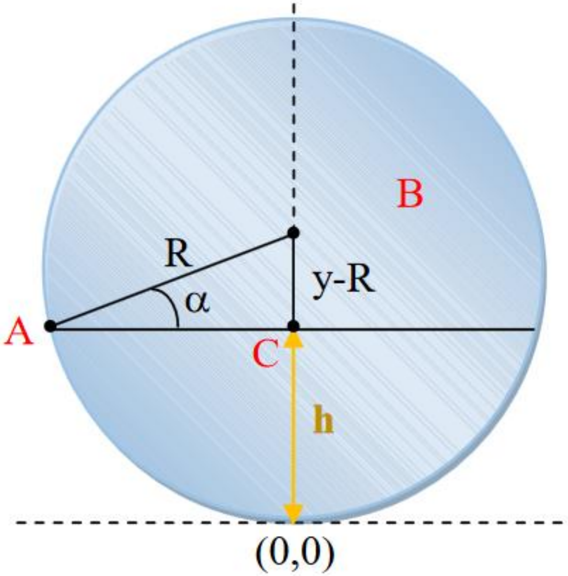
$$x_1 = \frac{\ln (I/I_2)}{\mu_2 - \mu_1} \qquad x_2 = \frac{\ln (I/I_1)}{\mu_1 - \mu_2}$$

- Knowing the height of the fluids inside the pipe, it is necessary to calculate the integral of the area occupied by each fluid, the volume fraction calculation is given below:

$$\alpha(x) = \frac{\pi R^2}{2} + R^2.\sin^{-1}\left(\frac{x - R}{R}\right) + (x - R).\sqrt{R^2 - (x - R)^2}$$

FORMULATION OF THE EQUATION

$$x^2 + (y-R)^2 = R^2 \therefore x(y) = \sqrt{R^2 - (y-R)^2}$$



$$S(h) = 2.\int_0^h x(y)dy$$

$$S(h) = 2.\int_0^h \sqrt{R^2 - (y-R)^2}dy$$ Eq. 1

ΔABC: $sen(\alpha) = \frac{y-R}{R} \therefore y = R + Rsen(\alpha)$ $\quad dy = Rcos(\alpha)d\alpha$

Eq. 2

$$\Rightarrow \; sen^2(x) + cos^2(x) = 1$$

$$\left(\frac{y-R}{R}\right)^2 + cos^2(\alpha) = 1 \therefore cos^2(\alpha) = \frac{R^2 - (y-R)^2}{R^2} \rightarrow cos(\alpha) = \frac{\sqrt{R^2 - (y-R)^2}}{R}$$

Eq. 3

Eq. 2, Eq. 3 $\rightarrow$ Eq. 1

$$S(h) = 2.\int_0^h R\cos(\alpha).R\cos(\alpha)d\alpha \rightarrow S(h) = 2R^2\int_0^h \cos^2(\alpha)d\alpha$$

$$S(h) = 2R^2\left[\frac{1}{2}(\alpha + sen(\alpha).\cos(\alpha))\right] \Vert \begin{matrix} h \\ 0 \end{matrix}$$

$$S(h) = R^2\left[arcsen\left(\frac{y-R}{R}\right) + \frac{y-R}{R} \times \frac{\sqrt{R^2-(y-R)^2}}{R}\right] \Vert \begin{matrix} h \\ 0 \end{matrix}$$

$$S(h) = R^2 arcsen\left(\frac{y-R}{R}\right) + (y-R) \times \sqrt{R^2-(y-R)^2} \Vert \begin{matrix} h \\ 0 \end{matrix}$$

$$S(h) = R^2 arcsen\left(\frac{h-R}{R}\right) + (h-R) \times \sqrt{R^2-(h-R)^2} - R^2 arcsen(-1) + (-R) \times$$
$$\times \sqrt{R^2-(-R)^2}$$

$$R^2 arcsen(-1) = \frac{3\pi}{2} \; e \; (-R) \times \sqrt{R^2-(-R)^2} = 0$$

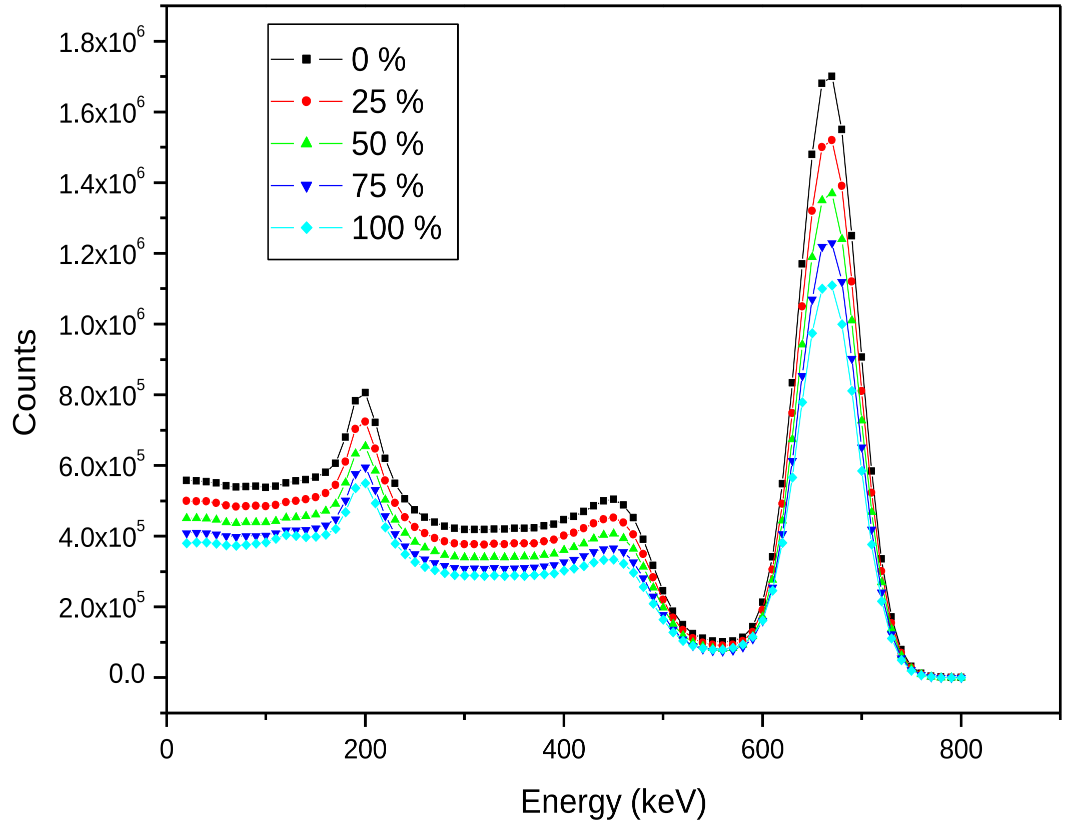
$$S(h) = \frac{\pi R^2}{2} \; R^2 arcsen\left(\frac{h-R}{R}\right) + (h-R) \times \sqrt{R^2-(h-R)^2}$$

RESULTS

Volume Fraction

- To study the volume fractions of each fluid, with different fractions of each fluid were simulated.

Oil-Gasoline



F8 Tally - MCNP

- The calculation of the volumetric fraction using the measurements by transmission was performed through the photopeak counts obtained by the detector.

Volume Fraction

- The results for the volume fractions were obtained using the Abouelwafa and our equations.

Gasoline - Oil				
	Squad pipe		Cylinder pipe	
Theoretical VF(%)	MCNP6 VF(%)	Error (%)	MCNP6 VF(%)	Error (%)
0.00	0.00	0.00	0.00	0
25.00	29.70	18.80	24.87	0.52
50.00	49.92	0.16	49.87	0.26
75.00	69.85	6.86	74.56	0.59
100.00	100.00	0.00	100.00	0

Although the absolute error at 25% is equal to 75%, the relative error is smaller at 75%.

Volume Fraction

Gas - Oil				
	Squad pipe		Cylinder pipe	
Theoretical VF(%)	MCNP6 VF(%)	Error (%)	MCNP6 VF(%)	Error (%)
0.00	0.00	0.00	0.00	0
25.00	29.85	19.39	24.93	0.28
50.00	49.97	0.05	49.74	0.52
75.00	70.22	6.37	74.74	0.35
100.00	100.00	0.00	99.96	0.04

- The maximum errors are about 20% for the approximation made by ABOUELWAFA. However, for measurements with the pipe filled with half of each fluid (50%) presents maximum relative error of 0.16%.
- The maximum error for the developed equation is 0.59% for all volume fractions.

CONCLUSION

- The measurement geometry developed in the MCNP6 code together with the NaI(Tl) detector allowed to give reliability to the methodology of calculation of volumetric fractions in biphasic systems in the stratified flow regime.

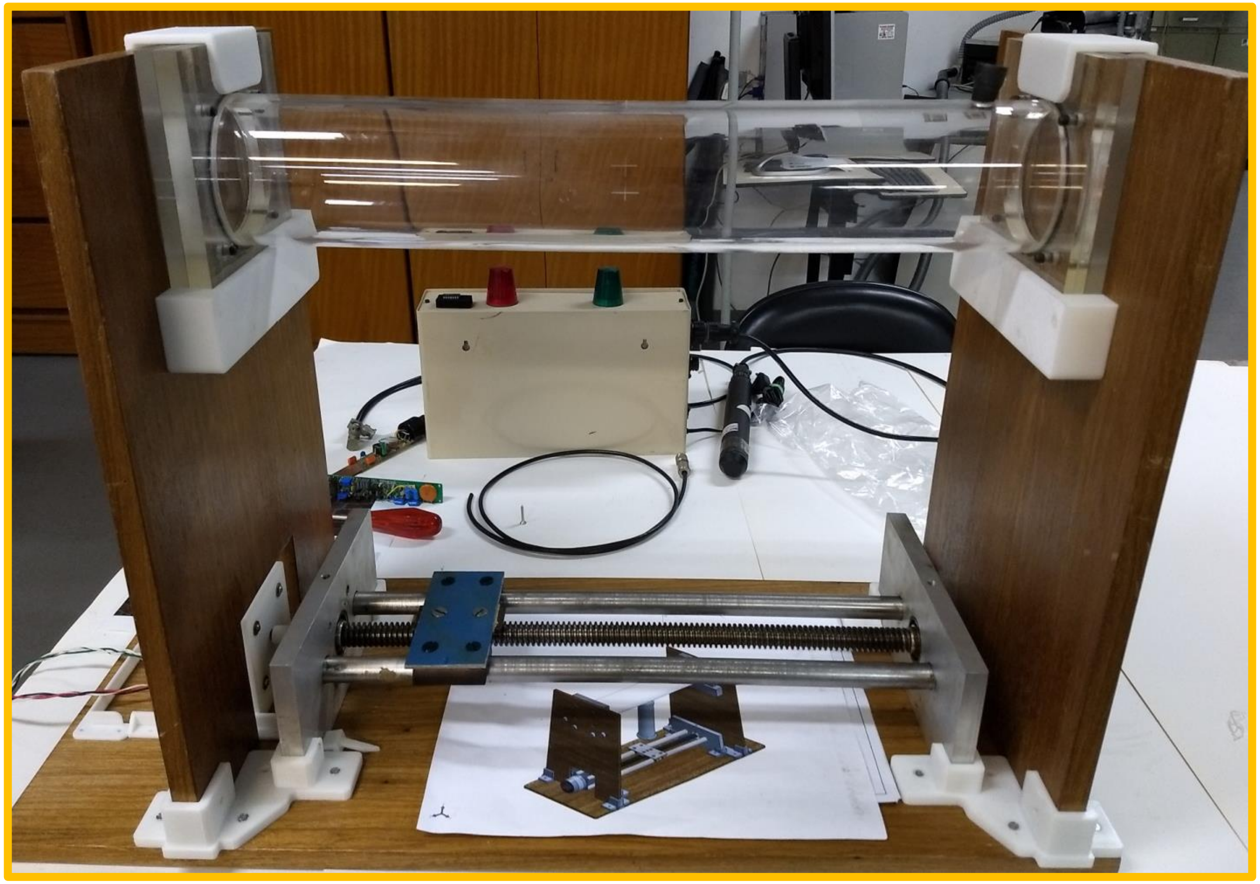
- The results obtained by the conventional equations showed a good approximation for the calculation with equal volume fractions with a maximum relative error of 0.16%, however, for different volume fractions, the maximum relative error was 19.39%. This result shows that these equations are not ideal for calculating volume fractions in cylindrical pipes, mainly for values less than 50%.

- The results for the developed equations presented a maximum relative error of 0.59%, showing that the obtained results correspond to the simulated volumetric fractions.

Future Actions

- Develop a broad beam equation, because this study was used for pencil beam.
- Design and construct a representative test section of the stratified flow regime to experimentally validate a methodology, is already in progress.

Test section



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