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MONITORING CATALYST FLOW RATE IN A FCC COLD PILOT UNITY BY GAMMA RAY TRANSMISSION MEASUREMENTS.

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ABSTRACT

A model for monitoring catalyst mass flow in riser of Fluid Catalytic Cracking – FCC, pilot unity as a function of air flow and solid injection is proposed. The fluidized FCC- catalyst bed system is investigated in an experimental setup the Cold Pilot Unity - CPU by means of gamma ray transmission measurements. Riser in CPU simulates the reactor in FCC process. By automation control air flow is instrumentally measured in riser and the solid injection is manually controlled by valve adjusting. Keeping a constant solid injection, catalyst level at the return column was measured by gamma transmission for several air flow values in riser. The operational condition reached a steady state regime before given to setup a new air flow value. A calibration of catalyst level as a function of air flow in riser is calculated, therefore, a model for solid feed rate is derived. Recent published work evaluates solid concentration in riser of the CPU by means of gamma ray transmission, and a correlation with air velocity is obtained. In this work, the model for solid feed rate was further investigated by carrying out experiments to measure catalyst concentration at the same air flow values. These experiments lead to a model for monitoring catalyst flow in riser as function of solid feed rate and air flow. Simulation with random numbers produced with Matlab software allows to define validation criteria for the model parameters.

1. INTRODUCTION

The process Fluid Catalytic Cracking – FCC, is an important tool developed to obtain gasoline. Investigations in FCC units and opaque multiphase reactors have had continuous scientific and technological development (Dantas, 2013).

The process of the FCC riser, which is the reactor, is a vertical tube is 6 meters tall, where the cracking reactions occur giving rise to products with higher added value.

The Fluid Group and Gamma Tomography Department of Nuclear Energy (DEN), of the Federal University of Pernambuco (UFPE), has investigated the FCC process using the beam of gamma radiation. Built a pilot plant FCC type cold, the UPF, Fluid to study the process of petroleum cracking.

The primary variables in the UPF are compressed air injection and injection of solids. These two variables are controlled by computer, and its result is given with the UPF in operation. The variables measured are air flow and pressure in the riser, these results are also obtained with UPF operation. Other variables can be measured as speed of solid, density and volume fraction.

The transmission gamma of measures were carried out by means of the detection system installed in the UPF with the source and detector, shielding and collimators positioned in the riser. The radioactive source containing the radionuclide ^{241}Am, with activity 7,4 x 10^9 Bq, half-life of 432.2 years and energy range equal to 0.06 MeV. The detector used is a scintillator of NaI (Tl) 2 "x 2" coupled to a multichannel analyzer.

2. METHODOLOGY

The catalyst density is measured by means of adjustment of the Beer-Lambert equation, adapted by Bartholomew and Casagrande (BARTHOLOMEW AND CASAGRANDE, 1957), applied to the measurement conditions in the riser:

$$\rho_m = \ln\left(\frac{I_v}{I_f}\right)\frac{1}{\mu_m D} \qquad (1)$$

Where:

ρ_m = average density along the trajectory of the gamma radiation (g/cm^3)

I_v = Intensity to the empty tube

I_f = Intensity of the tube flow conditions

μ_m = Mass attenuation coefficient of the solid (cm^2/g)

D = Internal diameter of the tube (cm)

The density of catalyst circulating in UPF varies with the flow of solids, by varying the pressure in the riser and mass flow, thus, write the density as a function of these three parameters, as described in the following equation:

$$\rho_m = f\,(V_a, \Delta P, W) \qquad (2)$$

Where:

Va = Flow of solids

ΔP = Pressure variation in riser (mmH2O)

W = Mass flow of catalyst (g m^{-2} s^{-1})

2.1 Planning

An experimental design was done in order to study the conditions of measurement with the UPF in operating and running simulations. A simulation physical was made to measure the intensity, with different densities of material in the return column, and a theoretical simulation to evaluate the irradiation geometry tubes. All measurements were experimentally performed a simulation, to evaluate the data obtained, and the same be validated by experimental measurements.

To measure the intensity is used the equation of beer-lambert, which is the mathematical law that equates the intensity with coefficient linear attenuation for monoenergetic sources and punctual.

$$I = I_0\, e^{-\mu\, x} \tag{3}$$

Where:

I = Intensity emerging

I_0 = Intensity incident

μ = Linear attenuation coefficient (cm^{-1})

x = Thickness of the absorbing material (cm)

Not is usual to use the linear attenuation coefficient, because it depends on the physical state of the material attenuator. Thus it replaces the linear attenuation coefficient, by mass attenuation coefficient, which is the linear attenuation coefficient divided by the density of the material, thus, the mass attenuation coefficient not depend of the physical state of the material attenuator (Turner, 2007).

$$I = I_0\, e^{-\mu_m\, \rho\, x} \tag{4}$$

Where:

μ_m = Mass attenuation coefficient (cm^2/g)

ρ = Density absorbent material (g/cm^3)

To measure the intensity of the gamma source to the empty tube, it is used for mass attenuation coefficient and density of the acrylic Equation (5). The measurement of the intensity of the empty tube is given by:

$$I_v = I_0\, e^{-\mu_{m_a}\, \rho_a\, x_a} \tag{5}$$

Where:

μ_{ma} = Mass attenuation coefficient of acrylic

ρ_a = Density acrylic

x_a = Thickness acrylic

To measure the intensity of the tube flow conditions I_f, the attenuation coefficient and density used in Equation (6), will be the catalyst:

$$I_f = I_v \, e^{-\mu_{m_c} \rho_c x_c} \qquad (6)$$

Where:

μ_{mc} = Mass attenuation coefficient of catalyst

ρ_a = Density catalyst

x_a = Thickness catalyst

2.2 Simulation In Column Of Return

The mass flow is calculated by:

$$W = \frac{m}{A\,t} \qquad (7)$$

Where:

m= Catalyst mass

A = Area of the return column

t = Time

When not in operation UPF, all catalyst is compacted in the return column. The highest point where there is still a catalyst is called the seal of the catalyst. The following figure illustrates the seal of the catalyst with the UPF not while running, the source and detector arrangement and two marks on the return column, s_1 e s_2, that will help to measure the mass of catalyst injected into the riser:

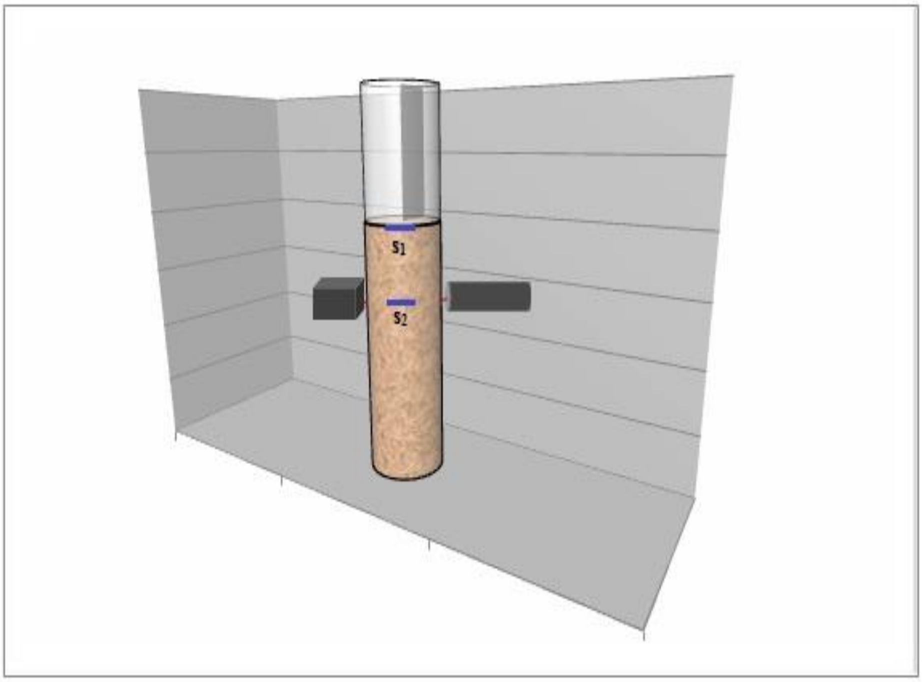

Figure 1: Catalyst UPF sealed when not in operation.

The UPF during operation, the seal of catalyst with low speed proportional to the air velocity constant of the catalyst an input. The catalyst when it returns to the return column, falls on the seal of a non-compacted, thus, density The reduction in material density cause low beam gamma attenuation material above the seal of the catalyst is lower than the own seal. The reduction in material density cause low beam attenuation gamma.

While the seal of the catalyst does not exceed the second mark, the value of the counts remains constant, within statistical variation of measured intensity.

The beam gamma is at the same height the second mark, as shown in Figure 1. The time t is measured, the seal required for the catalyst moves from s_1 to s_2. After the seal exceeds s_2, the number of counts will be increased, and know that the catalyst has traveled the desired distance.

The product of the distance traveled by the catalyst and the area of the return column is equal to the volume of catalyst injected into the riser.

$$v = \Delta s \, \pi \, R^2 \tag{8}$$

Where:

R = Inner radius of the return column (cm)

$\Delta s = s_1 - s_2$

The density of the catalyst was measured in previous experiments ρ_c, 0,85 g/cm^3 (Dantas, 2013), therefore, by the following expression can measure the mass of catalyst injected into the riser:

$$m = \rho_c \, v \tag{9}$$

With the given mass in Equation (9), and the time obtained in the experiment illustrated by Figure 5, Get the data to calculate the mass flow by means of Equation (7).

2.3 Simulation experimental

Consists of simulating, by different densities of the solid, intensities in the return column with UPF in operation.

The simulation occurs in a trunk riser, produced with the same material as the return column, and with the same catalyst used for the UPF. Styrofoam balls of different diameters are placed in the return riser, together with the catalyst to simulate different densities material. The choice of the Styrofoam ball is given by its mass attenuation coefficient (0,1875 cm^2/g), be close to the air (0,1870 cm^2/g), and because of its low density (0,01 g/cm^3).

Measurements were carried out with the intensity of the radiation simulated density and the density calculation was performed with Equation (1).

2.4 Simulation In *Riser*

To determine the catalyst density in riser is necessary to obtain the radial profile gamma of the same, to know its possible irregularities, asymmetry and the effect of the side wall.

The intensity for the empty tube is simulated using Equation (5). The mass attenuation coefficient and density of the material are constant, the incident intensity is the intensity without attenuator materials, thus, the only variable in the equation (5) be material thickness attenuator.

2.4.1 Modelling

Depending on the point where the radiation tube passes through may be more or less attenuation. The reason this occurs is that the closer the side walls, the greater wall thickness that gamma radiation has to cross. To illustrate the effect of varying the wall thickness of the tube which passes through the beam gamma used the following figure:

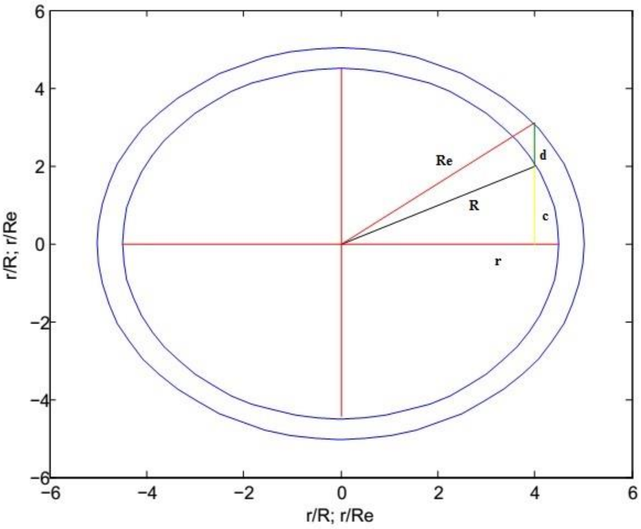

Figure 2: Determination of the radiation attenuation along the radius of the riser tube.

Where:

R = Inner radius of the tube (cm)

Re = Outer radius of the tube (cm)

c = Rope tube (cm)

r = Distance from the center of the tube (cm)

d = Tube Wall Thickness (cm)

Figure 2 helps to illustrate that the closer the side walls, the greater thickness that gamma radiation there through. In the center of the riser wall thickness is less than the outer radius of the inner, and the higher r, the greater the thickness of the tube wall. The following equations assist in the determination of the tube wall through which the beam gamma (Dantas et al, 2006):

$$R^2 = c^2 + r^2 \tag{10}$$

$$Re^2 = (c+d)^2 + r^2 \tag{11}$$

Combining Equation (10) to (11), and isolating in terms of d, gets the following equation, to determine the wall thickness:

$$d = \sqrt{Re^2 - r^2} - \sqrt{R^2 - r^2} \tag{12}$$

The thickness d is multiplied by 2, assuming that the tube is symmetrical in accordance with the hypothesis of the simulation.

The formulation for a model that can describe the radial profile includes the term d in Equation (15), (Dantas et al, 2006; Dantas et al, 2008), is described below:

$$y_v = a_1\, e^{(a_2\, d)} \tag{13}$$

Where:

a_1 and a_2 = Parameters are fitted to experimental data by the method of nonlinear least squares, using the command nlinfit Matlab.

With this model given in Equation (13), can then be, simulating the profile gamma ray tube from the outside and inside are known. Comparing this theoretical profile with the experimental data it was possible to evaluate errors due to non-symmetry, irregularities and cumulative effects of the measures at the extremity of r / R.

The radial profile includes planning and setting the scan interval r, with measures I_0 before and after the tube, as shown in Figure 3, and the number of points to be measured along the transmission gamma of the radius. Each of these points corresponds to a chord c, which will replace the inner diameter D in Equation (1). So i will be strings, a sampling trajectories i gamma. To obtain an experimental profile suitable for comparison with the theoretical profile, was performed the linear interpolation of the experimental points with the i command intrep1, of Matlab, such a profile was obtained at n points, which can be seen in Figure 3.

2.5 Determination Of The Mass Of Catalyst In *Riser*

Considering the density measurement calculated by Equation **(1)** is associated with a volume V, that is estimated by the cylinder volume, where, the area of the riser beam height gamma, (Dantas et al, 2013), the Equation (14) calculates the volume associated with this density**:**

$$V = \pi R^2 \Delta h \tag{14}$$

Where:

Δh = Beam height gamma (cm)

The volume was calculated using Equation (14), and density using Equation (1), it is possible to determine the mass of catalyst:

$$M = \rho_1 V \tag{15}$$

3 RESULTS

3.1 Radial Profile

The graph in Figure 3 shows the experimental and theoretical radial profile of the riser, where the x axis shows the normalized radius r / R, and the y-axis the relative intensity. Along the sweep gamma may be the side walls of the riser, left and right, correspond to the points -1 e 1, respectively, and the center is indicated on the tube 0.

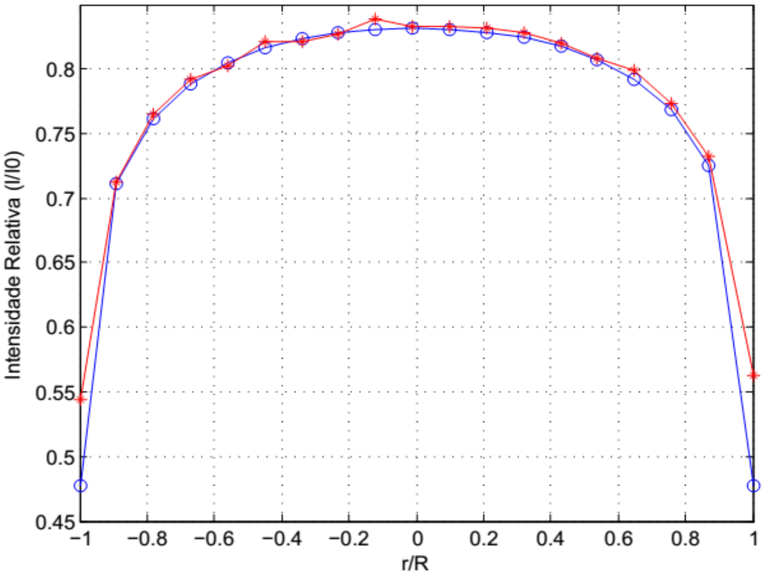

Figure 3: Graph of theoretical radial gamma profile (blue) and experimental (Red) riser.

The theoretical profile has a symmetrical tube and without irregularities in wall thickness. As shown in Figure 2 at the side walls beam gamma will traverse a greater wall thickness, therefore these points is smaller intensity, and the closer to the center thickness less, result in a higher intensity value, as is observed in figure 3.

The experimental profile shown in Figure 3, shows that the intensity of the side walls is greater than the value obtained with the simulation, This is due to the closer side walls, larger errors are, as already described in this work. The closer to the center, higher intensity, But the experimental profile, the highest intensity may not necessarily be in the center of the tube. Figure 3 also shows that the tube is not symmetrical, But even with the asymmetry and irregularities riser has the same characteristics observed in the theoretical profile.

3.1.1 Radial profile under flow conditions

Was made a chart analyzing the relative intensity for the empty riser and under flow conditions.

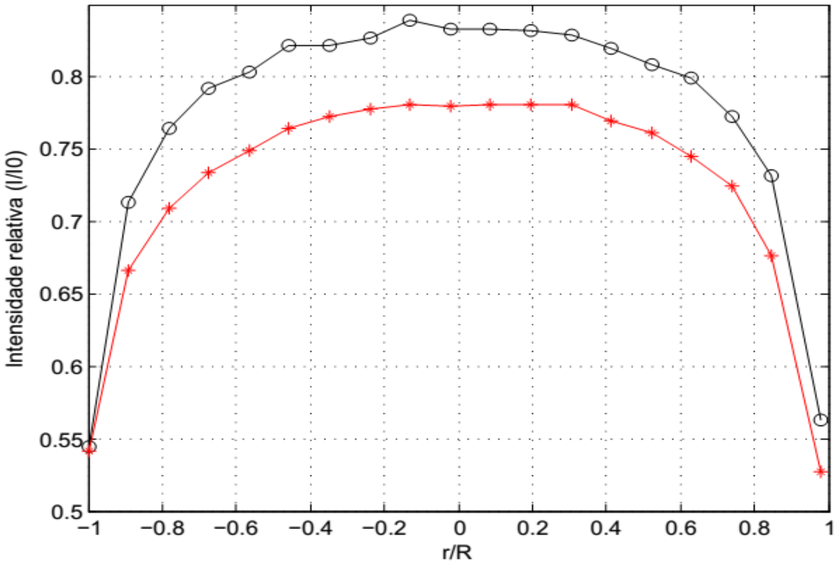

Figure4: Intensity gamma with the empty riser (blue) and under flow conditions (red).

In Figure 4 is shown a graph of intensity throughout the scan range of the experimental data, can observe a flow of the dilute catalyst indicated by the proximity of the two profiles.

3.2 Mass Flow Of Catalyst

The simulation of the density variation in the return column is shown in the figure as follows:

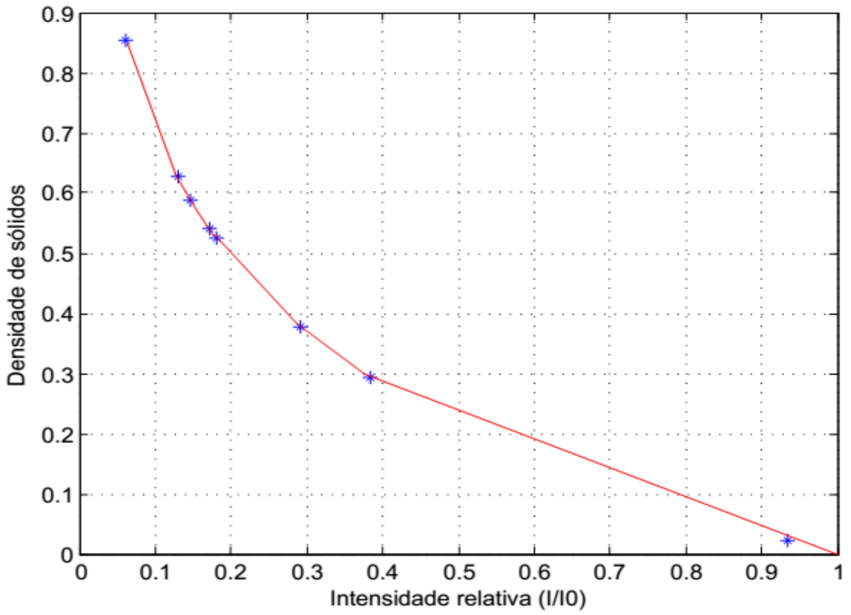

Figure 5: Variation of the density function of the intensity

The higher the density of catalyst, the greater the attenuation of gamma beam, thus the lower the intensity. The graph of Figure 5 will assist in determining the passage of catalyst seal by the mark s_2 shown in Figure 1.

The mass flow of catalyst was measured air flow equal to 650 Lmin^{-1} and Pressure 25, 30 e 35 mmH$_2$O. The measured velocity of the catalyst in the riser was 2 m/s, the relationship of mass flow of catalyst per catalyst density in the riser is represented in the figure as follows:

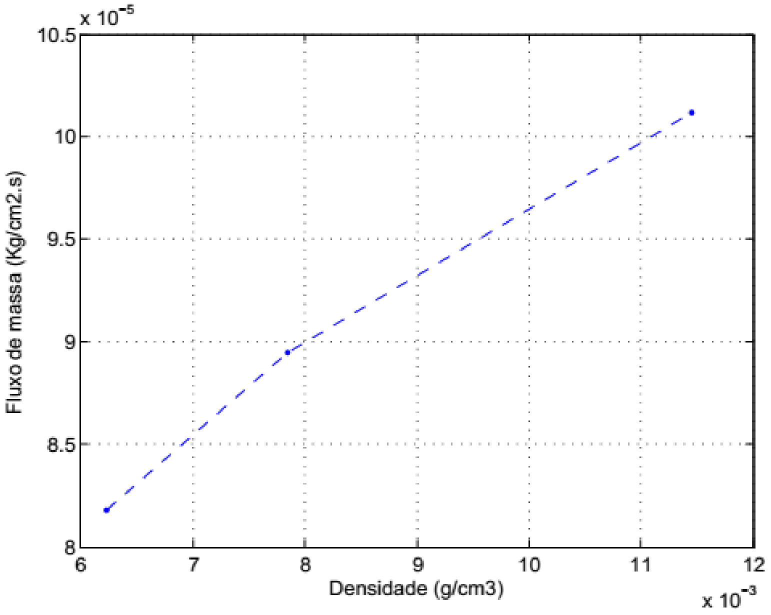

Figura6: Flow of catalyst mass as a function of the density of catalyst

It is observed that the higher the density, the greater the mass flow of catalyst, because the higher density, the greater the mass of catalyst injected, soon, the shorter the time for the injection of the whole mass of the catalyst.

4. CONCLUSIONS

It was concluded that the riser UPF presents some irregularities and asymmetries, despite this, it has the same characteristics observed in the theoretical radial profile, and its radial profile points is required which has a characteristic irradiation geometry, because the wall thickness of the tube through, depends on the point where the beam is positioned. The CT was gamma effective for measuring the catalyst density in the UPF movement, without the flow disturbance. The mass flow of catalyst can be measured by catalyst density in the return column, or by varying the intensity of the empty tube and under flow conditions.

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