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# OIL FLOW RATE MEASUREMENTS USING $^{198}$Au AND TOTAL COUNT TECHNIQUE

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## ABSTRACT

In industrial plants, oil and oil compounds are usually transported by closed pipelines with circular cross-section. The use of radiotracers in oil transport and processing industrial facilities allows calibrating flowmeters, measuring mean residence time in cracking columns, locate points of obstruction or leak in underground ducts, as well as investigating flow behavior or industrial processes such as in distillation towers. Inspection techniques using radiotracers are non-destructive, simple, economic and highly accurate. Among them, Total Count, which uses a small amount of radiotracer with known activity, is acknowledged as an absolute technique for flow rate measurement. A viscous fluid transport system, composed by four PVC pipelines with 13m length (12m horizontal and 1m vertical) and ½, ¾, 1 and 2-inch gauges, respectively, interconnected by maneuvering valves was designed and assembled in order to conduct the research. This system was used to simulate different flow conditions of petroleum compounds and for experimental studies of flow profile in the horizontal and upward directions. As $^{198}$Au presents a single photopeak (411,8 keV), it was the radioisotope chosen for oil labeling, in small amounts (6 ml) or around 200 kBq activity, and it was injected in the oil transport lines. A NaI scintillation detector 2”x 2”, with well-defined geometry, was used to measure total activity, determine the calibration factor F and, positioned after a homogenization distance and interconnected to a standardized electronic set of nuclear instrumentation modules (NIM), to detect the radioactive cloud.

## 1. INTRODUCTION

Throughout the oil production chain, it is essential to use pipes in transport, which are called pipelines. In such a transport system, several factors adds advantages to processes: maintenance cost, environmental benefits, transport of large volumes at competitive costs, for example. However, these units require a regular inspections process constantly and shall be subject to the strict security requirements and monitoring the internal pressure of the pipeline and its flow [1].

In order to oil, and its derivatives, flow through the ducts, it is necessary to use pumps that promote the movement of fluids, under pressure and flow rate constant, because without these characteristics, it is impossible to measure the volume transported [2]. According to that author, even after separation processes, presence of gas, water and sediment is observed. This fact is extremely undesirable, because, besides to promoting wear of pumps and meters components, leads to inaccurate measurements.

Several methods are employed to calculate the flow rate and Ribeiro [2] cited that the most commonly used methods require a measurement device to stay in direct contact with the fluid and, in many cases, due to the abrasive effects / corrosive oil and its derivatives with the moving parts of the meter causes wear on their components, causing slipping - fluid passage without being measured – and hence, influencing the accuracy of the measurements. In this way, the sensor should go through maintenance constantly and calibrated with some periodicity. In general, the flow uncertainties of the types of positive displacement and Coriolis are around 0.3% and ultrasonic 2%. These values are for new meters and at operations similar to laboratory conditions. The author also pointed out that, for the employment of flow meters at pipeline transportation of petroleum and its derivatives often requires the installation of auxiliary equipments that interfere with measurement accuracy. However, these drawbacks could be avoided. When the case of using of radiotracers techniques, they are minimized by the penetration of radiation in matter, that allows the use of noninvasive techniques, independent of the dimensions of the systems analyzed, because, for each case, it is built the correct calculation of the activity needed and the measurement geometry [3]. Techniques using radiotracers consist of the use of statistical functions of the residence time distribution (RTD) in their systems analysis and data acquisition. These techniques are recognized for their safety, effective precision, competitive costs and have their employment governed by international certifications [4].

Among the techniques of flow measurement with radiotracers, the two most commonly used are the: Transient Time and Total Count, the last one being used in this research work focused primarily measure flow and the first one used for comparison results.

### 1.1: Measure the flow by Total Count Technique

The Total Count Technique is recognized as a technique for measuring absolute flow. In 1957, Hull [5] measured the amount of flow in a duct line between the American States of Colorado and Utah, with this technique. Total Count Technique has as main advantages: 1) the independence of the internal volume of the transport duct, which can be applied in the presence or absence of obstructions, 2) no restriction on the nature of the product or material to be conveyed; 3) it is a noninvasive technique that enables real-time diagnosis; 4) uses only one detector.

Total Count in the art, a small amount of radiotracer with known activity, $\boldsymbol{A}$, is detected by a detection system with well-defined geometry, which, positioned after homogenization distance, provides a total count, $\boldsymbol{N}$. The flow rate, $\boldsymbol{Q}$, can be obtained by Equation 1.

$$Q = \frac{A \cdot F}{N} \tag{1}$$

Where ***F*** is the calibration factor obtained at laboratory, and it has constant value, specific to each measurement system.

With an uncertainty calculated by Equation 1,

$$\delta Q = Q \cdot \sqrt{(\frac{\delta A}{A})^2 + (\frac{\delta F}{F})^2 + (\frac{\delta N}{N})^2} \tag{2}$$

Observing Equation 2, we note that the contribution of relative uncertainty concerning to activity, (*δA/A*), is low because the calibration sets of detection allows to reach low values. The same rushes with relative uncertainty concerning to the F factor, (*δF/F*), as the adjustment function to the experimental data gives a coefficient of determination, $R^2$, very close to unity, as can be seen in Figure 1.1. The contribution of relative uncertainty concerning total counts recorded, (*δN/N*), depends mainly on the accuracy of the discrimination scores for the photo peak of contributions due to background radiation. Low activities injection can make it difficult such discrimination.

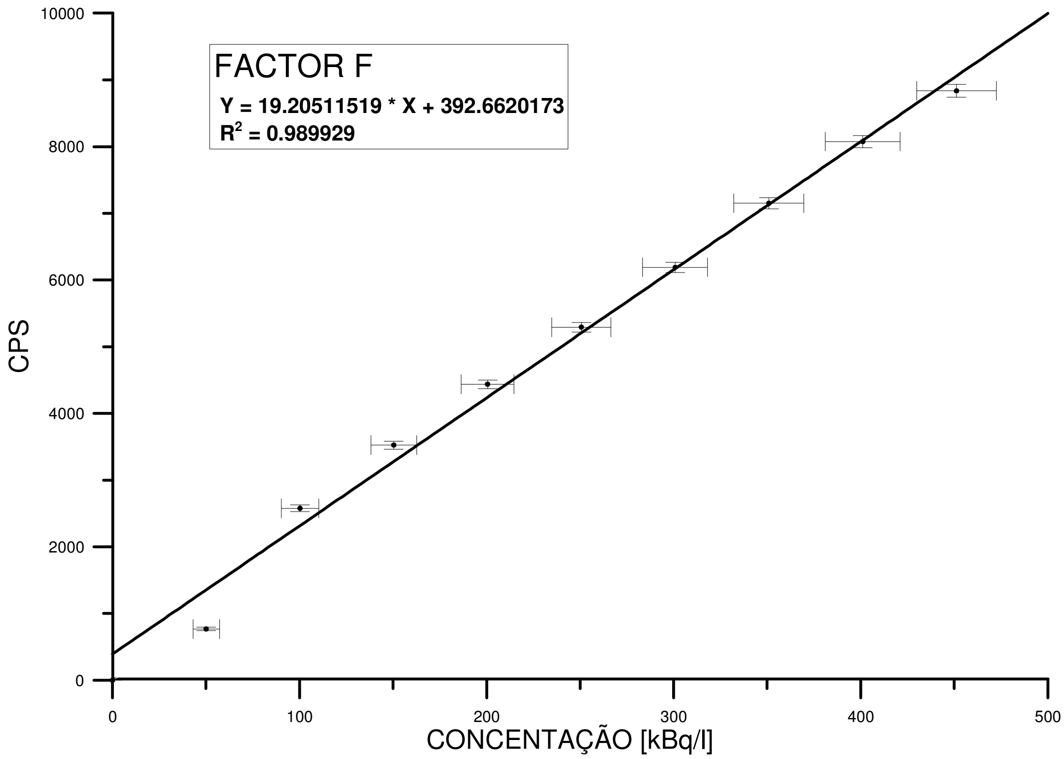


**Figure 1.1: Curve matching concentrations injected the radiotracer and the counting rates of radiotracer to determine the factor F**

## 1.2: Determination of the calibration factor F

The calibration factor F is a fundamental parameter to employ Total Count Technique. It is determined experimentally through a replica of detection conditions in the transport line. In this apparatus, as shown in Figure1.2, were deposited successively aliquots of radiotracer with activity (25.1 ± 0.2) kBq in 500ml of oil contained in the PVC pipe.

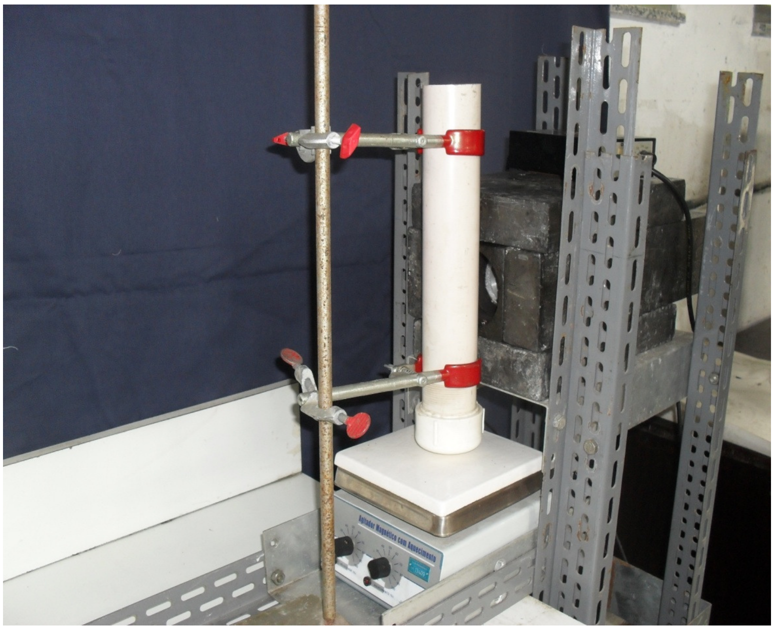

**Figure 1.2: Experimental device constructed for the determination of the calibration factor F.**

## 1.3: Flow Measure by Transient Time Technique.

In the Transient Time Technique a small amount of radiotracer is injected instantly in a straight transverse duct section defined and constant, $\boldsymbol{S}$. After homogenization distance, two detectors ($\boldsymbol{D_1, D_2}$) are arranged externally at a distance $\boldsymbol{x}$ from each other, so that the passage of the radioactive cloud by the position occupied by one detector does not interfere with detection of the other cloud.

After data acquisition, by using the RTD function, $\boldsymbol{E(t)}$, and through the first statistical moment, $\boldsymbol{M_1}$, obtains the average residence time and $\boldsymbol{\tau}$ corresponding to the transient time between the signals recorded by $\boldsymbol{D_1}$ and $\boldsymbol{D_2}$.

The flow rate Q is given by Equation 3:

$$Q = \frac{S \cdot x}{t_1 - t_2} \tag{3}$$

Where: $\boldsymbol{S}$ is the cross-sectional area of the pipe, $\boldsymbol{x}$, the distance between the detectors $\boldsymbol{D_1}$ and $\boldsymbol{D_2}$, $\boldsymbol{t_1}$ and $\boldsymbol{t_2}$ are the average residence times in the region of the radioactive cloud detection by the detectors $\boldsymbol{D_1}$ and $\boldsymbol{D_2}$, respectively, and their uncertainty given by:

$$\delta Q = Q \cdot \sqrt{(\frac{\delta S}{S})^2 + (\frac{\delta x}{x})^2 + (\frac{\sqrt{(\delta t_2)^2 + (\delta t_1)^2}}{(t_2 - t_1)})^2} \quad (4)$$

Observing Equation 4, we note that the contributions of the uncertainties concerning the cross sectional area of the pipe, ($\delta S/S$), and the distance between the detectors, ($\delta x/x$), can be negligible, because the first is measured by a high precision caliper, in the other, despite the uncertainty of the measuring instrument (tape) is also small, the detectors are spaced at $\boldsymbol{x}$ value much greater than the uncertainty of the measuring device.

Therefore, the uncertainty in flow measurement is mainly due to uncertainty of the measurements of the average residence times. This fact is mainly due to irregular shape of the injected pulse and the increased dispersion of the cloud along its way through the pipeline, as longer the path, the dispersion will be greater, thus leading to a longer duration passing through the sensitive detection region. One way to decrease the dispersion is to produce a radiotracer injection pulse like a piston.

The Transient Time Technique is widely used in industry, but its efficiency has an important limitation: the need to know the cross-sectional area, and furthermore, it is necessary that it is constant throughout the duct and the volume is fulfilled by the fluid. These limiting factors make the use of this technique in oil pipelines restrict, which often occurs fouling on the inner walls, altering cross sectional area of the ducts.

## 2. MATERIALS AND METHODS

### 2.1: Transport lines installation.

To conduct the research, took the design and assembly of a metal frame that supported two reservoirs polypropylene cylindrical with 0.65 m diameter and 1.05 m in height, each with individual capacity of 250 liters, as shown in Figure 2 .1. Then, it was designed and assembled the transportation system of viscous fluid to simulate different oil flow conditions. This system is composed by four lines of PVC pipe gauge ½ "¾", 1 "and 2" interconnected by maneuvering valves, with each line measuring 13 m, 12m horizontal and 1m vertically for purposes of experimental flow profile in the horizontal and upward as shown in Figure 2.1. The use of two reservoirs had the motivation to avoid recirculation of the radiotracer in the system and do not cause an increase in background radiation, that it would become so difficult to discriminate the passage of radioactive cloud.

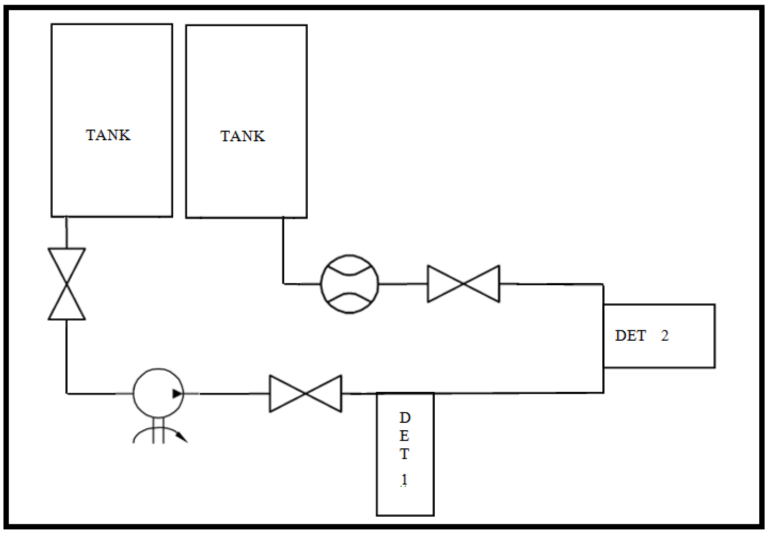


**Figure 2.1: layout of transport line to organic compounds installed in the laboratory.**

Due to maneuver valve system, transportation lines can operate individually or in combination, allowing the simulation of deviations, leaks and pressure variations.

Mechanical flow meter, injection system and a flow control valve complement the transportation line.

## 2.2: Radiation Detection Systems

To detect the radiotracer injected into the line to determine the calibration factor F and measuring the radioactivity of the samples were used NaI scintillation detectors 2" x 2" interconnected to a standardized electronic set of nuclear instruments modules (NIM) by coaxial cables.

## 2.3: Material transported

The use of the technique Total Count is independent of the nature of the material under study, since the guidelines for the choice of the radiotracer in marked [1]. For the implementation of the research were used 200 liters of oil Lubrax Essential© 20W50 API SJ / SJ ANP. 0139.

## 2.4: Marking the oil

Two radioisotopes as tracers were tested, $^{198}Au$ and $^{82}Br$. As the Total Count Technique is critical to accurate knowledge of the area under the photo peak, and the emission spectrum of gamma radiation by $^{82}Br$ three peaks occur at energies very close (554.3 keV, 619.1 keV, 776.5 keV), $^{198}$Au was chosen for the experiments because it has to present a single photo peak (411.8 keV) and the characteristics listed [1].

### 2.5: Flow measurement

Two NaI scintillation detectors 2" x 2" were used to flow measure. The first detector is positioned to 2.50 meters from the injection point to ensure the perfect radiotracer homogenization. The second detector was positioned to 4.66 meters far from the first one. The second detector is installed in the vertical position of carriage with purpose of minimizing the effects of back-scattering from laboratory floor.

At the beginning of experiment, oil was left to flow freely through the line 2" diameter for five minutes in order to stabilize the system, then, started data acquisition. After that, making sure that the data acquisition system processed pulses stably, it was injected (6.00 ± 0.05) ml radiotracer $^{198}$Au. The mean time to acquisition was approximately 20 minutes.

**Table 1: Values of the activity injected.**

| | **ATIVIDADE [kBq]** |
|---|---|
| **EXPERIMENTO 1** | 178.4 ± 1.1 |
| **EXPERIMENTO 2** | 167.2 ± 0.9 |

### 2.5.1: Flow measurement by employing a mechanical meter

The mechanical flow meter was inserted into the transport line in order to also be another yardstick comparative data. In this way, relevant information provided by conventional meter, the flow presented significant variations, around 7%, during the whole period of the experiment.

**Table 2: Measures the flow through the mechanical meter**

| | **FLOW [$l \cdot min^{-1}$]** | **δFLOW [$l \cdot min^{-1}$]** | **UNCERTAINTY RELATIVE [%]** |
|---|---|---|---|
| **Experiment 1** | 1.835 | 0.015 | 0.1 |
| **Experiment 2** | 1.905 | 0.016 | 0.1 |

### 2.5.2: Flow measure by employing Total Count Technique

Data recorded by Total Count Technique listed in Table 3, shows uncertainties around 4%, and high similarity with the mechanical meter.

**Table 3: Measures the flow through Total Count Technique**

| | FLOW [$l \cdot min^{-1}$] | $\delta$FLOW [$l \cdot min^{-1}$] | UNCERTAINTY RELATIVE [%] |
|---|---|---|---|
| **Experiment 1** | 1.794 | 0.08 | 4.2 |
| **Experiment 2** | 1.939 | 0.09 | 4.7 |

### 2.5.3: Flow measure by employing Transient Time Technique

Analyzing the data shown in Table 4, we note that presented values are conflicting answers regarding the mechanical meter, listed in Table 2.

**Table 4: Measures the flow through Transient Time Technique**

| | FLOW [$l \cdot min^{-1}$] | $\delta$FLOW [$l \cdot min^{-1}$] | UNCERTAINTY RELATIVE [%] |
|---|---|---|---|
| **Experiment 1** | 3.113 | 2.923 | 93.9 |
| **Experiment 2** | 3.009 | 2.447 | 81.3 |

## 3. CONCLUSIONS

The use of Total Count Technique to measure the oil flow was performed. The flow measurement by this technique showed reproducibility and accuracy, with values around 2% over the mechanical meter results.

The use of Time Transient Technique as comparative method was not possible. The occurrence of factors, large dispersion and the injection did not respond to criterion for pulse piston, led to huge uncertainties around 85%, relative to its results.

As future work are the following suggestions: (1) installing a frequency controller, at the pump, as a way to control and stabilize the flow in the transport line, (2) development of a pneumatic injector, in order to enable an injection piston, providing the best values in the uncertainty of the results obtained by the technique of transient time.

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