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Development of a scintillator detector set with counter and data acquisition for flow measurements

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Abstract

A portable counter with data acquisition system for flow measurements was developed, using the pulse velocity technique. This consists in determining the tracer transit time mixed homogeneously to the liquid or gas pipelines. The counter comprises: (a) two CsI(Tl) crystals solid state detectors, associated with Si PIN photodiodes, with compatible sensitivity to the injected radiotracers activities; (b) amplification units; (c) analogue-to-digital interface, which processes and displays the detectors counting separately and in real time, but in a same temporal axis, via a computer screen and (d) 30-m coaxial cables for signals transmission from each detector to the processing unit. Experiments were carried out for the detector and associated electronic characterizations. The equipment showed to be suitable for flow measurements in an industrial plant, in the real situation. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Scintillator; Radiation detector; Flux measurement; Radiotracer; Transit pulse

1. Introduction

For flow measurements of liquids or gases in industrial processes plants, the radiotracer methodology shows to be the most suitable, since it enables the evaluation without interrupting the production or introducing derivations in the hydraulic systems. The radiation detector offers the advantage of allowing the measurements to be done without physical contact, mechanical movement and even through walls pipeline. In addition, as a fundamental characteristic, the radiation emitted by a radioisotope does not change the properties of the temperature, pressure, viscosity or any other parameter, which can affect the element the radioisotope is mixed to. So, since the conditions of the mixture and homogenization were satisfied, the behaviour of the interest element can be evaluated studying the radiotracer behaviour. Among the several radiotracer methodologies [1,2], the pulse velocity technique presents great applicability, using the tracer transit time mixed homogeneously to the pipeline liquids or gases.

The pulse velocity technique consists in placing two radiation detectors separated at appropriate distance in the external part of the pipeline, which carries fluid of an unknown flow. The radiotracer is injected in the flux, in the short pulse shape. The first detector records the radiotracer passage in the first point of the pipeline. Subsequently, the second detector records the passage of the same radiotracer in the second point. The flow can be

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obtained, knowing the time range of the radiotracer passage between the first and second detector, as well as the pipeline characteristics [3]. The scheme of this technique is presented in Fig. 1.

The gamma radiation is the most suitable to be used, since due to its penetrability, it can be measured without interrupting the production, placing a radiation detector on the tube wall. The radiotracer often used to flow measurements of liquids is ^{82}Br (γ–radiation 0.55 and 1.32 MeV), because: (a) it presents short half-life (35.34 h), and low absorption in the interaction with the material [3,4].

The detection limit is dependent on the used detector. The detector often used to measure gamma radiation is built using a photomultiplier coupled to a NaI(Tl) crystal. The photomultipliers have excellent characteristics with low internal noise and high signal. However, for use as portable counters, one of their main disadvantage is the need to operate at high voltage applied to the photomultiplier [5,6]. For portable equipment, the reverse bias is supplied for increasing the battery tension around thousand volts in order to obtain suitable polarization of its dynodes. The stability of the multiplication process depends on the battery condition and this can affect the results as the time passes. On the other hand, to conduct the high-volt tension in the cable can be dangerous for the worker, due to electrical shock. Besides, the photomultiplier is sensitive to the magnetic field and mechanical shocks. The use of the PIN silicone photodiode overcomes these limitations, because they are not sensitive to magnetic fields, may be operated to low bias, and are not much dependent on the power supply compared to the photomultiplier. Besides this, the photodiode has small dimension and its spectrum has a good match with the CsI(Tl) crystal spectrum, which permits to project heavy duty and compact detector at a low cost.

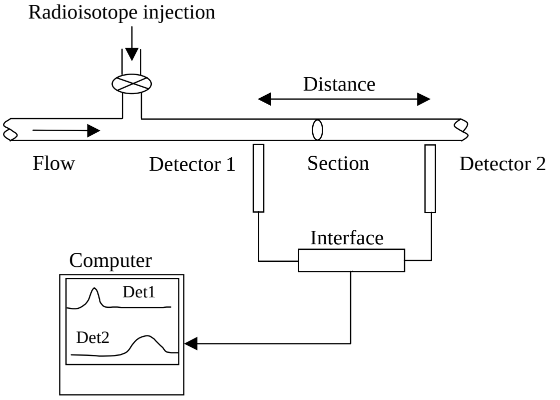

Fig. 1. Schematic model of flow measurement by pulse velocity technique using radiotracers.

In this paper, the development of a portable counter with data acquisition system for flow measurements using the pulse velocity technique was described. This portable counter was developed using CsI(Tl) crystals coupled to a PIN photodiode [5,6] with compatible sensitivity to the injected radiotracers activities. Using the developed equipment, measurements were carried out in real situation, in an industrial plant, to determine the liquid flux in the pipeline. For flow measurement in a slow speed process, the data can be obtained manually, using a two-detector system. However, in the measurements in a high-speed process, the measurements are limited due to the processing velocity. The developed equipment overcame the existing limitation, processing and displaying the detector counting, separately and in real time, in a same temporal axis.

2. Experimental procedure

The portable counter was built according to the scheme shown in Fig. 2. The detection efficiency of the system was measured as a function of the radioisotope energy ranging from 100 to 1500 keV. The minimal detectable activity (MDA) of the system was determined for ^{82}Br, usually used for hydrology application. The MDA was calculated as being

$$\mathrm{MDA} = \mathrm{background} + 3\sqrt{\mathrm{background}}.$$

For validation of the detector system, two measurements of the different liquid flows were carried out based on the real situation in an industry. The experiment was achieved by

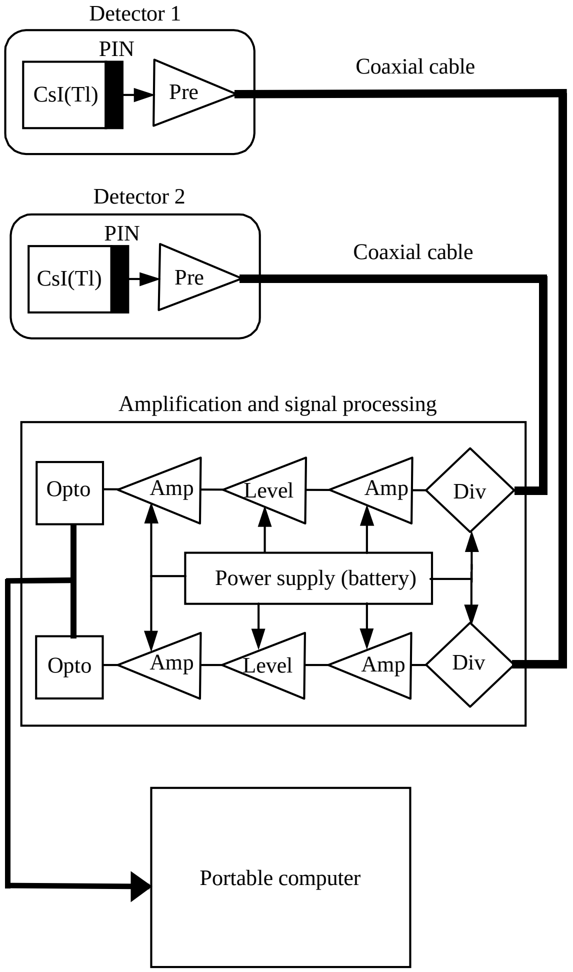

Fig. 2. Block diagram of the radiation detector with data acquisition system.

injection of 26×10^6 Bq of the ^{82}Br in the KBr form for each measurement. The following procedures were carried out:

The detectors were fixed in the pipeline separated at a distance of 34.5 m from each other. The possible maximum distance should be maintained in order to avoid the temporal superimposing of the pulses in the high-pulse velocities.

The distance from the ^{82}Br radiotracer injection point to the first detector was 5 m. The detector set and the computer remained switched on until the two-transit time of the radiotracer injected in the pipeline had been observed in the monitor. The data of the pulse counting rate in function of the time were simultaneously fed in archive ".dat".

The pipeline sections were of 166.0 cm^2 (tube diameter 7.3 cm) and 322.69 cm^2 (tube diameter 10.2 cm).

The liquid flow was determined as being:

$$\text{Flow} = \frac{\text{Detector Distance}}{\text{Transit Time}} \times \text{Section}$$

where detector distance was 34.5 m and transit time was determined using the pulse centroid by integration method [7].

3. Results and discussion

Fig. 3 shows the picture of the developed portable counter. The equipment filled the existing limitation, mainly in events of short duration, in high-speed flux processes. The lengths of the 30 m cables have two advantages: (a) allow the detectors to be apart up to 60 m, assuring the pulses not to overlap, in short transit events and (b) enables to cope with problems of physical pipeline distribution, among different rooms or floors, where the detectors should be placed. The developed software reads the analogic states of the parallel communication gate of the computer associated to a numerical result for each state set. This numerical value allows the program to identify the pulses and counts.

The efficiency and the detectable minimal activity for gamma ray from ^{82}Br were determined using the developed detectors, amplification units and signal processing. For application in this work, all interaction types were counted. Fig. 4(a) shows the absolute detection efficiency of the system as a function of the energy. The obtained efficiency values are good, considering the small volume of CsI(Tl) crystals of 2.5 cm^3. Fig. 4(b) shows the obtained counts as a function of the ^{82}Br activity, compared to that counted for background. From these results, the minimal detectable activity was determined as being 5.18 kBq.

The data acquisition system made possible to count pulses in the time range from 0.05 s to any value. The short time ranges are in particular recommended for high-speed flux processes in

Fig. 3. Picture of the portable counter, constituted of two CsI(Tl)–PIN photodiode detectors, amplification units and signal processing.

order to obtain well defined shape of the transit pulse. On the other hand, the measurements in short time range need more injected activity to obtain the same counting, implying in more exposition rate.

This problem is partially solved by an acquisition system that counts in the same temporal baseline, but in the separated temporal axis. This characteristic enables to use the pulse integration method in order to obtain the centroid of the transit time. The mathematical process of this method provides more identification sensitivity of the transit time centroid, as a consequence of lower injected activity [3,8].

Fig. 5 shows the pulse shapes observed in the pipeline section of 166.00 cm^2 (tube diameter 7.3 cm) and 322.69 cm^2 (diameter 10.2 cm) in a real situation in an industry. The distance from the radioatracer injection point to the first detector was of 5.0 m and the distance from the first detector to the second one was of 34.5 m for both measurements. As it can be observed, the detectors record the radiotracer passage clearly, in two different places of the pipeline.

The temporal distance between two detectors was determined by two methodologies: (a) the direct observation of the range between two peaks of the pulse and (b) the pulse centroid determined by the integration method. The liquid flow was determined using these results. Table 1 summarizes the comparative finding obtained by the two methodologies for both pipelines. As indicated in the table, the difference in the transit time value between the two methodologies was of 2.5% for a pipeline with 322.65 cm^2 section, while for a 166.0 cm^2 section pipeline was of 15.4%. The pulse centroid values obtained by the integration method are more exact because it finds the point where 50% of the radiotracer weight flows to the pipeline.

The peak found by observation of the largest counting is not necessarily the central point of the transit pulse. So, the integration method should be preferably used to obtain a more exact value. According to the values from Clayton tables [7], the precision of the pulse centroid method, using a tube with a diameter of 7.0–10 cm and a distance of 5.0 m from the radiotracer injection point to the first detector, is around 10%.

The values of the efficiency and minimal detectable activity obtained for the portable counter permitted to carry out the experiment in the real situation injecting 26×10^6 Bq in ^{82}Br. These results indicate that a radiotracer activity

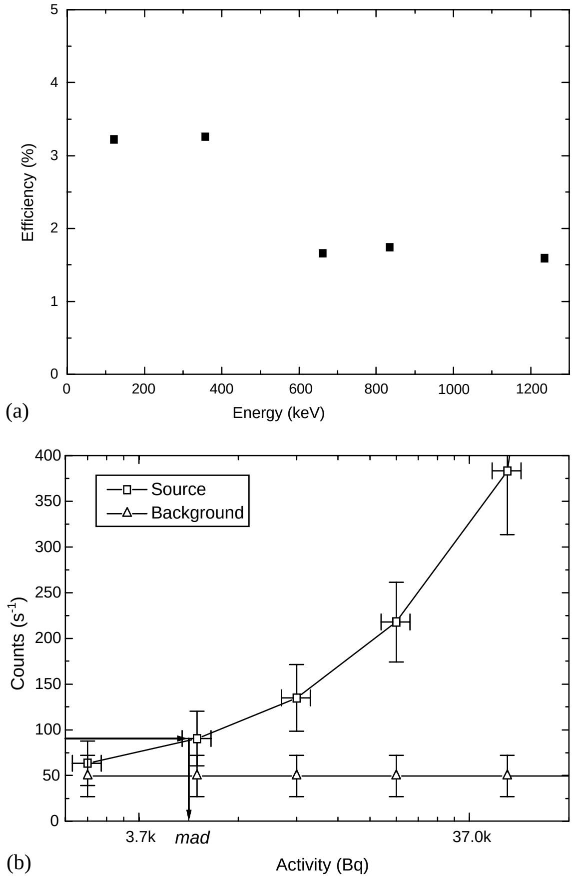

Fig. 4. Total absolute efficiency of the detector system as a function of the energy (a) and counts number obtained as a function of ^{82}Br activity (b).

four times lower could be used, which meets the purpose of minimizing problems with the workers and environmental exposition rate. In order to control the quantity of the radioactive material discharge in the sewage system, the safety standards for radioactive waste permit a discharge of a maximum activity of 3×10^8 Bq/m^3 for the ^{82}Br soluble in water. Admitting that the industry works 8 h per day and in the minimal flow, the charge of the 26×10^6 Bq injected radioisotope will discharge in the concentration of 86×10^3 Bq/m^3, which is a concentration of about a thousand times lower than the maximum permitted.

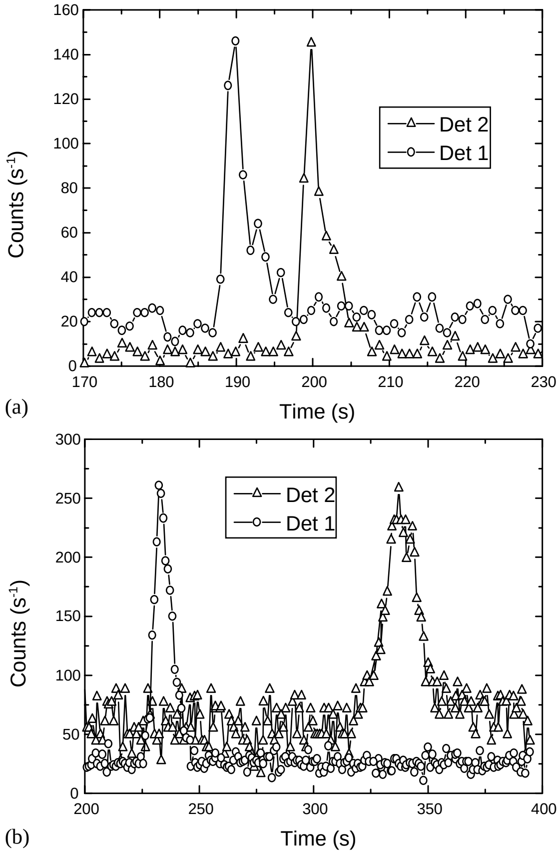

Fig. 5. Pulse observed in the pipeline of 166 cm^2 (a) and 322.69 cm^2 (b), by the transit time technique, using the developed portable counter and ^{82}Br radiotracer.

Table 1
Results of the liquid flux and transit time obtained by: (a) the observed peak value and (b) integration time in pipelines

Method	Section of the pipeline (cm^2)	Pulse 1 (s)	Pulse 2 (s)	Transit time (s)	Flux (l/s)
Peak value	322.69	233.4	337.2	103.8	10.7
Integration		235.2	341.7	106.5	10.5
Peak value	166.0	189.9	199.8	9.9	57.8
Integration		189.5	201.2	11.7	48.9

4. Conclusion

The equipment showed to be fully suitable for its application in the flow measurements. The total portability of the system showed it suitable for external experiments, with quality and quickness.

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