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Original Article

Diagnosing Plant Pipeline System Performance Using Radiotracer Techniques

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ABSTRACT

This study presents an experimental work in a petrochemical company for scanning a buried pipeline using Tc^{99m} radiotracer based on the measured velocity changes, in order to determine the flow reduction along a pipeline. In this work, Tc^{99m} radiotracer was injected into the pipeline and monitored by sodium iodide scintillation detectors located at several positions along the pipeline. The flow velocity has been calculated between every two consecutive detectors along the pipeline. Practically, six experiments have been carried out using two different data acquisition systems, each of them being connected to four detectors. During the fifth experiment, a bypass was discovered between the scanned pipeline and another buried parallel pipeline connected after the injection point. The results indicate that the bypass had a bad effect on the volumetric flow rate in the scanned pipeline.

1. Introduction

Radiotracers can be used for troubleshooting and solving several problems in several industrial applications [1–4]. The main advantages of using radiotracers in industrial applications are higher detection sensitivity, detection being carried out online, and the availability of many radiotracers that can be used in different phases [5]. Flow rate measurement is required for several purposes such as calibrating the installed flow meters, measuring the flow rate in systems that do not have flow meters, measuring the flow distribution in a network, or measuring the pump's efficiency [6]. Radiotracers can be used for flow velocity by injecting a radiotracer at the upstream of two detector locations, and then the peak time at the detector positions is determined. If t_1 and t_2 are the peak times of the tracer at the first and second detector positions, respectively, and L is the distance between the two detectors. The flow velocity V can be calculated as follows [7]:

$$V = L/(t_2 - t_1) \quad (1)$$

Radiotracers have been used for flow rate measurement of liquids, gases, and solids in many industrial processes. Previously, Hull [8] used a radiotracer for studying the flow pattern of materials in large units of industrial plant equipment such as moving bed pilot plant, catalytic cracking reactor, gas lift pipes for catalyst, baffles in the

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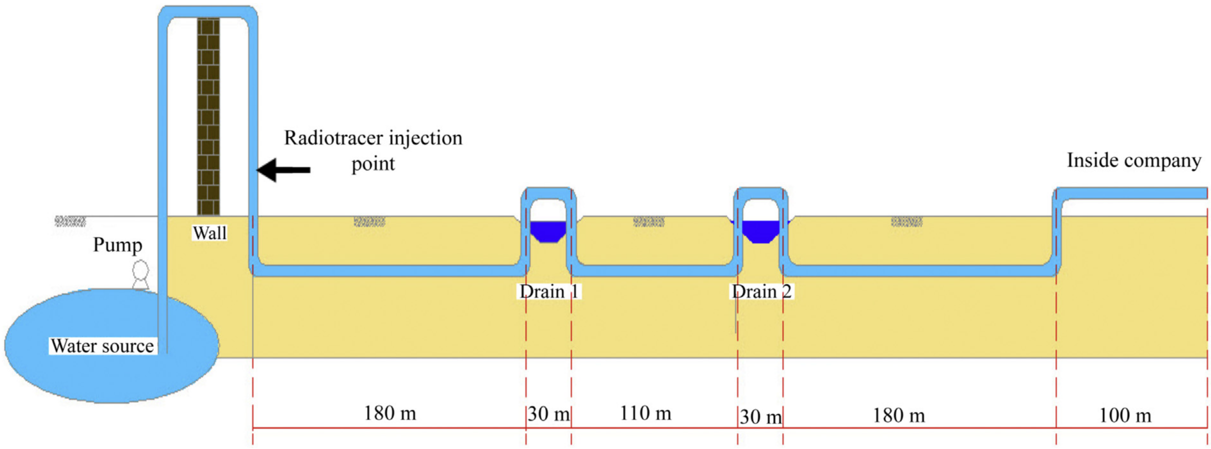

Fig. 1 – Layout description of the scanned pipeline.

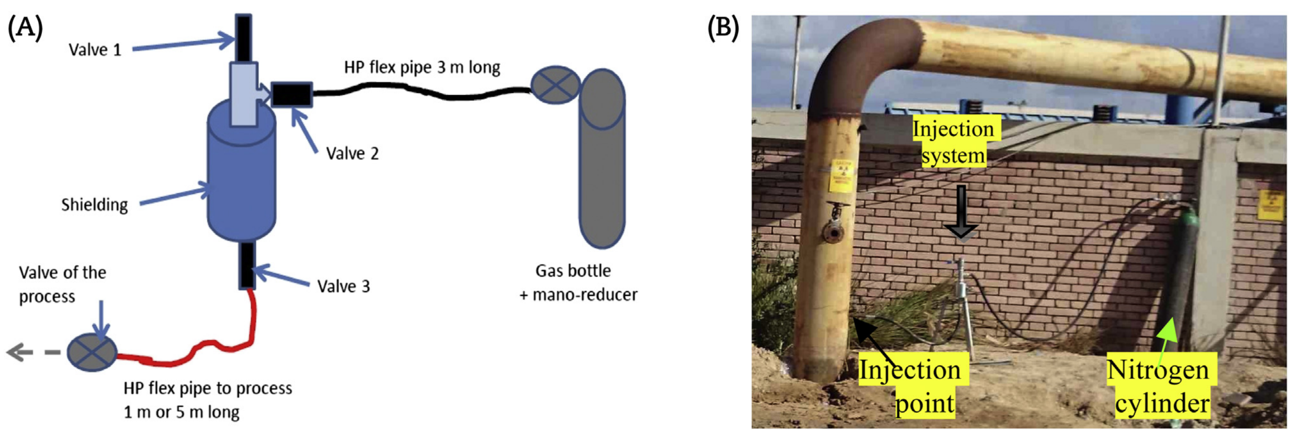

Fig. 2 – Radiotracer injection. (A) ALTIX injector model INJ-SWNB. (B) Injection process.

catalyst seal leg, and trays of the distillation column. The results show that the radiotracer can be used for measuring the uniform flow in the moving beds of solids, and malfunctioning of the moving bed processes can be diagnosed. Dunn and Gardner [9] utilized the dual tracer sphere technique for determining channel velocity and radius by measuring the velocities of two tracer spheres of different radii. The experiments indicate that the tracer sphere technique can be used for flow rate measurements with high relative accuracy.

Recently, Pant [10] used Co^{60} pellet for evaluating flow rates produced by two different propellers called PR-L and PR-R manufactured by two different companies and used in a draft tube crystallizer. The results proved that the flow rates produced by the propeller PR-L were higher than the propeller PR-R. Tugrul and Altınsoy [11] used Na^{24} for measuring the flow rate in open channel. The results showed that, the radiotracer can be used for flow rate measurement in the open channels under in situ conditions. Sugiharto et al. [12] used the I^{131} radiotracer for flow rate measurement in a multi-phase flow

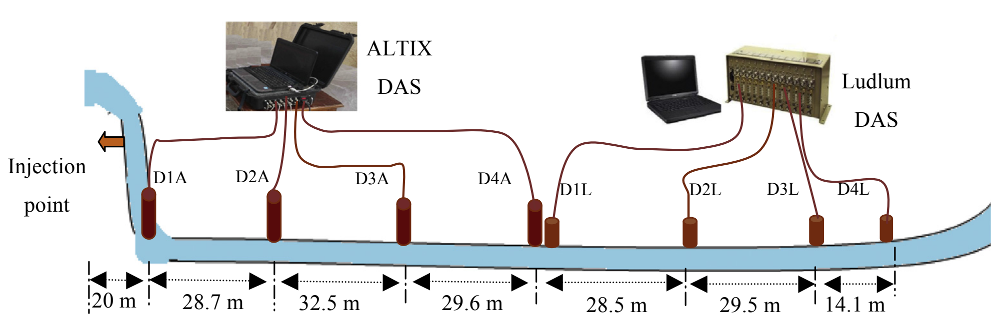

Fig. 3 – Configuration of the monitoring systems in the first experiment. DAS, data acquisition system.

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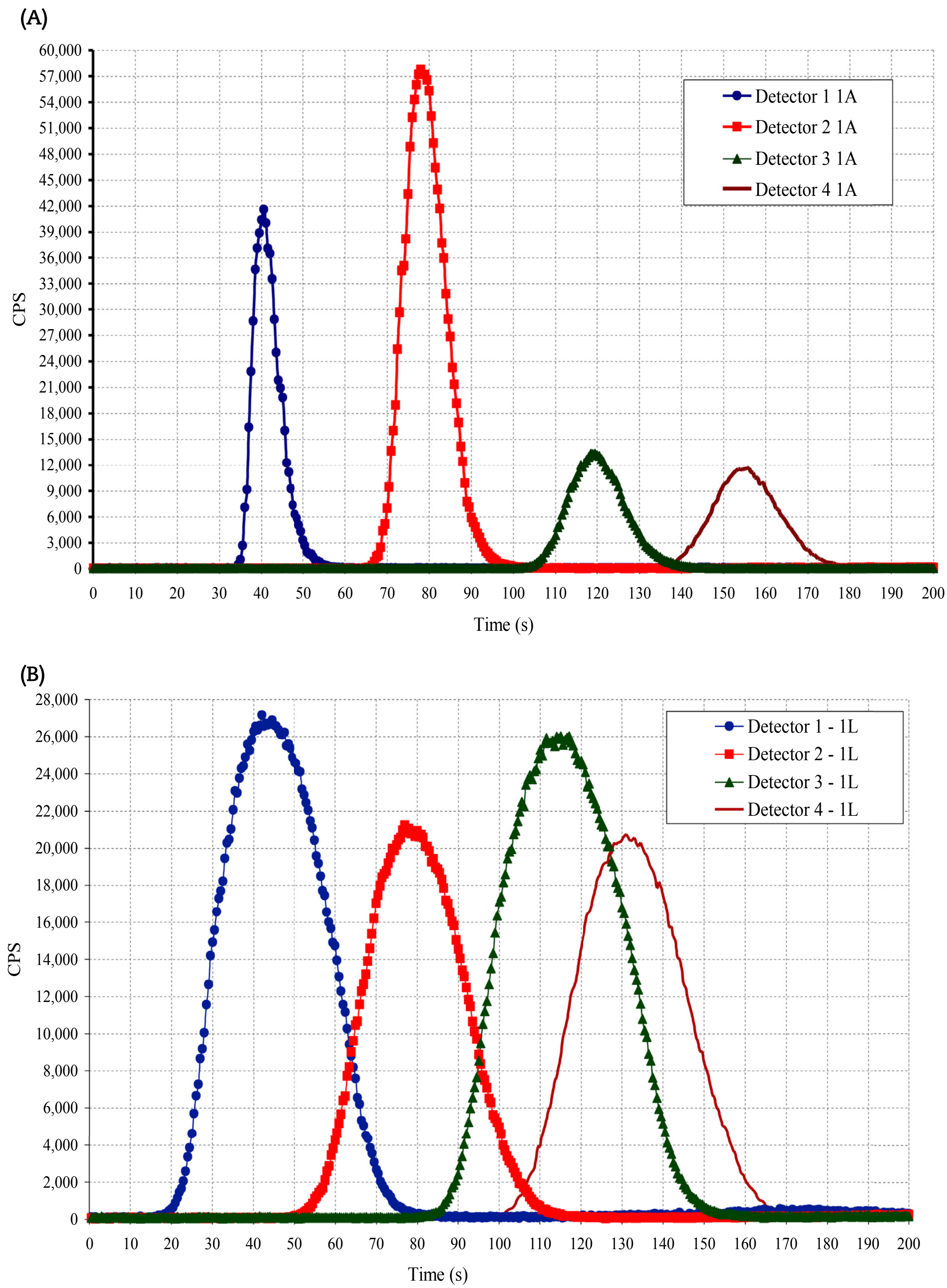

Fig. 4 – Data collected from the monitoring systems in the first experiment. (A) Data collected from ALTIX DAS. (B) Data collected from Ludlum DAS. CPS, counts per second; DAS, data acquisition system.

Table 1 – Velocities through the pipeline section of the first experiment.

DAS	Detectors	Distance between detectors (m)	Peak time at first detector (sec)	Peak time at second detector (sec)	Flow velocity (m/h)
ALTIX	D1A–D2A	28.7	40.5	78	2,755
	D2A–D3A	32.5	78	119.5	2,819
	D3A–D4A	29.6	119.5	155.5	2,996
Ludlum	D1L–D2L	28.5	44.5	77	3,156
	D2L–D3L	29.5	77	115	2,794
	D3L–D4L	14.1	115	131	3,172

DAS, data acquisition system.

24 inch diameter of hydrocarbon transport pipeline the flows are; crude oil and water. The results show that, the water flow is faster than the crude oil flow. Sugiharto et al. [13] described the measurement of a transfer function using radiotracer technique and implementation of the axial dispersion model to quantify the dispersion of water flowing in a pipe.

In this study, Tc^{99m} radiotracer has been used for determining the flow velocity along a water pipeline. The rest of the paper is organized as follows. Section 2 presents a description of the problem handled in this study. The investigated radiotracer experiments and the results are presented in Section 3. Section 4 presents the results and discussion. Finally, Section 5 gives the concluding remarks.

2. Problem description

A petrochemical company needs about 2,000 m^3/h of water daily for different industrial purposes during full-capacity operation. The company has two identical parallel water pipelines made of iron steel, each of them being 1,800 m in length, and having 16-inch diameter with wall thickness of 2–3 cm. The designed flow rate for each pipeline is 1,250 m^3/h. One of the two pipelines provides 1,100 m^3/h water; this is an acceptable amount for the company, and we named it "proper pipeline." The second pipeline provides only 650 m^3/h under the same operating conditions. This was a problem, so we named this pipeline "the scanned pipeline." A length of 550 m of each pipeline, from the water source till the entrance of the company, is outside the company. The rest of the pipeline is inside the company. It was found that the outside part of the pipeline (550 m) was an old pipeline that was used previously for waste petroleum disposal, while the rest of the pipeline inside the company was newly constructed.

Thus, the main problem in the pipeline lies outside the company, starting from the water source till the entrance of the company (550 m). Moreover, it is difficult to replace this part of the pipeline because it is mostly buried at a depth of 1.5–6 m, and it passes under several main roads and railways, making the cost of the pipeline replacement very high. Therefore, we thought of using the scanning method to determine the water flow rate through every part of the pipeline for detecting the cause of flow rate reduction. The pipeline outside the company, which was to be scanned, consists of five main sections; three of them are buried and two sections are passing over water drains, as shown in the layout description in Fig. 1.

The radiotracer technology offers a solution to measure the flow rate reduction by injecting a radiotracer at the inlet of the pipeline and placing the radiation detectors at different places along the pipe, and to calculate the water flow velocity between each two successive detectors to determine the changes of velocity along the pipeline.

3. Radiotracer experiment investigation

3.1. *Radiotracer preparation and injection*

As the medium in the pipe is liquid (water), a liquid tracer should be used. We considered using one of the following four radiotracers: iodine 131 (I^{131}), bromine 82 (Br^{82}), sodium 24 (Na^{24}), and technetium 99 (Tc^{99m}). Tc^{99m} was selected because it has a short half-life (about 6 h), and so it is safer than the other radiotracers and is also available commercially. A molybdenum–technetium

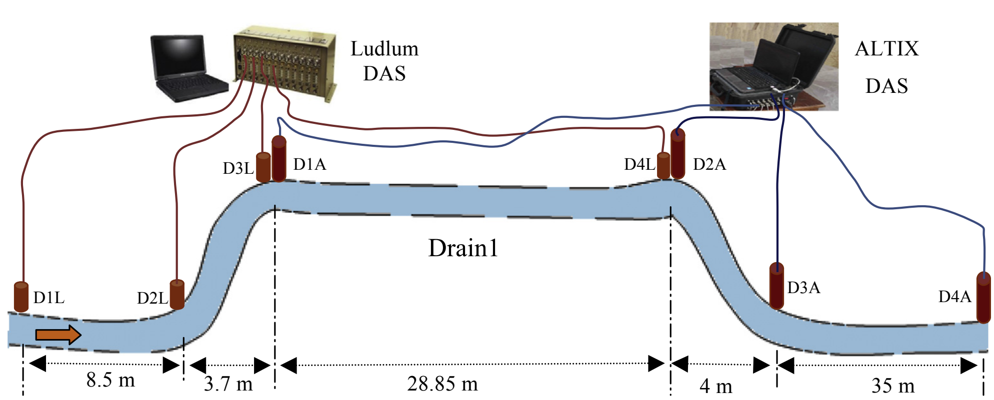

Fig. 5 – Configuration of the monitoring systems in the second experiment. DAS, data acquisition system.

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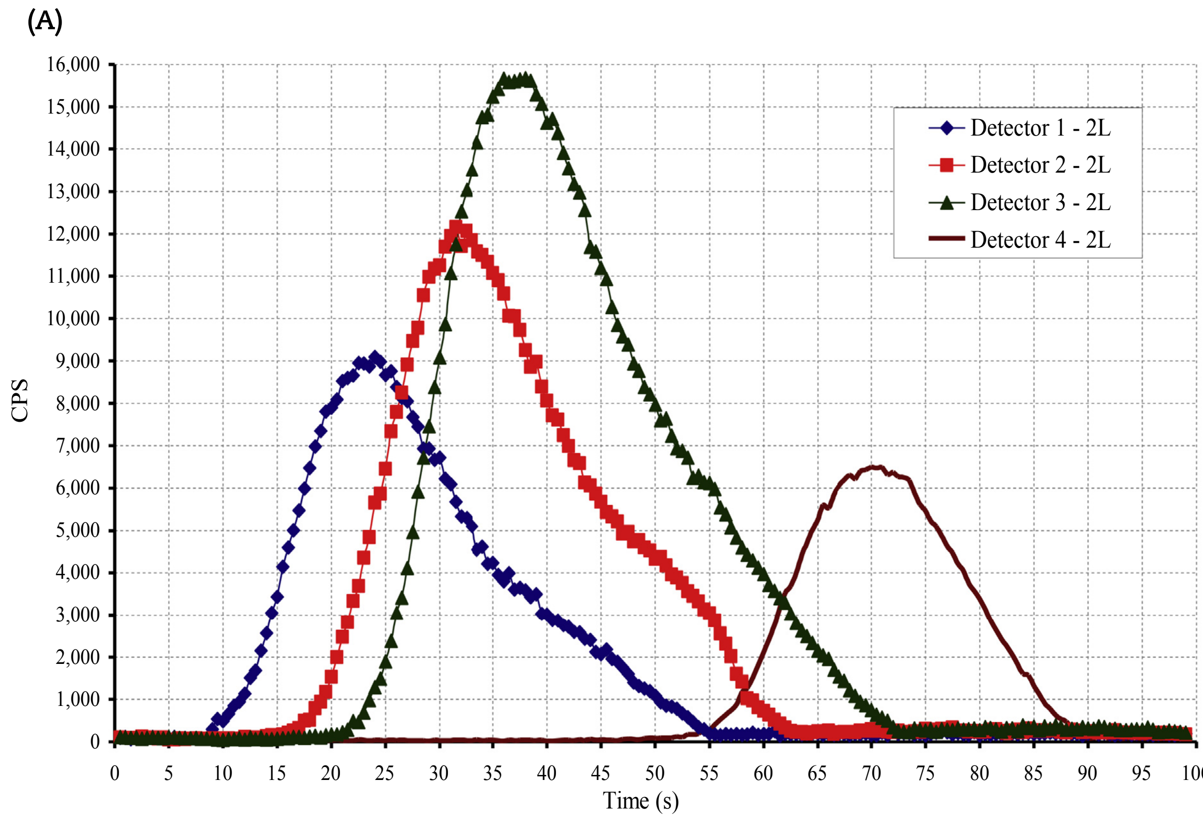

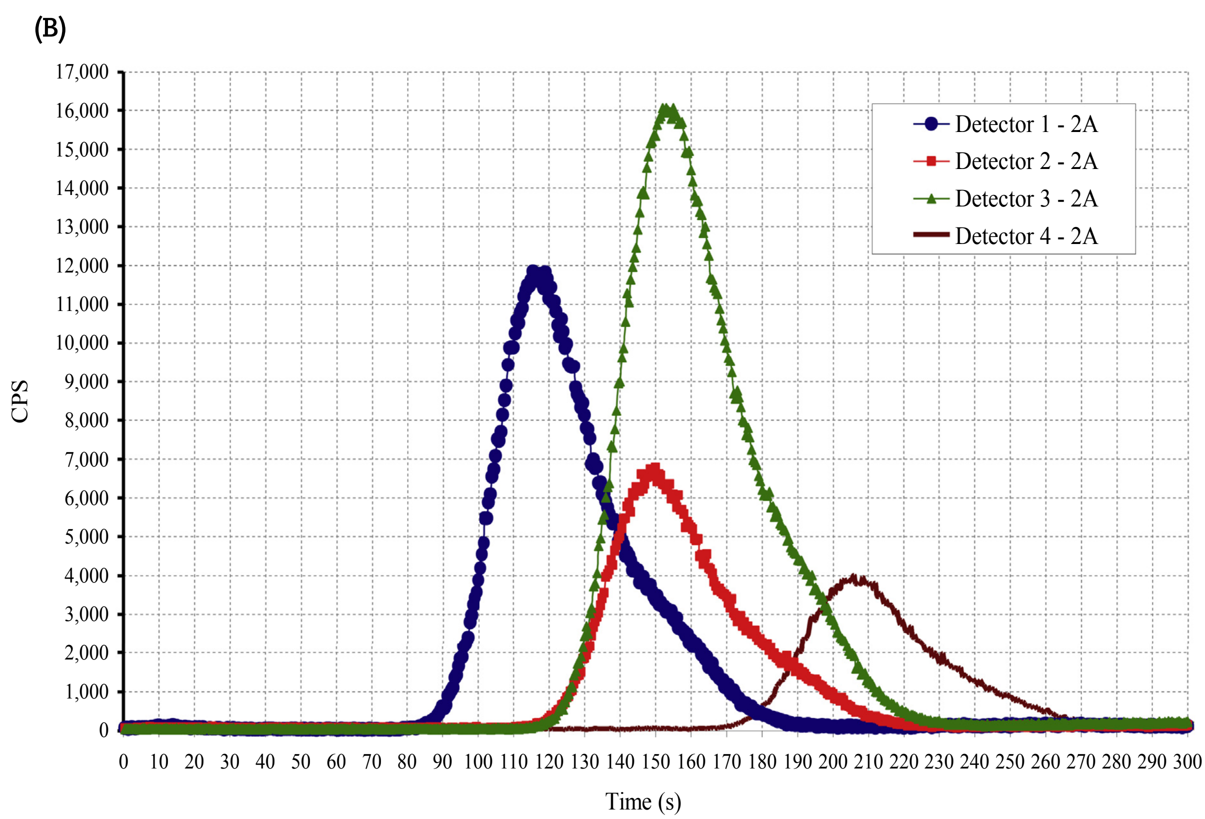

Fig. 6 – Data collected from the monitoring systems in the second experiment. (A) Data collected from Ludlum DAS. (B) Data collected from ALTIX DAS. CPS, counts per second; DAS, data acquisition system.

generator of 50 GBq was used as the Tc^{99m} radiotracer source. Six injections were prepared and used within 3 days. Tc^{99m} was eluted, and the radioactive material was prepared at the site according to need. Tc^{99m} was injected very quickly (as an impulse function) to have a narrow signal of the sharp peak to ensure that it did not have any effect on the steady flow of the scanned pipeline during mathematical calculations.

To ensure the steady flow of the system, the injection point was selected at the earliest possible point after the pump and after the wall, as shown in the layout in Fig. 1. The pressure after the pump is high (4.2 bar), and so a high pressure injector system that was designed by ALTIX Company (injector model INJ-SWNB), as shown in Fig. 2A, was used. One side of the injector was connected to a nitrogen cylinder (pressure, 10 bar) through Valve 2, and the other side was connected to the scanned pipeline at the injection point through Valve 3, as shown in Fig. 2B. The radiotracer was placed inside the injector, and then the pressure in the nitrogen cylinder was increased to 10 bar. After that the injector valve, which was connected with the pipeline opened, so the radiotracer was able to shoot into the pipe.

3.2. *Radiotracer monitoring*

To monitor and record the radiotracer along the pipeline, two different data acquisition systems (DASs) have been used, with each one being connected to four detectors. The first DAS is a 12-channel ALTIX module running CAESAR 12 software designed by ALTIX Company, which was used to collect the signals from sodium iodide scintillation detectors connected to it via coaxial cables. The second DAS is a 12-channel Ludlum Model 4612 DAS running MIDASII data acquisition software, which was used to collect the signals from sodium iodide scintillation detectors connected to it via coaxial cables. These detectors were fixed firmly to touch the surface of the scanned pipeline after cleaning and polishing the surface.

3.3. *Experimental investigation*

Experiments were carried out using six different injections with different activities, as will be discussed below. In the first three injections, two DASs with eight detectors were used, so six sections were covered during each injection of this stage. In the last three injections, only the ALTIX DAS with four detectors was used, as the Ludlum DAS was shut off. All the measurements covered 650 m of the pipe.

3.3.1. *First experiment*

The first-generator elution was 1,500 mCi (55.5 GBq). The first experiment was conducted by injecting 750 mCi (27.75 GBq) into the scanned pipeline. Through this experiment, the first 180 m of the pipeline (after the injection point) was scanned; detector positions are shown in Fig. 3. The scanned pipeline is totally buried in this section, so a hole in the land surface was prepared to allocate scintillation detectors. The first detector was placed after 20 m from the injection point, to ensure and maintain complete mixing of radiotracer with the medium inside the scanned pipeline. The following seven detectors were placed in sequence. The results obtained from the two monitoring systems (counts per second (CPS) versus time) are shown in Fig. 4. Table 1 shows the calculated velocities across the scanned section during the first experiment.

Fig. 4A shows the signal measured by ALTIX DAS, and Fig. 4B shows the signal measured by Ludlum DAS. For each DAS, the four signals are measured by four sodium iodide scintillation detectors. The results show that there is no significant difference in flow velocity along this section of the scanned pipeline.

Table 2 – Velocities through the pipeline section of the second experiment.

DAS	Detectors	Distance between detectors (m)	Peak time at first detector (sec)	Peak time at second detector (sec)	Flow velocity (m/h)
Ludlum	D1L–D2L	8.5	24	31.5	4,080
	D2L–D3L	3.7	31.5	38	2,065
	D3L–D4L	28.85	37	70	3,147
ALTIX	D1A–D2A	28.85	117	150	3,147
	D2A–D3A	4	150	153	4,800
	D3A–D4A	35	153	206	2,377

DAS, data acquisition system.

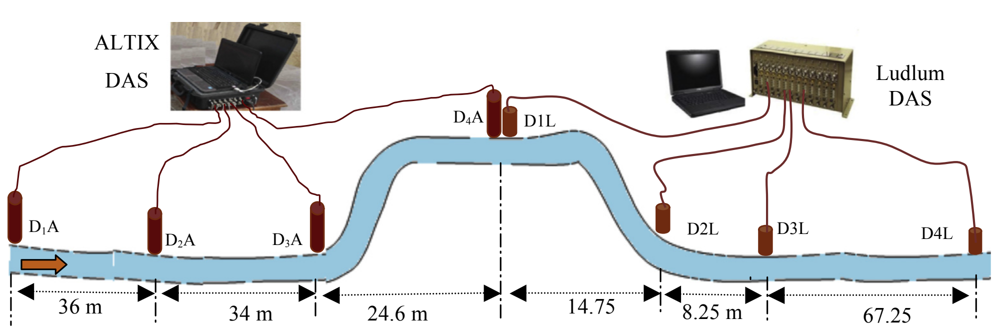

Fig. 7 – Configuration of the monitoring systems in the third experiment. DAS, data acquisition system.

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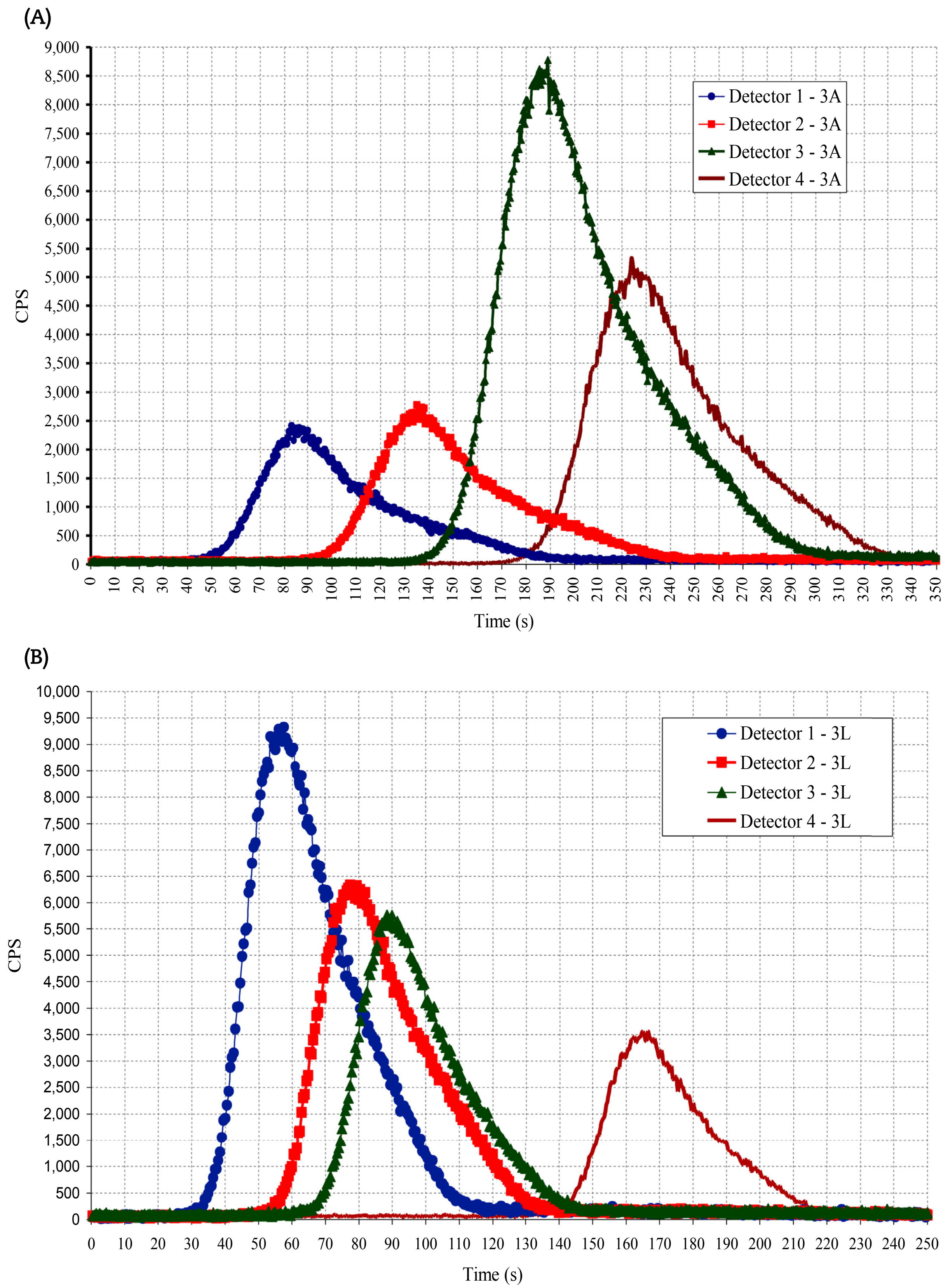

Fig. 8 – Data collected from the monitoring systems in the third experiment. (A) Data collected from ALTIX DAS. (B) Data collected from Ludlum DAS. CPS, counts per second; DAS, data acquisition system.

Table 3 – Velocities through the pipeline section of the third experiment.

DAS	Detectors	Distance between detectors (m)	Peak time at first detector (sec)	Peak time at second detector (sec)	Flow velocity (m/h)
ALTIX	D1A–D2A	36	83	135	2,492
	D2A–D3A	34	135	189	2,266
	D3A–D4A	24.6	189	224	2,530
Ludlum	D1L–D2L	14.75	57.5	77.5	2,655
	D2L–D3L	8.25	77.5	88.5	2,700
	D3L–D4L	25.45	88.5	165	1,198

DAS, data acquisition system.

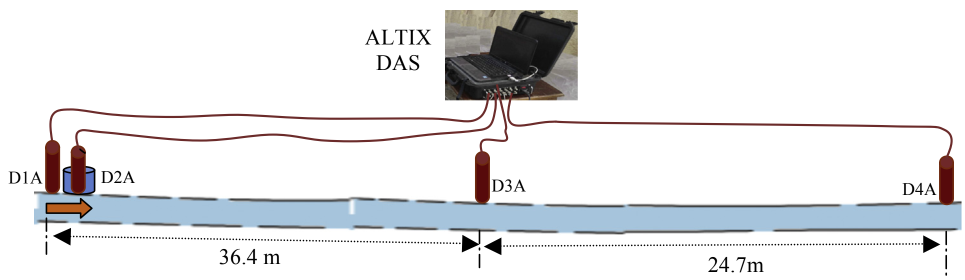

Fig. 9 – Configuration of the monitoring system in the fourth experiment. DAS, data acquisition system.

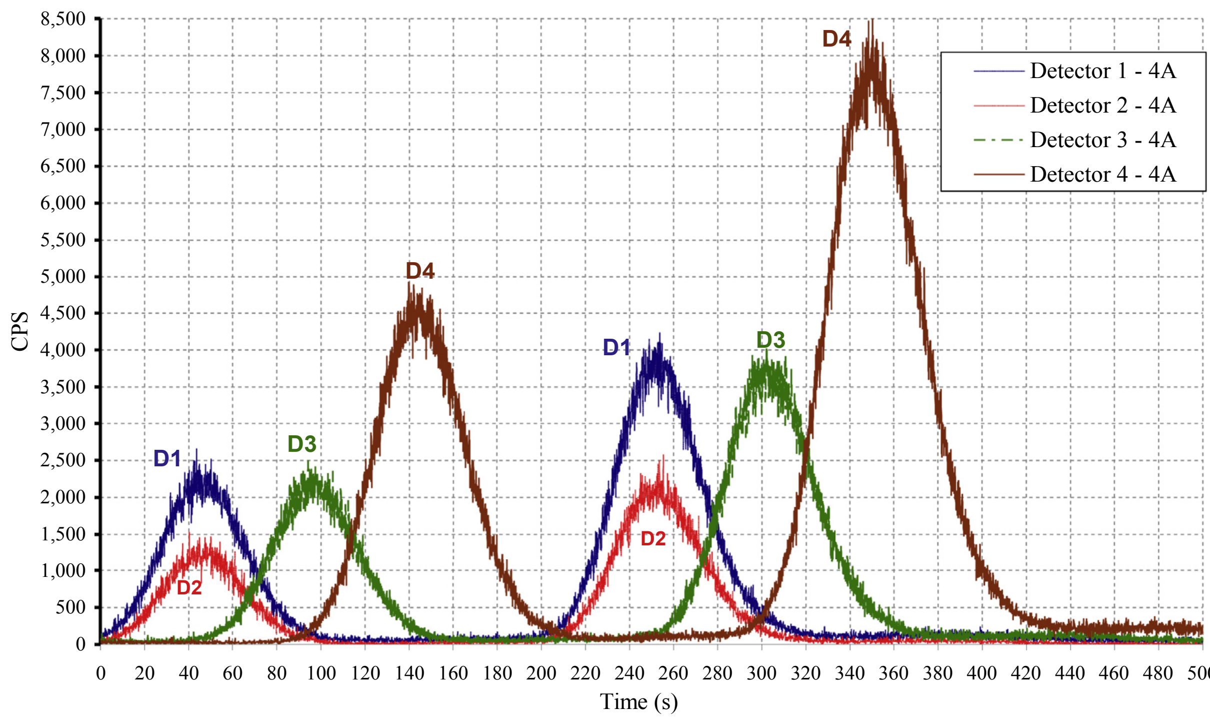

Fig. 10 – Data collected from the monitoring systems in the fourth experiment. CPS, counts per second.

3.3.2. *Second experiment*

The second generator elution was 1,300 mCi (48.1 GBq). The second experiment was conducted by injecting 650 mCi (24.05 GBq) into the pipeline. In this experiment, the pipe over Drain 1 and 35 m after it (which was buried 6 m deep) were scanned, as shown in Fig. 5. The flow velocity over Drain 1 was calculated twice using two monitoring systems to compare the efficiency of calculations between the two systems. The result was identical.

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The results of this stage are shown in Fig. 6. Table 2 shows the velocities calculated during the second experiment.

3.3.3. *Third experiment*

The third experiment was performed by injecting 600 mCi (22.2 GBq) into the pipeline. Through this experiment, the pipe over Drain 2, 70 m before it, and 75 m after it were scanned; the detectors positions are shown in Fig. 7. The results obtained from the two monitoring systems are shown in Fig. 8. Table 3 shows the calculated velocities through the pipeline section scanned during the third experiment.

3.3.4. *Fourth experiment*

In this experiment, the generator elution was 450 mCi (16.65 GBq). The fourth experiment was performed by

Table 4 – Velocities through the pipeline section of the fourth experiment.

DAS	Detectors	Distance between detectors (m)	Peak time at first detector (sec)	Peak time at second detector (sec)	Flow velocity (m/h)
ALTIX	D1A (D2A)–D3A	36.4	47.8	95.6	2,741
	D3A–D4A	24.7	95.6	142	1,912

DAS, data acquisition system.

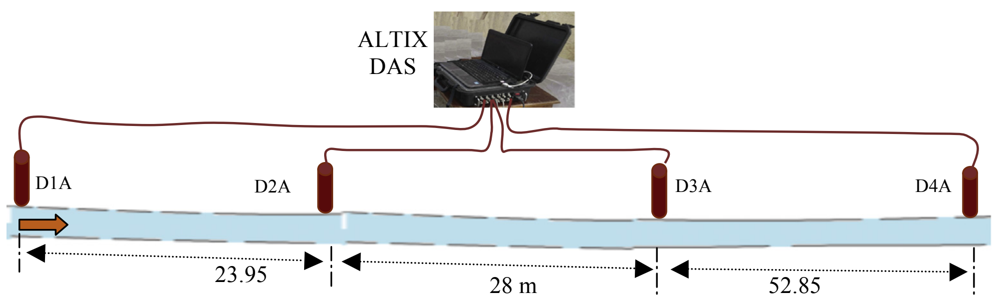

Fig. 11 – Configuration of the monitoring system in the fifth experiment. DAS, data acquisition system.

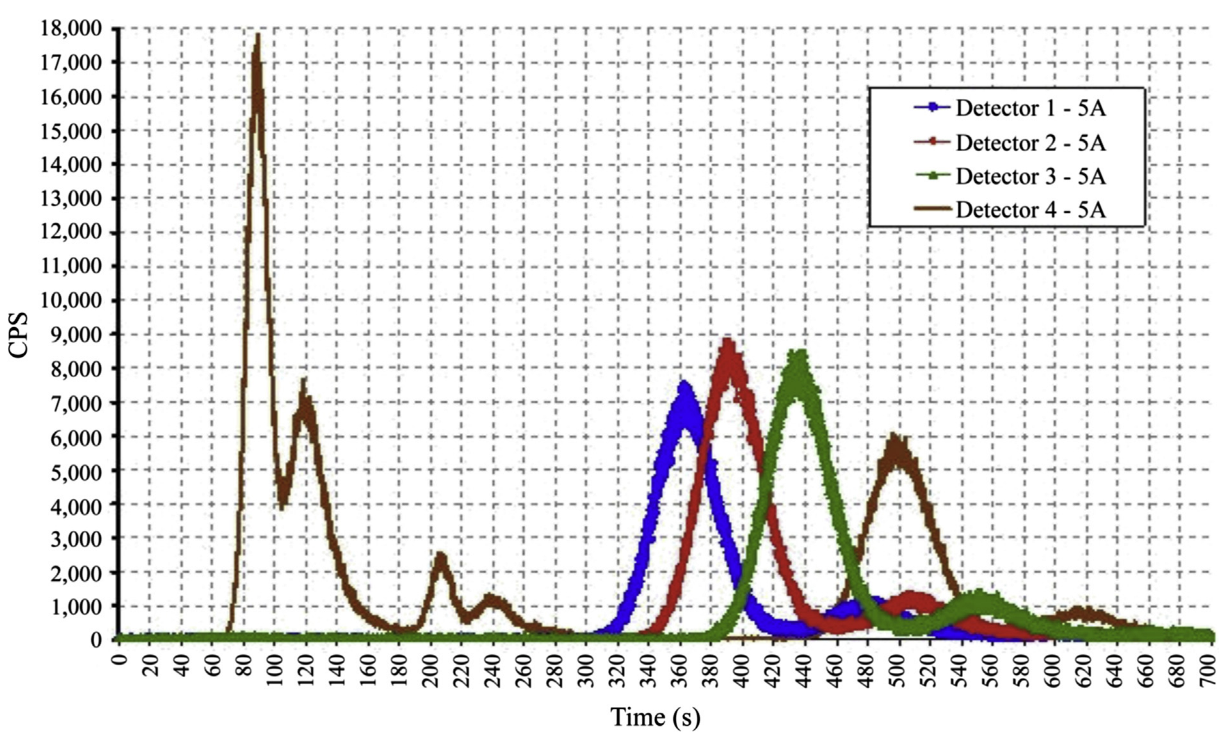

Fig. 12 – Data collected from the monitoring systems in the fifth experiment. CPS, counts per second.

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injecting 400 mCi (14.8 GBq) into the pipeline in two fast injections consecutively. Due to logistics, as the main road and a railway pass over this section, only three holes have been drilled in this section. We placed two detectors at the same position, but one of them was shielded to evaluate the effect of the shield on the measurement. Detector positions are shown in Fig. 9. The results obtained from the monitoring system are shown in Fig. 10. The duplication in the curve was due to the second pulse of nitrogen to the injector, which allowed the leftover tracer to be able to be pushed in the pipeline. Table 4 shows the calculated velocities through the pipeline section scanned during the fourth experiment.

3.3.5. *Fifth experiment*

In this experiment, the generator elution was 350 mCi (12.95 GBq). The fifth experiment was conducted by injecting 300 mCi (11.1 GBq) into the pipeline. Through this experiment about 100 m of the pipe inside the company was scanned, as shown in Fig. 11. The results obtained from the monitoring system are shown in Fig. 12. Table 5 shows the calculated velocities through the pipeline section scanned during the fifth experiment.

Prior to beginning the work, it was supposed that the scanned pipeline was completely isolated from the second pipeline (proper) or any other pipelines during the work, especially before the injection point. However, surprisingly, a bypass was discovered by analyzing the results, where Detector 4 recorded a radiotracer signal before Detectors 1, 2, and 3 and then it recorded the signal again in normal sequence, as shown in Fig. 12. The tracer traveled two paths: one is direct through the scanned pipeline (slow speed because the scanned pipeline had a problem) and the other is indirect, but fast, through the proper pipeline so that it arrived quickly at D4 that was located after the bypass inside the company; the tracer then arrived at the four detectors by the direct pass through the scanned pipeline, as shown in Fig. 13.

It was found that the pipeline under investigation was connected to the second parallel pipeline after the direct injection point and the bypass inside the company was opened, so we found the bypass. Since the second pipeline worked efficiently, the water flow velocity was faster than in the scanned pipeline. This bypass had a bad effect on the volumetric flow rate in the scanned pipeline.

Table 5 – Velocities through the pipeline section of the fifth experiment.

DAS	Detectors	Distance between detectors (m)	Peak time at first detector (sec)	Peak time at second detector (sec)	Flow velocity (m/h)
ALTIX	D1A–D2A	23.95	362.3	390.6	3,046
	D2A–D3A	28	390.6	431.4	2,470
	D3A–D4A	52.85	431.4	500	2,773

DAS, data acquisition system.

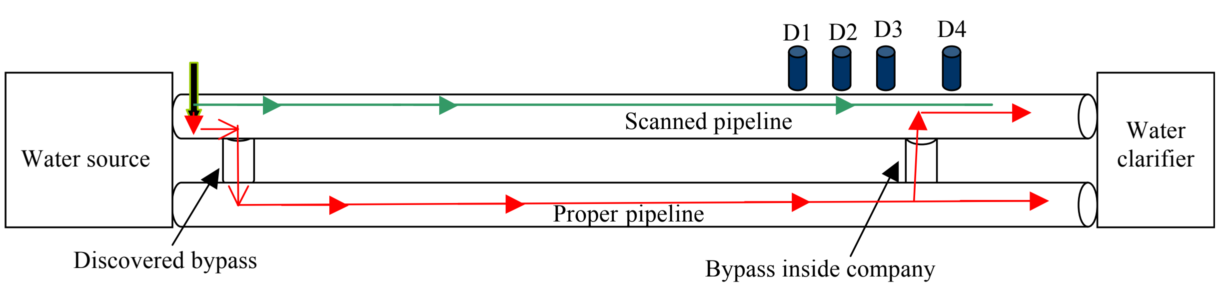

Fig. 13 – Radiotracer paths in the fifth experiment.

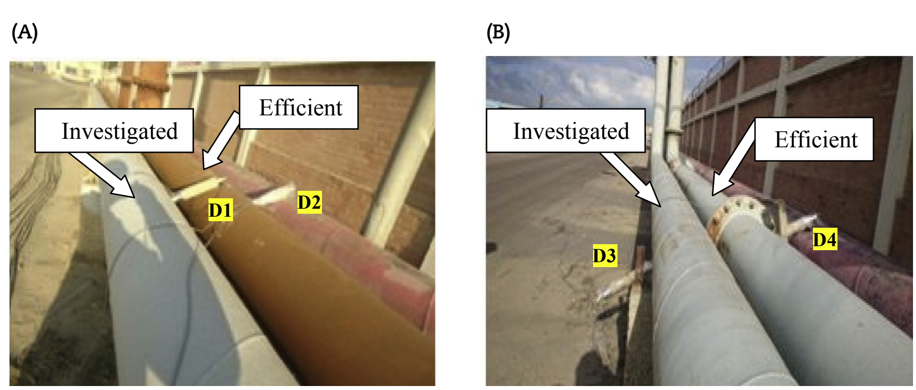

Fig. 14 – Flow rate comparison of the two pipelines. (A) Detectors 1 and 2. (B) Detectors 3 and 4.

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3.3.6. *Sixth experiment*

The last experiment was carried out for measuring and comparing the flow rate of the two connected pipelines. This experiment was carried out by setting two detectors on each pipeline. The distance between the two detectors was 100 m, as shown in Fig. 14. This experiment was carried out by injecting 400 mCi (14.8 GBq) into the pipeline. The results obtained from the monitoring system are shown in Fig. 15. From the above configuration and results, the velocity through this section could be calculated, and by using the pipe cross-section area, the flow rate was calculated for the two pipes, as shown in Table 6.

4. Results and discussion

The main task of the work is determining the flow rate reduction along the scanned pipeline. The velocity diagram along 650 m of the pipeline versus its length was constructed as shown in Fig. 16. From the velocity diagram, we observe that the approximate average value of water velocity of the pipeline was 3,000 m/h. However, we have two significant points on the velocity diagram at lengths of 190 m and 230 m from the injection point, where the velocities were 4,090 m/h and 4,830 m/h, respectively. From these two peaks of water velocity, we may conclude that the inner diameter of the scanned pipeline was narrower at these two points. In addition, the unsteady velocity along the 650 m showed that the inner diameter of the scanned pipeline was not constant.

During collecting data from the monitoring systems in the fifth experiment we observed that Detector 4 recorded a signal before Detectors 1, 2, and 3, and then it recorded the signal again in normal sequence. We concluded that a bypass existed between the two pipelines after the injection point, as we were sure of that. The second pipeline worked efficiently, so that Detector 4 could read before Detectors 1, 2, and 3. The bypass had a bad effect on the volumetric flow rate in the scanned pipeline and it decreased the flow to 39%.

According to the water flow rate comparison between the two pipelines inside the company, we found the following:

- The water velocity in the proper pipeline is 5,661 m/h, while that in the scanned pipeline is 3,455 m/h.
- The water flow rate in the proper pipeline is 734.467 m^3/h, while that in the scanned pipeline is 448.258 m^3/h.
- The pump actual rate is 1,182.725 m^3/h passes over the two pipelines where 61% passes through the proper pipeline and 39% passes through the scanned pipeline.

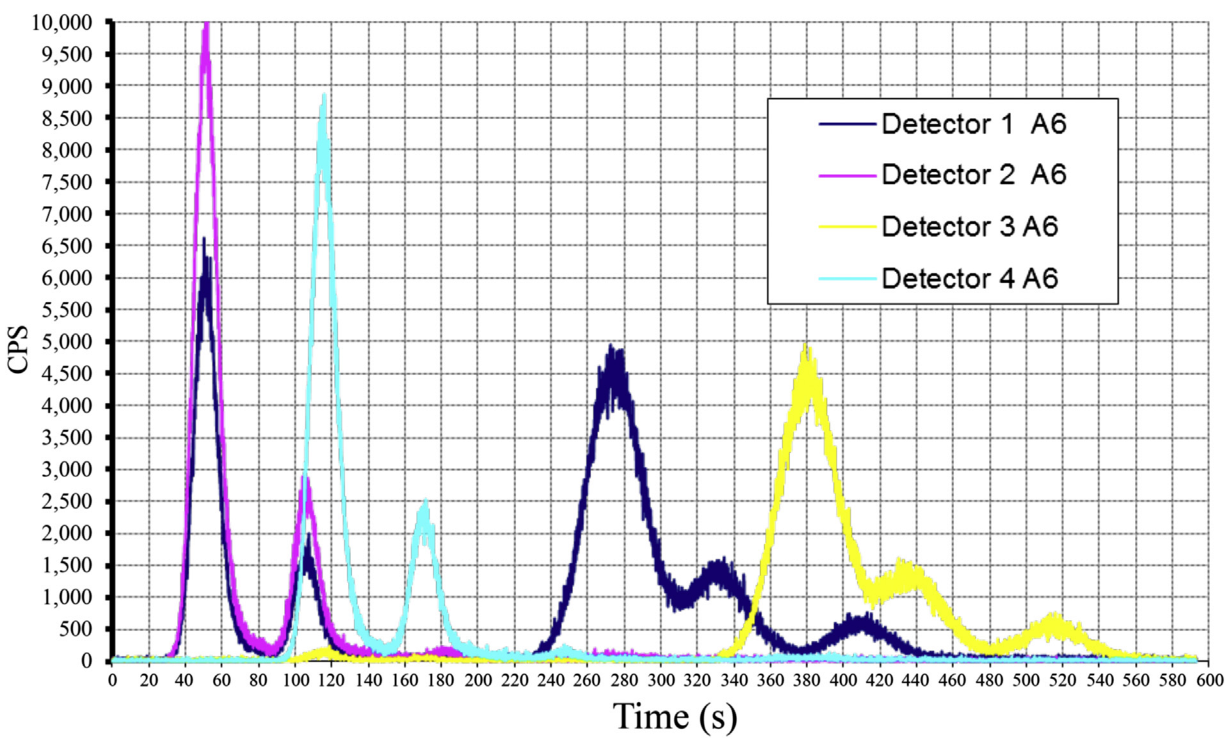

Fig. 15 – Flow rate comparison results. CPS, counts per second.

Table 6 – Velocity and flow rate comparison between the two pipelines.

Pipeline	Detectors	Peak time at first detector (sec)	Peak time at second detector (sec)	Flow velocity (m/h)	Flow rate (m^3/h)
Scanned	D1–D3	274.1	3,788	3,455	448.258
Proper	D2–D4	52	115.9	5,661	734.467

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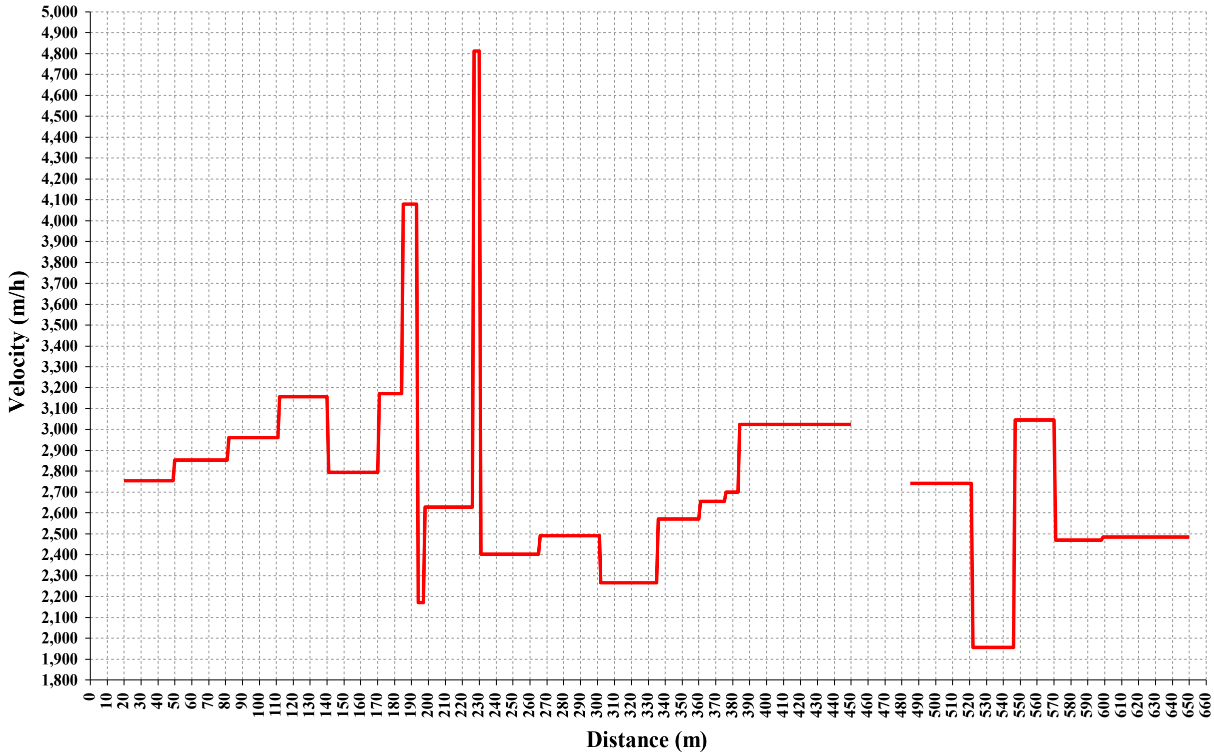

Fig. 16 – Velocity through the scanned pipeline.

5. Conclusion

This paper presented an experimental work for the determination of flow rate reduction in a buried pipeline using Tc^{99m} radiotracer applying the velocity change method. In this method, a radiotracer pulse was injected into the pipeline and monitored by gamma ray detectors located in holes dug in the pipeline. The velocity of the radiotracer pulse in each section was calculated. The velocity drop in any section determined the locations of the changing in velocity. The results showed that a bypass existed after the injection point between the scanned pipeline and another parallel pipeline; this bypass had a bad effect on the volumetric flow rate in the scanned pipeline.

Conflicts of interest

All authors have no conflicts of interest to declare.

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