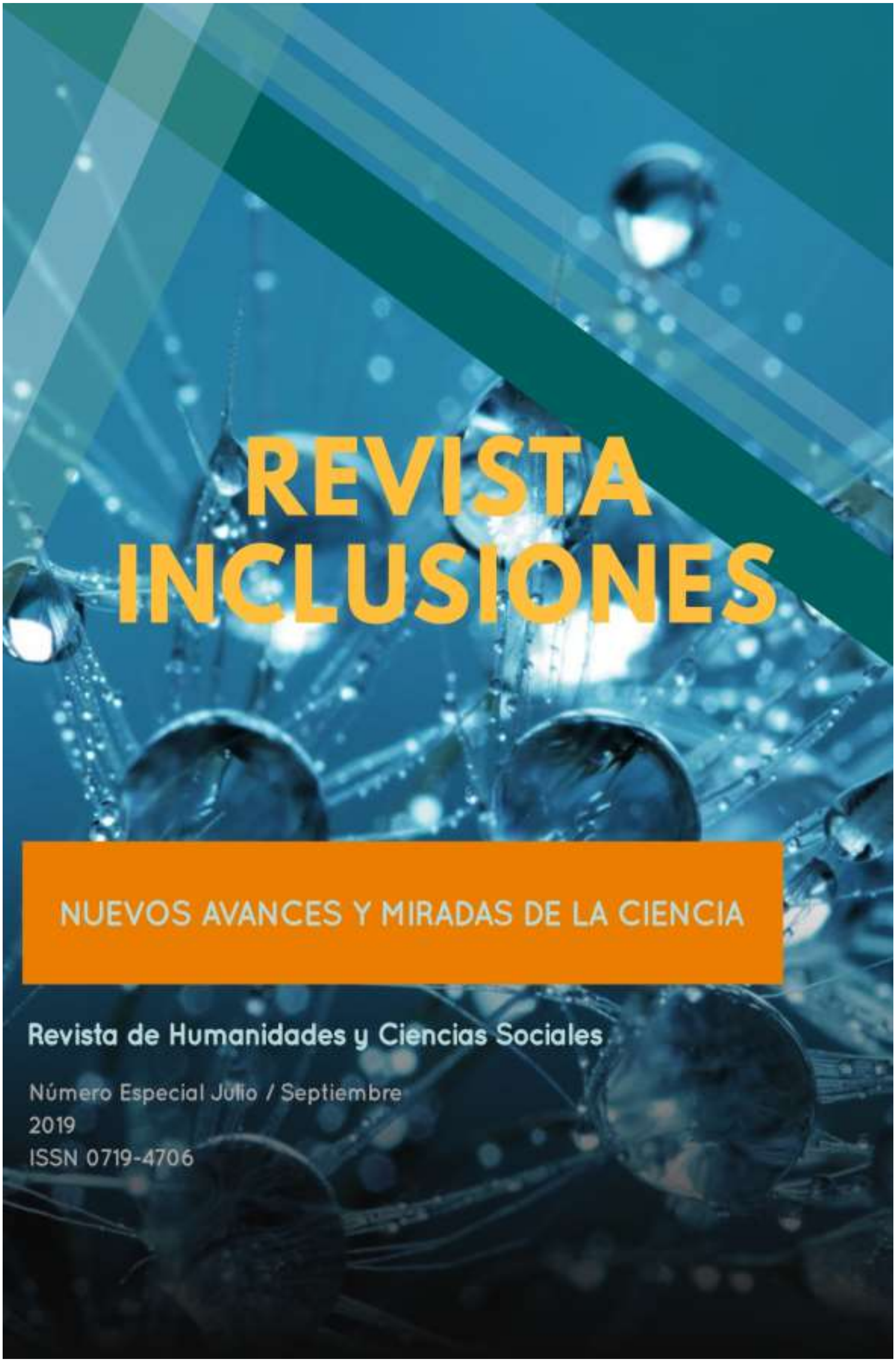
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DETERMINATION OF LEAKS IN THE MAIN: PIPELINE BY "PRESSURE WAVE"

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Abstract

This paper describes a method for determining the coordinates of leakage and mass flow, based on the change in pressure over time in the cross-section of the linear part of the main pipeline. Two possible cases of pressure drop are considered: with constant pressure at the end of the pipeline and with a changing pressure at the end of the pipeline. Based on a mathematical model describing the flow of a fluid in a pipeline with leakage, as well as using the Fourier transform, parameters of the oil product and the pipeline, calculation formulas were obtained to determine the parameters of the leakage from the pipeline.

Keywords

Leakage – Main pipeline – Pressure sensor – Leakage control – Pressure wave

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Introduction

The main reason for the leakage of the main pipelines is long service life. Most of the pipelines have a life of more than 20 years. As they age, they begin to fail, there are leaks in structurally weak joints, corrosion points in areas with slight structural damage to the material. Leaks can occur through seals in pumps and valves. Also important is the problem of unauthorized tie-ins to the linear part of the pipeline to steal oil products[1]. The main task of leak detection systems (SDAs) is to identify the fact of a leak and determine its location. The LDS provides for the generation of an alarm signal about the possible presence of a leak and the display of information that helps to decide on the presence or absence of leaks.

Pipeline leak detection systems are of great importance for pipelines operation, as they allow to reduce pipeline downtime[2].

Detection of leaks from the pipeline is a rather complicated technical task, the solution of which requires special equipment and a professional approach. The appearance of even the smallest leakage may indirectly cause another, more serious accident, such as an explosion of released gas, as well as a pipeline rupture, which increases repair costs. It follows that it is economically advantageous to detect leaks at an early stage of their appearance[3]. In this paper, a mathematical model for a method for detecting leaks from a pressure wave and checking the applicability of this model in a short section of the main pipeline.

Methods

The method of negative pressure waves (estimated parameter) is based on the phenomenon of a discharge wave at the moment of leakage. Discharge waves propagate on both sides of the leak and are recorded by the equipment. The accuracy of the method strongly depends on the hydrodynamic noise in the pipeline, on the magnitude of the leak. Also, when the flow discontinuity or the presence of gas bubbles, the velocity of propagation of the pressure of the vacuum pressure wave decreases, as a result of which the signal will be blocked or will carry inaccurate information. All existing parametric SOU is not without drawbacks. Taking into account modern safety requirements, the use of only parametric SOU by companies involved in the transportation of oil, gas and petroleum products is insufficient. Accordingly, the main requirement for the LDS is its accuracy, provided by an integrated approach, i.e. using a group of leak detection methods based on various physical principles, both methods of periodic and continuous monitoring.

The pressure wave method is based on the analysis of transient processes in pipelines in the event of a leak. At the time of occurrence of leakage of fluid in the pipeline, there are discharging waves, propagating to the ends of the pipeline with the speed of sound. Pressure sensors installed at the ends of the pipeline, record the time of arrival of the pressure wave. The use of double pressure

[1] A. F. Bulatov and A. G. Lyutov, Bulletin USATU (Ufa: USATU, 2013).
[2] A. S. Volkov; I. E. Volkova and P. A. Zemskov, “Proceedings of NSTU. R. bE. Alekseeva”, N. Novgorod Vol: 5 num 107 (2014): 166-170.
[3] V. A. Belyaeva, Oil and gas construction. Under total (Moscú: OMEGA-L., 2008).

sensors at the ends of the diagnosed section of the pipeline allows determining the direction of the pressure wave and ignoring those detected pressure waves that came from outside the protected area of the section. The implementation of the method is divided into two parts. The first part of the method is performed in the controller, ensuring that the pipeline pressure is monitored in real time. The second part, at the top level of the system, provides an analysis of the recorded pressure waves for leaks. This distinction has reduced the load on the data transmission channel and save server resources. The computational procedure processes the results of the incoming information, taking into account: the sequence of incoming signals, the distance between the pressure sensors, the speed of propagation of sound waves, etc. The difference (t1-t2) of the moments of arrival of the waves indicates the displacement of the place of leakage relative to the middle of the considered section[4]. It is assumed that the oil pipeline between oil pumping stations is a straight-line segment of equal diameter, filled with liquid, without additional inserts and outlets. The length of the pipeline with fixed coordinates are two pressure sensors at a certain height.

Figure 1 shows a schematic of a method for monitoring leaks in a section of a trunk pipeline.

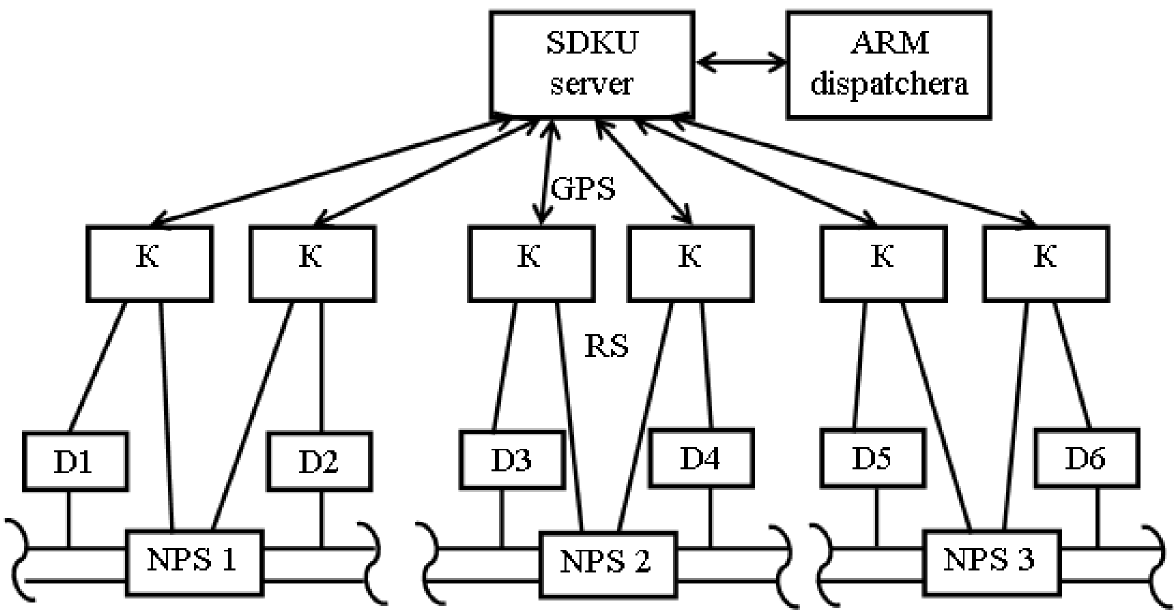

Fig. 1
Leak detection circuit

To solve this problem of leak detection, two possible cases of pressure drop were considered: with constant pressure at the end of the pipeline (Figure 2), with varying pressure at the end of the pipeline (Figure 3).

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[4] S. E. Kutukov, "The problem of increasing the sensitivity, reliability, and speed of leak detection systems in pipelines". Oil and Gas Business Vol: 2 (2004): 29-45.

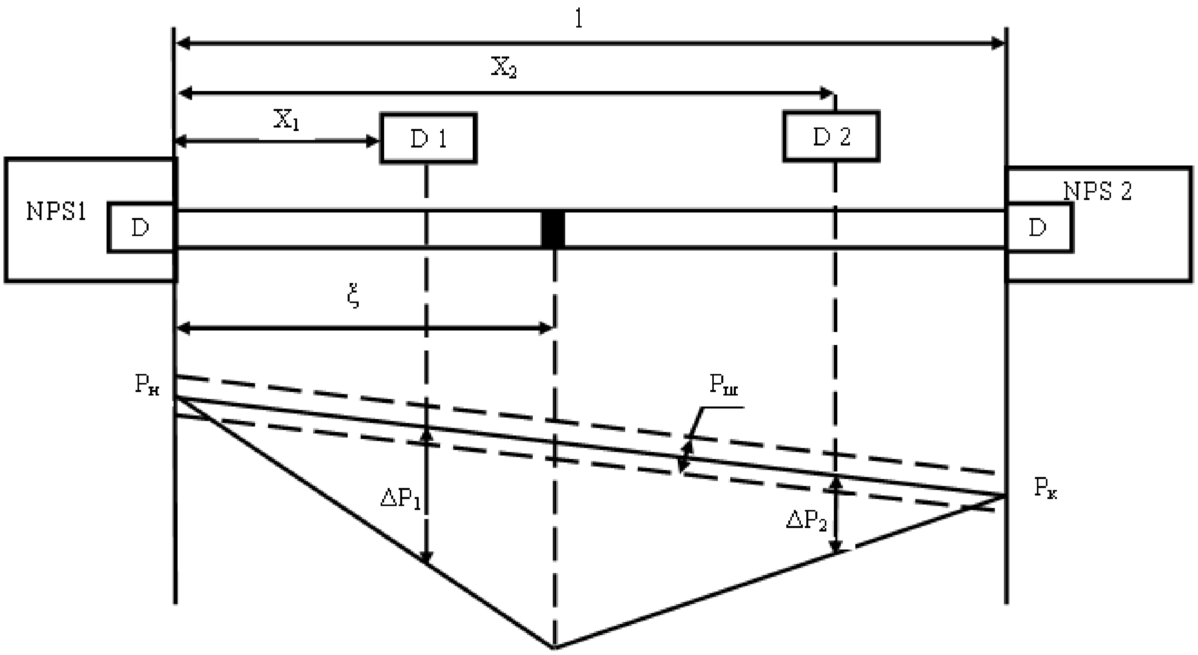

Fig. 2.
Leak detection method at the constant outlet pressure

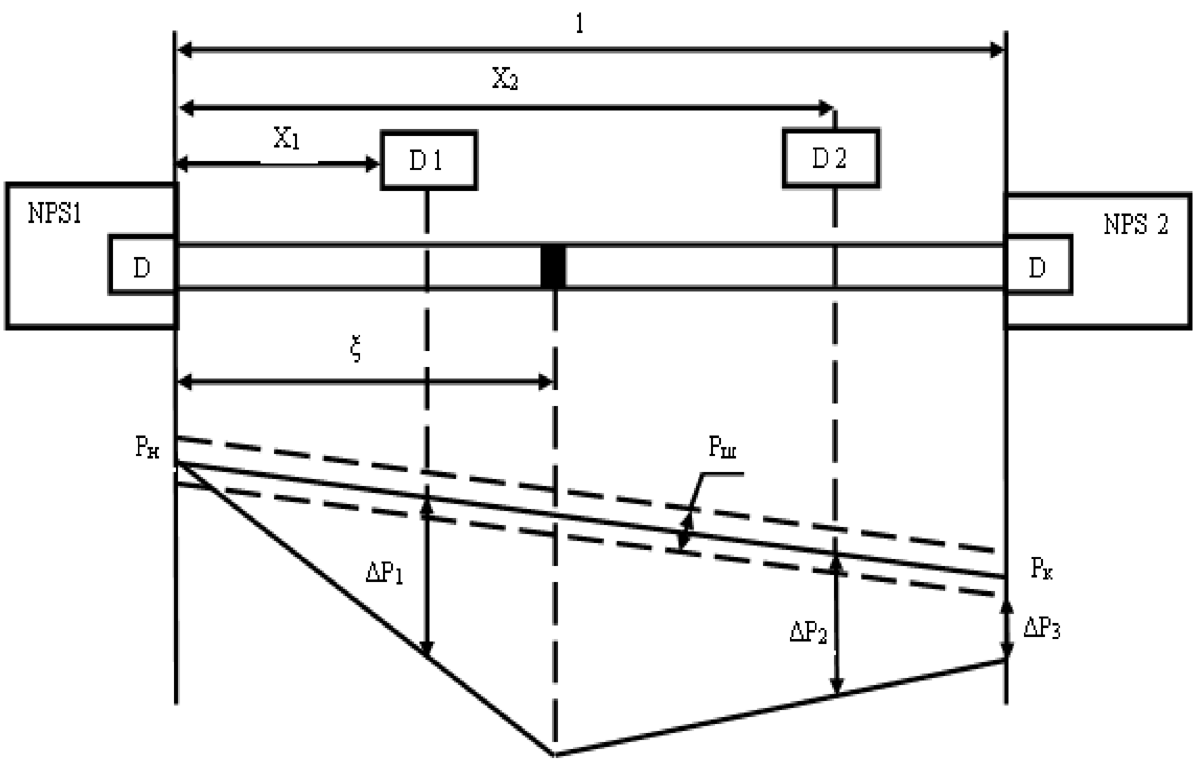

Fig. 3
Leak detection method when changing outlet pressure

The characteristics of the method depend on the dynamic characteristics of the sensors (D), the level of noise ($P_{ш}$), the ability of the controller to process information with the necessary speed (0.01 sec), the accuracy of determining the speed of sound (s).

A mathematical model in the form of a differential equation and single-valued conditions describing the flow of a fluid in an oil pipeline with a leak has the form:

$$\frac{dp}{dt} = \tau \cdot \frac{d^2p}{dx^2} - \frac{c^2}{S} \cdot \sigma \cdot \delta(x - \varepsilon) \tag{1}$$

$$\tau = \frac{c^2}{b}, b = \frac{\lambda \cdot \omega}{2d} \tag{2}$$

$$p(0, x) = p_{н} - \frac{p_{н} - p_{к}}{l} \cdot x \text{ при } x = 0 \; p = p_{н}, \text{при } x = l \; p = p_k \tag{3}$$

where: p – line pressure (Pa), t – time (s), x - distance to the sensor (m), c - wave propagation velocity in the pipeline (m / s), λ– pipeline drag coefficient, ω – oil product speed (m / s), ε – Leakage Coordinate (m), σ– mass flow rate of the fluid (kg / s), land d is the length and diameter of the pipeline (m), S is the cross-sectional area of the pipeline (m^2) ,.

Based on the solution of equations (1) and (3), using the Fourier transform, the parameters of the oil product and the pipeline, as well as the data obtained from pressure sensors, calculation formulas were obtained to determine the parameters of pipeline leakage:

$$\varepsilon = \frac{lK}{(l - x_2)\left(p_1 - p_{н} - \frac{x_1}{l}(p_{к} - p_{н}) + \left(z_1 - z_2 - \frac{x_1}{l}(z_{к} - z_{н})\right) \cdot \rho g\right) + K} \tag{4}$$

$$\sigma = \frac{F(K - l + x_2)}{l \cdot 2\alpha \cdot x_1(l - x_2) \cdot \rho g}\left(p_1 - p_{н} - \frac{x_1}{l}(p_{к} - p_{н}) + \left(z_1 - z_2 - \frac{x_1}{l}(z_{к} - z_{н})\right) \cdot \rho g\right) \tag{5}$$

$$K = x_1(p_2 - p_{н} - \frac{x_2}{l}(p_{к} - p_{н}) + \left(z_2 - z_1 - \frac{x_2}{l}(z_{к} - z_{н})\right) \cdot \rho g) \tag{6}$$

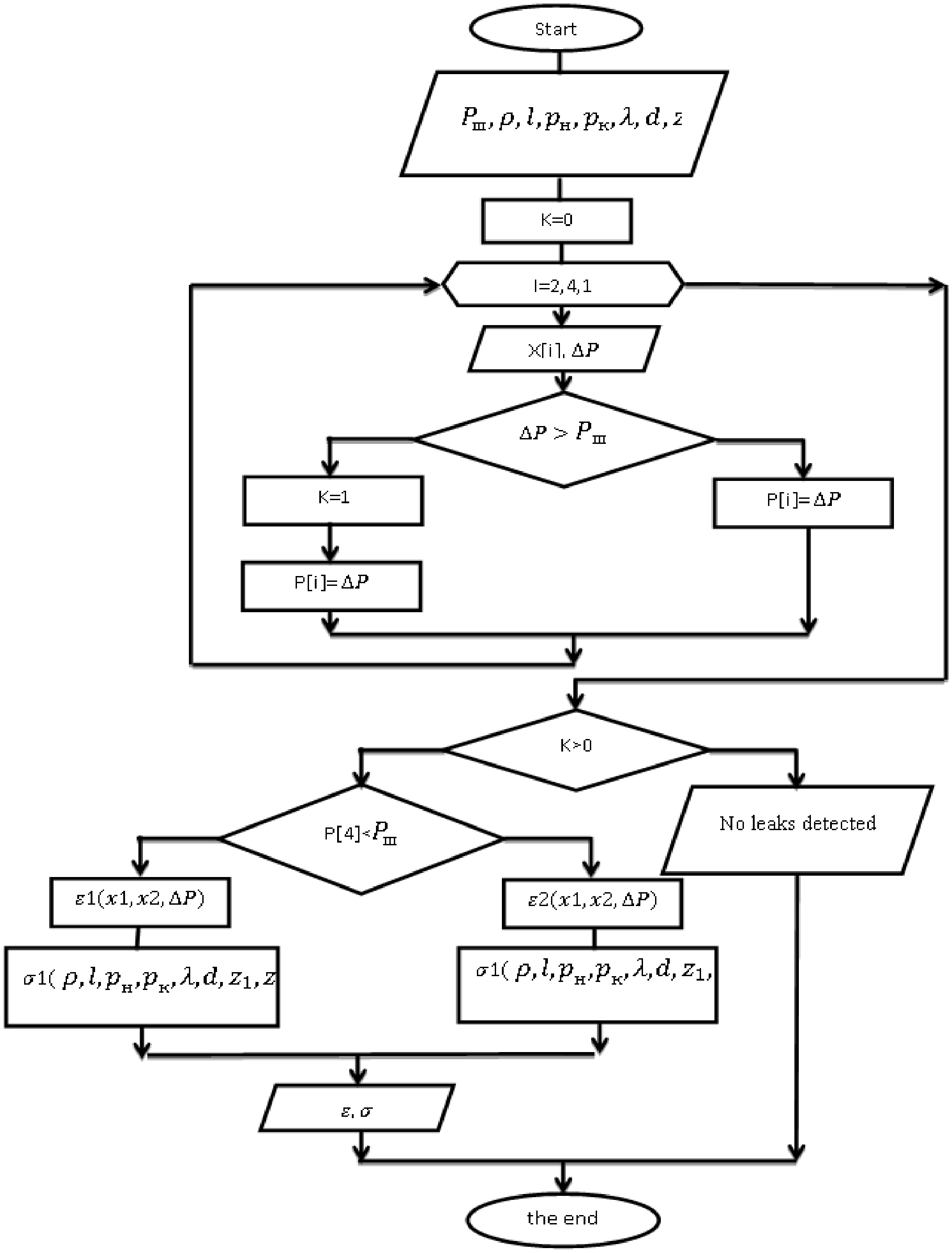

Fig. 4
Leak Detection Flow Chart

To implement this algorithm, a special program operates in the controller or at the top level. The program for the top level is presented on the example of the Pascal ABC programming language. To verify the correctness of the compiled mathematical model, an experimental setup is assembled, schematically presented in Figure 5.

The letters denote pressure sensors, fixed with the help of tees, imitating a pump-pumping station (NPS), the leak is simulated by opening a valve with a known angle of rotation of the valve.

Three possible options for the occurrence of leakage concerning pressure sensors D1-D2 are considered.

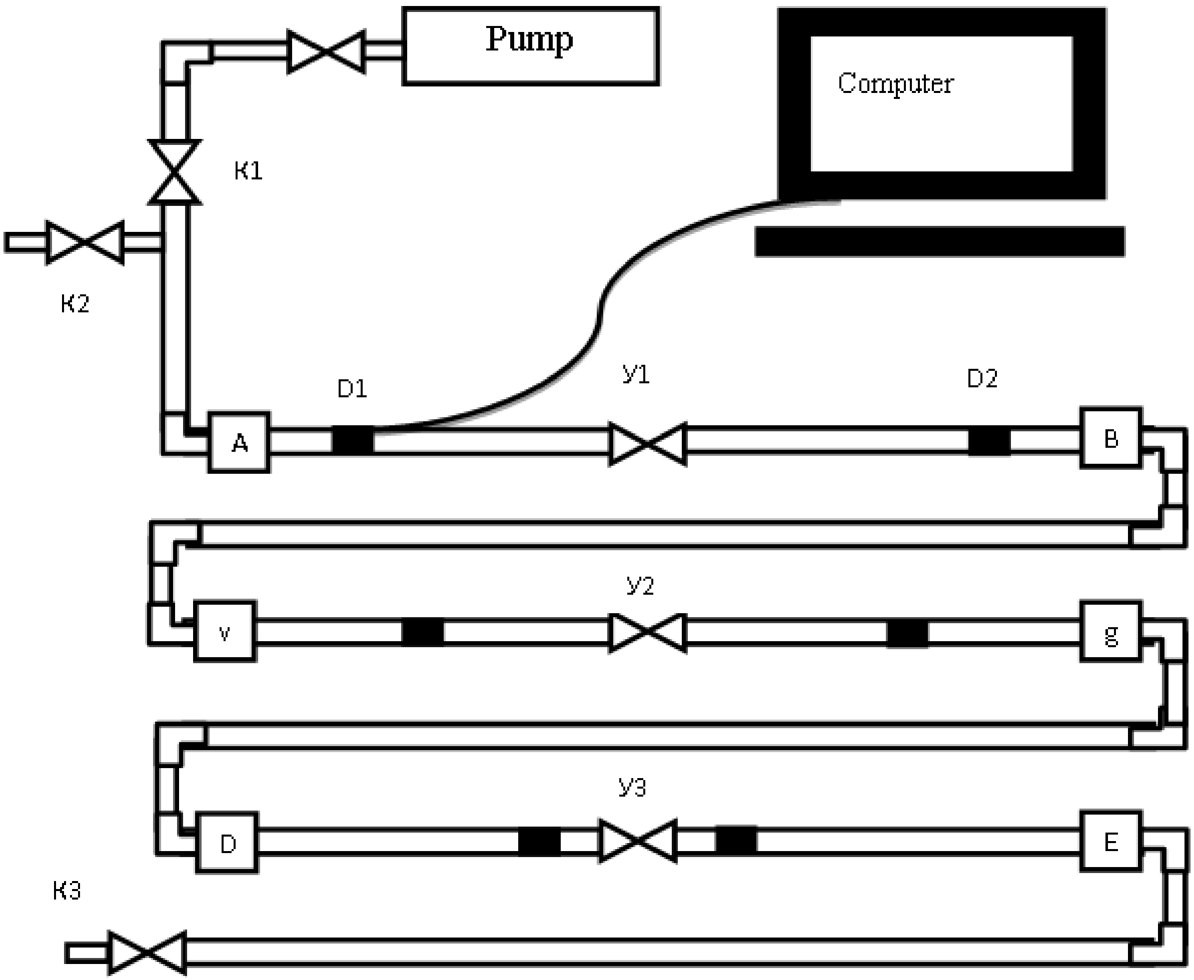

Fig. 5
The scheme of the experimental setup

Results

At the laboratory bench in the process of testing, the universal measuring transducer MTU - universal pressure gauge MTU-04.02. XX was used.

Information arrives at MIKON-827, for its reading on the experimental object a portable module was installed to collect information MSI-07, which can be connected via adapter AD-04 to the sealed connector of the sensor. The module records recorded information from the sensor into non-volatile memory. In experimental studies, a universal sensor was also connected to an electronic computer using a free COM port.

Monitoring the status of the sensor, launching it into operation and reading data from the instrument's memory is provided by a top-level program. In this case, the RS-485 protocol is used, and the unified port exchange rate is 9600 bps.

To normalize the signal of the serial interface of the microcontroller in the RS-485 standard, microcircuit-interfaces are used.

Measurement range (VPI) overpressure, MPa	2,5; 4; 6; 10; 16; 25; 40; 60; 100
Limits of the measurement channel error pressure in the range of operating temperatures, % of VPI	±0,25
Operating temperature range, °C	-40... 85
Temperature measurement range, °C	-20... 100
Limits of the allowed absolute error of the channel temperature measurement, °C	±0,5 (±0,25)
Measurement Resolution	1 c... 1 day
Power supply, V	3,6
Weight, kg, not more	1,8

Table 1
Technical specifications of the device

Discussion

An experimental study was conducted as follows:

The first stage: All taps are closed; the water is pumped through the pump through the open valve 1. At this time, valve 2 is closed and valve 3 is open. After the air is removed from the pipeline, taps 1 and 3 are closed and the pump is stopped.

The second stage: The pressure sensor is installed at the beginning of the simulation pipeline and its end at the required distance. On a computer, we launch a specialized program, we prepare sensors for recording signals using its initialization.

The third stage: In the receiver of the compressor we create the required pressure. When the valve 2 is closed, open the valve, which is located at the outlet of the compressor receiver.

The fourth stage: We start up our pressure sensor via a computer.

Fifth stage: When conducting experiments without leakage on the pipeline, taps U1-U3 always remain closed. We send a high-pressure impulse to the simulated pipeline. For several seconds, the pressure sensor records the change in pressure over time, and then stop it and shut off valve 2.

When conducting experiments with leakage, the required valve opens a couple of seconds before opening valve 2 and the device records the pressure change. A signal is given to the program, which calculates the coordinate and leakage flow.

Findings

During the experiment, the trunk section of the Kaleykino PS pumping station of Transneft Prikamye JSC was modeled from the Kaleykino receiving point (PSP) to OPS 3 on a reduced scale with a length of 1500m.
Input data on the object are presented in table 2.

Options	Data from PSP Kaleykino	Experimental data
Initial pressure	0,94 MPa	0,94 MPa
Final pressure	0,86 MPa	0,86 MPa
Fluid density	900кg/м^3	900кg/m^3
Pipeline Diameter	0,1m	01 m
The height of the sensors relative to each other	0, m	0, m
Pipeline resistance	0,005	0,001
Hydrodynamic noise level	3-5 Kpa	3-5 Kpa

Table 2
Data on the object OPS "Kaleykino"

The distance to simulated leakage in all 3 cases was 5.5 m

The installation coordinates of the pressure measurement device were as follows:

In the first case: $x_1 = 1$ м$x_2 = 9$ м

In the second case: $x_1 = 3$ м$x_2 = 7$ м

In the third case: $x_1 = 5$ м$x_2 = 6$ м

The resulting pressure drop graph is presented in Figure 6.

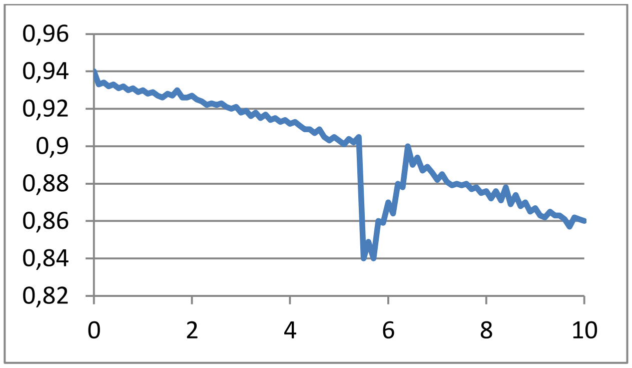

Fig. 6
Pressure drop curve

The results of the program for all the considered methods of installation of the device are shown in Table 3.

Sensor coordinates	ε, м	σ, кг/с
The data obtained experimentally	5,5	6,460
Data received by the program		
$x_1 = 1$ м $x_2 = 9$ м	5,623	6,483
$x_1 = 3$ м $x_2 = 7$ м	5,656	6,520
$x_1 = 5$ м $x_2 = 6$ м	5,609	6,475

Table 3
The results

Evaluation of the accuracy of the method of determining the coordinates and flow rates of leakage are given in Table 4

	$x_1 = 1$ м $x_2 = 9$ м	$x_1 = 3$ м $x_2 = 7$ м	$x_1 = 5$ м $x_2 = 6$ м
δ_ε, %	0,224	0,284	0,198
δ_σ, %	0,356	0,929	0,232

Table 4
Evaluation of the accuracy of the method

Conclusion

Summarizing the results of the work, we can come to the following conclusions: the introduction of leak detection systems in pipeline transport is relevant since it allows to significantly reduce environmental damage from the spill of products and to minimize the time of forced downtime of the pipeline. The error in localizing leakage using the "pressure wave" method is minimal, which is a good result and confirms the adequacy of the model. However, when using this method on long pipelines, it is necessary to consider the possibility of increasing the absolute value of the error.

Acknowledgments

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