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

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Abstract. This paper describes a method of leakage and mass flow coordinate determination, based on pressure change in time in the cross section of the linear part of the main pipeline. Two possible cases of pressure drop are considered: with a constant pressure value at the end of the pipeline and with a changing pressure value at the end of the pipeline. Based on the mathematical model describing the fluid flow in a leaky pipeline, and using the Fourier transform, the parameters of the oil product and the pipeline, calculation formulas were obtained to determine the parameters of leakage from the pipeline. The digital leak detection system in the pipeline is able to detect the smallest leak with the accuracy up to 1 meter during several seconds without any delays in operation or risk.A modern approach to a pipeline leak detection system is an extremely versatile solution that can be used to detect leaks in both liquid and gas environments in various industrial applications.

Key words: leakage and mass flow coordinate, Two possible cases of pressure drop, digital leak detection.

1 Introduction

The main reason for the violation of the main pipeline tightness is their long service life. Most of the main pipelines have a service life of more than 20 years. As they age, they begin to fail, leaks appear in structurally weak joints, corrosion points, and the areas with minor structural damage to the material. Leaks can occur through oil-seal packing of pumps and valves. Also the problem of unauthorized tapping into the linear part of the pipeline with the aim of embezzlement of petroleum products is important (Bulatov & Lyutov, 2013). The main task of leak detection systems (LDS) is to detect the fact of a leak and determine its location. LDS provides the alarm signal about the possible presence of a leak and the display of information that helps to make a decision about the presence or absence of leaks.

Pipeline leak detection systems are of great importance for the operation of pipelines, since they can reduce pipeline downtime (Volkov et al, 2014: Pajeti & Bahalgardi, 2017).

The 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 leak can indirectly cause another, more serious accident, for example, an explosion of released gas, as well as a pipeline rupture, which increases repair costs. It follows that it is economically feasible to detect leaks at an early stage of their appearance (Belyaeva, 2008). They develop the mathematical model for the method of leak detection by a pressure wave and the test of this model applicability in a short section of the main pipeline (Vainshtok, 2004: Kingsley et al, 2002: Kvet & Matiasko, 2018).

2 Methods

The method of negative pressure waves (estimated parameter) is based on the phenomenon of a rarefaction wave appearance during 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 oil pipeline, and on the amount of leakage. Also, when there is discontinuity in flow continuity or the presence of gas bubbles, the propagation velocity of the discharge pressure wave decreases. Thus, the signal will be blocked or will carry false information. All existing parametric LDSs are not without drawbacks. Taking into account modern safety requirements, the use of only parametric LDSs by the companies involved in the transportation of oil, gas and oil products is insufficient. Accordingly, the main requirement for LDS is its accuracy, provided by an integrated approach, i.e. using a group of leak detection methods based on various physical principles, both periodic and continuous monitoring methods.

The pressure wave method is based on the analysis of transients in pipelines when a leak occurs. At the time of a fluid leak, rarefaction waves occur in the pipeline, propagating to the ends of the pipeline at the speed of sound. Pressure sensors installed at the ends of the pipeline record the time of pressure wave arrival. The use of double pressure sensors at the ends of the diagnosed section of the pipeline allows you to determine the direction of the pressure wave and ignore 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, providing real-time monitoring of pipeline pressures. The second part provides the analysis of the recorded pressure waves for leakage at the top level of the system. This distinction made it possible to reduce 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 signals, the distances between the pressure sensors, the propagation velocity of sound waves, etc. The difference (t1-t2) of wave arrival moments indicates the displacement of the leakage point relative to the middle of the considered section (Kutukov, 2004). It is assumed that the pipeline between the oil pumping stations is a rectilinear section of equal diameter, completely filled with liquid, without additional inserts and bends. There are two pressure sensors at a certain height along the length of the pipeline with fixed coordinates (Gorny, 2008: Gerhard, 2003: Wang & Carroll, 2007).

Figure 1. schematically shows the method for leak monitoring in trunk pipeline section.

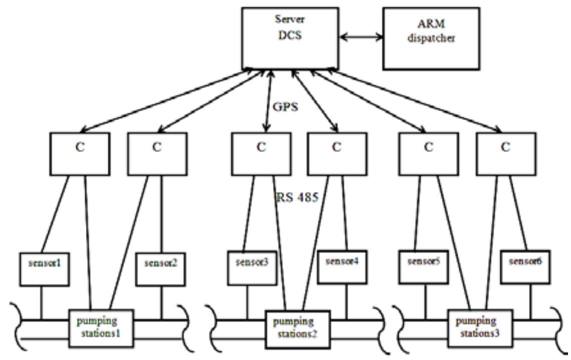


Figure1. Leak detection scheme

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

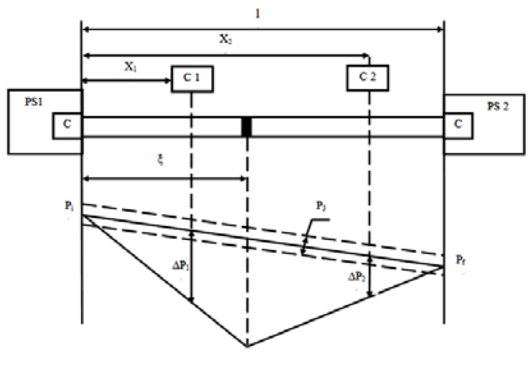


Figure 2. Leak detection method at constant outlet pressure

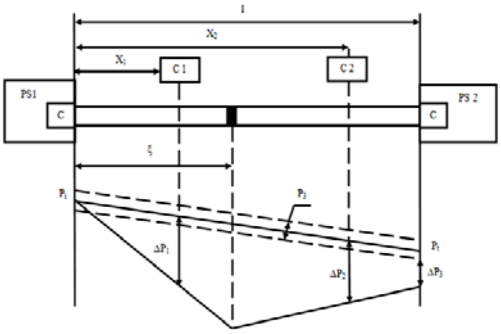


Figure 3. Leakage detection method at varying outlet pressure

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

The mathematical model in the form of a differential equation and uniqueness conditions describing the fluid flow in a leaky oil pipeline has the following form:

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

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

$$p(0,x) = p_н - \frac{p_н - p_к}{l} \cdot xnpux = 0\ p = p_н, npux = lp = p_k \qquad (3)$$

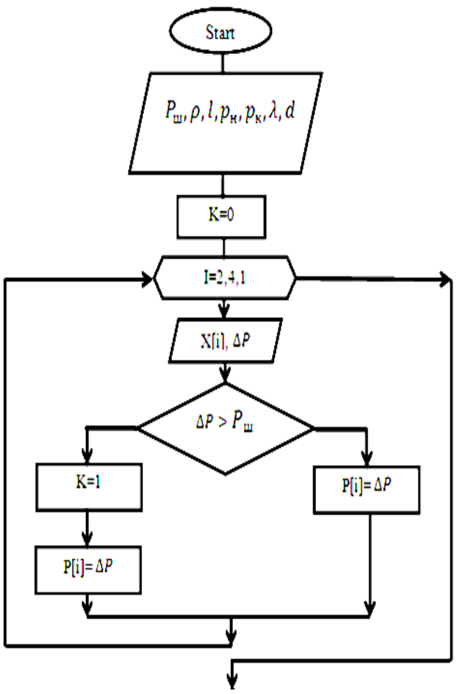
where p is the pressure in the line (Pa), t is the time (s), x is the distance to the sensor (m), c is the wave propagation velocity in the pipeline (m/s), λ – the resistance coefficient of the pipeline, ω – the speed of the oil product (m/s), ε – the coordinate of the leak (m), σ – the mass flow rate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

Based on the solution of the equation (1) and (3), using the Fourier transform, the parameters of the oil product and the pipeline, as well as the data obtained from the pressure sensors, they obtained calculation formulas for leakage parameter determination from the pipeline:

$$\varepsilon = \frac{lK}{(l-x_2)\left(p_1 - p_н - \frac{x_1}{l}(p_к - p_н) + \left(z_1 - z_2 - \frac{x_1}{l}(z_к - z_н)\right)\cdot \rho g\right) + K} \qquad (4)$$

$$\sigma = \frac{F(K-l+x_2)}{l \cdot 2\alpha \cdot x_1(l-x_2)\cdot \rho g}\left(p_1 - p_н - \frac{x_1}{l}(p_к - p_н) + \left(z_1 - z_2 - \frac{x_1}{l}(z_к - z_н)\right)\cdot \rho g\right) \qquad (5)$$

$$K = x_1(p_2 - p_н - \frac{x_2}{l}(p_к - p_н) + \left(z_2 - z_1 - \frac{x_2}{l}(z_к - z_н)\right)\cdot \rho g) \qquad (6)$$



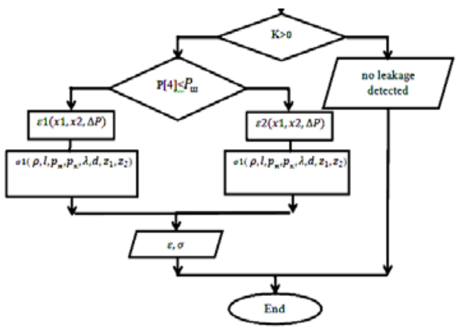


Figure 4. Leak detection algorithm flowchart

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

Letters denote pressure gauges secured with tees, simulating a pumping station (PS), leakage is simulated by opening a tap with a known angle of valve rotation.

Three potential leakages are considered with respect to pressure sensors D1-D2.

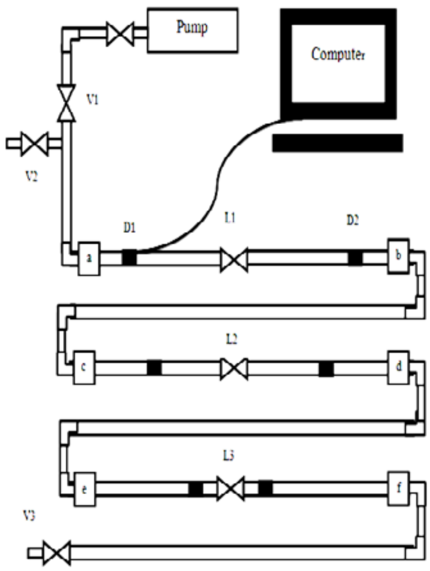


Figure 5. Experimental device scheme

3 Results

During the tests, a universal pressure measuring transducer MTU was used at the laboratory bench - universal pressure gauge-thermometer MTU-04.02.XX.

The information arrives at MIKON-827. A portable module MSI-07 was installed to collect information for data reading at the experimental unit, which can be connected via the AD-04 adapter to the airtight sensor connector. The module provides recording of registered information from the sensor into non-volatile memory. In experimental studies, a universal sensor was also connected to an electronic computer via a free COM port.

Monitoring the sensor status, the implementation of its launch and data reading from the device memory is provided by a top-level program. In this case, the RS-485 protocol is used, and the exchange rate on the unified port makes 9600 bps.

To normalize the serial signal by the interfaces of the microcontroller, microcircuits interfaces are used for RS-485 standard.

Table 1. Technical characteristics of the device

Range of measurement (URL) of excessive pressure, MPa	2,5; 4; 6; 10; 16; 25; 40; 60; 100
Limits of the reduced error of the pressure measurement channel in the range of operating temperatures, % of URL	±0,25
Operating temperature range, °C	-40... 85
Temperature measurement range, °C	-20... 100
Limits of allowed absolute error for temperature measurement channel, °C	±0,5 (±0,25)
Measurement resolution	1 s... 1 day
Power voltage, V	3,6
Weight, kg, no more than	1,8

4 Discussion

The experimental study was carried out as follows:

First stage: All taps are closed, water is pumped through an open tap 1. At this time, tap 2 is closed and tap 3 is open. After the air is removed from the pipeline, we turn off tap 1 and 3 and stop the pump.

Second stage: We install a pressure sensor at the beginning of the simulation pipeline and at its end at the required distance. We run a specialized program on the computer, prepare the sensors for signal record using its initialization.

Third stage: We create the required pressure the compressor receiver. When the valve 2 is closed, open the valve located at the outlet of the compressor receiver.

Fourth stage: We launch our pressure sensor through the computer.

Fifth stage: When they conduct experiments without leakage in the pipeline, U1-U3 valves always remain closed. We send a high pressure pulse to the simulated pipeline. For several seconds, the pressure sensor records the change in pressure over time, and then we stop it and turn off the valve 2.

During the conduct of experiments with leakage, the required valve opens a couple of seconds before opening valve 2 and the device records pressure change. The signal is given to the program that calculates the coordinate and the flow rate of the leak.

5 Conclusions

During the experiment, the main section of the Kaleykino pump station of "Transneft Prikamye" JSC was simulated from the Kaleikino acceptance point (AP) to the pump station 3 on a reduced scale, with the route length of 1500 m.

The input data for the object are presented in table 2.

Table 2. Data on the pumping station "Kaleikino"

Parameters	Data from the pumping station "Kaleikino"	Experimental data
Initial pressure,	0,94 MPa	0,94 KPa
End pressure,	0,86 MPa	0,86 KPa
Fluid density,	900 kg/m^3	900кг/m^3
Pipe diameter,	0,1m	01 m
The height of the sensors relative to each other	0, m	0, m
Pipeline internal resistance	0,005	0,001
Hydrodynamic noise level	3-5 KPa	3-5 KPa

The distance to the simulated leak in all 3 cases was 5.5 m.

The coordinates of the pressure measuring device installation 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 pressure drop graph obtained is shown on Figure 6.

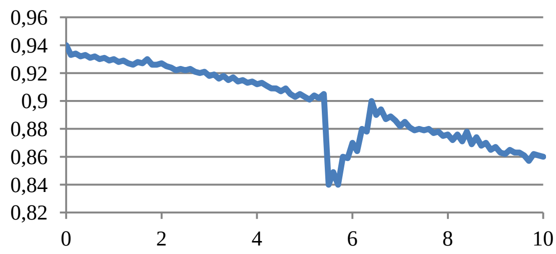


Figure 6. Pressure drop curve

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

Table 3. obtained results

Sensor coordinates	$\varepsilon, м$ (m)	$\sigma, кг/с$ (kg/s)
Experimentally obtained data	5,5	6,460
Data obtained via software		
$x_1 = 1\,м x_2 = 9\,м$	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

The method accuracy assessment in respect of coordinate and leakage rate determination is given in table 4.

Table 4. Evaluation of the method accuracy

	$x_1 = 1\,м x_2 = 9\,м$	$x_1 = 3\,м x_2 = 7\,м$	$x_1 = 5\,м x_2 = 6\,м$
$\delta_\varepsilon, \%$	0,224	0,284	0,198
$\delta_\sigma, \%$	0,356	0,929	0,232

6 Summary

Summarizing the results of the work, we can come to the following conclusions: the introduction of leak detection systems in pipeline transport is relevant, because it significantly reduces environmental damage from product spills and minimizes pipeline downtime. The error at leak detection using the “pressure wave” method is minimal, which is a good result and confirms the adequacy of the model. However, when they use this method, it is necessary to take into account the possibility of the error absolute value increase for long pipelines.

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Literature

1. Belyaeva, V.A.: Oil and gas construction, and others, ed. by Prof. Mazur I.I. and Prof. Shapiro V.D. - M.: OMEGA-L, 2008. 774 p.
2. Bulatov, A.F., Lyutov, A.G.: Bulletin of USATU. Ufa: USATU, V.17, No. 5 (58), 2013, 86-92 p.
3. Gerhard, G.: Principles of Leak Detection, Fundamentals of Leak Detection. Oil & Gas. Oklahoma: Krohne, 2003, 46 p.
4. Gorny, M.: Monitoring acoustic noise in steel pipelines, Proceedings of IPC2008 7th International 135. October. Alberta: Calgary, 2008. Pipeline Conference. September 29, 123–3 p.
5. Kingsley, E., Abhulimen, A., Susu, A.: Liquid pipeline leak detection system: model development and numerical simulation. Chemical Engineering Department, Nigeria, Lagos: University of Lagos, 2002.
6. Kutukov, S.E.: The problem of increasing the sensitivity, reliability and speed of leak detection systems in pipelines, Oil and gas business, v.2. 2004, 29-45 p.
7. Vainshtok, S.M.: Pipeline transportation of oil. Vasiliev G.G.; Korobkov G.E.; Korshak A.A. et al. ed. by Weinstock S.M. Nedra-Business Center LLC, v.2, 2004. - 621 p.
8. Volkov, A.S., Volkova, I.E., Zemskov, P.A.: Transactions of NSTU named after R.E. Alekseev. - N. Novgorod, No. 5 (107), 2014. 166-170 p.
9. Wang, S., Carroll, JJ.: Leak detection for gas and liquid pipelines by online modeling. SPE Projects, Facilities & Construction. 2(02), 2007. 1-9 p.
10. Pajeti, A.G., & Bahalgardi, N.F.: Improving energy consuming in WSN using mobile sink. UCT Journal of Research in Science, Engineering and Technology, *5*(01), 2017. 1-8 p.
11. Kvet, M., Matiasko, K.: Temporal Data Performance Optimization using Preprocessing Layer. Journal of Information Systems Engineering & Management, 3(2), 2018. 13 p.

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