Technical and methodological support of leak-detection systems at Transneft’s facilities

by R.Z. Sunagatullin, S.A. Korshunov*, and Yu.V. Datsov
Pipeline Transport Institute, LLC, Moscow, Russian Federation

This article analyses the current situation in the global market for leak-detection systems (LDS). The main operational problems for existing parametric LDSs are identified based on a comparative analysis of statistical data on leaks in European and American trunk pipeline operators, and the proportion of leaks detected by LDSs. Reasons are formulated for these problems, which lead to deterioration in LDS characteristics. The study includes a brief classification and description of the most commonly used leak detection methods. Based on comparison of regulatory documentation in the field of LDSs in Russia and abroad, provisions are identified describing the requirements and important processes within the design and operation of LDSs, which are missing in the domestic regulatory framework and are recommended for inclusion. A comprehensive approach is proposed for the task of improving and introducing parametric LDS, as used by the Pipeline Transport Institute.

Key words: leak-detection systems, parametric methods, leak detection statistics, trunk pipelines

Introduction

Oil and oil product leakage is a serious problem for pipeline transportation not only in Russia, but also elsewhere. Leaks carry a serious threat to environmental safety, and cause significant economic damage in the form of costs for pipeline repair work, oil-spill response, and punitive damages. They also affect the efficiency of oil transportation and negatively impact on the image of oil transportation companies.

The main causes of leaks [1] can be classified as related to natural wearing of pipes over time; natural phenomena; operator errors; damage inflicted during maintenance and repair works; and illegal tapping, which, according to official data [1-3], is becoming an increasingly significant problem.

Comparative analysis of leak occurrence and detection statistics: problems in the operation of existing LDSs

One pertinent question is whether it is possible at present to ascertain a noticeable reduction in the trend of the average number of leaks in trunk pipelines (TP) over recent years. Judging by statistical data for oil pipeline operation in Russia, the United States, and Europe, the answer to this question is no.

According to Rostekhnadzor - Russia’s Federal Environmental, Industrial and Nuclear Supervision Service - dozens of accidents involving fossil fuel leakages occur at the linear part of trunk pipelines every year in the Russian Federation. Similar statistics can be observed for Europe [1] according to the

Corresponding author’s contact details:
email: korshunovsa@niitnn.transneft.ru
European Association of Oil Companies (Conservation of Clean Air and Water in Europe - CONCAWE). The average number of leaks is not decreasing (Fig.1).

At the same time, this fact does not imply there has been no improvement in the quality of designing and operating trunk oil pipelines. These statistics are largely due to the ageing of the transport systems in operation, as well as the increased complexity and length of the pipelines, which naturally entails an increase in the likelihood of oil leaks.

Furthermore, a significant factor contributing to the total number of oil leaks on trunk pipelines (henceforward TPs) is the theft of fossil fuels through illegal pipeline tapping. For example, a sharp increase in recorded oil leaks for the period from 2010 to 2014 (Fig.1) was precisely caused by thefts. This is also illustrated by statistics for attempts at such crimes at European pipelines, as shown in Fig.2.

Thus, the statistics for leaks from TPs mean it can today be stated with confidence that the organizations operating oil- and product pipelines have a serious demand for effective pipeline leak-tightness control systems. Moreover, given the present situation of complex infrastructure involving long and inaccessible TPs, automated leak-detection systems (LDSs) are of particular importance in terms of safely and efficiently operating pipeline facilities.

According to current forecasts [4], there will be steady growth in the market for leak identification systems in the near future. The positive trends forecast for the development of the global LDS market are influenced by a number of factors, such as the general prediction of increasing global oil consumption and oil production (Fig.3), the expectation of high energy consumption in Asia and in developing countries and, as a result, infrastructure development and expanding pipeline systems.

Thus, given the current demand for leak-detection systems among oil transportation companies, and predicted pipeline system development, the efficiency of existing LDSs is an urgent issue.

A comparative analysis of historical data on the occurrence of leaks and their detection by LDSs demonstrates significant problems in the pipeline tightness control systems currently in use in Russia as well as elsewhere.

According to data from the Office of Pipeline Safety under the Pipeline and Hazardous Materials Safety Administration of the USA (OPS...
Fig. 2. Statistics for attempted thefts from transportation pipelines (source - CONCAWE).

Fig. 3. Predicted global oil consumption and oil production, million barrels per day (Source - BP Statistical Review of World Energy, 2015).

Fig. 4. Leak detection (total 960) in oil pipelines from 2002 to 2012 (source - PHMSA).

Fig. 5. Detection of “serious” leaks (total 71) in oil pipelines from 2002 to 2012 (source - PHMSA).
PHMSA), it can be ascertained that despite the assurances of LDS manufacturers and LDS suppliers, the systems in use are currently capable of identifying only a small proportion of leaks [5]. Thus, Fig. 4 shows general statistics for leak detection based on the analysis of American trunk pipeline operation. The number of leaks identified by LDSs was about 5% of the total number [6].

Furthermore, as shown in Fig. 5, such a small percentage of detected leaks cannot be unequivocally attributed to the low intensity of most leaks. Low-intensity leaks are genuinely difficult to identify due to their insignificant impact on the technological parameters of pumping [6].

According to these statistics, from 2002 to 2012 the LDSs installed in American TPs were able to detect only 20% of so-called ‘serious’ leaks. These leaks resulted in losses of more than 1000 barrels of oil, which is a small fraction of the total number of such leaks.

The ‘effectiveness’ issues surrounding existing LDSs are also confirmed by statistical data [1] from operating European TPs (Fig. 6). Despite the slight upwards trend in the average number of leaks detected over the past 40 years, largely attributable to growth in the length of TPs, great volatility can be seen in the proportion of leaks detected by LDS; while the annual values for the proportion of detected leaks are consistently less than 50%.

**LDS classification**

Work has long been ongoing aiming to build LDSs to solve the issue of reliable and prompt leak detection on trunk pipelines. During this time, many leak detection methods have been suggested as a basis for LDS, and many corresponding classifications proposed [7-12].

For the convenience of the following account, one of these classifications will be used, based on dividing LDSs into ‘external’ and ‘internal’. This takes into account the principles on which their functioning is based (Fig. 7). This type of classification is given in regulatory document API 1130 [13], which is one of the most authoritative standards regarding tightness control systems on TPs.

Over the past 10 years, ‘external’ LDSs mainly based on remote, fibre-optic, and acoustic leak-detection methods have developed significantly.

Despite the objectiveness of the leak detection principle used in remote methods [14], such methods rely on periodic monitoring and have a number of significant limitations related to the inaccessibility of TP routes and weather conditions, which suggests it is expedient...
to use them only as supplementary LDSs. The clear advantage of fibre-optic methods [14] is their potential ability to detect leaks with very low rate, and their high accuracy in determining the coordinates of such leaks along the TP route, thanks to the physical nature of such systems. The leak signal is formed on the basis of the interaction of the leaking oil or oil product with the sensitive distributed element of the system directly at the point of leakage. However, along with acoustic systems, these systems have serious disadvantages, which means they can be considered only as auxiliary monitoring systems. This is the very high cost of equipping trunk pipelines with a correctly operating system, and the high level of false alarms.

‘Internal’ LDSs deserve the most attention and, in particular, parametric methods of leak detection. These are currently the most widely used in the world, and look to continue this trend in the future, according to current forecasts [4]. The wide distribution of parametric LDSs was achieved thanks to their ability to function using the telemetry equipment already installed on a TP, as well as their ability to work in any geoclimatic conditions along trunk pipeline routes.

The so-called RTTM-method (real-time transient modelling) and its variations should be singled out here [14]. This method is based on modelling non-stationary real-time TP operating modes. They are becoming an increasingly integral part of parametric LDSs, because of their ability to function independently of the operating mode at the process section. It should be taken into account that such methods require knowledge of a number of pipeline parameters (diameter, wall thickness, topology, location of...
equipment) and oil properties (bulk modulus, viscosity, density), which may introduce additional errors.

**Causes of operating problems for LDSs**

Improvements to LDSs aimed at solving the problems listed in the first part of this article are not possible without understanding the root causes of these problems.

In the authors’ opinion, the main reason leaks are missed on trunk pipelines as a result of incorrect LDS operation is the insufficient level of understanding of how the performance characteristics of these LDSs (such as location accuracy and leak rate, system response time, false alarms) depend on a large set of parameters for the process of oil pumping. Numerical estimates must be known for the impact on the LDS ability to detect the presence of a leak, and to determine the location and the volume of such parameters as the time of development and existence of a leak, the errors in measuring instruments and data-transmission channels, the discreteness of data acquisition, the threshold for data transmission, as well as many parameters of the current operating mode of the TP process section. Correct entire estimating these relationships for LDSs is not possible without understanding how these relationships are arranged for each parametric method separately.

The reason mentioned above indicates the insufficient degree of detailing the existing regulatory framework for designing and operating LDS. Due to the uncertainty of requirements for choosing leak-detection methods and telemetry characteristics, this in turn adversely affects the efficiency of LDS operation, which ultimately results in missed leaks.

**A brief analysis of regulatory documentation for leak-detection systems in Russia and abroad**

In order to unify the approach to developing and operating LDSs, as well as to define and specify the requirements indicated in the previous section, it is necessary to make a comparative analysis of the regulatory documents in the field of LDS used in Russia and elsewhere.

Major international organizations currently support several key regulatory documents defining requirements and recommendations for the design, implementation and operation of LDS: API 1130, API 1149, API 1175 (USA), CSA-Z662 (Canada), TRFL (Germany).

In Russia, the requirements for LDSs are determined by the regulatory documents of Transneft PJSC, which are divided by methods of leak detection in the following systems:

- parametric systems – OTT-13.320.00-KTN-051-12 (General Specifications);
- fibre-optic systems – RD-35.240.00-KTN-076-12 (Guiding document);
- combined systems (a combination of parametric LDS and LDS based on monitoring the passage of pressure waves caused by a leak) – RD-13.320.00-KTN-223-09 (Guiding document).

At present, one of the most credible organizations outside Russia in the field of safety regulations for the oil and gas industry is the American Petroleum Institute, which has an extensive regulatory framework of standards covering many issues of LDS design and operation.

In contrast to Russian regulatory documents, the standards of the USA, Canada, and Europe do not contain requirements for LDS characteristics such as sensitivity to the minimum detectable leakage, accuracy in determining leak coordinates, or detection time. Nevertheless, they determine the need for the existence and specific character of the use of methods which make it possible to obtain the characteristics listed with better indicators. The regulatory documents of the API details the methodology for
implementing LDS, taking into account measurement errors and the technological features of pipeline oil transportation. API also issues guidelines for constructing an interface in order to minimise the number of false alarms, operator actions in emergency situations, and training personnel to improve the efficiency of leak detection. Presented in this way, the material is a step-by-step guide to build the parametric LDS on the basis of data for the pumped fluids, taking into account the accumulated experience and most known factors affecting the required characteristics.

A comparative analysis of regulatory systems in Russia and elsewhere shows that some of the existing requirements and descriptions of technological processes presented in domestic regulatory documentation can be supplemented by the provisions of API standards, in order to improve LDSs:

- recommendations for using parametric methods for detecting leaks, taking into account the tasks to be solved and the level of TP instrumentation;
- recommendations for equipping trunk pipelines with measuring instruments for correct LDS operation;
- provisions regarding the dependence of the possibility of leak detection on the size and complexity of a TP, and the reliability and errors of the measuring instruments installed at the TP;
- recommendations for developing a methodology for the algorithmic control of various parametric methods of leak detection in the LDS framework.

Methods of solving problems: the integrated approach taken by the Pipeline Transport Institute to the task of improving LDS

Among the many important tasks at present in the field of mathematically modelling the processes of pumping oil and oil products, developing specialized software and computer systems, as well as performing thermal and hydraulic calculations, the Pipeline Transport Institute has been assigned with one more task: to establish the Pipeline Transport Institute as the main developer and supplier of parametric LDSs for the needs of pipeline transportation for Transneft PJSC. The Institute’s goal is to develop, upgrade, and implement an efficient LDS to the organizations of the Transneft system, which meets the highest requirements of sensitivity, reliability, accuracy, and sustainability.

Solving this task involves a combination of research, methodological, technical, and organizational measures, which are already being put into practice at the Pipeline Transport Institute. The procedure for implementing measures in order to achieve the above-mentioned goal is presented below.

1. In the first place, it involves research and development (R&D) work aimed at identifying existing problems, understanding the principles of how LDS characteristics depend on a whole range of process parameters, as well as studying and identifying opportunities to improve the accuracy and reliability of leak-detection methods.

Within the framework of the R&D projects underway at present, the Institute is studying the fundamental principles of the impact on characteristics of leak-detection parametric methods of factors such as the operating mode of the TP process sections, the presence of gravity-flowing sections, the presence of several leaks at the TP process section, the degree of completeness, discreteness, reliability of the measuring instrument readings, and other parameters. Numerical estimates are being made for the maximum attainable capabilities.
of parametric methods; and algorithmic approaches to combining methods are being investigated, with the aim of developing an approach to improving parametric LDSs.

In addition to the R&D activity within the framework of the task of improving LDS, the Institute is developing specialized software to facilitate a comprehensive approach to solving technological problems in oil pipeline transportation. At the moment, the Pipeline Transport Institute has created and is already introducing the software and computer package ‘Automated workstation for the process engineer’ (AWPE) into industry standards. An ‘Automated system for monitoring trunk pipeline process parameters’ (PC flow-monitoring system) is currently at the development stage.

The AWPE software (Fig.8) is a software tool unified for the Transneft system that provides process engineers in system organisations with essential functional possibilities:

- input and storage of process data:
  - construction of process section diagrams
  - identification of equipment characteristics
- conducting hydraulic calculations
- work planning and analysis of the actual operation of the process section

The PC flow-monitoring system (Fig.9) is a specialized software package for monitoring the operating parameters of a trunk pipeline, including:

- calculating process parameters for pipeline operation in real-time mode on the basis of the mathematical model developed;
- monitoring and identifying possible reasons for the technological parameters to deviate from the calculated and planned values;
- identifying the process operating modes for the TP;
- tracking pipeline runs of cleaning and inspection devices

A module for monitoring pipeline leak-tightness with determining detected leak parameters is also provided within the framework of the PC flow-monitoring system, based on the hydrodynamic model of oil flow through a process section taking into account a number of process factors. At the present time, the Institute is working on the development and future improvement of this
module, taking into consideration parallel studies of mechanisms and numerical estimates of the maximum attainable characteristics of parametric methods for leak detection. A unified information field is thus created for the integrated solution of pipeline transport technological problems.

2. The next step is expansion, refinement, and specification of the existing regulatory documentation requirements at Transneft PJSC in the field of LDSs. This should be based on R&D, comparative analysis of regulatory frameworks in Russia and elsewhere, as well as on upgrading programs and methodologies for testing LDSs. Improving the regulatory framework makes it possible:

- to clarify requirements for accuracy and leak-detection time for various cases where LDS characteristics deteriorate, caused by the process features of the pumping mode;
- to clarify the requirements for determining the occurrence of a leak, taking into account that the leak must be confirmed by various algorithms;
- to harmonize the solutions for the procedure and number of LDS tests at the process section of the TP.

3. The final step, which is interconnected with the previous one, is a detailed analysis of the operational characteristics of the measuring instruments and data-transmission channels installed in a process section of a TP, given that the correct operation of parametric LDS is not possible without the use of telemetry of the appropriate quality. This work should include:
• a primary evaluation of retrospective SCADA data using statistical analysis applied at LDS telemetry facilities, in order to draft a list of out-of-spec deviations and propose recommendations for their elimination;
• developing criteria for evaluating the characteristics of measuring instruments based on dependencies which determine the sensitivity of parametric LDSs on the frequency of data acquisition and amplitude fluctuations caused by errors in measuring instruments and vibrations in the transported fluids;
• analysis of SCADA data for LDS telemetry facilities in accordance with the criteria developed, with the aim of determining the maximum attainable LDS characteristics for leak-detection accuracy at the TP process sections under consideration.

Conclusion

Analysis of the current situation in the field of oil and oil products transportation points to the conclusion that automated leak and illegal tapping detection systems are in great demand. These systems are based on the parameters of the pumped fluids. The integrated approach, implemented within the framework of work at the Pipeline Transport Institute, makes it possible to create an LDS with improved characteristics, and has potential for its further development. It also allows important requirements for the characteristics of measuring instruments to be defined and relevant changes to existing regulatory documentation to be introduced.

References