Methods Of Decreasing The Influence Of The Factors Disturbing The Reliability Of Leak Detection Systems

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Mateusz Turkowski, Andrzej Bratek

Abstract:
During implementation of leak detection and localization systems for liquid and gas pipelines the authors have met serious problems concerning reliability. The main problems were integrity (i.e. discontinuities) and quality of the input data acquired from telemetry systems, such as damages, bad calibration and drift of the measuring instruments and transmitters, bad balance between fluid entering and leaving the system and incorrect installation of temperature transmitters. The proposals how to overcome these problems have been presented.

Keywords: *leak detection, leak localization, reliability*

1. Introduction

The leak of the gas or liquid pipeline brings always large losses of various kind: suspending the product transport, the cost of reparation of the damage and loss of transported product. In case of explosive or/and flammable or/and dangerous to environment media (e.g. petroleum and other petrochemical products), the leak causes hazard for safety of the people and the equipment as well as environmental contamination. Events like that induce high social and financial costs, which are proportional to the leak intensity and duration.

At all stages of pipeline building and operating must be therefore fulfilled the regulations and recommendations of numerous standards and regulations, whose purpose is to provide long-lasting operation of pipeline system. However, even if the pipeline has been designed and built very carefully, there is always a potential of leaks.

If in spite of all precautions a leak happened, its effects can be minimized only by fast detection and localization of the leak point enabling quick dispatcher reaction (stopping pumping, closing the valves, organizing provisional damage repair etc.).

Pipeline leak detection systems play therefore a key role in minimization of the leaks probability and impact. A lot of technologies of leak detection and localization are commercially available today, the background information about them has been presented in [1].

In case of long range pipelines most of the leak detections methods are analytical (internal) methods based on comparison of the pipeline mathematical model data with the real measurement data obtained from the telemetry or SCADA systems.

For the purposes of the leak detection and localization systems the following parameters are measured and processed:

- pressure at the inlet, at the end, and at as much as possible points located along the pipe, i.e. at the valve stations, metering and regulating stations, terminals,
- flow rate at the inlet and if possible at the outlet of the pipeline,
- temperature usually at the same places that pressure measurement or minimum at inlet and outlet,
- if possible density of the transported liquid at inlet of the pipeline.

Most important parameters for the procedures of leak detections are pressure and flow-rate. Measurements of other variables (temperature, density) are auxiliary but they can significantly increase the system accuracy.

Measured pressure p is compared with calculated pressure p_{cal}, in the simplest case (static model) the following formula can be used for gas:

$$p_{cal} = \sqrt{p_0^2 - \frac{1.62114 q_{st}^2 \rho_{st}^2 ZRT\lambda L}{D^5}} \tag{1}$$

where p_0 – pressure at inlet of the pipeline, q_{st} and ρ_{st} – flow rate and density at standard conditions, Z – compressibility coefficient, R – gas constant, T – absolute temperature λ - friction coefficient (function of Reynolds number and pipe roughness), L – pipeline length, D – pipe internal diameter.

In most cases, however, much more complicated, but more accurate dynamic models in form of differential equations system are used [2, 3], i.e. for liquids:

$$\frac{\partial w(x,t)}{\partial x} + \frac{1}{E}\frac{\partial p(x,t)}{\partial t} = 0 \tag{2}$$

$$\frac{\partial p(x,t)}{\partial x} + \rho(x)\frac{\partial w(x,t)}{\partial t} = -\rho(x) g \sin\alpha - \frac{\lambda(x)\rho(x)}{2D} w(t)\left|w(t)\right|$$

where:
x – coordinate along the pipeline
t – time
w – average velocity of liquid
E – elasticity modulus of liquid-pipeline system
ρ – liquid density
α – inclination angle of the pipe.

Apart of the physical models some neural, additive, fuzzy, swarm particles models are used, sometimes supported by data mining methods [4]. They do not need precise information about the pipeline, so they are suitable in all cases when the leak detection system has to be installed in old pipelines.

Almost all methods are based on the constant comparison of the measured and calculated data. If the differences (residua) override a certain limit the alarm is generated and localization procedures are started.

The algorithms of leak detection and localization are very sensitive to the data discontinuity, fluctuations of measuring signals, resulting from instruments noise, uncertainty [5] and systematic errors of the instruments. The quality of the measurement data is therefore of greatest importance. It is evident, that bad quality of the data will strongly influence the leak detection systems and can generate false alarms which can be as dangerous as the leak itself – the dispatcher cease to react even to the real leak alarms.

2. Discontinuity of the data

The data acquired from the telemetry or SCADA system usually contain a lot of discontinuities.

The discontinuities are particularly frequent in the systems based on the GPRS connection, usually when the network is overloaded or the distance from the nearest antenna is great. Fig. 1 presents the example of data (pressures) from one of the gas metering and regulating stations installed in the gas pipelines system – object of the research.

The number of discontinuities can be great, sometimes up to 30 – 35 % of all measurements. In case of data lack, the data from telemetry system has to be replaced by the approximated values. This can be fulfilled by the linear approximation – the straight line is calculated from the previous data with the use of least squares method.

In case of long data absence the reconstruction is however suspended and the signal is no more taken into account by the leak detection system (Fig. 1).

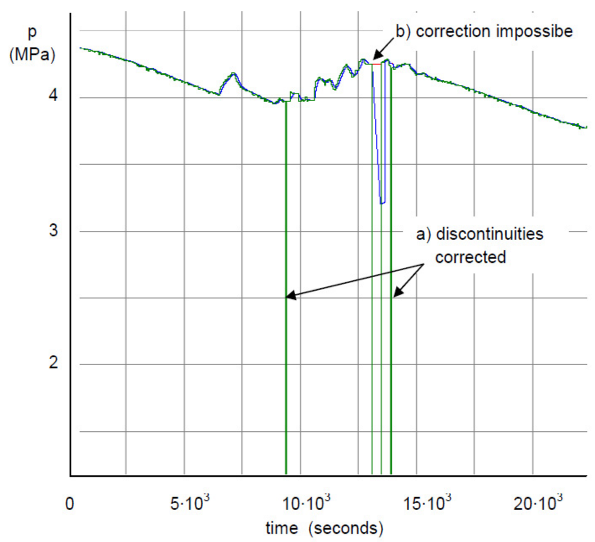

Fig. 1. Pressure signal transmitted from the gas pipeline, possibilities of the signal correction

Another example, for liquid pipeline, is presented in Fig. 2. This is an example of dedicated (not public, as in case of GPRS) telemetry system. The temporary disturbances are occasional, but even the short-lived disturbance of the signal used by the system can induce false alarms or leak localization faults.

The changes of the operational conditions i.e. change of the pumped medium, switching the sending/receiving tank (see Fig. 2), start or stop of the compressor in gas compressor station change the parameters of the pipeline system. It can have negative influence on the performance of the leak detection system.

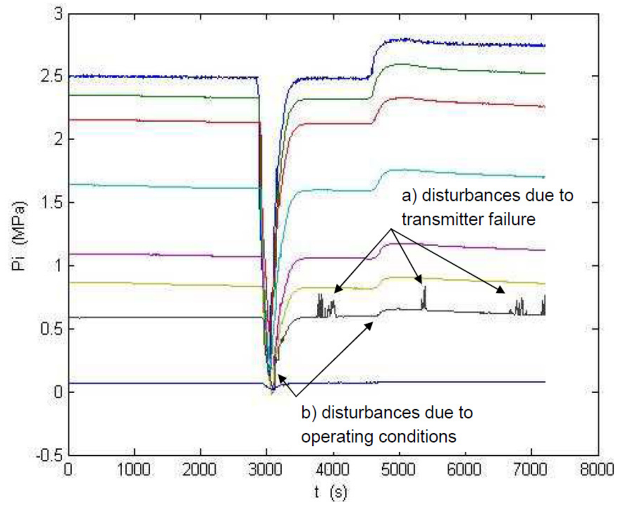

Fig. 2. Disturbances of signals from 8 pressure transmitters installed in subsequent places on the liquid pipe

The system should recognize, identify and distinguish between the disturbances due to operational conditions (i.e. starting or stopping pumping) and disturbances due to measuring transmitter failure.

The measuring signals recognized as wrong, are eliminated from the leak detection process whereas occurrence of signal disturbances identified as caused by operational maneuvers need special treatment by the detection and localization algorithms. The identification of wrong signals is based on the observation of the momentary changes of the measured parameters ant their comparison with the values calculated from the model. The parameters witch have the values out of typical for the pipeline parameter ranges are rejected, as well as the values which speed of change is to high and not justified by the operational changes of pipeline parameters. The exclusion of the wrong transmitters can be fulfilled automatically or manually.

3. Transmitter calibration problems

The serious problem is a bad calibration of the pressure transmitters. Sometimes the offset of the transmitter signal may caused that positive changes of pressure along the pipeline are observed, what is contradictory to the fundamentals of physics. In such cases the transmitter characteristics can be corrected with the use of the model data.

It must be underlined that each calibration (which is seen by the system as the rapid pressure change) must be done in close cooperation with the detection system supervisor, which has to temporary exclude the calibrated transmitter from the system.

4 Efficiency of the filtration methods

Before the measuring signals are utilized through the system they have to be filtered to decrease the noise influence to the system efficiency. The various low pass filters were considered but the time averaging of the signals at various time constants has been proved as very useful. Such averaging can be written in the form

$$y = \frac{\sum_{i=0}^{n-1} x(k-i)}{n}$$

where n – number of averaged samples; multiplied by sampling interval represents averaging time constant, x – input signal, y – filtered signal.

The effects of such data processing is presented in Fig. 3.

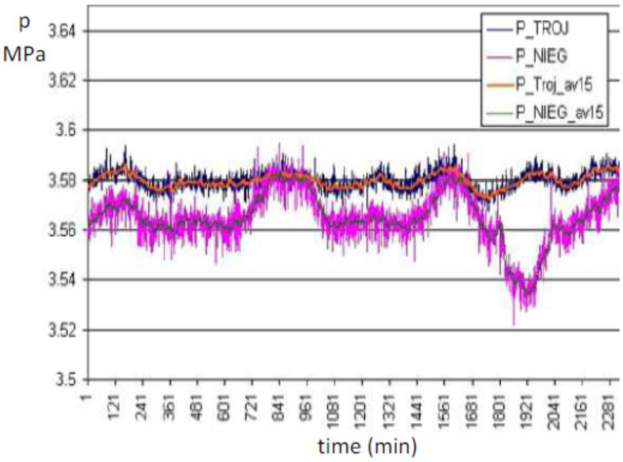

Fig. 3 Diagram of the pressures at two gas station, rough and averaged. Averaging with time constant 15 s

The most effective method for liquid pipes was the double filtration with time averaging wit the use of time constant 1 s and 10 s.

Lower time constant (1 s) was used to detect the occurrence of the leak fast and the higher (10 s) – to stabilize measurement results for the purpose of precise leak localization.

5. Tunning of the model

The data introduced in the model is never perfect. During operation i.e. the roughness of the pipeline due to corrosion or dirt can change (so the friction coefficient λ also changes).

The system need therefore permanent tunning to assure consistency between model and the real pipeline system. The method of tunning can be described as follows:

a) During stable state of the pipeline (constant flow, no technological operations) the values of the friction coefficients should be permanently computed from the formula (4). They should be calculated for subsequent pipe sections between pressure measurement points.

$$\lambda_i = \frac{2D}{\rho w^2 L_i}\left[(p_i - p_{i+1}) + \rho g(h_i - h_{i+1})\right]$$

where D – internal pipe diameter L_i – length of pipeline section, g – acceleration due to the gravity, ρ – density, p – pressure, w – fluid velocity, h – height, subscript i – number of the pipeline section.

b) For the calculation of the friction coefficient the mean values of the pressures and velocities for the period equal about the time of stabilization of the disturbances propagation in the pipeline should be used.

c) Periodically, during stable conditions, the consistency between model data and measured data for subsequent pressure measurement points should be checked.

d) In case of recognition in the section i the difference between calculated and measured pressure greater then the accepted threshold value dP, the friction coefficient λ in the i-th section should be corrected. The threshold value should be determined taking into account the normally existing pressure variations.

In order to do not overlook the real leak in each step only the small part of the correction should be introduced, according to the recursive formula (5) with the coefficient ζ which can be equal i.e. 0.01.

$$\lambda_i = \varsigma\lambda_{i-1} + (1-\varsigma)\lambda_i \tag{5}$$

During such procedure of tunning, despite only the value of the friction coefficient l is modified, all the slowly changing parameters i.e. instrumentation drift between calibrations, are compensated.

6. Imbalance

Parallel to the analysis of the pressure distribution in the system the balance of the fluid flowing in and out of the system should be monitored. For this purpose some index proposed in [6] should be calculated; in case of gas according to the formula (6):

$$\tau(t) = \Delta V_{st,in}(t) - \sum_{i=1}^{n} \Delta V_{st,out}(t) - V_{st,acc}(t)$$

The variable t(t) can be called corrected flow imbalance at the moment t. This is the difference between the volume of gas flowing into the pipeline system D$V_{n,in}(t)$ and the volume that has flown out of the system $\sum_{i=1}^{n} \Delta V_{s,out}(t)$ (n is the number of output stations), minus the volume of the gas accumulated in the pipeline $V_{st,acc}(t)$; subscript st denotes standard conditions. The term $V_{st,acc}(t)$ depends on the gas temperature, pressure and composition and can be calculated with the use of the formula

$$V_{n,acc}(t) = V_g \rho_{st} \frac{p_{avg} T_{st}}{p_{st} T Z}$$

where V_g is the geometrical volume of the pipeline system, T absolute temperature. and p_{avg}, average pressure in the pipeline section can be calculated as

$$p_{avg} = \frac{2}{3}\left(p_i + \frac{p_{i+1}^2}{p_i + p_{i+1}}\right) \tag{8}$$

Calculation of the $\tau(t)$ can give important information about the leak intensity, which can be used as input parameter in some procedures of leak localization. This parameter fluctuates about some medium value m, mainly due to the instruments drift, gas meters systematic errors (changing with the flow rate) or uncontrolled temperature changes. These fluctuations can be characterized with the variance σ^2. Let us denote the momentary deviation from the mean value m, as Δm. Than, the cumulative sum $\alpha(t)$ given by the formula (8) can constitute one of the criterions of alarm generation when it excess some level, an adequate procedure has been presented in [6]. This level can vary depending of the state of the pipeline, in steady state it can be rather low, and during the technological operations generating instabilities, transients etc. it can be set to the higher value.

$$\alpha(t)=\alpha(t-1)+\frac{\Delta m}{\sigma^2}\left(\tau(t)-m-\frac{\Delta m}{2}\right) \quad (9)$$

During the research authors have encountered difficulties trying to make the use of the formulae (6) and (9). Both the differences between the incoming and outgoing flow rate and the cumulative sum exceeded significantly the expected values (fig. 4).

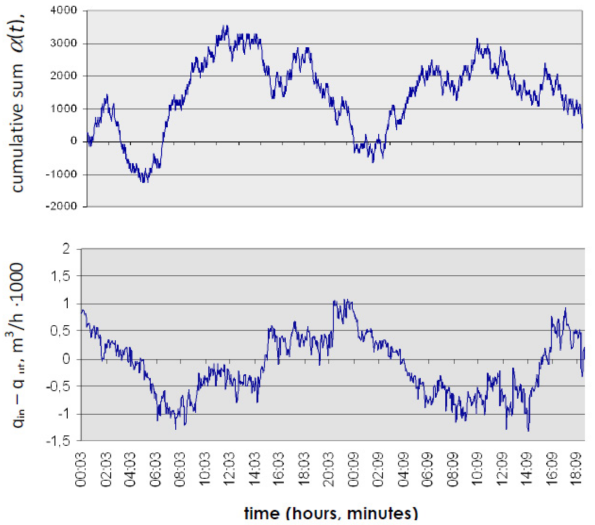

Fig. 4. Cumulative sum (upper diagram) and difference between incoming and outgoing flow rate of gas (lower diagram)

The excessive values were attributed to the improper temperature measurement method, because they were strongly correlated with the day/night cycle. Probably the inventory volume of the gas in the pipeline was therefore calculated not correctly.

7. Temperature measurement

Temperature influences the density and viscosity, so Reynolds number and in consequence friction coefficient λ. It also influences the inventory volume of the fluid in the pipeline and can be the source of problems described in previous chapter.

The problem is the right localization of temperature sensor. The natural place is the valve system, usually situated above the ground level. Especially for gas it can be source of significant errors. Because of low gas heat transfer coefficient measured temperature in winter is lower than the actual temperature of gas, and in summer – higher.

The simulation of the gas temperature distribution with the use of Computational Fluid Dynamics (CFD) is presented in Fig. 5.

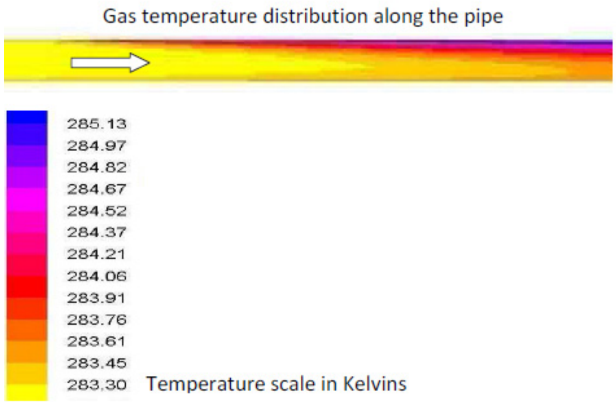

Fig. 5. CFD simulation of the gas temperature in the pipeline heated in the upper part to t = 40 °C (313 K), by solar radiation, temperature of the incoming gas is 10 °C (283 K)

The temperature difference between gas flowing under ground can differ from that measured above the soil up to several degrees.

Underground installation of the temperature sensors may be a solution, as shown in Fig. 6.

Fig. 6. Superficial temperature sensor and the method of its installation

The new temperature sensors have been installed during upgrading the measurements instruments of a gas pipeline to make it possible installation of the leak detection system. Because it would be very costly to install the thermowell in the pipe under pressure (gas transport can not be interrupted), the surface temperature sensors were chosen. The sensors must be isolated, both against the moisture and thermally.

Probably the excessive changes of the difference between incoming and outgoing gas presented in Fig. 4 were due to the improper temperature sensor installation.

8. Conclusions

This paper can seem discouraging for the potential user or designer of the leak detection and localization systems, but most of the problems can be kept to a minimum or even eliminated during implementing such systems.

In most of cases the existing, dedicated for the routine maintenance, measurement and telemetry system have to be retrofitted to comply with the needs of the leak detection and localization system.

The short discontinuities of the signal can be eliminated by extrapolation of the previous data, the longer discontinuities, however, demand the exclusion of the measured parameter from the system.

The bad calibration of the measuring transmitters can be corrected in some extent, with the use of model data. The operator of the Leak Detection System must however close cooperate with pipeline operator, it concerns mainly the procedures of calibration of field transmitters, because the currently calibrated transmitters should be ignored by the system.

The slowly changing parameters, as instrumentation drift, changes of pipe roughness etc. can be compensated by the tunning of the model.

The manner of the installation of temperature sensors may have important influence on the system performance. It is preferable to install the temperature sensors underground, because the temperature measured above ground may be not representative, it concerns mainly gas pipelines. The use of the superficial sensors makes it possible the retrofitting easily and without disturbances of gas supply.

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AUTHORS:

Mateusz Turkowski* – professor in the Institute of Metrology and Biomedical Engineering, Warsaw University of Technology, ul. św. A. Boboli 8, 02-525 Warsaw, Poland, m.turkowski@mchtr.pw.edu.pl

Andrzej Bratek – Industrial Research Institute for Automation and Measurements, Al. Jerozolimskie 202, 02-486 Warsaw, Poland, abratek@piap.pl

*Corresponding author

References:

[1] M. Turkowski, A. Bratek, M. Słowikowski, "Methods and Systems for leakage detection in long range pipelines", *Journal of Automation, Mobile Robotics and Intelligent Systems*, vol. 1, no. 3, 2007, pp. 39-46.

[2] M. Turkowski, A. Bratek, M. Słowikowski, "The improvement of pipeline mathematical model for the purposes of leak detection". In: *Recent Advances in Mechatronics – 7th International Conference Mechatronics*, Warsaw, Poland, 2007, pp. 573-577.

[3] R. Sobczak, M. Turkowski, A. Bratek, M. Słowikowski, "Mathematical modeling of liquid flow dynamics in long range transfer pipelines". In: *Problemy eksploatacji*, Part 1, ITE, Radom, 2007.

[4] J.M.Kościelny, M. Syfert, Ł. Tabor, "Sequential Residual Design Method for Linear Systems". In: *Conference on Control and Fault-Tolerant Systems SysTol'10*, Nice, France, 2010.

[5] A. Bogucki, M. Turkowski, "The influence of the measuring instruments accuracy on the reliability of the leak detection and localization systems". IN: ACADEMIC NETWORK EVENT at EGATEC2011, The European Gas Research Group, Copenhagen, Denmark, 12th-13th May 2011.

[6] R. Beuhausen *et al*., "Transient leak detection in crude oil pipelines". In: *Proceedings of International Pipeline Conference*, 4th–8th October, 2004 Calgary, Alberta, Canada.