Methods and Systems of Leak Detection in Long Range Pipelines

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Abstract:

No matter how carefully the pipeline is designed and built, there is always a probability of leaks. Pipeline leak detection systems play therefore a key role in minimization of the occurrence of leaks probability and their impacts. As the vast assortment of technologies is available today, the paper provides the background information to facilitate the choice of leak-detection system. The paper deals with external methods based on external measurements and with some internal methods based on flow and pressure measurements in the pipeline: pressure wave detection and volume balance method; then gradient and analytical methods were described. Additionally, the discussion of error sources and final conclusions are presented.

Keywords: leak detection, leak localization, integrity of pipelines, transport pipelines, pipelines safety

1. Introduction

Construction of the transport pipeline is always very costly. Therefore all stages of its building (beginning with a project, and finishing with the tests and commissioning) and operating must fulfill the regulations and recommendations of numerous standards and regulations [1], which purpose is to provide long-lasting operation of pipeline system.

The damages may be caused by corrosion or erosion (Fig. 1) of external and internal walls, inhomogeneity or crack of the welds, indentation of the walls and material defects. Counteraction may consist in installing cathodic protection systems (earlier passive, but nowadays predominantly active, under surveillance of the telemetry system).
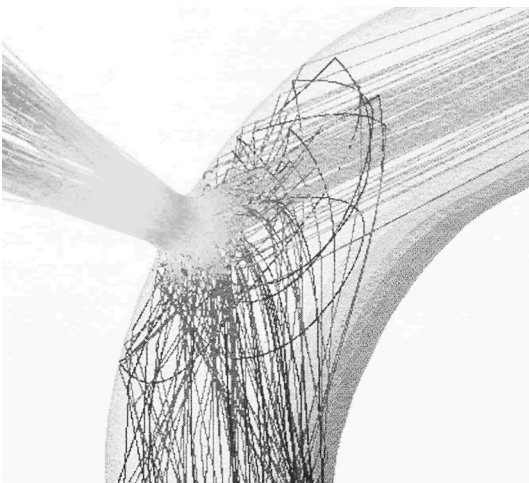

Fig. 1. Numerical visualization of the leak caused by erosion [2].

Fig. 2. Consequences of inattentive diggings [3].

Degradation of the pipeline material may occur as a result of stresses alterations that are caused by changes of the pressure and the deformations of the pipeline caused by the soil dislocations, which lead to the fatigue and forming of the micro-gaps.

During operation periodical inspections of the pipeline condition are carried out with the use of so-called intelligent pistons, it enables to detect and localize damages or leaks at a very early stage of development.

Despite of that the occurrence of leaks is rather inevitable. They are caused by oversight or by underestimating progress of the specific defects during the tests. However, considerably more often damages are caused by people operations: accidental - careless diggings (Fig. 2), building or repair works in the proximity of the pipeline, or conscious - i.e. illegal stealing of the transported media. Also possible terrorist attacks cannot be neglected.

The leak brings always large and various losses: suspending of the product or material transport, the cost of the damage reparation and loss of transported product. In case of explosive or/and flammable or/and dangerous to environment media (e.g. petroleum and other oil products), the leak causes hazard for safety of the people and the equipment (including the pumping installation), as well as an environmental contamination. Events like that induce high social and financial costs, which are proportional to the intensity and duration of the leak. The recultivation costs of the polluted ground may reach several millions euro.

If a leak happened, then its effects can be minimized only by extremely fast detection and localization of the leak point and quick dispatcher reaction (stopping pum-

ping, closing the valves, organizing provisional damage repair etc.)

Damages of pipelines transporting natural gas are not neutral for environment as well. Methane, the main component of natural gas - is one of the greenhouse gases. Moreover, natural gas mixed with atmospheric air in amount 4-15% becomes very sensitive for sparkling or flame, causing an explosion of this mixture - as is shown in the Fig. 3.

Fig. 3. Burning pipeline a water curtain is applied. Photo by M. Turkowski.

Particularly dangerous leaks of a gas pipeline happen in the winter. Under frozen crust of the earth gas may penetrate in long distance, and an explosion may happen in quite unexpected places.

That is why for over 30 years research in the domain of leak detection and localization systems is carried out all over the world. Leak detection problems in single segments of pipeline in the steady state are generally solved. Up to now, however, a universal reliable system, which can work in every operating condition, for every pipeline system and during transients does not exist. Therefore, the issue of leak detection will be probably topical for a long time. Complications came from fact that individual pipelines differ from each other, and in each case one has to place special emphasis on totally different circumstances, which are crucial for given detection system.

The examples of such differences between gas and liquid pipelines are presented in table 1.

Configuration of liquid pipeline is usually quite simple - most often we have a single pipeline, starting at the supplier and ending at the recipient of medium, the branches are rather rare. A uniform gasification of an area requires however much more complicated configurations. It is clearly shown on the maps at the websites of gas and liquid pipelines operators [4, 5].

The inertia of a fluid has not great influence on the gas pipelines because of the low gas density (unless sudden and big changes of demand or very high pressures and diameters of the pipe), whereas the inertia can never be omitted in case of liquid pipelines.

The medium compressibility has great influence in the case of gas pipelines and it is less important for liquid pipelines. Liquid compressibility joined with elastic deformations of pipeline lead however to sustained (tens of minutes) transient states after technological operations (start of pumping, valves operations), which may cause a water hammer phenomenon. Compressibility is less significant for stationary flows.

The flow rate in liquid pipelines is usually constant, close to the nominal flow rate, limited by pumps efficiency and by pressure drop along the pipeline. In gas pipelines the flow rate is a function of gas demand, on which gas supplier does not have much influence. Gas demand is variable during twenty-four hours cycle (rising within a day) and during the year (rising within low temperature periods).

Table 1. The influence of various factors on pipeline behavior and leak detection systems in liquids and gas pipelines.

Nr	Criterion	Liquid	Gas
1	complication level of the pipeline system	not large	large (except wide-ranging transit-pipelines)
2	inertia of liquid	large	small
3	compressibility of medium	small	large
4	elastic deformations of the pipeline caused by changes of pressure	large	small
5	variability of flow	steady, near to nominal (except the transient states)	various between day and night and depending on the season
6	continuity of work	interrupted flow	constant flow
7	presence of the second phase	large influence	small influence

Liquid pipeline can be switched on and off periodically, depending on contracts between the supplier and the recipient. On the contrary, a gas pipeline once started should be operated continuously for all operating time (often for several dozen years), excepting possible failures.

Presence of gas inclusions in liquid have a fundamental effect on liquid compressibility (1% of gas inclusions in form of uniformly spaced tiny bubbles can multiply compressibility of such mixture even several hundreds times), whereas similar content of liquid aerosol in gas may be neglected from the point of view of detection system.

The table 1 refers also to plant technological pipelines, they are however much shorter than long-range transport pipelines, and because of that the influence of some factors may be omitted.

2. Tasks and general classification of the leak detection and localization methods

Detection of the gas pipelines leaks system should comply three following tasks:
- Leak detection.
- Alarm generation.
- Leak localization.
- Estimation of the flow rate of leaking medium.

Very important factor, which decides on usefulness of the method and detection algorithm, equivalent to sensibility for real damages, is also resistance to disturbances. That means non-generation of false alarms, i.e. caused by technological operation (starting/stopping compressor/pump, change of supply tank, change of the type of transported medium, closing/opening valves, changing receiving tanks).

The methods of leak detection may be divided into two general categories [6, 7]:
- Direct (external) - the detection is done from outside the pipe through application of specialized sensors or visual observation.
- Indirect (analytical, internal) - the detection is based on measurements and analysis of flow parameters (mainly pressure and fluid flow rate/velocity, sometimes temperature and density).

Indirect methods may be divided into three categories:
- Based on detection of the acoustic wave caused by the leak.
- Based on mass balance concept, taking into consideration accumulation.
- Analytical - based on mathematical model and measurement of an object acquired from telemetry or SCADA system - these methods consist in pipeline modeling in real time, and continuous comparison of the model with the object.

3. Direct methods

Conventional direct methods are so-called **network rounds** combined with visual observation of the area and, if possible, sensing with portable detectors of transported medium. Better results may be obtained with help of trained dogs that can trace amounts of leaking medium. The use of the helicopters can give faster but less accurate information.

Acoustic methods [8] are based on detection of noise generated by leak. They request the installation of acoustic sensors (specialized microphones with wide band of transmission) along the pipeline. The noise is then analyzed to identify what causes it - leak or maybe another phenomenon. During system activation the background noise is analyzed, which makes easier the identification of noise caused by leaks. Acoustic methods enable leaks detection as small as 4 dm^3/h for liquids and 40 dm^3/h for gases, the sensors must however be spaced at short distance one from another - not greater that several hundred meters. Moreover, in cases of large turbulent flows, the leaks effect may be affected by background noise generated by the turbulence.

Cable sensors are composed of two circuits [8] (Fig. 4). One of them is a continuity circuit monitoring condition of the cable (checking possible physical damages). The second one - the alarm circuit - is a normally open circuit, shorting only in the case of a leak. There is a possibility to use various mechanisms. If transported medium is conductive, the short happens naturally, because the conductive liquid facilitates current flow between the cables. For hydrocarbons a special polymer is used as insulation. The polymer degrades in the presence of the hydrocarbons allowing the cables to touch. Measurement of voltage drops in the circuits enables to pinpoint the position of the leak.
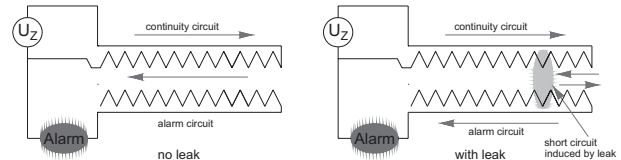

Fig. 4. Cable leak sensor.

A **concentric cable** with a hydrocarbons permeable insulation can also be used. If hydrocarbons penetrate a cable after leak, the impedance of the cable changes locally. An electromagnetic pulse is sent down to detect an impedance change. The change of impedance alters the echoes returning to the detection system and triggers an alarm.

An optical wave-guide situated along a pipeline is in fact an intrinsic detector reacting for local temperature changes. As a result of adiabatic expansion (Joule-Thompson effect), drop in temperature appears in pipelines at the leak points. **Optical** wave-guide let also determine the temperature profile along the pipeline that makes possible to localize the position of the leak. This method cannot be used for liquids. Cable sensors are suitable rather for use in short plant piping and are not practical for long-range pipelines.

4. Methods based on pressure wave detection

This is one of the indirect methods. Fig. 5 presents how gas pressure and flow rate along the pipeline are changing after a leak has happened.
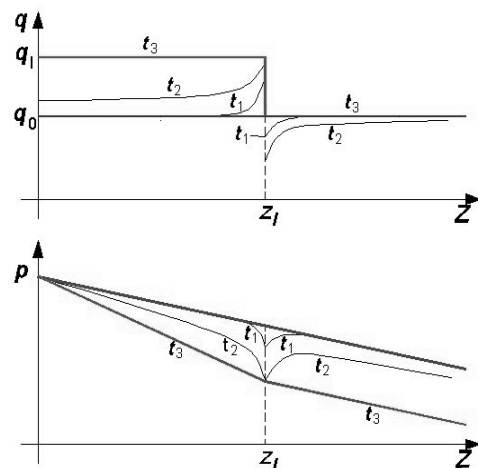

Fig. 5. Gas pressure and flow rate after the leak.

At the initial instant (t_1) at the leak point a rapid

pressure drop occurs, which propagate to both sides of the pipeline. The flow rate just upstream the leak point increases, downstream this point decreases. The pressure wave propagates with the sound speed. The gas mass flow rate increases upstream the leak point (instant t_2), whereas downstream this point it increases on a while, and then goes back to the primary value. After several minutes the new state of the pipeline can be observed (instant t_3). Upstream the leak point the mass flow rate increases by the value of flow rate of leaking gas, and downstream returns it to the primary value. Pressure gradient along the pipeline increases upstream the leak point, and downstream the pressure gradient returns to its initial value. Method based on pressure wave detection [9] and [10] consists in pressure measurements at the selected points distributed along the pipeline.

If quick pressure change caused by acoustic (pressure) wave appears, one have to verify, whether similar change will take place at subsequent points, and whether it appears in the time resulting from the acoustic velocity and the distance between measurement points.

Sufficient quick pressure transducers (precision is not most important) must be installed at several kilometers intervals (Fig. 6). To ensure precise synchronization of time measurement usually the satellite navigation system GPS is used. It generates an accurate time information based on atomic clocks installed at system satellites. This method is relatively fast (the leak detection and localization time is about few seconds.
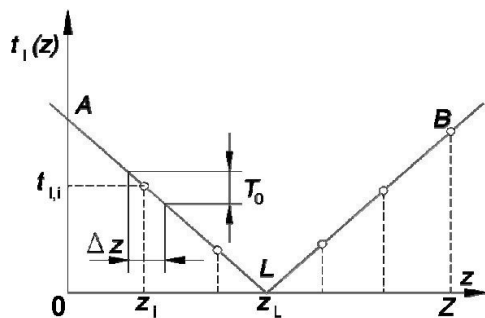

Fig. 6. Leak localization method based on pressure wave detection.

In the Fig. 6 the abscissa represents distance z from the beginning of pipeline 0; pressure sensors are installed at points z_i. Axis of ordinates represents acoustic wave propagation time t_l as a function of the distance from the leak point z_l. Fig. 7 presents the scheme of such system according to [11].

Leak point is calculated as intersection point L of A-L and L-B lines. Point A denotes the time of pressure wave front transition to pipeline beginning and point B - transition time of pressure wave to pipeline end. The accuracy of leak localization is about $(2-3)cT_0$, where T_0 is signal-sampling period. Therefore, signal-sampling period should be as short as possible, at least few times per second.

Elimination of the stochastic noise becomes possible by the use of various types of analogue or digital filters, and especially correlation methods [9]. If the leak is not detected immediately (as a result of temporary system failure, the leak will remain undetected forever. This

method makes it possible to detect and localize the leak, but it is impossible to assess directly the leak intensity unless the amplitudes of pressure waves will undergo further analysis.
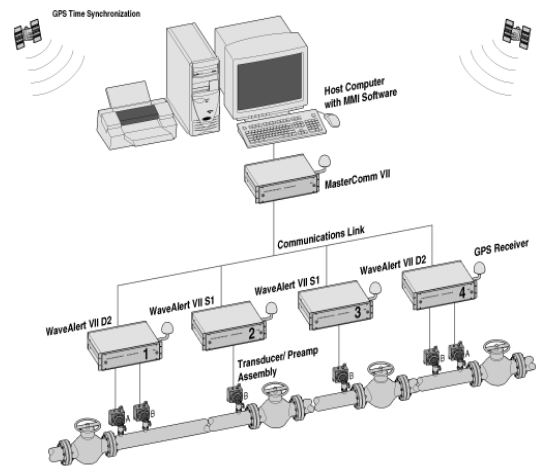

Fig. 7. Leak detection system based on pressure wave detection, acc. to [11].

5. A method based on mass balance concept

This concept of leak detection is based on mass conservation principle. The total quantity (mass, flow rate, volume) of fluid entering and leaving a network must be balanced by the inventory variation (accumulation) inside the network. This is apparently the simplest and most natural method. However, changes of liquid quantity, which depends on pressure and temperature, should be carefully considered. These changes are especially crucial for gas pipelines. Very important are also uncertainties and drift of flow, temperature and pressure transducers.

To apply this method is necessary to calculate step-by-step current value of certain variable $\tau(t)$ at regular sample intervals. For gas net with single input and n outputs (gas receiving stations), the variable $\tau(t)$ for standard conditions can be written as

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

This variable $\tau(t)$ may be defined as a corrected flow unbalance term at time t. This is the difference between the gas volume entering the pipeline $\Delta V_{n,in}(t)$ and the volume that flowed out from the pipeline

$$\sum_{i=1}^{n} \Delta V_{n,out}(t)$$

(where n is number of outputs, that is gas stations located along the pipeline), reduced by the volume of gas accumulated in the pipeline $V_{n,a}(t)$; index n denotes standard conditions.

Expression $V_{n,a}(t)$ represents changes of gas content in a pipeline. It depends on pressure, temperature and gas composition. Therefore, it can be written (without taking into account the pipe elastic strain) as follows

$$\Delta V_{n,a}(t) = V_g \varrho_n \frac{pT_n}{p_n TZ} \qquad (2)$$

and should be calculated step by step from the average temperature and pressure values for every pipe section

(branch). V_g is the geometrical volume of the pipeline, p and T - absolute pressure and temperature in the pipeline; index n as formerly, denotes standard conditions.

Parameter $\tau(t)$ usually fluctuates around the non-zero mean value m, due to drift of measurement instruments and gas meters errors (which depend on the flow rate) or as a result of changes of conditions (e.g. temperature along a pipeline). These fluctuations can be characterized by a σ^2 variance. Let us denote Δm the instantaneous deviations from average value. To generate a leak alarm the following cumulative sum is examined:

$$\alpha(t) = \alpha(t\text{-}1) + \frac{\Delta m}{\sigma^2}\left[\tau(t)\text{-}m\text{-}\frac{\Delta m}{2}\right] \qquad (3)$$

The alarm is generated when the sum $\alpha(t)$ exceeds the given value. This value should be determined experimentally and can be changed, i.e. during technological operations producing greater disturbances of flow parameters larger acceptable value $\alpha(t)$ is set.

To eliminate false alarms caused by slow drift of measurement transducers, one modifies m value very slowly, with the use of measurement data from periods without leaks.

For the reason of relative simplicity this method is often applied even for complicated pipe networks. However, direct localization of leak point is impossible; one only can localize a section (between two measurement points) in which a leak happened.

6. Gradient method

Contemporary analytical methods are developed from gradient methods [12, 13, 7]. Fig. 8 shows the pressure drop along the liquid pipeline before and after leak.
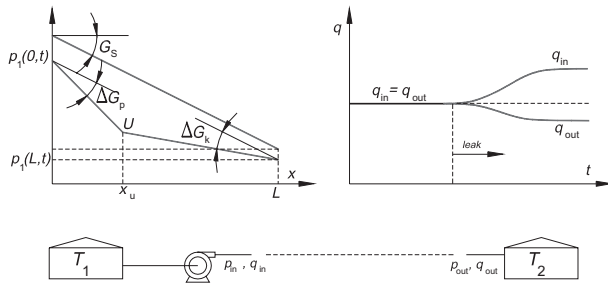

Fig. 8. Pressure drop along the liquid pipeline before and after leak.

Liquid is transported from a tank T_1 to tank T_2. In non-leak state the pressure gradient along the pipeline is constant, equal to G_s (blue line). When leak begins, after new conditions were established, one can observe following phenomena:

- The pressure drops both at the pipeline input and output,
- Increase of pressure gradient upstream the leak point,
- Decrease of pressure gradient downstream the leak point,
- Increase of flow rate upstream the leak point,
- Decrease of flow rate downstream the leak point.

Usually along a pipeline every several kilometers are situated shut-off valves assemblies, where pressure transducers integrated in the telemetry or SCADA system

are installed. They enable to calculate pressure gradients. The coordinate of the leak point x_u is then equal

$$x_u = L\left[1 + \frac{tanG_s}{\Delta tanG_k}\right]^{-2} \qquad (4)$$

The flow rate of the leak can be calculated from the formula

$$q_1 = q_0\left(1 - \sqrt{\frac{1 - \dfrac{\Delta G_k}{G_s}}{1 - \dfrac{\Delta G_p}{G_s}}}\right) \qquad (5)$$

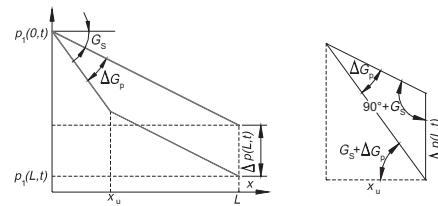The situation changes in some extent in the case of gas pipelines, that is shown in Fig. 9

Fig. 9. Pressure drop along the gas pipeline before and after leak.

Research carried out into gas pipelines [14] shows that at the beginning of a pipeline pressure drop are negligible (Fig. 9). There also is not a decrease of gas flow rate downstream the leak point because the pipeline ends with a gas regulating station. Such stations are very tolerant to changes of input pressure, so gas flow rate is only a function of gas demand. Pressure gradient downstream the leak point changes are not noticeable.

In situation like that one can approximately calculate the leak point coordinate from the formula [14]:

$$x_u = \Delta p(L,t)\frac{cosG_s sin(90°\text{-}G_s\text{-}\Delta G_p)}{sin\Delta G_p} \qquad (6)$$

Pure gradient methods are effective only in steady flow conditions, without disturbances caused by change of operating conditions.

7. Analytical methods

Basis of the analytical methods is modeling in the real time the phenomena inside a pipeline with the use of suitable mathematical models (modeling flow velocity as a function of pressure or pressure as a function of velocity), and comparison of the values calculated from the model with values acquired from the real pipeline. When the differences between the measured and calculated values (so called residua) are high, the alarm is generated and procedures of leak localization are activated.

Both static and dynamic models are acceptable, however it must be proceeded by careful analyze. For gas the static model based on conservation of mass principle (which can be written as continuity equation) and known from hydraulics formulas for pipelines [15] has a following form:

$$\rho wA = \rho q_v = q_m = const \qquad (7)$$

$$q_m = \frac{\pi D^2}{4} \sqrt{\frac{p_1^2 - p_2^2}{2ZRT\left[ln\dfrac{p_1}{p_2} + \dfrac{\lambda L}{2Dp}\right]}} \qquad (8)$$

where
q_m – stream of mass, kg/s
p_1 and p_2 – absolute pressure at input and output of the gas pipeline, Pa
D – inner diameter of the gas pipeline, m
Z – compressibility factor, dimensionless
R – gas constant, J/(kgK)
T – absolute temperature, K
L – length of modeled gas pipeline section, m
λ – linear losses factor.

A dynamic model for gas pipeline can be expressed by a set of partial differential equations, which may be derived from conservation of mass and conservation of momentum principles [7]

$$\frac{A}{c^2}\frac{\partial p}{\partial t} + \frac{\partial q}{\partial z} = 0 \qquad (9)$$

$$\frac{1}{A}\frac{\partial q}{\partial t} + \frac{\partial p}{\partial z} = -\frac{\lambda c^2}{2DA^2}\frac{q|q|}{p} - \frac{g\sin\alpha}{c^2}p \qquad (10)$$

The resolution of dynamic model demands large processor capacity and the calculations are time consuming. It is possible to check if the dynamic model is really necessary by calculating the value of the term related to the change of momentum in time, therefore

$$\frac{1}{A}\frac{\partial q_m}{\partial t} = \frac{1}{A}\frac{\partial(\rho q_v)}{\partial t} = \frac{\partial(\rho w)}{\partial t} \approx \frac{\Delta(\rho w)}{\Delta t} \qquad (11)$$

Comparing it with other terms of the equation. If its value is negligible, the simple static model (7,8) can be used.

For liquid pipelines, because of larger transported masses, usually dynamic model [6] has to be applied.

In order to describe the liquid pipeline dynamics for the modeling purposes the pipeline is arbitrarily divided into sections at x_i points where measuring transmitters were installed on the real pipeline. It enables the direct comparison of the variables values obtained by simulation with the real ones, recorded in the real pipeline. Additionally, each pipeline section between x_i and x_{i+1} points has to be divided into shorter, equal parts Δx_j.

Every segment fulfils a set of partial differential equations as a result of the law of mass and momentum conservation. In the case of a leak-proof pipeline (that is a pipeline for which neither mass decrement nor momentum decrement are observed) and taking into account that $w(x,t) << c$, where c is the sound speed, these equations, according to [6] can be written as

$$\frac{\partial w(x,t)}{\partial x} + \frac{1}{E}\frac{\partial p(x,t)}{\partial t} = 0 \qquad (12)$$

$$(13)$$
$$\frac{\partial p(x,t)}{\partial x} + \rho(x)\frac{\partial w(x,t)}{\partial t} = -\rho(x)g\sin\alpha - \frac{\lambda(x)\rho(x)}{2d}w(t)|w(t)|$$

and the sound speed of a liquid in a pipeline is given by formula commonly known [15] as Żukowski-Allevy formula:

$$c = \sqrt{\frac{E_C}{\rho(x)\left(1 + \dfrac{D}{b}\dfrac{E_C}{E_R}\right)}} \qquad (14)$$

where
E_C - the elasticity coefficient of a liquid (Pa),
E_R - the direct elasticity coefficient of a pipeline material (Young's modulus) (Pa),
b - the pipeline wall thickness (m),
D - the pipeline inner diameter (m),
$\lambda(x)$ - the pipe friction factor,
α - the angle of inclination of a pipeline segment.

The mathematical model should however also reconstruct as accurately as possible the static and dynamic characteristics of all other elements of a pipeline system as well as interactions between these elements [17].

No matter if a model is static, dynamic, for liquid or gas, it should be completed with procedure of pipe friction factor λ calculation. It is a function of roughness k and the Reynolds number Re. In cases of more complex pipeline system the Moody formula can be very useful for its simplicity. It has a form

$$\lambda = 0.0055\left[1 + 10\left(10k + \frac{10^3}{Re}\right)^{\frac{1}{3}}\right] \qquad (15)$$

When large residua (differences between the model and the real object) occur, the localization procedure is activated. There are few methods. Usually a leak is introduced in the model and by successive approximations of its localization and intensity is matched to get compatibility of a model with a real pipeline again, or in another words minimize the residua. The use of gradient method is also possible for leak localization as far as the measurement system allows the pressure gradient determination.

8. Error sources for various methods of leak detection, and how to reduce them

In case of analytical methods a fundamental source of errors are uncertainties of liquid properties measurement or calculation. True liquid properties (density, flow resistance) may differ from properties used to calculation. Uncertainties of density calculation or measurement and of pipe diameter measurements have a direct influence on model precision. Moreover, uncertainties of viscosity, diameter and pipeline roughness assessment affects λ indirectly.

Gas inclusion in liquid has a radical effect on an elasticity module of liquid - pipeline system, downgrading vitally model precision. Gas bubbles in *circa* 1% quantity of whole volume can increase even several hundreds times compressibility of such mixture. Liquid

phase inclusions in gas are not so important, although they should not be disregarded in case of large quantity of liquid phase in gas.

Next errors source is due to the fact that the temperature along the pipeline is not constant. Temperature of the ground changes, influencing the density and viscosity. The temperature depends on ambient temperature and other conditions such thermal conductivity of the ground (wet - dry), so from the weather. Computed density and pipe friction coefficient values for temperature measured at pipe ends may then differ from real values.

Obvious source is uncertainty, especially instability (drift) of measurement transducers.

Data entered into a model are always charged by some errors - so data correction is a necessity. The criterion of correction is the residua minimization. The data should be corrected as often as possible (always, when we know that there is no leak and in steady state).

In each step one should introduce only little correction. Usually the recursive formulas are applied for this purpose. Although physically the corrected parameter is usually the pipe friction factor λ, in fact all slowly varying factors (i.e. instrumentation drift) are corrected.

9. Summary

Every detection method has its advantages and disadvantages. For example, sensitivity of analytical methods increases dramatically together with increase of the flow rate in a pipeline, as a consequence of square relationship between the pressure drop and the flow rate, which is shown in the Fig. 10.
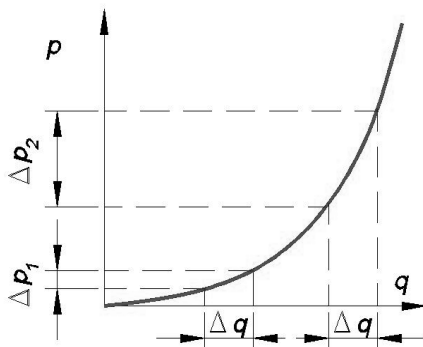

Fig. 10. Effects caused by the same leak for various flow rates as pressure drop changes.

At larger values of flow rate effects of leak (pressure change Δp_2), caused by an leak of value Δq, are distinct, while at small flow rate this effect (Δp_1), caused by identical leak, is significantly smaller and the threshold of detection ability, and detection errors could achieve dozens % [14].

For low flow rates probably the method based on mass balance concept would be better. However, with the use of this method the precise localization of leak is difficult. Methods based on pressure (acoustic) wave detection demands special measurement and instrumentation solutions (hydrophones) destined only for this purpose, while analytical methods can use measurement instruments already installed in the pipeline for operating purposes. The advantage of pressure wave method (in comparison with analytical or mass balance method) is however little

requirements for precision of measurement equipment. Moreover, the particular information about pipeline parameters (accurate diameters, roughness, etc. (that for old pipes are hard to obtain) is not necessary. On the other side the pressure wave system needs high frequency of sampling - the precision of the method is then greater. As the acoustic wave methods have greater sensibility to disturbances they have been successfully implemented in long transmission pipelines without branches along the pipeline, pumps or compressors stations [11]. For more complex pipelines systems with branches, pumps or compressors the method at the present level of development and state of the art does not give satisfactory effects because of false alarms generation. However, consecutive researches are carried out in this field with the use of correlation techniques. Acoustic methods have another serious defect: if one overlooks the beginning of damage, one will never find it out by this method.

For the reasons described above the most effective systems of leak detection and localization can be built through joining various described above concepts, operating in parallel.

At present there are a lot of commercial systems of leak detection and localization. Before one takes a selection decision it is worth to formulate a set of control questions to the system supplier, which depends on configuration and operating conditions of a given pipeline. For example, the most important technical questions are:
- What leak intensity can be detected using the given method?
- How much time passes between the leak and detection of it?
- Is the system able to localize leak point, and if yes with what precision?
- Is the system able to determine leak intensity, with what precision?
- Is the system able to detect earlier existing leaks or only the new ones?
- Does the system function in pipeline section between two closed valves or in case of lack of flow in the pipeline?
- Does the system function for more complicated networks (branched configurations, with many of medium input and output points), or for simple pipe sections only?
- Does the system function during transients - technological operations i.e. turning on/off compressor/pump, opening/closing the valves, switching supply/receiving tanks from one to another, or only in steady state?
- How often false alarms are generated by the system (especially in described over conditions)?
- Could the system be installed retrofitting) on already existing pipeline, and which additional equipment is necessary?

Next group of questions is connected with economical point of view:
- How high is the cost of the complete system installation (including necessary additional instrumentation)?
- Operating costs, calibration and tuning frequency, etc.

Because of every system has some disadvantages, it is worthwhile to install two systems working in parallel, complementing one another. For example, analytical method for large flows could be supplemented by mass balance method in cases of small flows. It applies particularly pipelines for transmission of expensive or dangerous (because of its explosive properties, or because of possibility environmental contamination) media.

Since 2005 authors of this paper carry out research on relatively difficult cases (from the point of view of leak detection system). Examples for liquid pipelines are transient states of any kind, transport of two or more media of different properties through the same pipeline one bath after another, or leak detection during pipeline standstill. Examples for gas pipelines are pipeline systems with complicated, branched structure and com pressor stations. Results of these researches will be published soon.

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References
[1] Michałowski Witold S., Trzop S., *Rurociągi dalekiego zasięgu* [Long-range pipelines], edition V, Warszawa: Odysseum Foundation, 2006.
[2] Peters J., "Guidance on erosion in pipework", *Flow Tidings*, issue 38, summer 2003.
[3] Gros M., *Leak and shock detection*. Cybernetics, Marseilles. Presentation at the expert meeting, Brussels, Jan. 2006.
[4] Web site of company PERN "Przyjaźń" SA www.pern.com.pl.
[5] Web site of Gas Transmission Operator "Gaz-System" SA www.gaz-system.com.pl .
[6] Bilman L., Isermann R.: „Leak detection methods for pipelines", *Automatica*, vol.23, 1987, no. 3, pp. 381-385.
[7] Kowalczuk Z., Gunawickrama K., "Detekcja i lokalizacja wycieków w rurociągach przemysłowych" [Detection and localization of leakages in industrial pipelines], Chapter 21 of the monograph edited by J. Korbicz and J.M. Kościelny, Warszawa: WNT Publishing House, 2002.
[8] Glen N.F., *A review of pipeline integrity systems*, Report No 2005/257, National Engineering Laboratory, East Kilbridge, 2005.
[9] Siebert H., Isermann R.: "Leckerkennung und Lokalisierung bei Pipelines durch on- line Korrelation mit einen Prozesrechnes", *Regelungstechnik*, 1977, nr 3 (25), pp. 69-74.
[10] Sobczak R., "Lokalizacja nieszczelności w rurociągach metodą śledzenia czół fal ciśnienia" [Localization of the detections in the pipelines through front faces method] *Przemysł Chemiczny*, no. 6/04, edition JCR.
[11] Technology and Qualifications Acoustic Systems Incorporated Whithorn Dr. Houston, Texas, USA www.wavealert.com.
[12] R. Sobczak, "Detekcja wycieków z rurociągów magistralnych cieczy" [Detection of the leakages from fluid arterial pipelines], *Nafta. Gaz*, 2001, no. 2, pp. 97-107
[13] R. Sobczak, "Gradientowa metoda lokalizacji nieszczelności w rurociągach magistralnych" [The gradient method of leakages' detection for arterial pipelines], *Przemysł Chemiczny*, nr 10/02 edycja JCR.
[14] Turkowski M., "Metody detekcji i lokalizacji nieszczelności rurociągów" [Detection and localization of pipelines' leakages methods], Proceedings of the conference *Technika opomiarowania gazu dziś i jutro TOp-Gaz*, Rogów, www.common.pl/aktu_rogow.html, 19-21.09. 2005, pp. 179-194.
[15] M. Mitosek M., *Mechanika płynów w inżynierii środowiska* [Fluid mechanics in environmental engineering], Oficyna Wydawnicza PW, Warszawa, 1997.
[16] L. Bilman, R. Isermann: „Leak detection methods for pipelines", *Automatica*, vol.23, no. 3, s. 381-385, 1987.
[17] Sobczak R., Turkowski M., Bratek A., Słowikowski M., Report of research project nr 3 T09D 033 27 entitled *Opracowanie systemu detekcji nieszczelności w rurociągach magistralnych ograniczającego zagrożenie środowiska wyciekiem paliw ciekłych i gazowych* [Developing leakages' detection system restricting natural environment for arterial pipelines], Warszawa, 2006.