# Measurement of natural gas pipeline hydraulic parameters in the course of operation

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**Content**



## 1 Why is the familiarity with real values of friction factor so important?

Hydraulic parameters of pipeline, represented by the friction factor $\lambda$, are one of the basic factors both in the time of designing, and in the course of the operation of gas pipelines.

Proper definition of friction factor value for individual parts of pipeline is very important when designing new pipeline. This value defines the pressure drop of pipeline at individual operation conditions. The pressure drop at maximum gas flow is the basic information for the definition of compressor power installed at individual compressor stations. Considering the huge investment costs on compressor station construction, we will really appreciate the importance of familiarity with hydraulic parameters of the pipeline.

The knowledge of friction factor value for individual pipeline parts is important also in the course of pipeline operation. From this value and particularly from the changes of this value, one can evaluate the state of inner pipeline wall, the presence of liquid or solid impurities, i.e. when evaluating the effect of regular pipeline pigging. Since during the pigging the gas losses are not negligible (when the pig is approaching the end of pipeline, the gas is vented to atmosphere), it is important to optimize the frequency of the pigging. The best base for this optimization is the increase of friction factor value above the optimizing limit.

Thus the results of friction factor measurement are the base not only for the definition of the most probable value of hydraulic resistance when designing new gas pipeline, but also it can make possible to estimate the changes of hydraulic behavior of pipeline in the course of pipeline operation. This detailed information affects the accuracy of determination of needed compressor power and prevent oversizing or undersizing of compressor stations.

Familiarity with real values of hydraulic behavior of individual pipelines parts can also substantially improve the process of pipeline operation modeling. This is very important when the model is used for calculations of transport capacity in present environment of pipeline capacity business.

## 2 How to determine the real hydraulic behavior of gas pipeline?

The base of pipeline operation model is some of the forms of flow formula, describing the pipeline pressure loss as a result of larger or narrower set of parameters.

Generally, the commonly used models of pipeline operation in steady (or quasisteady) mode are derived from simplified flow formula calculating the energy dissipation in the conditions of steady isothermal one-direction flow

$$\frac{dP}{\rho} = \lambda \frac{v_0^2 . \rho_0^2}{2 . \rho^2} . \frac{dl}{D}$$

When integrating this formula we can reach a relatively simple flow formula defined in SI system (SI units) and at standard physical conditions:

– either in the form for velocity

$$P_1^2 - P_2^2 = \lambda . v_0^2 . \rho_0 . z . T . \frac{P_0}{z_0 . T_0} . \frac{L}{D}$$

– or in the form for flow

$$P_1^2 - P_2^2 = \lambda . Q_0^2 . \rho_0 . z . T . \frac{16 . P_0}{\pi^2 . z_0 . T_0} . \frac{L}{D^5}$$

The good deal of the parameters are – with proper accuracy – either defined by technical parameters of pipeline (the length, diameter), or transported gas parameters (pressure, temperature), or can be calculated from the gas composition (density, compressibility factor). All those parameters are put into the model having appropriate accuracy (the operation parameters are commonly taken on-line from telemetry).

Nevertheless in both formulas there are presented two mutually connected parameters, the friction factor $\lambda$ and either flow $Q_o$, or velocity of flowing gas $v_o$. The value of friction factor can’t be directly measured. The flow velocity is usually measured using operating gauge with accuracy level some ±3%. The flow is commonly calculated from flow velocity measured by means of the gauges above mentioned. Only in the case of trade flow meters at delivery stations, the gauges accuracy is quite better, from ±0.5 to ±1%.

In case we perform the analysis of relative uncertainty of calculated value of friction factor based on the individual relative uncertainties of measured values of individual parameters in the formula,

$$E_{r,\max} = \pm\left( \begin{aligned} &\left|\frac{\partial \ln\lambda}{\partial P_1}\cdot E_{P1}\right| + \left|\frac{\partial \ln\lambda}{\partial P_2}\cdot E_{P2}\right| + \left|\frac{\partial \ln\lambda}{\partial D}\cdot E_{D}\right| + \left|\frac{\partial \ln\lambda}{\partial Zs}\cdot E_{Zs}\right| + \left|\frac{\partial \ln\lambda}{\partial Q}\cdot E_{Q}\right| \\ &+ \left|\frac{\partial \ln\lambda}{\partial Ts}\cdot E_{Ts}\right| + \left|\frac{\partial \ln\lambda}{\partial \tau}\cdot E_{\tau}\right| + \left|\frac{\partial \ln\lambda}{\partial \rho_0}\cdot E_{\rho 0}\right| + \left|\frac{\partial \ln\lambda}{\partial L}\cdot E_{L}\right| + \left|\frac{\partial \ln\lambda}{\partial \rho_0}\cdot E_{\rho o}\right| \end{aligned} \right)$$

we find that – considering the accuracy of typical operational gauges – the biggest impact is derived from the accuracy of pressure gauges (at both ends of pipeline) and the accuracy of measurement of the flow or velocity of gas.

Contemporary electronic pressure gauges reach the accuracy of ±0.1 %. This is enough for precise calculation of the friction factor. On the contrary, the values taken from operational flow or velocity gauges, give unusable results of friction factor calculation.

Even the values measured by precise trade flowmeters at delivery stations, either orifice, turbo or ultrasonic, lead to the uncertainty of friction factor range more than ±20%.

That is why the indirect method of friction factor measurement was developed, using for the calculation the mean velocity of gas, derived from measured time of flow of the gas between the beginning and the end of a measured part of gas pipeline.

## 3 The principle of measurement of friction factor of pipeline in the course of operation

The following method has been specially developed for this reason. It is based on precise measurement of all the parameters in flow formula in the form for velocity.

This equation describes the relation between the pressure drop and the diameter, length and friction factor of pipeline, physical and chemical parameters of gas flowing through the part of pipeline.

The velocity of gas flow is measured indirectly, when hydrogen trace is injected into the gas flow at the beginning of a measured part of the pipeline, later the hydrogen trace is detected at the end of the part, and mean value of the velocity is calculated from the pipeline part length and the flow time.

The measurement must be performed in conditions of steady or quasisteady flow. It means that in the time of measurement and several hours before, the transport flow must not be changed (small fluctuation in the frame of several percent is allowable). The measurement can be done at pipeline parts at the length from 10 to 100 km, and in the course of measurement, all the off-takes from the measured pipeline part shall be closed.

The formula used for the calculation is adapted from SI units to standard technical units (MPa, km, seconds)

$$\lambda = 3{,}70950210^{-7}.\frac{D.z_s}{\rho_0}\frac{T_s}{P_s^2}\frac{\tau^2}{L^3}\cdot\left(P_1^2 - P_2^2\right)$$

For the calculation of relative roughness $\delta_S$, the implicit Hofer formula (from seventies) was used

$$\lambda = \frac{1{,}325475}{\ln^2\left(\frac{1{,}962142}{\mathrm{Re}}.\ln\left(\frac{\mathrm{Re}}{7}\right) + \frac{1}{3{,}71}.\frac{\delta_S}{D}\right)}$$

The pressure at both ends of the measured part of pipeline is measured by very precise electronic gauges/recorders having the accuracy of ±0.05% and the reproducibility of measured value is ±0.01%.

The temperature at both ends of the measured part of pipeline, is measured by the same gauges/recorders (accuracy ±0.1 K), either with the probe immersed into the oil in the thermowell welded onto pipeline wall for the operating gauge sensor, or with the contact probe, fixed to the aboveground pipeline part, right where pipe protrudes from the soil, where the wall temperature is the same as the temperature of gas.

The values measured are usually recorded in 3 minute intervals. This is enough for the checking the steady state of the gas flow.


**High-precise gauge/recorder of pressure and temperature**

**Upper part of the thermowell**

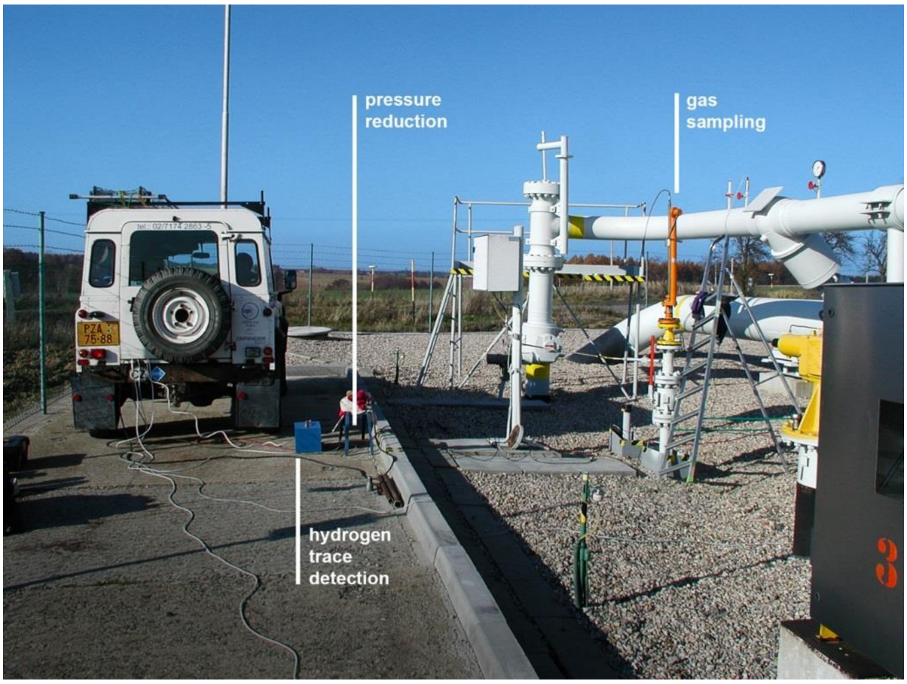
The data dealing with the length of the measured pipeline part and of the altitude (above sea level) of the beginning and end of the part are taken from operator´s documentation.

The pipes diameter and its tolerance are taken from delivery conditions archived from the time of pipeline construction. The hydrogen trace is injected into the gas flow from the adapter filled from standard pressure bottles (200 bar).

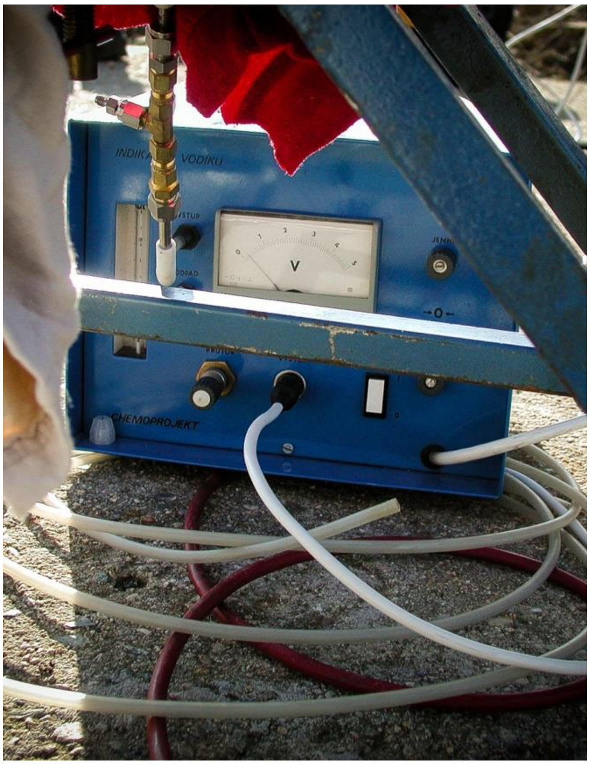
**The injection of hydrogen into the line**

Special inserted probe takes the gas samples exactly from the center of pipeline, i.e. it is immersed directly close to the longitudinal axis of pipe. The probe can be put into the pipeline at full operational pressure up to 100 bar. The DN 50 or DN 80 off-take from the pipeline with ball valve or gate valve is necessary for inserting of the probe.

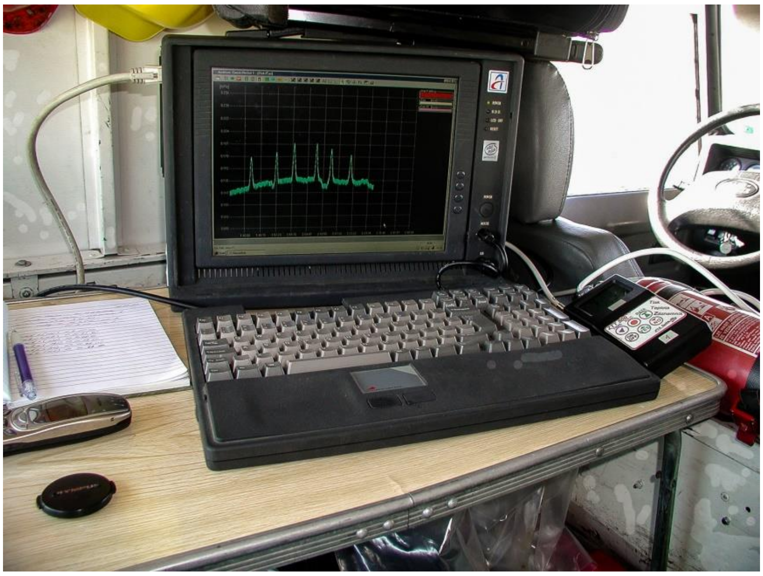
For the detection of hydrogen trace it was developed special device, containing a pressure reducer, a by-pass for releasing gas at low-pressure (it is necessary to minimize the dead time of the detection) and a detector with thermal stabilization. The detector itself uses TCD (thermal conductivity) principle. The detector unit is connected via RS 232 interface to computer.




**End of measured pipeline part**



**The probe taking gas samples from the pipeline** **The detection system**



**The record of six hydrogen traces at the end of measured part of DN 1400 gas pipeline with length of 50 km. The traces were injected into the gas flow in the intervals of several minutes.**

The values of compressibility factor and viscosity at standard and operational conditions, and the value of density of gas at standard conditions, are calculated from the gas composition measured by chromatograph at up-stream delivery station, considering the time interval needed for gas to flow from the station to the beginning of measured part of pipeline. In case there is not any delivery station equipped with the chromatograph neither up-stream, nor down-stream, it is necessary to take the gas sample in the place of measurement and make the chromatographic analysis individually.

# 4 Reproducibility of the measurement

The method has been used for the evaluation of hydraulic parameters of nearly 2000 km high-pressure natural gas pipelines with diameter DN 800, 900, 1000 and 1400 in the course of 10 years.

In every set of experiments several measurements were done. The reproducibility of results is better than ±3%, that is one order better than the results from using values of operational measuring devices.

Time series of results from the measurements performed over several years interval gave the information, how the hydraulics of pipeline develops in the course of its operation. This provides more exact data both for new pipeline designing and for pipeline operation modeling.

To minimize the effect of flow fluctuation, the value of 80-percentile was used as a proper result of every measurement set.

# 5 Example of measurement performed on the pipelines DN 1000 DP 80

Two types of measurement were performed on the DN 1000 pipelines.

- The first type of measurement of friction factor was carried out on the same part of pipeline built from the pipes 1020 × 11.4 mm with inner coating.
- The same measurement was executed after six years of pipeline operation.

The aim of the experiment was to evaluate if, or how, the hydraulic parameters of pipeline are changing in the course of its operation.

Both cases of the measurement were performed at very similar flow conditions. In the first case the Reynolds number value was $Re = 1.5 \,.\, 10^7$, in the second one the value was $Re = 1.3 \,.\, 10^7$.This difference is negligible.

The second type of measurement was focused on comparison of friction factor of pipelines built from the pipes with or without inner coating. The set of measurements was performed on the 200 km long section of pipeline with inner coating and the second set on the 350 km long section of pipeline without it.

**The results of measurement of time changes of friction factor**

| | **80-percentile $\lambda$** | **80-percentile $\delta_s$** [mm] |
|---|---|---|
| After start of operation | 0.0087507 | 0.01124 mm |
| After six years of operation | 0.0086421 | 0.01002 mm |

**The results of comparative measurement of friction factor on the same size pipeline with and without inner coating**

The pipeline branch with inner coating consists from 7 parts in total length 200 km, there were performed 34 measurements

The pipeline branch without inner coating consists from 7 parts in total length 350 km, there were performed 37 measurements

| | **80-percentile λ** | **80-percentile $\delta_S$** [mm] |
|---|---|---|
| With inner coating | 0.0086421 | 0.01002 mm |
| Without inner coating | 0.0103514 | 0.03805 mm |

**Example of measurement performed of DN 1400 pipeline close to pigging**

The measurement was performed on DN 1400 in the time of regular pigging. The aim of the experiment was to evaluate the hydraulic effect of pigging.

| **Day** | **80-percentile λ** | **80-percentile $\delta_S$** [mm] |
|---|---|---|
| -1 | 0.010865818 | 0.08429 mm |
| **Day of the pigging** | | |
| +1 | 0.010589527 | 0.06580 mm |
| +2 | 0.009562680 | 0.03459 mm |
| +3 | 0.009427918 | 0.03097 mm |
| +5 | 0.009557961 | 0.03354 mm |
| +14 | 0.009600395 | 0.03565 mm |

The results of measurement indicate that the value of friction factor doesn't fall down after the pigging, but it decreases during several days. It corresponds with the results observed during the measurement on the other pipeline, where the friction factor value even increased at the first day after the pigging and then several days decreased. In 3–4 days after the pigging, the value of friction factor reaches the minimum, then it little bit increases and stabilizes.

Final comparison of friction factor values just before the pigging (0.010865818) and after the stabilization of environment inside the pipeline (0.009600395) shows the decrease of friction factor by nearly 12%.

In this case, the result of pigging was the increase of transport capacity by 3.5%.

# 6 Conclusion

The method of evaluation of friction factor, using the indirect measurement of mean velocity of gas flow with hydrogen trace provides reproducible and reliable results. These results make the hydraulic description of gas pipeline when developing and establishing the models of pipeline operation much more precise.

The measurement carried out on Czech gas transmission grid has taken place for years, starting in eighties. The results reached can be concluded

- The value of friction factor of different parts of the same gas pipeline can be different because of different geometric configuration,
- The mean value of friction factor of individual part of pipeline stabilizes in the first years of operation and then it is more or less constant,
- The pipeline pigging improves the hydraulic behavior of the pipeline, but this effect is not so much revolutionary from the point of view of transport capacity and lasts probably only several months, it seems that the techno-economic assessment plays very important role when preparing pigging program.

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