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RESEARCH OF WATER CONDENSATION IN GAS TRANSMISSION PIPELINES

Abstract: *The domestic gas industry has been set an ambitious goal in the form of a state programme for extensive gasification of Polish cities and towns. This provides for transition of the municipal thermal energy and of the municipal economy to natural gas. Ensuring of reliable and safe transport of the gaseous fuel is also a part of this programme. The article discusses the problems of transporting of the nitrogen-rich natural gas from the local mines, related to water of unknown origin appearing in it. The events that can confirm that there is a possibility of moisture condensation from the gas and its migration deep into the distribution network have been analysed. The actual level of moisture in the natural gas, which is already directly supplied to the consumers, has been experimentally tested. It has been proved by the computer calculations that in the conditions of high pressure in the network, there is a possibility of such condensation, depending on the external atmospheric conditions and physicochemical parameters of the gas. It has been proposed to change the existing designing and construction legal provisions in order to protect the gas networks against water accumulating in them in a better way.*

Keywords: *natural gas, water condensation, gas transport, high pressure, gas moisture.*

Introduction

The historical orientation of the fuel balance of Poland towards solid fuel causes huge technical, economic and ecological problems for the country, also on an international scale. The Polish government has announced a broad programme of ensuring of energy security of the country by diversification of the natural gas supply from various sources and directions thanks to the effective use of the LNG terminal on the Polish coast and creation of new cross-border connections (Project 2019). It anticipates development of the gas supply industry in the coming years and at an unprecedented pace [6].

Therefore, technologically advanced, effective and environmentally friendly conversion of the domestic heat power engineering and municipal economy into gas fuel becomes a call for the Polish gas industry. It is these devices that constitute the most numerous and very dispersed group of thermal technology devices. Currently, they are characterised by low efficiency and significant impact on environmental pollution in the places where people live and work. The exhaust fumes from these devices are discharged into the atmosphere through low chimneys or just above the roof of buildings. The issue of the global warming and the obligations of Poland to reduce greenhouse gas emissions are also significant. Combustion of natural gas ensures CO_2 emissions that are almost twice lower compared to hard coal (the maximum content of carbon dioxide in natural gas flue gas is 11.8% by volume in comparison with 21% by volume for coal).

In the conditions of the anticipated development of the domestic gas industry, the key issue is to increase the capacity of the Polish natural gas transmission network and to ensure reliability of the gas supply process as well as its appropriate quality [5]. One of the acute problems from this point of view is the moisture content of the gas fuel [9]. This problem is further intensified by the increasing scale of the use of the liquefied natural gas being technologically associated with the cryogenic processes.

Analysis of the principles for gas supply in terms of moisture content

It is not widely known that water may appear in the gas pipelines that distribute the natural gas directly to the consumers. On the other hand, the specialists in the field of operation of the gas networks deal with this phenomenon on a daily basis. Where does this water come from? Certainly not through the leakage places arising on the network due to mechanical damage or corrosion, as the gas pipeline is always under positive pressure.

The natural gas extracted from the ground is usually contaminated with solid fractions and loaded with moisture as well as has caustic properties. The previously dried gas taken from the underground gas storage facilities is also saturated with water. The presence of water in the natural gas is undesirable because it intensifies corrosion of pipes and equipment, especially in the presence of H_2S and CO_2, while in winter it forms ice plugs. It may also contribute to formation of the hydrates that block the flow of the gas, especially in case of liquid hydrocarbon recovery processes, such as freezing or cryogenic processes [1].

Moisture removal is the key stage in the pre-treatment of the natural gas directly at the point of its extraction and further processing before sale. Over the time, a stereotype that "dry gas" should be delivered to the consumers has developed. In the aforementioned PN-C-04753 standard, humidity of the gas is not even mentioned among "the values relevant for the assessment of gas quality". This stereotype resulted in the fact that the dehydrators installed previously at each connection and even under the gas installation risers disappeared from the designing practice.

In fact, the dried natural gas cannot be "dry", i.e. completely devoid of moisture. Even the already criticised standard, not setting any requirements in the field of the moisture content in the gas, paradoxically speaks about the processes that "may cause formation of water condensates". The resulting contradiction is also based on the measurement technology. Using the chromatographic analysis methods to determine the gas fuel composition, the sample is first subjected to drying. Therefore, the analysis shows not moist ("real" or "working"), but so-called "dry" gas composition, without the moisture content.

The gas suppliers are aware of the contradiction described above. To ensure adequate gas properties, the transmission network operators provide declarations regarding the properties of the transmitted fuel on their official sites. They include *inter alia* the permissible moisture content in the form of the maximum dew point temperature t_r, separately for summer and winter. The safety of the gas in transport and further use depends on it directly and its efficiency is important from the point of view of fulfilment of the contractual tax obligations [3].

The t_r value in the certificates analysed in the work [9] ranged from +4°C to –6°C. In general, these values are very close to the requirements for the gas quality in the transmission networks [4] (–5°C in winter and up to +3.7°C in summer). However, tests of the gas samples taken from the network showed that the dew point temperature could reach even +20°C. This means that in the winter season gas saturation with water vapour with its subsequent condensation is inevitable. It may be therefore concluded that determination of the t_r value, which may possibly be higher than the gas distribution temperature, in the certificate indicates a high probability of condensation forming in the gas pipelines.

The dew point means that water in the gas composition is in a saturated state, i.e. the partial pressure of the water vapour p_p is equal to the water saturation pressure p_p^n at a given temperature. For example, at 0°C $p_p = p_p^n = 611$ Pa [8]. The thermodynamic calculations show that under normal conditions (0°C and 101325 Pa) the absolute humidity of the gas in the saturated state (water vapour content in 1 m^3 of the moist gas) is 4.88 g/m^3 and the molar share of the water vapour corresponding to the dew point is 0.0061 (0.61% by volume).

The financial conclusions are quite obvious. If gas humidity only oscillates on the edge of the dew point, an example boiler room that needs 1 million m^3 of the gas annually "consumes" over 6000 m^3 of the water vapour in its composition. The meter indicates this volume as the gas and the user pays for it. In addition, 1% of the water vapour by volume reduces the calorific value of E-group high-methane gas by approx. 0.37 MJ/m^3, which is more than 1% [9]. The efficiency of the gas devices is proportionally reduced.

However, the hazards arising during the operation of the gas networks in case of presence of the condensed water in the gas pipelines are much more important. That is why it is so important to analyse each failure and the resulting conclusions thoroughly – in terms of the causes of the abnormal states and disturbance of the stability of the supervised systems as well as of the ways to prevent such events in the future. The authors have attempted to conduct such analysis on the basis of the gathered data on gas network failures and their own measurements.

Analysis of failure causes connected with natural gas waterlogging

The analysed failures have different scale, reach and publicity in the media. The most well-known failures include the one of the Russian gas transit system (supplier – Russian State Concern Gazprom), when the Polish customer (Operator Gazociągów Przesyłowych Gaz-System S.A.) announced suspension of all gas supplies from the Yamal gas pipeline on 22 June 2017. This was done due to the failure of the Russian gas drying instance in fear of the safety of the Polish gas pipelines. In this information, it was stated that Poland did not have its own installation for drying of such gas flows and that the closest one was in Germany.

Despite the international scale of the failure and huge quantities of the raw material, it did not affect the gas supplies for the consumers. The gas tanks performed their task and already on 23 June 2017 at 6:00 a.m., due to improvement of the quality parameters of the natural gas, Gaz-System resumed reception of the fuel to the national transmission system at the Interconnection Point. Therefore, it can be considered an accidental phenomenon, as in general, the gas drying installations at Gazprom operate in a faultless way. The most commonly used solutions are glycol installations and the supply system is stabilised in such a way that it provides the opportunity to choose the optimal time of contact of the gas with the glycols. Even the effective trade agreements ensure such stabilisation of supplies, as in case of lower consumption, the generated surplus of the transit gas is injected into the underground warehouses all over Europe.

The gas drying cycles operate in a much worse way in the regional gas distribution systems based mainly on the local wells with the nitrogen-rich gas mines. These systems are characterised by large fluctuations of the flows during the transitional periods (spring and autumn), in case of sudden changes of the weather and even during the day. Then, the drying processes encounter a big problem due to lack of the possibility to stabilise the gas-glycol contact time. This situation occurs in all distribution networks in Poland supplying the L_w and L_s subgroup natural gas to the customers.

The entire coastal zone in the central part of western Pomerania, including Kołobrzeg, is supplied with the natural gas from the L_s subgroup. In the distribution systems, there are still some engineering interventions aimed at ensuring of high quality of the gas supply as well as of widely-understood security. Such events are both planned and unexpected, classified as failures. They are thoroughly analysed in terms of potential threats and undesirable effects. A number of instructions, guidelines and regulations, which together form a specific technological regime in the field of designing, construction and operation of each distribution network, are created.

Many typical failures are currently very well analysed and described in the field of the actions to be taken. Even the failures that are very well known to the public are often typical and the extent of their consequences determines their publicity. Another type of the events includes the ones which surprise the specialists, since they do not have well-developed and proven methods of action.

One of such unexplained failures on the low-pressure gas network was the sudden suspension of the natural gas supply to the Spa District in Kołobrzeg in February 2016. Kołobrzeg has a specific layout. The Spa District, situated along the coastline, is practically "cut off" from the rest of the city by railway tracks. This results in difficult access to it in terms of the road, municipal as well as gas infrastructure. Development of the heating technology based on the natural gas has quickly forced an increase of the gas supply to this district.

At that time, at the end of the 1980s, the technology of construction of the polyethylene pipe networks was not used in Poland yet and the gas was supplied to the customers only by low-pressure networks (1.3-1.6 kPa). It was a natural solution to replace the supply gas pipeline with 100-150 mm diameter with a new one with 300 mm diameter. For many subsequent years, the gas was supplied to the district in a stable manner and the occurring slight pressure drops were explained by the continuous increase of the demand resulting from expansion of the existing facilities and construction of the new ones. Over the time, more and more pressure problems began to appear, especially in winter during the holidays. On 2 February 2016, the employees of the Gasworks in Kołobrzeg recorded numerous reports on lack of gas pressure.

Pressure measurements at the sampling points showed unacceptable values in the range of 0.65-0.82 kPa. At that time, the reduction stations supplied the gas at the right pressure with a large capacity reserve. This indicated that the main gas pipeline was no longer permeable. The network layout and the foundation ordinates, the pressure measurements, the lay as well as the type of land development and utilities were analysed. As a result of this analysis, the characteristic points on the gas network where the control excavations had to be made were selected. Measurements were made with the use of a double bag-positioning device. In this way, the search site narrowed to a section of about 15.0 m at the lowest point of the terrain.

After cutting of the pipe, water escaped from it instead of the gas and a pump was installed instead of the bag-positioning device. In total, about 500 litres of water were pumped out, which meant geometrically that a section of the gas pipeline of the length of almost 7.50 m was completely flooded with water. The sections flooded with water were also found in other areas of the network system (Fig. 1).

Figure 1. *Cutting of the DN300 gas pipeline at Myśliwska Street in Kołobrzeg*

The analysis of the causes of the incident from the side of the gas plant was conducted only in one direction – the search for a potential place of leakage which would allow for penetration of such quantity of water into the gas pipeline from the outside. Such a place was not found until these gas pipelines were replaced with new polyethylene ones. Therefore, the thesis that water got into the gas pipeline through the places of leakage has never been proved unambiguously.

We may also refer here to the case of the famous accident that took place in Zielona Góra on 30 November 2010. Then, as a result of a failure of the gas reduction system, the medium-pressure gas penetrated into the low-pressure housing estate gas network at three housing estates, causing an explosion of flats and fires [10]. The analysis conducted by the public prosecutor's office proved that one of the main factors of the failure was undoubtedly water which froze in the devices and pipes of the gas station regulation and safety systems. However, the experts decided *a priori* that it was water from precipitation. No observations and studies in this direction were undertaken. Again, the prevailing stereotype that the natural gas is a dry gas, as highlighted in this article, worked.

Experiment conditions and experimental studies results

All analyses and research in the field of natural gas humidity have always concerned the area of mines, high-pressure transit gas pipelines and – to lesser extent – medium-pressure gas networks. The current water protection system ends with dehydrators installed as a standard on the inlet systems of the medium-pressure gas stations. There is no data on the study of this phenomenon at the side of the low-pressure network, i.e. directly in front of the consumer. As it has already been said, there are currently no provisions requiring the use of the dehydrators in the low-pressure systems as well.

The author's analysis of a number of failures has showed that the low-pressure systems may contain water, the presence of which cannot be explained by leakages or penetration of precipitation into the network. Therefore, it has been decided to carry out an analysis of the water content in the low-pressure natural gas that is supplied directly to the customers. The local gas network system in the Kołobrzeg zone distributing the medium-pressure L_s subgroup gas with subsequent reduction to 1.3 kP pressure was selected for the study. The point, at which the sampling was carried out, was at a household customer supplied directly from the medium-pressure gas network. The low pressure is obtained thanks to a household gas regulator, which only has a standard inbuilt tissue filter. Such conditions of the experiment allowed for examination of the moisture content after leaving of the high-pressure station and before passing through the dehydrators at II° gas stations.

The measurements were carried out with the use of XENTAUR portable dew point analyser, HPDM type (Fig. 2). It is a microprocessor-controlled, battery-powered moisture meter, equipped with a dry chamber for storage of the sensor. This allows for obtaining of a reliable result after moving of the sensor to the measuring cuvette, ensuring the maximum possible tightness and the lowest possible gas exchange between two chambers during the sensor movement.

FIGURE 2. *XENTAUR moisture meter, HPDM type*

The thermodynamic calculations allow for calculation of the experimentally obtained dew point temperature value based on the known conditions in the higher-pressure gas pipelines. The generally accepted principles of such recalculation are based on the Goff-Gratch formula or on a similar method of the World Meteorological Organization. In the work, the JSC Ecological Sensors and Systems humidity calculation software [2], which allows for comparison of the results according to both methods and for changing of the type of the analysed gas, has been used. Both the measured values and the ones obtained as a result of such calculations are presented in Table 1.

TABLE 1. Natural gas humidity measurement and recalculation results

Date of measurement	Dew point temp., °C	Gas humidity, g/m³	Recalculation into medium-pressure conditions			Recalculation into high-pressure conditions		
			Pressure, MPa	Dew point temp., °C	Gas humidity, g/m³	Pressure, MPa	Dew point temp., °C	Gas humidity, g/m³
25.06.19	−29.4	0.322	0.298	−16.1	4.36	4.2	16.4	46.42
06.06.19	−22.1	0.66	0.292	−7.7	13.84	2.5	19.1	88.83
20.06.19	−25.5	0.461	0.297	−11.9	9.92	4.23	22	83.53
21.05.19	−27.5	0.385	0.293	−14.4	9.75	4.22	18.7	104.33
22.05.19	−27.7	0.366	0.293	−15.2	12.56	4.19	17.5	133.38
13.06.19	−25.8	0.362	0.296	−14.8	6.9	4.2	17.9	72.94
21.06.19	−27.9	0.362	0.298	−14.9	8.25	4.21	17.7	86.76
23.06.19	−28.1	0.351	0.294	−15.7	10.62	4.15	16.8	112.05
21.06.19	−28.2	0.35	0.298	−15.4	6.61	4.3	17.7	72.2
01.07.19	−28.3	0.35	0.297	−15.4	6.98	4.1	16.9	72.91
01.09.19	−28.3	0.344	0.296	−15.4	4.89	4.02	16.7	50.13
26.06.19	−28.5	0.34	0.297	−15.5	4.59	4.13	16.9	48.19
24.06.19	−28.7	0.331	0.299	−16	6.84	4.31	16.8	74.61
24.05.19	−28.8	0.329	0.294	−16.3	7.12	4.22	16.3	76.95
06.08.19	−28.9	0.327	0.297	−16.2	6.17	4.02	15.6	63.07
27.06.19	−28.9	0.325	0.298	−16.3	7.31	4.02	15.3	74.56
02.07.19	−29.2	0.316	0.298	−16.8	8.24	4.29	15.8	89.68
21.08.19	−29.4	0.305	0.3	−17	6.51	4.25	15.3	69.78
22.06.19	−29.9	0.293	0.299	−17.6	6.61	4.09	14	68.39
16.06.19	−30	0.289	0.298	−17.8	6.9	4.21	14.2	73.63

Measurement conditions: t = 22°C, p = 1.13 kPa ($p_{abs.}$ = 0.102625 MPa).

The Table 1 data shows that the gas with a very low dew point temperature is formally transported through the low-pressure network. On the other hand, the recalculations into the medium- and high-pressure conditions show that the same water vapour content before pressure reduction does not exclude the possibility of water condensation in the domestic climate conditions. The performed analysis of the reports on the supervision over the dehydrators located on the high-pressure network in the Gas Plant in Koszalin, conducted in the period from January 2016 to December 2019, showed that water was pumped out from the dehydrators in the quantity of about 3.700 litres. The maximum quantity of water utilised from one dehydrator was 375 l.

The failures analysed above show that in the conditions of higher pressures and high gas velocities, penetration of liquid water through the dehydrators and then through the reduction station equipment into the low-pressure network cannot be excluded.

Summary

In the recent years, along with development of the polyethylene pipe technology, a growing tendency to move away from the old principles for designing and construction of the gas networks, proved over the years, has been observed. The declines of the laid gas pipelines are only forced naturally by the fall of the terrain and upon the repairs and replacements of the steel network with the PE one, the old dehydrators are massively removed at the lowest points of the network. In most cases, this does not cause problems in the further operation, even if in such a system a part of the network is already made of polyethylene pipes and a part is still made of steel. But usually these are the systems supplied by the E subgroup gas, where the main supplier seeks the permissible moisture content in the gas. It is bound by the supply agreement specifying the maximum dew point temperature value.

The situation is different in the systems supplied by the L_w or L_s subgroup gas from the local mines.

The changing designing trends result in the fact that the dehydrators are less and less installed on the networks. The suddenly appearing water, causing failures, surprises the employees of the gas plants, who are unable to explain the reasons for this phenomenon.

This is what happened in the case of the analysed failure in Kołobrzeg. At that time, the use of the dehydrators during construction of passages under the tracks was definitely required due to greater deepening with creation of a natural trap. However, this requirement was omitted during network modernisation.

Appropriate conclusions were drawn only after the failure. Figure 3 shows the dehydration system prepared for installation during replacement of three sections of the gas pipelines running under the tracks with a new PE gas pipeline with the main diameter DN 355 mm upon the request of the network operator in Kołobrzeg.

***FIGURE 3.** Polyethylene dehydrator with diameter DN 355 (without inspection pipe)*

Conclusions

1. The research results presented in the article prove that water condensation in the higher-pressure networks, having the consequence of penetration through the I° and II° reduction stations, may be the source of significant quantities of water in the low-pressure networks. No studies have proved or excluded the possibility of water entering directly the low-pressure gas pipelines through leakage places.
2. The analysed failures prove that regardless of the source of water, it is unjustified to dispose of the dehydrators, especially in a mixed gas network made of polyethylene and steel pipes distributing the gas from the local wells of the L_w and L_s subgroups.
3. The target action would be to introduce appropriate changes to the "Rules for designing n of low- and medium-pressure steel gas pipelines and polyethylene gas pipelines" and the Regulation of the Minister of Economy of 26 April 2013 "On technical conditions to be met by gas networks and their location" in terms of introduction of the legal conditions relating to the possibility or necessity to use the dehydrators in the specific cases.

Conflicts of Interest: The author declares no conflict of interest.

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