AGH DRILLING, OIL, GAS • Vol. 33 • No. 2 • 2016

http://dx.doi.org/10.7494/drill.2016.33.2.433

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# PRESSURE REGULATING STATION AT ACTUAL CONDITIONS

## 1. INTRODUCTION

Transport of natural gas via the transmission network is characterized by a high pressure gas flow. At the exit point of the transmission network, natural gas pressure is often reduced (in line with the terms of delivery). This process takes place in buildings known as gas pressure regulating and metering stations.

At these stations, gas pressure is reduced by throttling the gas under adiabatic and isenthalpic conditions. During this process a change occurs in the temperature of the gas. The value of the change in temperature is proportional to the pressure difference before and after the reduction process. This phenomenon is called the Joule-Thomson effect. At actual conditions, in a pressure regulating station, the temperature of the gas decreases by about 5 K/MPa, which under certain conditions may have an adverse impact on the functioning of pressure regulators and other elements in the station.

In order to avoid improper functioning of some appliances in pressure regulating stations, it is necessary to heat up the gas stream before its pressure decrease. This is accomplished by the heating system which consists of a natural gas boiler, a heat exchanger, pipes and a working medium that circulates in the system (describing in simple terms). The surfaces of a thermally uninsulated heating system have a temperature above the ambient temperature, which could be the cause for heat loss and thus, waste in energy used to overheat the working medium.

Understanding energy efficiency, also called efficient energy use, as a goal to reduce the amount of energy needed to regulate gas pressure , and knowing the amount of heat loss occurring in the heating system, one can determine the thickness of insulation required to cut back gas consumption for heating the working medium.

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## 2. THE JOULE–THOMSON EFFECT AND THE HEATING SYSTEM AT PRESSURE REGULATING STATIONS

Real gases take part in various thermodynamic processes, so they can exchange heat with the environment, perform the work, change their original state of matter, etc. For the pressure regulation, the most important thermodynamic process is throttling gas under adiabatic and isenthalpic conditions. The reduction of gas pressure under these conditions is connected with the Joule–Thomson effect, mentioned in the introduction. The process of throttling the gas in a pressure regulating station occurs as a result of the reduction of the cross-section for gas stream in the seat of pressure regulator. This process is very short, so it is possible to assume that the pressure regulator is adiabatically insulated. Knowing the temperature and the pressure of the gas before and after its pressure reduction, it is possible to determine the ratio between the relative change in temperature and the change in pressure. This ratio is called Joule–Thomson coefficient. Its value can be calculated based on the knowledge of the type of gas and its pressure, and the temperature before the pressure reduction. As a result, the Joule–Thomson coefficient allows to specify the change in gas temperature due to the reduction of the pressure [1].

This coefficient can be considered as a measure of deviation from an ideal gas. For real gases, the coefficient takes positive and negative values. A positive value indicates that, during the gas pressure drop, its temperature decreases, and a negative value indicates that, during the gas pressure drop, its temperature increases. Natural gas, being transported at the temperature and pressure which usually occur at pressure regulating stations in the transmission network, is characterized by the Joule–Thompson coefficient of about 5 K/MPa. The pressure in these stations is typically dropped by several MPa, therefore it may induce a fall in temperature below 0°C. This decrease in temperature can cause the following problems, related to the functioning of pressure regulators and other elements of the station [2]:

- accelerated corrosion, being the result of condensation of water vapor contained in the natural gas;
- crystallization of water vapor in the seat of pressure regulator, which may cause instability and even lock the device;
- freezing of the elements of a pressure regulator, such as the pilots which operate the pressure regulators;
- formation of hydrates which have a negative impact on the equipment performance, in the pressure regulating station. In an extreme case, hydrates may reduce the capacity of the station.

Preventing the occurrence of these problems is an important element in ensuring safe operation of the station. Mainly, it is connected with preheating of natural gas before its pressure is reduced. At pressure regulating stations, the most widely used way to increase the temperature of natural gas is its heating in a straight tube heat exchanger (gas heater). Formerly, water or steam were most commonly used fluids as a heating medium. In situations where the air temperature was negative or the installation worked periodically, antifreeze fluids were used. Currently, only glycol-based antifreeze liquids are being applied. The heated working medium circulates through the exchanger shell, releasing heat to the flowing gas stream. The heating medium is heated up in a natural gas boiler, and the connection between the boiler and the heat exchanger is assured by steel pipes. This scheme can work in an open system (under the influence of gravity) or in a closed system (with a circulator pump) [3]. The scheme of the heating system, operating with a circulator pump, is presented in Figure 1.

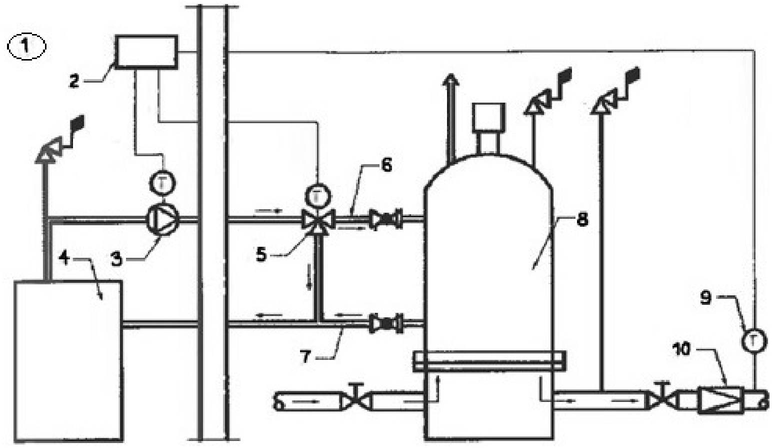

**Fig. 1.** Scheme of the heating system, operating with circulator pump [3]

1 – Boiler room, 2 – temperature regulator, 3 – circulator pump, 4 – natural gas boiler, 5 – mixer (regulation of heating medium temperature), 6 – inlet of the heating medium to the heat exchanger, 7 – outlet of the heating medium from the heat exchanger, 8 – heat exchanger, 9 – temperature sensor, 10 – pressure regulator

## 3. MECHANISMS OF HEAT TRANSFER

The heat transfer is a common phenomenon that occurs when temperature difference arises inside one or between several systems. According to the second law of thermodynamics, the heat energy is transferred from a higher to a lower temperature system. The relationships which determine the quantities of energy transferred as heat result from the first law of thermodynamics. Heat transfer is accomplished basically in three ways: conduction, convection and radiation. These methods differ from each other in terms of physical mechanisms that are used. Another mechanism of heat transfer with its practical meaning is heat penetration. Heat penetration is a heat transmission from (or to) a fluid (which is in motion) to (or from) the surface which is in contact with this fluid. This phenomenon is described by surface (film) conductance which tells about heat transmitted in a unit of time per unit of surface area per degree temperature difference between the surface and the fluid. Measured in units of watts per square meter Kelvin [4].

Conduction is a mechanism of heat transfer that consists in kinetic energy transport of the molecules movement. Rapidly moving or vibrating molecules interact with neighboring molecules, transferring some of their energy (heat) to these neighboring particles. This transfer proceeds from a place with a higher temperature to a place with a lower temperature. It is important that the particular molecules of the concerned system do not exhibit macroscopic motion. Heat conduction takes place in gases, liquids and solids, although mainly applies to solids [5].

Convection is characteristic for fluids (liquids and gases). It occurs when the individual particles of a concerned system, to which the heat is transferred, change their location. In other words, particular molecules exhibit macroscopic motion. Heat transfer takes place as a result of mixing the fluid, therefore the movement of the medium (to which the heat is transferred) determines the occurring of convection. When the motion of the molecules is generated by the wind, a fan or pumps, forced convection occurs. When the motion is caused by the action of mass forces, which arises from the existence of differences in density caused by the temperature difference in the system, then natural (free) convection occurs [4].

Heat penetration is often used interchangeably for convection, although it is a wider term. By heat penetration we understand heat transfer between the surface of a solid and a fluid flowing inside or around this surface. In the area of a fluid, where its flow velocity is high enough to the occurrence of turbulent flow, heat transmission takes place by convection. However, in a thin laminar layer which occurs near the surface, where the lines of flow are parallel to this surface, heat transfer takes place as a result of conduction. Thickness of this layer has an influence on its thermal conductivity, therefore the laminar layer is thinner the more intensive is the transmission of heat between the fluid and the surface. Thus, convection makes up a considerable part of heat penetration [6].

Thermal radiation consists in emission of electromagnetic waves by all materials which have a temperature above the temperature of absolute zero. This radiation is transmitted by electromagnetic waves with a wide range of wavelength; however, the wavelengths range of 0.80 to 400 microns are. This range covers a large part of the infrared radiation. Thermal radiation does not require matter to spread, thus, as opposed to convection and conduction, can propagate in the vacuum. In the phenomenological approach, heat transfer by thermal radiation consists in generating electromagnetic waves of thermal radiation. These waves are re-converted into internal energy of the matter, as a result of a partial or complete passage through the concerned material. In the statistic approach, heat transfer by thermal radiation consists in that the atoms in excited state emit photons which transport the energy. These photons are moving in a vacuum or some matter, until they encounter another material, where they are absorbed [6, 7].

Phenomena associated with thermal radiation may occur in the entire volume of the matter, however, the photon energy of thermal radiation is small and therefore, it is relatively not much sharp. Due to the low density of gases, they may be treated as a radiant in the entire of their volume. In solids and liquids the range of radiation is shallow and is limited to the surface layer (approximately several micrometers) [7].

## 4. TEST RIG AND CALCULATION OF HEAT LOSSES

Total heat loss of the heating medium can be calculated from the equation (1) [8]:

$$Q = V_w \cdot \left(T_{iw} - T_{fw}\right) \cdot \rho_w \cdot c_{p_w} \tag{1}$$

where:

- $V_w$ – volumetric flow rate of the heating medium [m$^3$/s].
- $T_{pw}$ – initial temperature of the heating medium [K],
- $T_{kw}$ – final temperature of the heating medium [K],
- $\rho_w$ – density of the heating medium [kg/m$^3$],
- $c_{pw}$ – specific heat for a constant pressure of a heating medium [J/(kg·K)].

Heat loss of the working medium, caused by the heating of the flowing gas stream, is calculated from equation (2) [2]:

$$Q_w = V_g \cdot \Delta T_g \cdot \rho_g \cdot c_{p_g} \tag{2}$$

where:

- $V_g$ – volumetric flow rate of the natural gas stream [Nm$^3$/s],
- $\Delta T_g$ – the temperature difference at which the natural gas stream is heated [K],
- $\rho_g$ – density of natural gas [kg/Nm$^3$],
- $c_{pg}$ – specific heat for a constant pressure of a natural gas [J/(kg·K)].

Heat losses of a heating system can be calculated from the equation (3):

$$Q_1 = Q - Q_w \tag{3}$$

where:

- $Q$ – total heat loss of the heating medium [W],
- $Q_w$ – heat loss of the working medium caused by heating of the flowing gas stream [W].

Heat generated from the combustion of natural gas can be calculated from the equation (4):

$$Q_b = \eta \cdot \mathrm{LHV_{NG}} \cdot \upsilon_g \tag{4}$$

where:

- $\eta$ – boiler efficiency [–],
- $\mathrm{LHV_{NG}}$ – lower heating value (net calorific value) of natural gas [J/ Nm$^3$],
- $\upsilon_g$ – volumetric flow rate of the natural gas stream [Nm$^3$/s].

Measurements were carried out in a pressure regulating and metering station in Gorzków. The owner of this station is Gas Transmission Operator GAZ – SYSTEM S.A. For the measurements five resistance temperature detectors (transducers) were used. These transducers were connected to two flowcomputers MacMAT II (microprocessor measuring devices). Additionally, from telemetry data, the volumetric flow rate of natural gas, the usage of natural gas in boiler room and the composition of natural gas were obtained. Measurements of these flow rates were done by a turbine and diaphragm gas meter, respectively.

Two of the five transducers were used to measure the temperature of the heating medium at the outlet from and inlet to the natural gas boiler. Thanks to that, the initial and final temperature of the heating medium were obtained. The next two transducers were used to measure the temperature of natural gas stream before and after the heat exchanger. Hereby, the temperature difference to which the natural gas stream is heated was obtained. The transducer of natural gas temperature after the heat exchanger is presented in Figure 2.


**Fig. 2.** Transducer of natural gas temperature after the heat exchanger
Phot.: Authors

All four transducers were placed in special thermowells/pockets which were filled with oil. The last of transducers was used to measure the temperature of the air in the container with pressure reduction. Hereby, the ambient temperature was obtained. These five resistance temperature detectors were connected by electrical wires to two flowcomputers MacMAT II. These microprocessor measuring devices made possible to read the data recorded every five minutes. Figure 3 shows a transducer which measures the final temperature of a heating medium.


**Fig. 3.** Transducer of final temperature of a heating medium
Phot.: Authors

Volumetric flow rate of a circulating heating medium and boiler efficiency were obtained on the basis of characteristics of the appliances. Specific heat and density of a heating medium (petrygo) and natural gas were obtained from the REFPROP program [9] as well as the lower heating value of natural gas. Total length of the pipelines of the heating system was measured by a tapeline. Calculations assume that the composition of the flowing natural gas is constant.

Measurements of the uninsulated heating system were performed first. After heat losses had been determined, a part of the system (about 30%) was thermally insulated and measurements were replicated. The polyethylene foam pipe insulation was used as an insulation material (thickness $d$ = 20 [mm]). A part of thermally insulated heating system is presented in Figure 4.

**Fig. 4.** View of thermally insulated gas heaters and pipelines
Phot.: Authors

## 5. PRESENTATION OF MEASUREMENTS RESULTS

Measurements of uninsulated heating system were performed for seven days, from 1st to 7th of January. Based on these recorded data, an hourly report of heat losses was compiled. The averaged values of heat losses for each day are presented in Table 1.

**Table 1**

Averaged values of heat losses of an uninsulated heating system

| | Total heat loss of the heating medium | Heat loss of working medium caused by heating of the flowing gas stream | Heat loss of a heating system | Heat generated from the combustion of natural gas | Average ambient temperature |
|---|---|---|---|---|---|
| Measurement day | $Q$ [W] | $Q_w$ [W] | $Q_l$ [W] | $Q_b$ [W] | $T_a$ [°C] |
| 1st January | 15004.37 | 5963.21 | 9041.16 | 15005.59 | 2.15 |
| 2nd January | 15761.63 | 6349.68 | 9411.95 | 15679.23 | 0.17 |
| 3rd January | 16233.00 | 6671.77 | 9561.23 | 16322.24 | –2.20 |
| 4th January | 16051.23 | 6799.24 | 9251.99 | 16402.14 | –1.13 |
| 5th January | 15374.68 | 6471.31 | 8903.37 | 15536.90 | 2.98 |
| 6th January | 14768.33 | 6021.16 | 8747.17 | 14622.96 | 6.37 |
| 7th January | 14755.92 | 6066.93 | 8688.99 | 14672.47 | 6.20 |

The data from Table 1 are presented in Figure 5.

The relation between the ambient temperature and heat losses of an uninsulated heating system is presented in Figure 6. The chart has been obtained on the basis of an hourly report.

Figure 6 shows a tendency for heat losses growth with a falling ambient temperature. The relation of the difference between the average temperature of the heating medium and the ambient temperature, and heat losses of an uninsulated heating system is presented in Figure 7. The chart has been obtained on the basis of an hourly report.

Figure 7 shows a tendency for heat losses growth with an increasing difference between the average temperature of the heating medium and the ambient temperature.

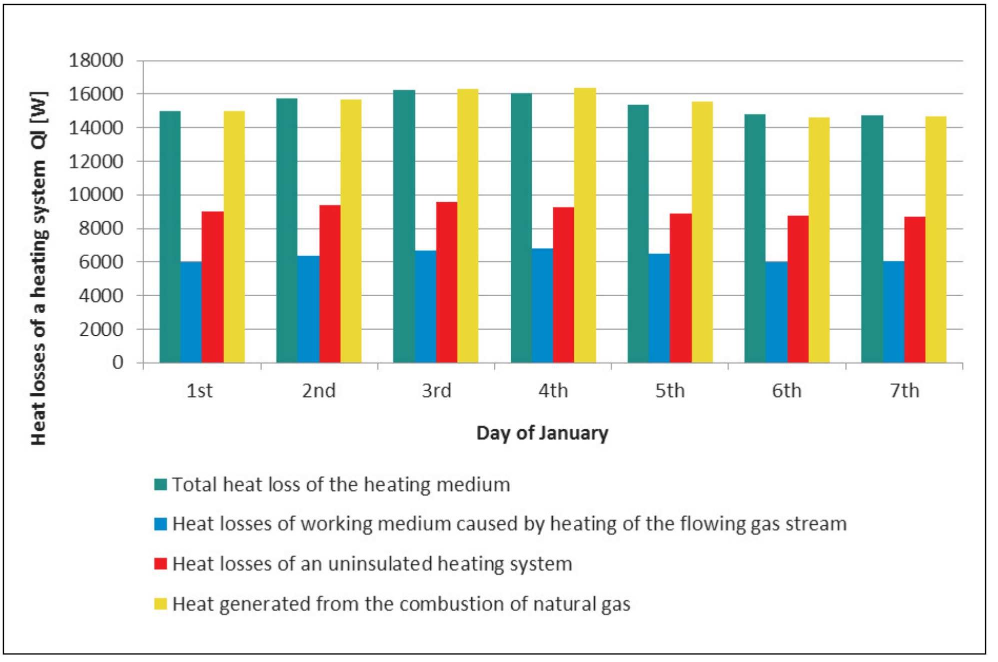


**Fig. 5.** Presentation of data from Table 1

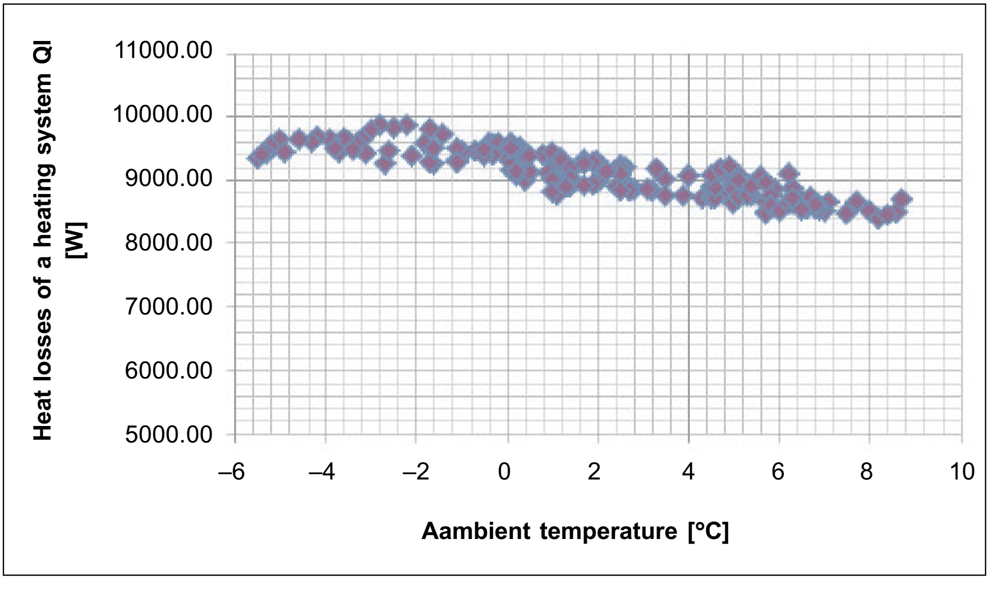


**Fig. 6.** Relation between ambient temperature and heat losses of an uninsulated heating system

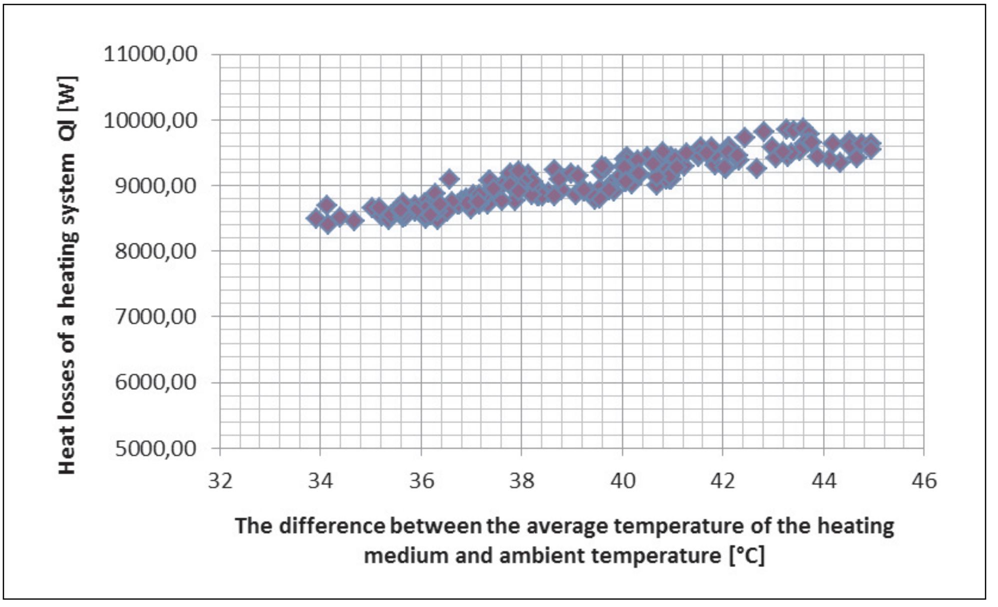


**Fig. 7.** Relation of the difference between average temperature of the heating medium and ambient temperature and heat losses of an uninsulated heating system

**Table 2**

Averaged values of heat losses of a thermally insulated heating system

| | Total heat loss of the heating medium | Heat loss of working medium caused by heating of the flowing gas stream | Heat loss of a heating system | Heat generated from the combustion of natural gas | Average ambient temperature |
|---|---|---|---|---|---|
| Measurement day | $Q$ [W] | $Q_w$ [W] | $Q_l$ [W] | $Q_b$ [W] | $T_a$ [°C] |
| 23th February | 11413.17 | 5113.14 | 6300.03 | 12095.91 | 9.43 |
| 24th February | 11616.26 | 5052.49 | 6563.77 | 12060.95 | 8.85 |
| 25th February | 11615.84 | 5256.80 | 6359.03 | 12304.41 | 8.29 |
| 26th February | 11721.98 | 5207.53 | 6514.45 | 12169.57 | 8.53 |
| 27th February | 11569.03 | 5175.45 | 6393059 | 12042.22 | 8.38 |
| 28th February | 11219.27 | 4918.04 | 6301.23 | 11450.41 | 10.24 |
| 29th February | 11272.76 | 4923.19 | 6349.57 | 11583.65 | 10.46 |

As mentioned above, after heat losses had been determined, part of the system was thermally insulated and measurements were replicated. Measurements of the insulated heating system were performed for seven days, from $23^{th}$ to $29^{th}$ of February. On the basis of these recorded data, an hourly report of heat losses was compiled. The averaged values of heat losses for each day are presented in Table 2.

The data from Table 2 are presented in Figure 8.

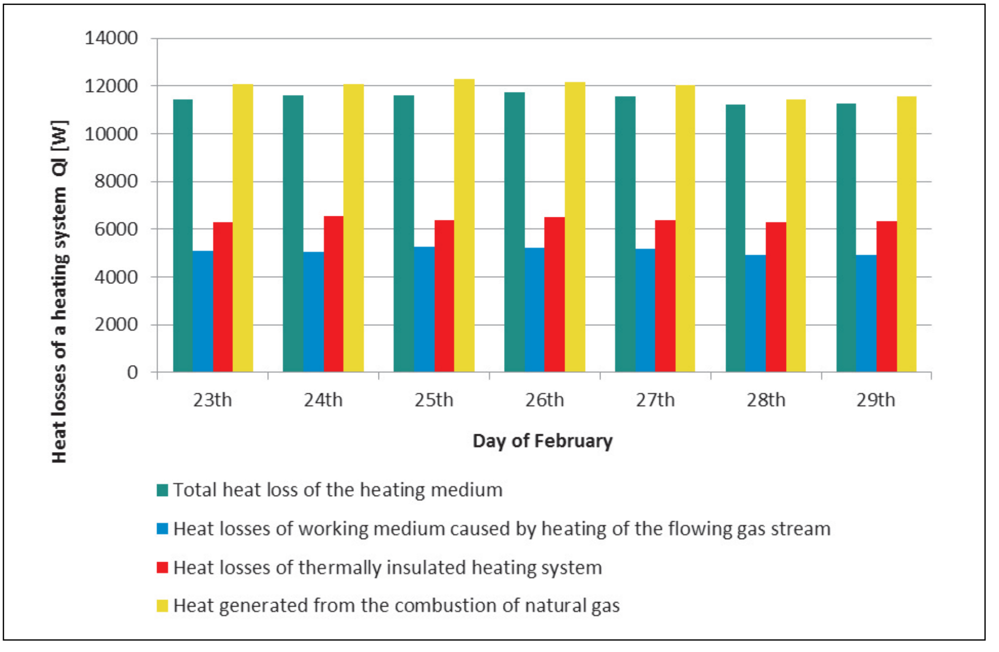


**Fig. 8.** Presentation of data from Table 2

As it results from the chart above heat losses of a partly insulated system make up about half of the total heat generated. In a completely uninsulated system this value is about 60% (according to Fig. 5). However, measurements of a partly insulated heating system were performed while the ambient temperatures were higher than during the measurements of an uninsulated heating system. Therefore, data from Table 1 and 2 cannot be compared directly. To allow this, Figures 9 and 10 (similar to Figs 6 and 7) were created based on February data. In Figures 9 and 10, part of January data which correspond along the abscissa were added as well.

On the basis of the Figures 9 and 10, the points which were measured in similar conditions were selected. First, based on Figure 9, a range of temperatures (from 4.2 to 8.8°C) was established. In this range data were generated while the system was both uninsulated and insulated. Likewise, from Figure 10, data for a range of temperature difference from 33.8 to 38.8°C were selected. Additionally, data selected from Figure 10 had to be measured in ambient temperatures ranging from 4.2 to 8.8°C.

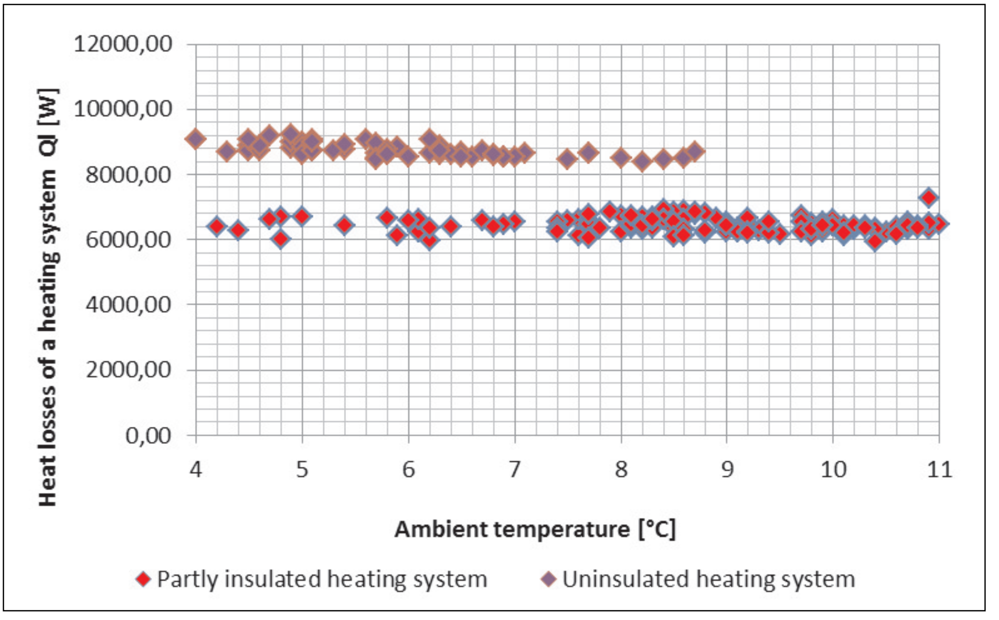


**Fig. 9.** Relation between ambient temperature and heat losses of a heating system

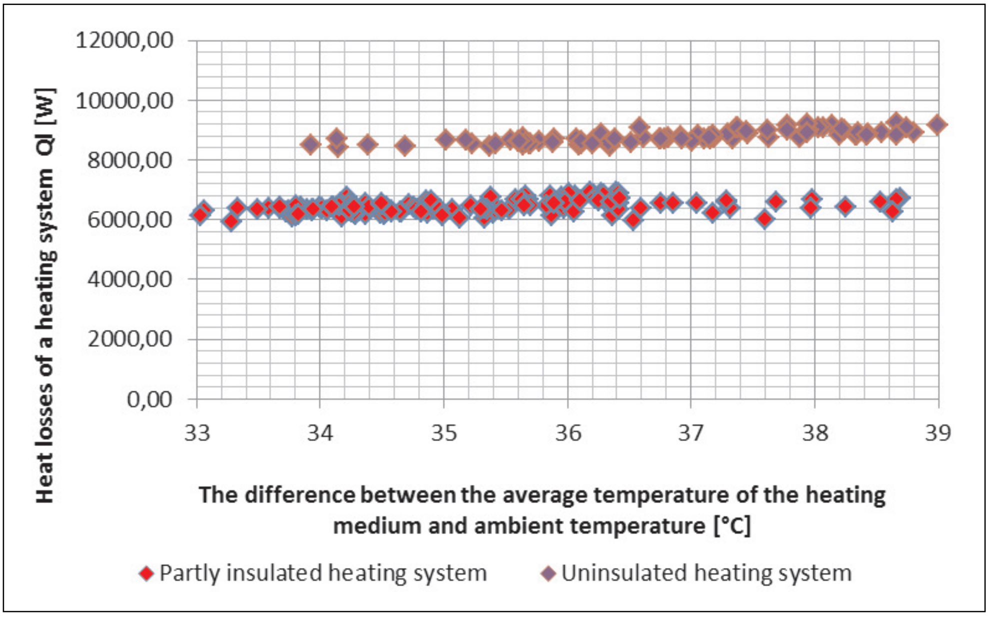


**Fig. 10.** Relation of the difference between average temperature of the heating medium and ambient temperature and heat losses of a heating system

The selected heat losses of both uninsulated and insulated systems were averaged. Hereby, the heat flux retained in a heating medium (due to a thermal insulation of the system) was estimated. The retained heat flux was converted to a reduced usage of natural gas which is combusted in a boiler. The results are presented in Table 3.

**Table 3**

Calculation results of the heat flux retained in the working medium

| Heat losses of an uninsulated heating system* | Heat losses of a partly insulated heating system* | Heat flux retained in the working medium | Economized usage of natural gas in boiler room due to insulation of installation |
|---|---|---|---|
| $Q_l$ [W] | $Q_l'$ [W] | $\Delta Q$ [W] | $\Delta v_g$ [Nm$^3$/h] |
| 8724.77 | 6504.24 | 2220.53 | 0.25 |

* averaged values of heat losses which were measured under similar conditions

## 6. CONCLUSIONS

Enhancement of energy efficiency is an increasingly important issue for the countries worldwide. Taking no account of ecological aspects, the efficient energy use may contribute to improve the competitiveness of national economies and individual market players. In the case of gas transmission operators, there is also place for improving energy efficiency.

As a result of the Joule–Thomson effect, gas temperature drops when its pressure is being reduced. This is the reason for using heating systems at pressure regulating stations. The energy efficiency studies of these systems identified significant heat losses. During the measurements carried out from 1$^{st}$ to 7$^{th}$ of January, heat losses achieved the average value of heat flux $Q_l$ = 9086.55 W. For as much as the average value of heat generated from the combustion of natural gas is 15461.65 W, it turns out that heat losses make up about 60% of produced heat. It suggests that the investigated station is a place where energy efficiency should be improved. By completely eliminating heat losses in selected days, it is possible to save 1.01 m$^3$/h of natural gas which is used as a fuel in the combustion process in a boiler room. Achieving a complete elimination of heat losses is virtually impossible (certainly not economically justified). It is also very difficult to estimate to what extent heat losses will decrease due to thermal insulation of the system. Therefore, measurements at actual conditions were needed and to that end the heating system was partly thermally insulated.

During the measurements from 23th to 29th of February, heat losses achieved the average value of heat flux $Q_l' = 6504.24$ W. Taking into consideration the usage of natural gas, it emerges that heat losses make up about 50% of produced heat (60% in an uninsulated system). What is more, theoretical calculations show that if the system had not been partly insulated, the heat losses would have been larger about $\Delta Q = 2220.53$ W, which can be swapped to the saved up stream of natural gas combusted in a boiler $\Delta v_g = 0.25$ Nm$^3$/h. Assuming that 40 days per year are characterized by similar conditions to these under which the measurements in February were carried out, it is possible to economize 240 Nm$^3$ of natural gas per year, owing to a partial thermal insulation of the heating system.

Another method of improving energy efficiency is to limit the overheating of the natural gas stream. It is sufficient when the gas, after its pressure has been reduced, has a temperature between 5°C and 8°C. Allowing a situation where the gas has a higher temperature causes overheating of the working medium. Considering the trends presented in Figures 6 and 7, it becomes clear that such a situation is unwanted. The greater the difference between the average temperature of the heating medium and the ambient temperature, the greater are heat losses. It is particularly relevant during the winter season, when the ambient temperature often drops below 0°C.

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