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APPLICATION OF PIPELINES MADE WITH THERMOFLEX® TECHNOLOGY FOR NATURAL GAS AND CARBON DIOXIDE TRANSPORTATION

1. INTRODUCTION

The most important issue related to pipeline transportation of hydrocarbons (natural gas, oil) and chemical substances (e.g. carbon dioxide) is to get the best transportation efficiency, taking into account technological and economical aspects. The main technological aspects are properties of the material from which the pipeline is made such as: the maximum operating pressure of pipeline (MOP), the heat transfer coefficient, the corrosion resistance of the material and the resistance to large temperature changes. Another technological aspect is surface roughness, which has an effect on the transported medium pressure drop. Also an important aspect, which impacts directly on the economics of the investment is a pipeline installation process and duration of this process. The basic material for the construction of pipelines operating at high pressure is steel. For pipelines operating at medium and low pressure polyethylene (HDPE) is used. The advantages of steel and polyethylene pipelines are combined in pipelines made with Thermoflex® technology.

2. OVERVIEW OF PIPELINES CONSTRUCTION TECHNOLOGIES

According to the Regulation of the Minister of Economy in Poland the following breakdown of gas pipelines is used due to the maximum operating pressure of the pipeline [1]:

a) low pressure gas pipelines: (≤ 10 kPa),
b) medium pressure gas pipelines (from 10 kPa to 0,5 MPa inclusive),
c) increased medium pressure gas pipelines (from 0,5 MPa to 1,6 MPa inclusive),
d) high pressure gas pipelines (>1,6 MPa).

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For the pipeline transportation of carbon dioxide, pressure should be considered in the range from 6 MPa (for the liquid phase) to 20 MPa (for the liquid phase in supercritical pressure conditions) [2].

Steel pipes are used for the construction of high-pressure natural gas pipelines or pipelines for carbon dioxide transportation. These are often seamless pipes thermomechanically rolled. The main steel grades used for high-pressure natural gas pipelines and pipelines transporting CO_2 by the standards of API 5L are: from X42 for natural gas and from X60 to X80 for carbon dioxide. According to the European standard EN 10208-2 equivalent above steel are alloyed steel quality L290MB (X42), L360MB (X52) and special alloy steel obtained by thermo-forming: L415MB (X60), L450MB (X65), L485MB (X70) and L555MB (X80) [2, 3]. These steels are characterized by a high value of yield strength and tensile strength, and in its composition dopant elements as vanadium, niobium or titanium are included.

Polyethylene (HDPE) is used for the construction of medium and low pressure pipelines [1, 4, 5]. This material has advantages. At present, practically no steel pipes are used for construction of medium and low pressure natural gas networks. HDPE has a relatively low density, high ductility, good dielectric properties, low water absorption and high chemical resistance. Polyethylene used for the construction of natural gas network has a density above 930 kg/m^3. From the standpoint of suitability for gas pipes, the biggest advantage of polyethylene pipelines is long term durability (life time), and resistance to slow and rapid crack propagation. The main aim of the design of polyethylene pipelines is a 50-year life. Another very important advantage is the very low absolute roughness of polyethylene pipes within 0.01 mm, which causes a lower pressure drop along the pipeline than steel pipes. Polyethylene has a low thermal resistance, operating temperature should not exceed 20 deg C. Operating at a significantly higher temperature reduces the lifetime of polyethylene pipes. Installation of polyethylene pipeline consists of electrofusion welding different sections of the pipeline. It is important that the installation does not damage the pipes. There are high local stress in place of damage, which causes cracking of HDPE pipes. Therefore, during transport and installation HDPE pipes should be specially protected.

Another material used for the construction of medium and low pressure natural gas networks is polyamide (PA) [1, 4, 5]. Polyamides are partially crystalline and partially amorphous. Such a structure of the polymer causes a very good mechanical properties. Circumferential tensile strength for the polyamide is 3 times higher than for polyethylene. The main advantages of this PA pipes: lightweight through the use of the smaller wall thickness. Polyamide pipes can be operated at temperatures up to 80 deg C due to much better resistance to high temperatures. Another advantage is resistance to degradation of the pipeline after location in the ground. Polyamide pipes exhibit tenfold lower natural gas permeability of the tube in relation to polyethylene pipes, it restricts the gas migration in the ground and minimize losses in the gas network. It has a high chemical resistance, including aromatic compounds, and oil substances. Moreover, the polyamide is produced from natural raw materials (castor oil) and the production process is fully recyclable. During installation process of polyamide pipelines, their individual sections are connected by bonding, which is characterized by very good properties. The main disadvantage of PA pipes is significant water uptake, which causes that mechanical and electrical properties are significantly deteriorated.

3. PIPES MADE WITH THERMOFLEX® TECHNOLOGY [6]

In order to optimize the pipeline transportation of hydrocarbons (including natural gas) and chemicals, such as carbon dioxide, one should search technology solutions that improve the efficiency of transportation. The materials used for construction of pipelines should have good technical properties and also the installation process should be relatively simple and less time consuming.

Pipelines made using Thermoflex® technology combine the advantages of steel, HDPE and PA pipes. Thermoflex® pipes consists of three layers (Fig. 1). The inner layer is made of the new polymeric materials, especially Ultramid® polyamide (nylon PA6/PA66) (conventional pipelines are made of polyamide nylon 11) or FORTRON material. FORTRON comprises a polyphenylene sulfide (PPS), connecting layer, and polyamide Ultramid®. Selection of layer depends on the projected and proposed medium for transportation. The middle layer is an innovative technology of aramid fiber strands. Two types of strands are performed: the first one (radial) increases the strength of the inner layer, which allows these pipes to be used to build high pressure natural gas pipelines. The second type of fibers (longitudinal) – minimizes the possibility of pipeline stretching. The third layer is the outer jacket designed to protect the strands of aramid fibers from mechanical damage and is made of polypropylene or nylon.

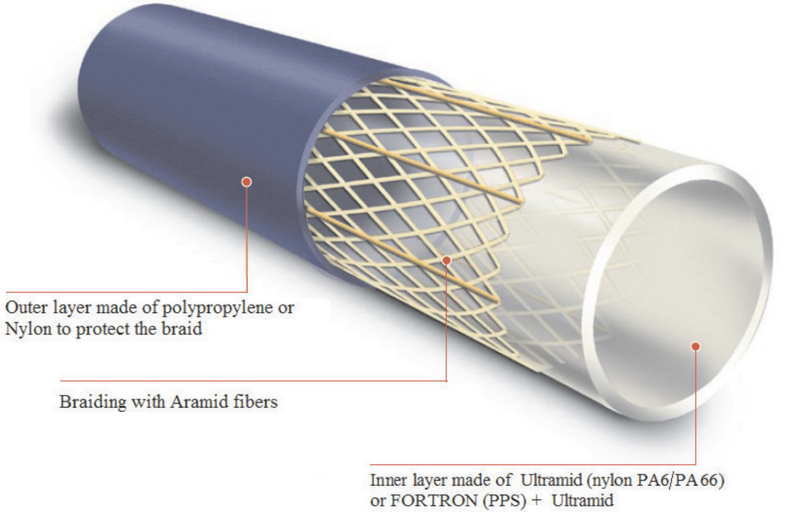

Fig. 1. Construction of pipes made with Thermoflex® technology

The advantage of pipes made using Thermoflex® technology is having a very low absolute roughness, which is comparable to a pipe made of polyethylene (0.01 mm) and significantly lower than conventional steel pipe. Low roughness allows to obtain lower pressure drops along the pipeline. These pipes have a double lower thermal conductivity compared to HDPE pipes, and twenty times lower in comparison to the steel (Tab. 1). This allows to keep the temperature of the transported medium.

Table 1

Thermal conductivity of selected materials

	Thermal conductivity [W/(mK)]
Air	0.3
Thermoflex®	2.8
HDPE	6.0
Steel	60.0

A complex layer structure enables the use of Thermoflex® pipes for high pressure pipelines construction. Depending on the pipe diameter maximum operating pressure (MOP) may be up to 138 bar for the small diameters and 52 bar for a diameter of 6" OD. Applied to the construction materials show a high resistance to the effects of high temperatures and may be used even to a temperature of 121 deg C. Pipes made using Thermoflex® technology also have a high resistance to corrosion and minimize the wear out effects of transported substances such as hydrogen sulfide, carbon dioxide and aromatic hydrocarbons, condensates, sulfur gas and oil derivatives. Thermoflex pipes cannot be used for the construction of high pressure pipelines and pipelines designed for large capacity and large volume flow rate, because in order to maintain the flexibility of Thermoflex pipes and to ensure a smooth transportation process, the biggest diameter is limited to 6" OD.

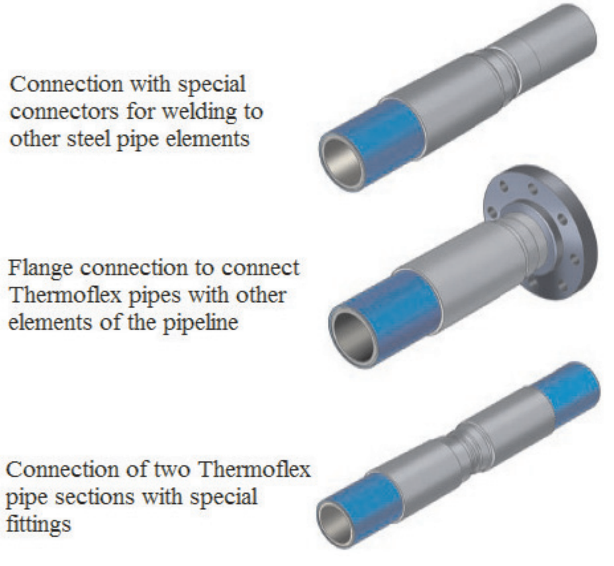

Fig. 2. Typical connections of pipelines made with Thermoflex® technology

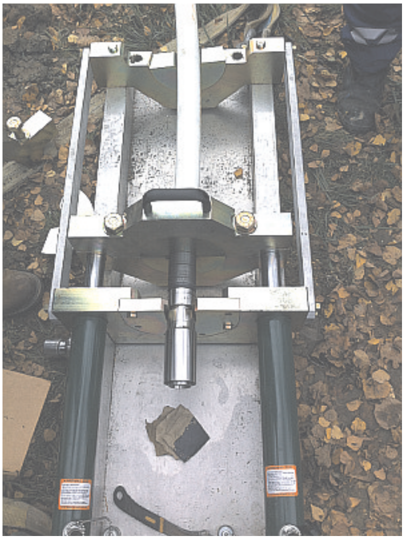

Fig. 3. Section endings of Thermoflex® pipes are pressed and swaged manually or mechanically, using a pneumatic machine

Pipes made using Thermoflex® technology are placed directly into the open trench from the spool, which may contain between 3600 (1" OD) and 300 (6" OD) meters of pipe on it depending on the pipe diameter. Installation process is simple and fast. Connection of the next sections of the pipeline is done using special Carbon steel or Stainless Steel fittings, in which every section the endings are pressed and swaged manually or mechanically, using a pneumatic machine (Fig. 3). There is no time-consuming process such as welding or gluing. Using special connectors and fittings it is also possible to connect Thermoflex® pipe with elements of steel pipelines by welding to a steel pipe or with flange (Fig. 2).

4. APPLICATIONS OF PIPELINES MADE WITH THERMOFLEX TECHNOLOGY

The main application of Thermoflex® pipes is the construction of pipelines for natural gas, petroleum products and chemicals. These pipes are successfully used in the United States of America for natural gas transportation from wellsites on conventional natural gas reservoirs to natural gas mine collecting installations. Natural gas transported from wellsites can be contaminated with chemicals such as hydrogen sulfide or carbon dioxide. Pipes manufactured using technology Thermoflex® have a high resistance to these substances.

Because of the short time of installation, application of Thermoflex® pipes should be considered in the development of natural gas conventional and unconventional reservoirs. It is important to start drilling wells and prepare for exploitation in the shortest time to improve the economics of these projects from a technical and economical point of view.

Using pipes made with Thermoflex® technology it is possible to shorten the time of the pipe installation and connect the wellsite to the processing unit.

Pipes made using this technology may be applied for pipeline transportation of pure carbon dioxide for the purpose of geological storing. Because of the small available diameters of Thermoflex® pipes it is possible to only transport a relatively small mass flow rate of CO_2 (maximum to 0.1 $MtCO_2$/year at a distance of 50 kilometers) assuming carbon dioxide transportation in the liquid phase.

Thermoflex® technology is also applicable in trenchless technology for reparation, modernization and upgrading of existing steel pipelines. Pipes with a smaller outer diameter can be pulled inside an existing steel pipeline with larger inner diameter thanks to the longitudinal fibers and to a lesser extent the radial ones (Fig. 4).

Fig. 4. Application of Thermoflex® pipes for trenchless technology of pipelines modernization

5. EXAMPLES OF FLOW SIMULATIONS IN THERMOFLEX PIPES COMPARED TO STEEL PIPELINES

Examples of flow simulations have been performed for the natural gas pipeline made of steel pipes and made with Thermoflex® technology. The following assumptions for the simulation of flow have been adopted:

a) the length of the pipeline: L = 30 km;
b) nominal diameter of steel pipeline DN = 100mm;
c) diameter of pipeline made using Thermoflex® technology: D = 4.5" OD (3.95" ID);
d) the average temperature of transported natural: T = 293 K;
e) maximum operating pressure (MOP): 5 MPa;
f) the gas composition is given in Table 2;

Table 2
Example of natural gas composition

Component	Molar fraction
CH_4	0.9160
C_2H_6	0.0315
C_3H_8	0.0105
i-C_4H_{10}	0.0021
n-C_4H_{10}	0.0007
N_2	0.0210
CO_2	0.0042

g) pseudocompressibility factor determined based using Redlich-Kwong gas equation of state for the maximum operating pressure: Z = 0.903;
h) relative density of natural gas: d = 0,588;
i) designed capacity of the pipeline: Q_n = 5 000 m^3/h.

For calculations and simulations, the Jacob energetic equation was used to determine the linear pressure drop [7]:

$$p_1^2 - p_2^2 = \frac{\lambda \cdot Z \cdot d \cdot T \cdot L \cdot Q_n^2}{0.001287 D^5} \tag{1}$$

The meaning of symbols in Equation 1:

- L – length of the pipeline [m],
- d – relative density of natural gas [–],
- Q_n – flow rate at normal conditions [m^3/s],
- D – inner diameter of the pipeline [m],
- Z – pseudocompressibility factor determined based using Redlich-Kwong gas equation of state for the maximum operating pressure [–],
- T – medium temperature [K],
- λ – coefficient of linear flow resistance determined by formulas:

For the steel pipeline by Prandtl-Nikuradse equation for flow zone V:

$$\lambda = \left(\frac{1}{-2 \cdot \log\left(\frac{\varepsilon_S}{3.71}\right)} \right)^2 \tag{2}$$

For Thermoflex pipeline by Colebrook-White equation for flow zone IV:

$$\frac{1}{\sqrt{\lambda_t}} = -2 \cdot \log\left(\frac{2.51}{\mathrm{Re}_t \sqrt{\lambda_t}} + \frac{\varepsilon_t}{3.71}\right) \tag{3}$$

Obtained results of simulations for the accepted input data and length of pipeline demonstrated the pressure drop for steel pipe on the level of 1.48 MPa, and for the pipeline using Thermoflex® technology on the level of 1.0 MPa. The pressure drop in the Thermoflex® pipeline is smaller by 32% compared to steel pipes with similar diameter. Comparison of pressure drop depending on length of pipeline and volume flow rate for steel and Thermoflex® pipes for input data is shown at Figure 5.

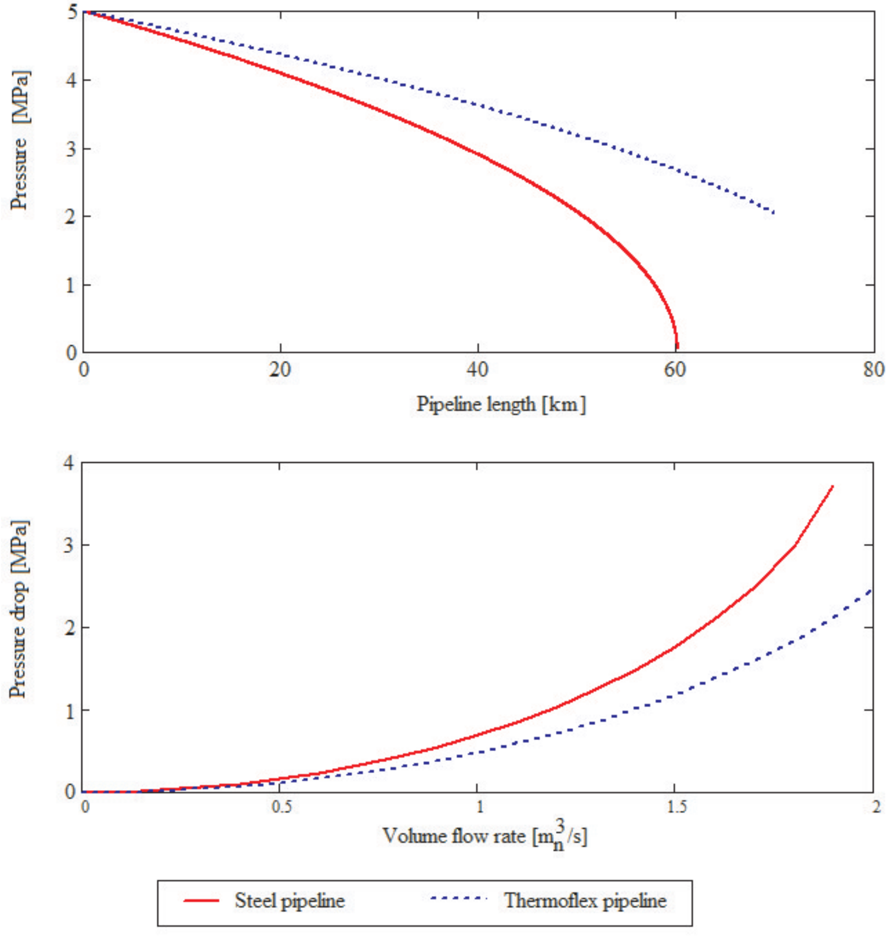

Fig. 5. Comparison of pressure drop for steel pipes DN100 and Thermoflex® pipes ID 3.95" depending on length of pipeline (upper figure) and volume flow rate (lower picture)

Another analyzed case is pipeline transportation of CO_2 with the use of pipes made with Thermoflex® technology. Carbon dioxide flow was assumed in the liquid phase at a maximum operating pressure of 5 MPa. Inlet temperature is lowered to 0 deg C for transportation CO_2 in liquid phase. Simulations of transported CO_2 temperature changes will also be performed for an ambient temperature of 10 deg C for steel and Thermoflex® pipelines. Nominal flow capacity will amount to 0.086 $MtCO_2$/year (5 000 m_n^3/h). It is possible to transport about 0.1 $MtCO_2$/year for a distance of 50 km with a maximum allowable operating pressure with the maximum diameter of the Thermoflex® pipes 6" OD (5.08" ID). In the analyzed case diameter of 4.5" OD (3.95" ID) was assumed as a comparison to the steel pipeline diameter of DN100. Figure 6 shows the pressure drop of the transported CO_2 stream depending on the length of the pipeline for steel and ®Thermoflex pipes. The pressure drop, increasing by distance is much lower for Thermoflex® pipes.

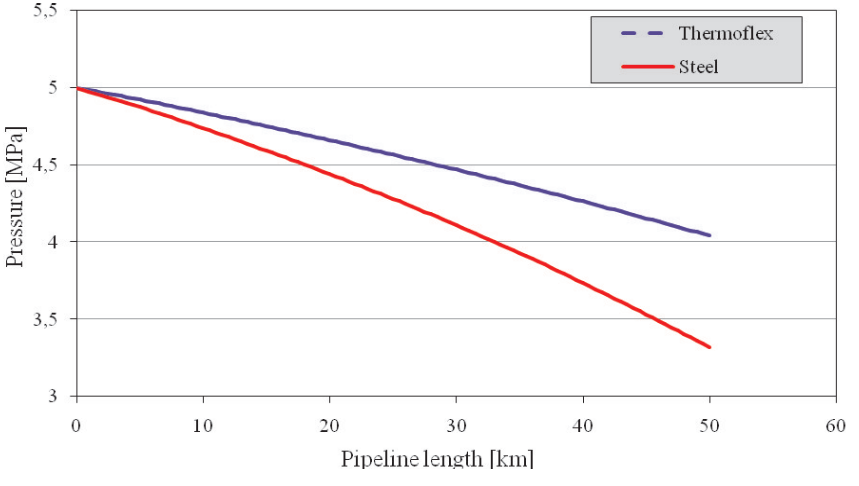

Fig. 6. Pressure drop of the transported CO_2 stream depending on the length of the pipeline for steel pipeline (DN100) and Thermoflex pipeline (3,95" ID)

The low thermal conductivity of the Thermoflex® pipes results in slower temperature changes of the transported medium compared to the steel pipe.

6. CONCLUSIONS

Thermoflex® technology combines the most important advantages of steel and polyethylene pipes. The main advantages of pipeline built using Thermoflex® pipes are:

a) reduced pressure drop compared to steel pipes;
b) better thermal insulation compared to steel pipes;
c) high pressure applications compared to HDPE;
e) very good chemical resistance properties;
f) reduced installation time and costs.

The easy installation process of Thermoflex® pipelines brings along cost reduction and can play an important role in the development of conventional hydrocarbon reservoirs and conventional and unconventional natural gas reservoirs. Very good chemical resistance allows the use of Thermoflex® pipes to transport natural gas with chemical additives e.g. carbon dioxide, hydrogen sulfide or natural gas with condensate and pure carbon dioxide and water or saline for injection into the well. This technology can also be used for trenchless modernization or reparation of existing pipelines. Pipelines made using this technology can also be applied for the development and modernization of medium pressure natural gas networks thanks to better technical parameters compared to polyethylene. Thermoflex® pipes can also be used for high-pressure pipelines limited to the available diameters and the maximum operating pressures.

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