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Types and purpose of pre-insulated pipelines:

- In Western countries, as early as in the 1970s, heating pipelines were commonly built using the technology of pre-insulated pipes, i.e. thermally and damp-proofed at the factory.
- During this period, several experimental sections of pipelines made of pipes and pre-insulated elements produced by companies such as Austrian KELIT, German PANISOVIT or Danish I.C. Moller.
- Currently in Poland they are used pre-insulated products from companies such as: Brugg, FINPOL ROHR (Warsaw), LOGSTOR (Elbląg, Żory, Zabrze, Gliwice), PRIM (Lublin), STAR PIPE (Poznań), THERMAFLEX, ZPU Kazimierz Jońca (Międzyrzecz).

Types and purpose of pre-insulated pipelines:

In a number of pre-insulated systems, the following are distinguished:

- composite pre-insulated pipes, in which the insulation permanently binds the outer casing pipe to the inner service pipe, and sliding ones, in which the insulation associated with the casing slides along the service pipe;
- pre-insulated pipes intended for the construction of pipelines laid directly in the ground with a polyethylene casing and overground pipelines with a "spiro" type casing pipe made of galvanized steel, aluminum or corrosion-resistant steel;
- traditional (rigid) pre-insulated pipes with a welded or seamless line steel pipe made of unalloyed low-carbon steel and flexible pre-insulated pipes with a thin-walled, corrugated steel line pipe, made of corrosion-resistant steel, with a line pipe made of PEX polyethylene, copper or polybutylene;
- pre-insulated pipes with a steel service pipe intended for the construction of high-parameter pipelines; with a line pipe made of copper and plastic for the construction of low-parameter pipelines;
- pre-insulated pipes manufactured using the "pipe in a pipe", "conti" (continuous) or "semi-continuous" method.
- pre-insulated pipes with one, two or four (only polybutylene and PEX) service pipes in one casing pipe.

Types and purpose of pre-insulated pipelines:

Factors influencing failure-free operation of pre-insulated pipelines:

In pre-insulated pipeline systems used for heat transmission, a number of factors affect failure-free operation of the pipelines:

- correctly made technological design of a heat network section, taking into account the design principles included in the PN-EN 13941: 2006 standard;
- quality of pipes and pre-insulated elements as well as products and raw materials used for their production, meeting the requirements of the group of standards „Heating networks - System of pre-insulated composite pipes for water heating networks laid directly in the ground”: PN-EN 253: 2005, PN-EN 448: 2005, PN-EN 488: 2005, PN-EN 489: 2005;

Factors influencing failure-free operation of pre-insulated pipelines:

- transport and storage in accordance with the guidelines of the manufacturer of pre-insulated pipes;
- reliably conducted construction and assembly works, including welding of steel elements and making joint sets, especially their hermetization;
- proper supervision over the execution of a section of the heating network;
- quality of network water as a heat carrier, at least corresponding to the requirements of PN-85 / C-04601.

Factors influencing failure-free operation of pre-insulated pipelines:

Polish heating companies have had theirs own internal documents, which contains detailed requirements for

- materials, elements and devices used;
- project documentation;
- assembly technology, execution, supervision over execution and required tests;
- storage, transport and collection
- for pre-insulated pipelines laid directly in the ground.

These documents are constantly updated. The introduced changes - resulting from the operating experience of the Companies, are approved by the Technical College and the Management Board of the each Company.

Quality of pipes and pre-insulated elements:

Pre-insulated pipes and elements delivered to the site should not have visible damage and deformation, the outer surface of the casing pipe should be smooth, and the deviation from the coaxiality of the service pipe and the casing pipe should not exceed the values given in PN-EN 253: 2005 at any point. Photographs 2 and 3 show the appearance of a flexible pre-insulated pipe delivered to one of the Polish Thermal Power Companies, which, due to poor quality, were returned to the manufacturer.

Delivery and storage of pre-insulated elements:

Pre-insulated elements delivered to the construction site should be stored on a flat surface or on soft underlays so that they are not overly compressed and that the casing pipe is not damaged or crushed. The inside of the line pipes are to be protected with anti-contamination caps, which can be removed directly before the pipelines are welded.

Photo 4 shows an anomaly which, after the pre-insulated pipeline is put into operation, will increase the amount of mechanical impurities in the network water.

Laying pre-insulated pipes:

Before starting the installation of the pipeline, the pipes should be placed in a trench. It is recommended to lay pipes on wooden sleepers. Determining the correct ordinates of the pipelines should be done by backfilling or undermining the sleepers. If the above method is not used, a leveled sand bed should be made before laying the pipes in the trench.

Photo 5 shows incorrect arrangement of pipes in the trench due to the lack of leveled ballast or wooden sleepers, which may result in failure to maintain an appropriate slope and prevent drainage of the pipeline.

Welding of steel pipes:

- Welding is one of the most important processes affecting the durability of a district heating network. Preparation of pipelines for welding, the electrodes used and the method of making the welds should be in accordance with the technical documentation;
- Welders must have appropriate qualifications (different, depending on the welding method, material groups and diameter range);
- It is allowed to weld several pipeline elements at ground level along the edge of the trench and lower the entire section of the prefabricated element into the trench so as not to damage the welded joints or the casing;
- After welding, the welded joints should be tested by appropriately qualified personnel.

Installing the connector assembly:

The installation of the joint assembly (assembly of sleeves / sleeves and insulation of welded joints) can be started after obtaining a positive result of the weld test. Before installing the joint, carefully cut the PUR foam layer at the ends of the pre-insulated elements to be joined, taking care not to damage the alarm cables, clean the surfaces of the conduit pipes without insulation from any mechanical impurities (e.g. sand, mud) and dry them if necessary. check the alarm system connections. The result of checking the connection of the supervision system wires should be confirmed with an appropriate protocol.

Photos 6 and 7 show situations that make it difficult to make a proper joint assembly.

Installing the connector assembly:

Photo 8 shows a joint with an ordinary HDPE sleeve with heat shrinkable patches, while photo 9 shows joints with the same sleeves with pressed-in plugs - after 10 years of operation. As a result of water penetration from the outside, not only insulation deteriorated (Photo 8), but also the conduit pipe corrosion (Photo 9).

Installing the connector assembly:

Photo 10 shows a non-cross-linked heat shrink joint after 4 years of operation in a wetland area. The view of the connectors indicates that the use of heat-shrinkable bands is of inappropriate quality, while the leakage of the joints (the cut-out was made to locate moisture and repair the failure) indicates assembly errors at the stage of shrinking the sleeves or the use of not the best quality couplings.

Photo 11 shows a badly shrunken new non-crosslinked heat shrinkable joint.

Installing the connector assembly:

Photo 12 shows a pre-insulated joint after 2 years of operation, made without proper supervision by untrained employees.

Photos 13 and 14 show the foam from the joint on the overhead pipeline after one year of operation. The joint was insulated by hand, without proper supervision, by untrained personnel.

Installing the connector assembly:

Photo 15 shows a poorly shrunk radiation cross-linked sleeve by a person who has not been trained in joint assembly.

Execution of ballast and sand backfill:

Sand around the pre-insulated pipeline, granulation up to 2 mm, must not contain sharp / large stones and debris that could damage the casing. Photo 16 shows an unacceptable method of laying pre-insulated pipes in a trench. Leaving bricks, stones, pieces of concrete in the ground around the pre-insulated pipeline may lead to deformation or even destruction of the casing in the future.

Execution of ballast and sand backfill:

Photo 17 shows the deformation of the casing of the pre-insulated pipe after 12 years of operation. The damage was caused by a fragment of a channel lining element left in the excavation (the new pre-insulated pipeline was laid along the route of the channel pipeline).

Execution of compensation zones:

At each bend of the pipeline, change of diameter and in the case of a branch without a fixed support, compensation zones should be made, enabling the pre-insulated pipelines to move after they are buried in the ground.

Photo 18 shows an incorrect way of laying the pipeline in the trench due to the limited space for compensation. Too close distance of the pre-insulated pipe from the trench walls may in the future lead to the destruction of the foam on the compensation bend.

Backfilling the pipeline:

After the stabilized sand backfill is completed, the route of the heat pipeline should be marked with a warning tape, which is of particular importance when it is necessary to make a pre-insulated open pit near the pipeline in the future.

Photos 19 and 20 show damage to the casing and the pre-insulated pipe due to the lack of marking the pipeline route with warning tape.

Accompanying works:

Installation of pre-insulated pipelines is often associated with the performance of works other than just joining pipes and pre-insulated elements together. The expected functionality and service life of the pre-insulated pipeline may depend on the method of execution and the quality of the accompanying works. Typical accompanying works include pre-insulated chambers on pipelines with uninsulated pipe sections, fittings, fittings and compensators. When designing and constructing chambers, the requirements of the PN-B-10405: 1999 standard should be followed.

Respecting certain rules during construction and assembly, with proper design and appropriate quality of its elements, can guarantee that **pre-insulated pipelines will work without failure. The service life of the pre-insulated network, estimated at 30 years, depends on the thermal durability of the insulation,** i.e. the actual temperature of the heat carrier. **The lower the temperature of the heating medium, the longer the expected lifetime of the insulation.**

Operation of pre-insulated pipelines:

In pre-insulated pipelines laid in polish district heating systems the number and arrangement of alarm cables depend on the nominal diameter of the pre-insulated pipeline:

- DN <= 400 -1 pair of signaling and alarm cables, spacing ten to two,
- 500 <= DN <= 700 -2 pairs of signaling and alarm cables, spaced around the circumference, every 180 °,
- 800 <= DN <= 1000 -3 pairs of signaling and alarm cables,
- DN> 1000 -4 pairs of signaling and alarm cables.

In order to be able to conduct an ongoing assessment of the technical condition of pre-insulated pipelines, it is necessary, already at the construction stage and during each replacement, to create and update as-built installation diagrams of the heating network and signaling and alarm systems.

Operation of pre-insulated pipelines:

Photos 21 and 22 show the cause and effect of the failure of the pre-insulated pipeline section that was not subject to inspection. The failure was caused by corrosion of the weld seam on the shut-off valve. Penetration of water deep into the foam caused the destruction of the insulation and the necessity to replace several meters of the pipeline.

Operation of pre-insulated pipelines:

Photos 23 and 24 show failures of axial bellows compensators installed in heating chambers between sections of pre-insulated pipelines, caused by errors made at the pipeline design stage and improper selection of compensation capacities.

Operation of pre-insulated pipelines:

Laying of the first sections of pre-insulated pipelines was carried out according to the guidelines of the producers of pre-insulated pipes from Denmark, Sweden and Germany, as Western European countries introduced this technology twenty years earlier. Over the years, employees of Polish Distict Heating Companies have gained more and more experience related to both the design and operation of pre-insulated pipelines. In the first years of operation, it was allowed, among others, to lay directly in the ground:

- "upper" venting and drainage panels with valves made of carbon steel, apart from pre-insulation, placed in manholes and hydrant boxes,
- cut-off panels in the entire range of pipeline nominal diameters with the drive located in the manholes.

Operation of pre-insulated pipelines:

Due to the corrosion process of fittings placed outside the pre-insulation - in manholes and hydrant boxes, found after several years of operation, an order was introduced in 2003 to use fittings with a body made of corrosion-resistant steel.

Photo 25 shows the corroded fittings, dismantled after 12 years of operation from the heating chambers.

Testing of pre-insulated elements:

- Laboratory tests of pre-insulated elements are aimed at assessing the compliance of their properties with the parameters declared by manufacturers in technical approvals or specified in standards;
- The quality of pre-insulated products and their correct assembly, as has been emphasized many times, determine the durability and lifetime of the heating network. The quality of insulation in pre-insulated pipes significantly affects the cost of heat delivered to consumers in centralized, extensive heating systems;
- At the request of manufacturers, pre-insulated products of such companies as: ZPU Kazimierz Jońca Międzyrzecz, STAR-PIPE Poznań, LOGSTOR Zabrze and LOGSTOR Elbląg, FINPOL Warsaw, PRIM Lublin, RADPOL Człuchów, BRUGG are regularly tested;
- At the request of District Heating Companies from all over Poland, control tests are currently carried out on pre-insulated products collected from deliveries under tenders.

Testing of pre-insulated elements:

Accredited laboratories carrying out tests are equipped with specialized equipment for testing elements such as:

- insulation (microscope with a camera, pycnometer, scales, Lloyd endurance test stand),
- pipe assemblies - sections of pre-insulated pipes (station for determining the value of the heat conduction coefficient (so-called "pipe apparatus"), test stands for determining the strength of PUR foam to radial deformation under stress (test of resistance to "creep"), tangential shear strength and axial and aging,
- joint assemblies (stand for testing ground load resistance (so-called "sandbox" and for testing water impermeability).

Testing of pre-insulated elements:

The apparent insulation density test:

- the apparent density of the foam is tested according to PN-EN 253 and PN-EN ISO 845: 2000,
- it has a fundamental influence on the properties of PUR foam,
- insulation in pre-insulated pipes must have a relatively high apparent density (according to the current edition of EN 253, it must not be lower than 60kg/m^3 at any point of the insulation), due to the need to ensure the appropriate strength parameters of the PUR foam and the pipe assembly;
- As the apparent density of the foam increases, its compressive strength and the creep and shear resistance of the tubing increase. On the other hand, its thermal insulation properties are deteriorating. For this reason, the apparent density of PUR foam should not exceed 100kg/m^3.

Testing of pre-insulated elements:

Testing of water absorption after boiling by PUR foam:

- water absorption demonstrated by the foam after cooking, tested according to PN-EN 253: 2005, should not exceed 10% in relation to the initial sample volume. In practice, it generally does not exceed 5%, which means that the new polyurethane insulation absorbs water very slowly,
- **according to the results of tests of insulation made of pre-insulated pipes, the water absorption shown by the foam after boiling increases to over 20% after several years of operation;**
- **for this reason, the perforation of the service pipe or the leakage of the cover may quickly lead to the dampening of the insulation over a large area and, consequently, to corrosion of the outer surface of the steel pipe. To ensure the possibility of locating dampness in the insulation as soon as possible, protection against the spread of water in the foam and the occurrence of failure, it is necessary to use effective failure detection systems in pre-insulated pipes.**

Testing of pre-insulated elements:

Investigation of the percentage of cells (pores) closed in foams:

- the foam in pre-insulated pipes should have a closed-cell structure. Due to the relationship between the participation of closed cells in the foam and its other properties:
- water absorption (the more closed pores, the lower water absorption),
- resistance to aging (the more closed cells, the greater the resistance to aging),
- heat conduction coefficient (the more open pores, the greater the variation in time of the heat conduction coefficient, the proportion of closed cells should not be less than 88%.

The percentage of cells closed in isolation is tested according to PN-EN ISO 4590: 2005, using a gas pycnometer.

Testing of pre-insulated elements:

Compressive strength tests of PUR foam:

- is performed in accordance with PN-EN 253: 2005 and PN-93 / C-89071, on a strength test stand;
- due to the highest loads on the foams in the direction perpendicular to the pipe axis, the sample is compressed in the radial direction during the test;
- the compressive strength of PUR foam in a pre-insulated pipe must not be lower than 0.3MPa.

Testing of pre-insulated elements:

Shear strength test of a pipe assembly:

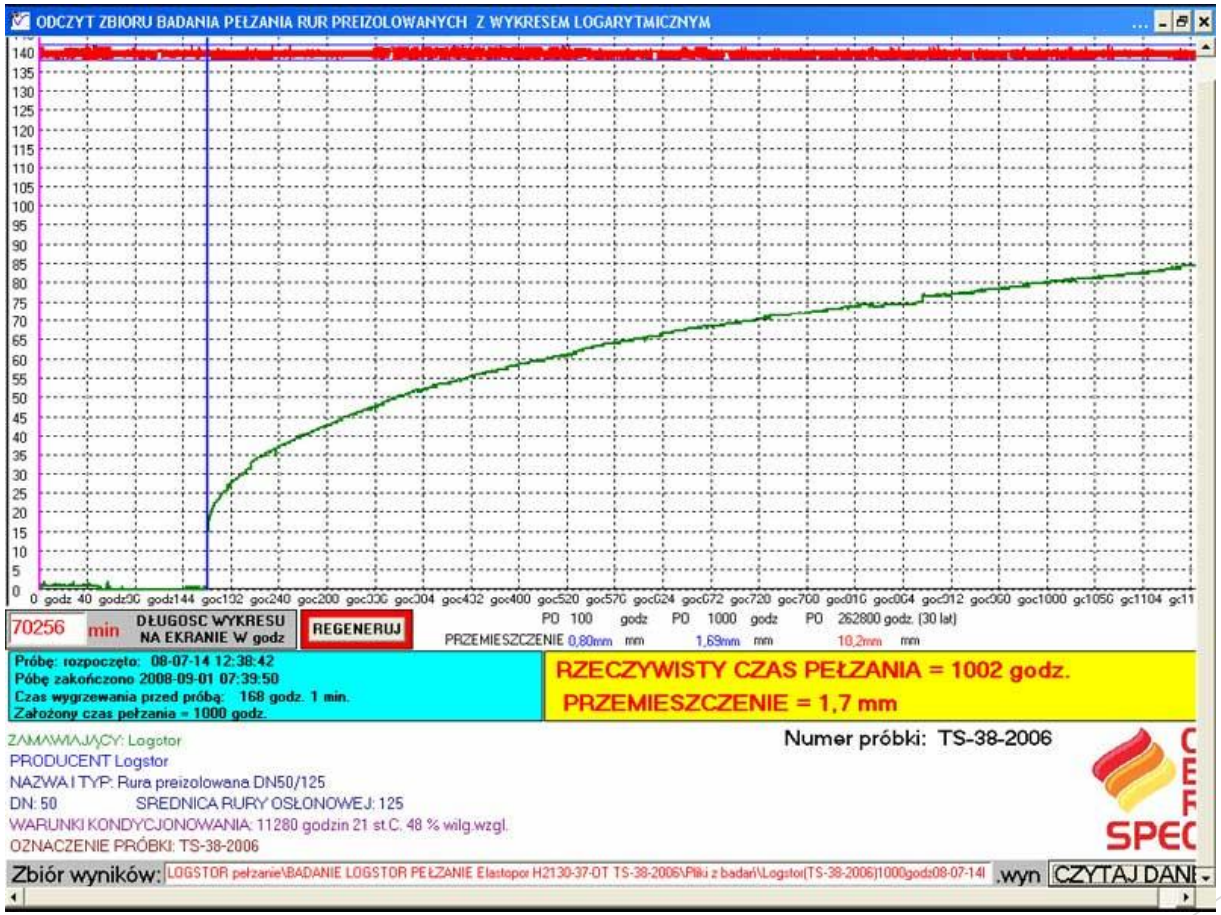
- tangential and axial shear strength of the pipe assembly is tested in accordance with PN-EN 253: 2005 on the shear test stand;
- photo 26 shows a sample that did not meet the required axial shear strength - the insulation "slipped out" from the casing pipe. The reason was improper preparation of the jacket during the production of the pre-insulated pipe before the foam injection. In case of improper preparation of the service pipe (eg. presence of contaminants on the outer surface), foam "slip" may occur along the steel pipe.

Testing of pre-insulated elements:

Testing the strength of foam in a pre-insulated pipe to radial deformation under stress:

- the creep resistance test is carried out according to the PN-EN 253 standard;
- like most of the tests, it is computer-controlled;
- photo 27 shows the creep test stand, fig. 4 shows the view of the computer screen during the test;
- the creep resistance test allows to determine how the PUR foam will behave (deform in the radial direction) after 20 years of operation of a pre-insulated pipeline buried in the ground, in which the continuous temperature of the heat carrier does not exceed 120 ° C.

Testing of pre-insulated elements:



Testing of pre-insulated elements:

Examination of the heat conductivity coefficient:

- the heat conductivity coefficient is determined in accordance with PN-EN ISO 8497: 1999 on a test stand, commonly known as "pipe apparatus„;
- according to PN-EN 253: 2005, the thermal conductivity coefficient of PUR foam insulation in pre-insulated pipes cannot exceed the value of l50 = 0.033W/mK;
- the "pipe apparatus" is mainly used to conduct insulation tests when manufacturers introduce new raw material systems, and tests commissioned by investors to check the value of the thermal conductivity coefficient of pre-insulated pipes delivered to construction sites.

Testing of pre-insulated elements:

Accelerated aging process:

- the accelerated aging process is carried out in accordance with the requirements specified in PN-EN 253: 2005, with the test pipe temperature significantly exceeding the continuous operating temperature of the PUR foam, after which the shear strength test is performed;
- if the shear resistance of the pre-insulated pipe assembly, tested after the accelerated aging process, meets the requirements of PN-EN 253: 2005, it means that the pipeline, due to the service life of the PUR foam, should operate without failure for at least 30 years.

Testing of pre-insulated elements:

Examination of the joint assembly:

- the test of the joint assembly according to PN-EN 489: 2005 consists in subjecting it to soil load and water impermeability tests;
- testing of the load from the ground of a set of pre-insulated joints in the so-called "Sandbox" (photo 28) is to assess the insulation sheathing on the welded joint of the pre-insulated pipeline in conditions similar to real ones;
- after testing in a box with sand, the joint subjected to the water impermeability test (Photo 29) should remain tight;
- the results of tests of radiation cross-linked heat shrinkable sleeves with welded plugs, carried out at LB OBRC in Warsaw on the ground load stand, prove that this is a product of incomparable quality with the currently offered solutions for making joints on pre-insulated pipelines up to DN 300. Out of ten tested radiation cross-linked joints with welded plugs, after testing the load from the ground, in conditions that meet (100 cycles - 3 joints) or significantly exceed (> 500 cycles - 2 joints, 1000 cycles - 7 joints) the requirements of PN-EN 489: 2005, none of the deformations during the test and they were all 100% airtight.

Conclusions:

- Due to the wide range of manufactured types of pipes and pre-insulated elements, it is possible to choose the right pre-insulated system depending on the needs;
- In pre-insulated systems used for heat transmission, a failure-free course of their operation is influenced by many factors, the most important of which is the proper design and assembly of the pipeline and the use of materials and components of appropriate quality. Defects and defects arising at the design, production and execution stages increase the number of failures and reduce the life of the heating network;
- Measurable effects in the form of increasing the durability of the heating network and reducing the number of failures are brought by operational supervision at the execution stage, training for investment supervision services and pipeline contractors, and the awareness that errors made at the construction stage do not appear immediately, but after several / several years of operation;

Conclusions:

- Respecting certain rules during construction and assembly, with proper design and appropriate quality of its elements, can guarantee that pre-insulated pipelines will work without failure. **The service life of the pre-insulated network, estimated at 30 years, depends on the thermal durability of the insulation, i.e. the actual temperature of the heat carrier. The lower the temperature of the heating medium, the longer the expected lifetime of the insulation**;
- Many years of District Heating Companies in Poland operating experience and the facts described in the professional foreign press show that the connections of pre-insulated pipelines (welds and sleeves / sleeves) are the place where by far the largest number of failures occurs. This means that, apart from a properly conducted welding process, the selection of appropriate insulation shields on welded joints (sleeves / muffs) and their correct assembly are of key importance for the trouble-free operation of the pipeline;
- Laboratory tests of pre-insulated elements are aimed at assessing the compliance of their properties with the parameters declared by manufacturers in technical approvals or specified in standards;

Conclusions:

- According to the results of tests of insulation made of pre-insulated pipes carried out by LB OBRC in Warsaw, the water absorption shown by the foam after boiling increases to over 20% after several years of operation. For this reason, the perforation of the service pipe or the leakage of the cover may quickly lead to the dampening of the insulation over a large area and, consequently, to corrosion of the outer surface of the steel pipe. To ensure the possibility of locating dampness in the insulation as soon as possible, protection against the spread of water in the foam and the occurrence of failure, it is necessary to use effective failure detection systems in pre-insulated pipes;
- the issues discussed in this presentation concern the entire Polish heating sector and are important from the point of view of its effectiveness;

Conclusions:

- Laboratory tests carried out at LB OBRC in Warsaw and operational assessments carried out in real operating conditions of the heating network indicate that the properties of the pre-insulated pipeline elements used in many cases differ from the required ones;
- Producers' awareness that their products can be inspected (tested) at the delivery stage affects the quality of the products offered.

Thank you very much!

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