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Possibility of using thermography at determination of heat conduction coefficient

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Abstract

The paper presents the possibilities of using thermography in measurement of thermal conductivity of prefabricated insulating sandwich panels and pipe/in/pipe assemblies according to EN and ISO standards. From data presented it can be seen that thermography could be successfully used in measurements of outer surface temperatures of the samples as well as thermocouples or other standard sensors. Thermography gives not only values of temperature on certain point, but also average surface temperature or average line temperature and some additional information of sample structure. Using thermography as additional tool in such measurements more useful information can be obtained in comparison with classical methods.

1. Introduction

Determination of steady state thermal transmission properties for thermal insulation and prefabricated insulating products, such as sandwich insulating panels or pipe/in/pipe assemblies, is of great importance. In conformity assessment procedures of such construction products the value of its thermal conductivity must be given to enable the designer to perform correct and efficient calculations and design. The following technical specifications lay down a test method and apparatus for determination of steady state thermal resistance and related properties:
ISO 8302:1998. Thermal insulation-Determination of steady state thermal resistance and related properties-Guarded hot plate apparatus;
EN ISO 8497:1988. Thermal insulation-Determination of steady state thermal transmission properties of thermal insulation for circular pipes:
EN 253:2003, District heating pipes-Preinsulated bonded pipe systems for directly buried hot water networks-Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polypropylene.
The apparatus proposed in technical specifications have been built in the Laboratory for Applied Thermodynamics, Faculty for Mechanical Engineering and Naval Architecture Zagreb and measurements of relevant parameters needed for the calculation thermal conductivity performed.

2. Insulating panels (ISO 8302:1998)

2.1 Apparatus principle

The guarded hot plate apparatus is intended to establish within specimens in the form of uniform slabs having flat parallel faces, a unidirectional uniform density of heat flow rate at steady state conditions.

2.2 Apparatus types

From the basic principle two types of guarded hot plate apparatus were derived:
- with two specimens (and central heating unit),
- with single specimen.

The type with two specimens has been designed and built in the Laboratory (see fig. 1. and fig. 3).
In two specimen apparatus a central flat plate consist of a heater and metal surface plates and this heating unit is sandwiched between two nearly identical specimens. The heat flow rate is transferred through the specimen to separate isothermal flat assemblies called the cooling units or to outer samples surfaces.

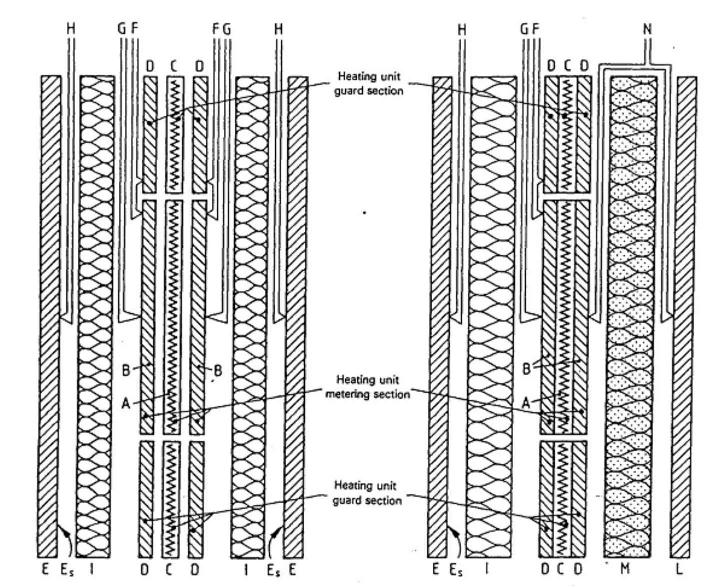

Figure 1. Schematic of test configuration for prefabricated insulating panels (see ISO 8302)

2.3 Heating and cooling units

The heating unit consists of separate metering section, where the unidirectional uniform and constant density heat flow rate can be established, surrounded by guard sections separated by a narrow gap. The cooling units may consist of continuous flat plate assembly.

2.4 Insulation and auxiliary guarded sections

Additional edge insulation and/or auxiliary guard sections are required, especially when operating above or below room temperature.

2.5 Experimental rig – two specimen apparatus

The guarded hot plate apparatus shown in figure 2 and 3 is designed and constructed in the Laboratory for Applied Thermodynamics according to specification in ISO 8302:1998. It consists of cooper heating unit and heating guard sections.
Test specimens are placed on both sides of the heater and thermocouples placed on the required positions. The flat plates of main heater and guard heaters are made of 7 mm cooper sheet with electrical heater between them. For temperature measurement 8 thermocouples type T were used and temperatures indicating the heat equilibrium between main and guard plates was measured with 16 thermopiles. The data were collected by an A/D converter type AGILEND and processed later.
The outer samples surface temperatures were measured by thermocouples and IR camera type ThermaCAM 2000 SC. The samples were heated to stationary state before the measurements start. The heating lasts about 35 hours.

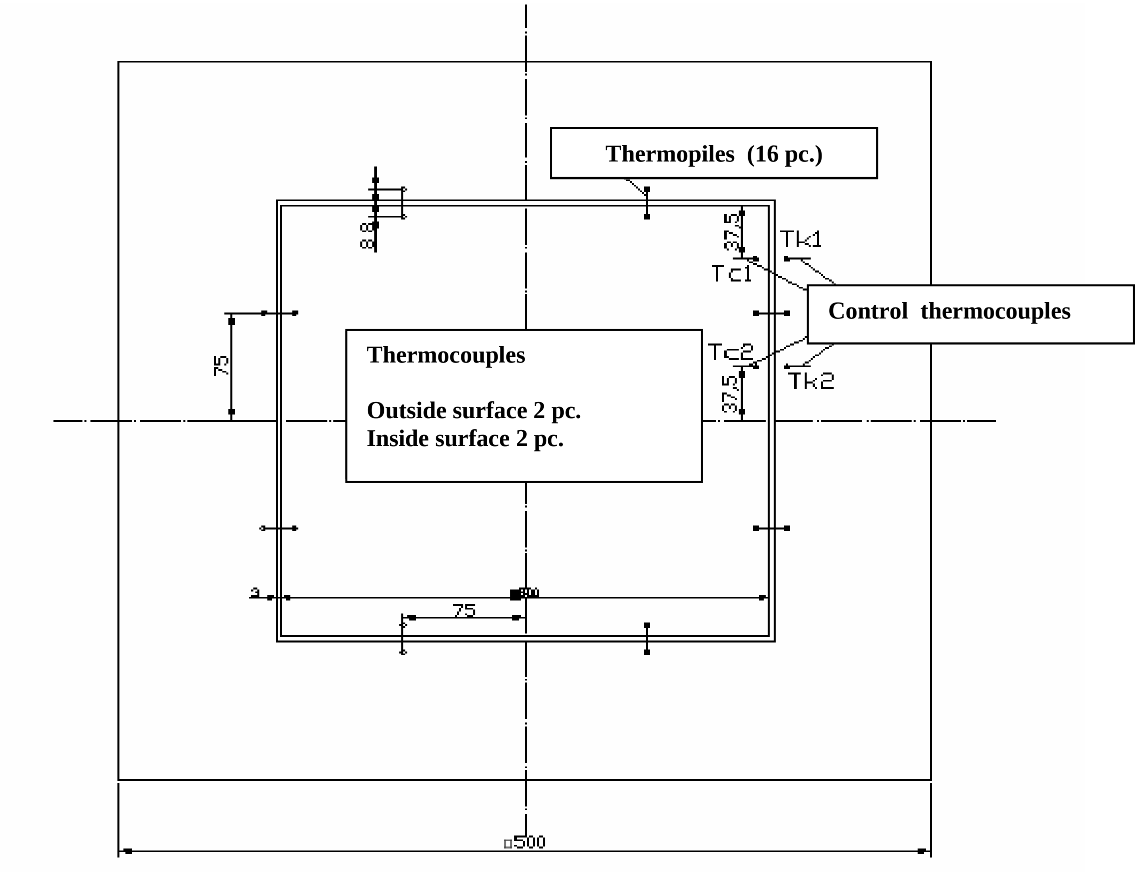

Figure 2. Position of thermocouples and thermopiles in testing apparatus

Figure 3. The test rig for prefabricated panel

2.6 Samples and thermographic measurements

The samples were flat polyurethane panels having dimensions of 300 x 300 mm and 60 and 80 mm thickness. The sample density was 46,1 kg/m^3 for 50 mm thickness and 52,3 kg/m^3 for 80 mm thickness.
Thermographic measurements were performed in stationary state in a conditioned room. All together 25 thermograms were recorded for each sample with following parameters:

Sample I (thickness 60 mm)
- emissivity: 0,95
- ambient temperature: 25,5 ºC
- relative humidity: 50 %
- recording distance: 1,4 m

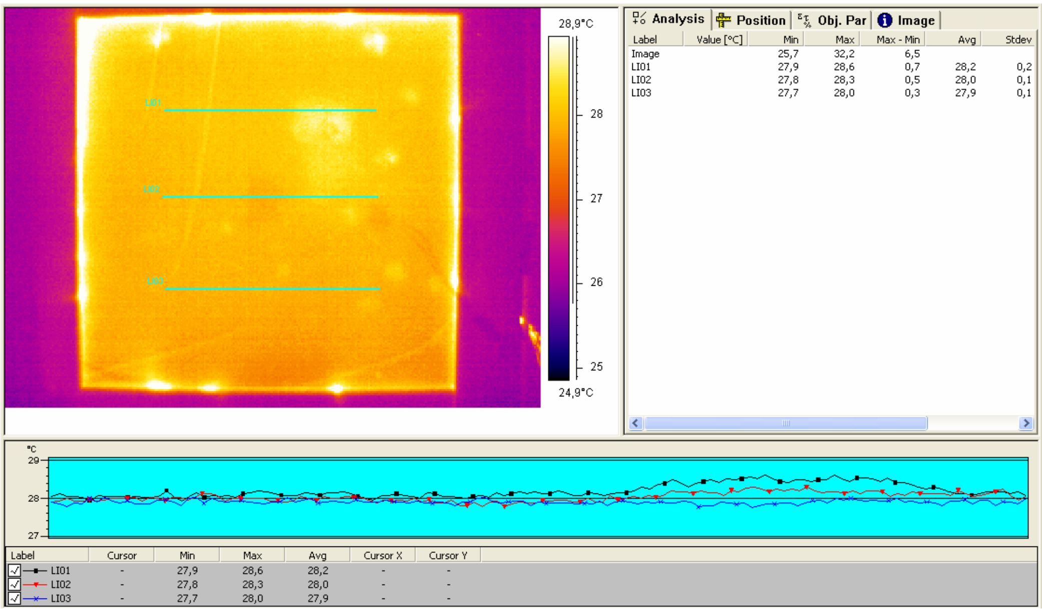

Figure 4. Thermogram of sample surface, side A
(Average surface temperature 28,03 ºC)

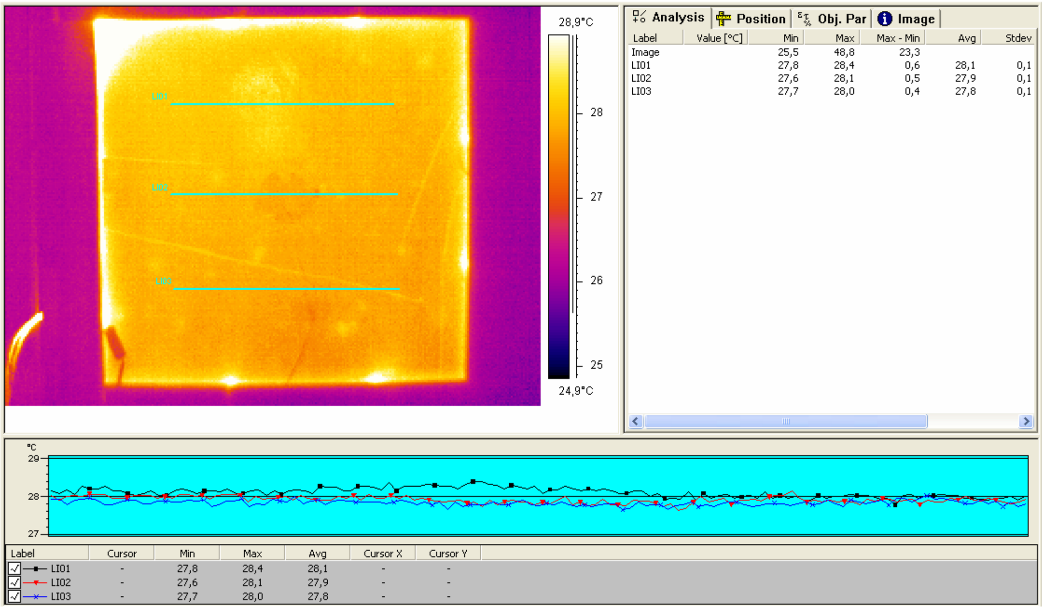

Figure 5. Thermogram of sample surface, side B
(Average temperature 27,95 ºC)

Sample II (thickness 80 mm)
- emissivity: 0,95
- ambient temperature: 27,4 ºC
- relative humidity: 50 %
- recording distance: 1,4 m

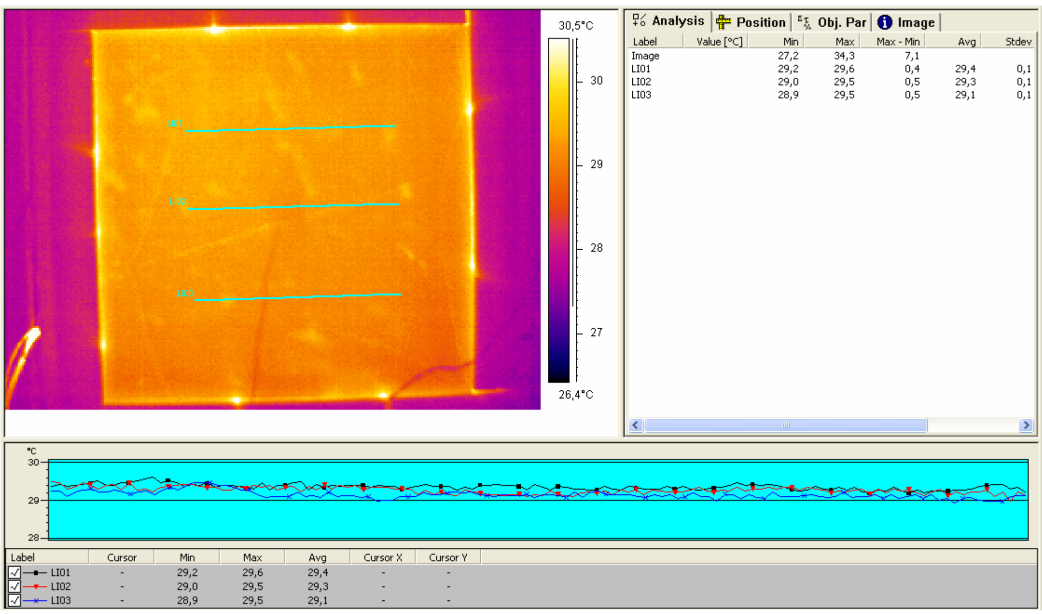

Figure 6. Thermogram of sample surface, side A
(Average surface temperature 29,16 ºC)

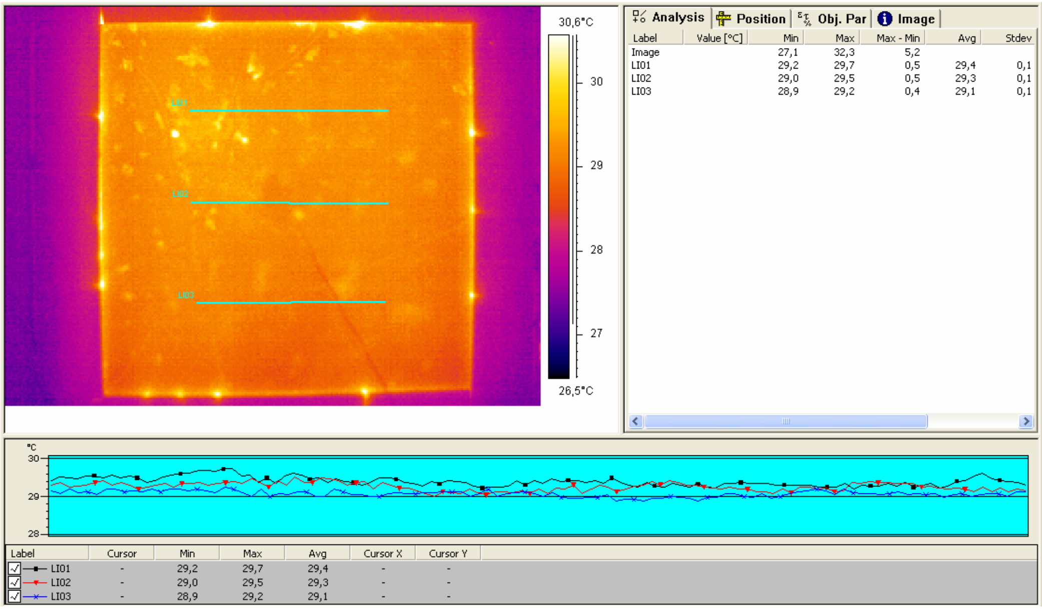

Figure 7. Thermogram of sample surface, side B
(Average temperature 29,26 ºC)

Thermograms show good uniformity of temperature distribution on samples outer surfaces. Some deviation from average temperatures can be seen in the areas between guards and outer insulation.

2.7 Thermal conductivity of measured samples

Thermal conductivity of the sample is calculated as:

$$\lambda = \frac{\Phi \cdot d}{A \cdot (T_1 - T_2)} \quad \text{W/(mK)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Were:
Φ – average power of central heating unit, W
T_1 – average temperature of inner sample surface, K
T_2 – average temperature of outer sample surface, K
A – surface area of central section according to standard, m^2
d – average sample thickness, m
T_v – temperatures measured by thermocouples, outer sample side
T_u – temperatures measured by thermocouples, inside sample surface
T_c – control thermocouples, heating unit
T_k – control thermocouples, guard heating units

Table 1. Results obtained for thickness 60 mm, sample I

T_{u1}	°C	64,0
T_{u2}	°C	64,0
T_{v1}	°C	27,6
T_{v2}	°C	27,7
T_{ok}	°C	25,6
T_{k1}	°C	62,7
T_{c1}	°C	63,8
T_{k2}	°C	62,9
T_{c2}	°C	64,0
U_k	V	10,51
U_c	V	8,614
P_c	W	3,484
λ	W/mK	0,030484

Table 2. Results obtained for thickness 80 mm, sample II

T_{u1}	°C	70,8
T_{u2}	°C	70,9
T_{v1}	°C	28,9
T_{v2}	°C	29,0
T_{ok}	°C	27,4
T_{k1}	°C	69,0
T_{c1}	°C	70,6
T_{k2}	°C	69,3
T_{c2}	°C	70,8
U_k	V	10,463
U_c	V	8,571
P_c	W	3,276
λ	W/mK	0,034432

The differences between thermal conductivities obtained from thermographic measurements and by means of thermocouples were within 2 % which satisfy the requirements of applied standards.

Table 3. Measurements results

Plate thickness	Density	Average thermal conductivity
60 mm	ρ = 46,1 kg/m^3	λ = 0,030484 W/(mK)
80 mm	ρ = 52,3 kg/m^3	λ = 0,034432 W/(mK)

3. Determination of the thermal conductivity of preinsulated pipes (EN ISO 8947:1994.)

3.1 Testing apparatus

Thermal conductivity can be measured by means of two types of apparatus defined in Standard EN ISO 8947:1994.

Guarded end apparatus uses separately heated pipe sections called "guards" located at each end of the metered test section having the length of $L \geq 1$ m. The guards shall be maintained at the test section temperature to eliminate axial heat flow in the apparatus, and to aid in achieving uniform temperatures so that all heat flow in the specimen test section will be in radial direction.

Calibrated end apparatus for which the heat loss through the end caps must be determined. This shall be obtained by making measurements on specimens with different length taken from the same pipe sample. Length of the test section shall be not less than $L \geq 2$ m.

3.2 Testing conditions

The test specimen shall be conditioned at room temperature for one week. Dimensions given in figure 8 must be measured with the following accuracy:

Casing diameter ± 0,5 mm

Service pipe diameter ± 0,2 mm

Thickness of the casing ± 0,2 mm

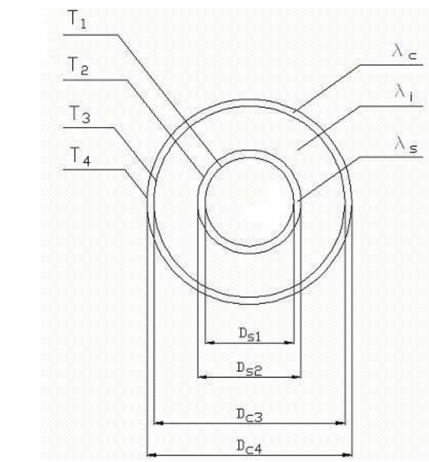

Figure 8. Symbols

Sensors for measuring the temperature of the specimen shall be attached on the service pipe inner surface and casing outer surface. The test section length shall be divided into at least four equal parts and at least one temperature sensor at the steel pipe and at the casing shall be longitudinally located at the centre of each part. The sensors shall be circumferentially equally spaced.

Ambient temperature of still air in the testing room must be 23 ± 2 °C may vary during the test by more than ± 1°C.

Test pipe temperature interval 70 °C to 90 °C measured at the inside surface of the service pipe. Tests are to be run at a minimum of three service pipe temperatures with accuracy ± 0,3 °C.

3.3 Thermal conductivity

Thermal conductivity at the mean temperature in the insulation material shall be calculated by linear regression using results obtained at different pipe temperatures. The result is reported as λ at the mean temperature T_m.

Heat flow rate	Φ	W
Test section length	L	m
Temperature of service pipe inner surface	T_1	ºC
Temperature of insulation inner surface	T_2	ºC
Temperature of insulation outer surface	T_3	ºC
Temperature of casing outer surface	T_4	ºC
Mean temperature of insulation	T_m	ºC
Service pipe inner diameter	D_{s1}	m
Inner diameter of insulation material	D_{s2}	m
Outer diameter of insulation material	D_{c3}	m
Outer diameter of casing	D_{c4}	m
Thickness of casing	t	m
Thermal conductivity of insulation material	λ_i	W/(mK)
Thermal conductivity of casing	λ_c	W/(mK)
Thermal conductivity of service pipe	λ_s	W/(mK)

$$\lambda_i = \frac{\ln\left(\frac{D_{c3}}{D_{s2}}\right)}{\frac{2\cdot\pi\cdot(T_1 - T_4)\cdot L}{\Phi} - \frac{1}{\lambda_c}\cdot\ln\left(\frac{D_{c4}}{D_{c3}}\right) - \frac{1}{\lambda_s}\cdot\ln\left(\frac{D_{s2}}{D_{s1}}\right)} \qquad (2)$$

$$T_3 = T_4 + \frac{\Phi}{2\cdot\pi\cdot L\cdot\lambda_c}\cdot\ln\left(\frac{D_{c4}}{D_{c3}}\right) \qquad (3)$$

$$T_m = \frac{(T_3 - T_2)}{2} \qquad (4)$$

$$T_2 = T_1 - \frac{\Phi}{2\cdot\pi\cdot L\cdot\lambda_s}\cdot\ln\left(\frac{D_{s2}}{D_{s1}}\right) \qquad (5)$$

3.4 Application of thermography for surface temperature measuring

Thermography can be successfully used for measuring the surface casing temperature instead of using standard sensors. It gives not only the possibility of recording the temperature of certain point but also on a chosen line or surface. Thermogram gives more accurate temperature recording than point by point measurement. Simultaneously, some non uniformities in the pipe structure can be seen, like position and influence of distancers.

In figure 9 and 11 the thermogram recorded during the measurement of pipe insulation characteristic is shown. Beside the temperature distribution on pipe surface the position of distancers can be clearly seen on thermogram because of different coefficients of thermal conductivity of distant rings and insulation.

3.4.1 Testing pipe I

Inside temperature of service pipe: 94,7 °C (stationary state)
Average temperature on outer casing surface: 22,5 °C (measured by thermography)
Ambient temperature: 21 °C
Input power: 57,81 W
Casing diameters: D_{C4} = 308 mm; D_{C3} = 302 mm
Service pipe diameter D_{S2} = 220 mm; D_{S1} = 213 mm
Thermal conductivity: λ_c = 0,4 W(/mK), λ_s = 50 W/(mK)
Length: L = 1,61 m

Using equations (2) to (5) we obtain:
λ_i = 0,0252 W/(mK)
T_3 = 22,68 °C
T_2 = 94,696 °C
T_m = 58,68 °C

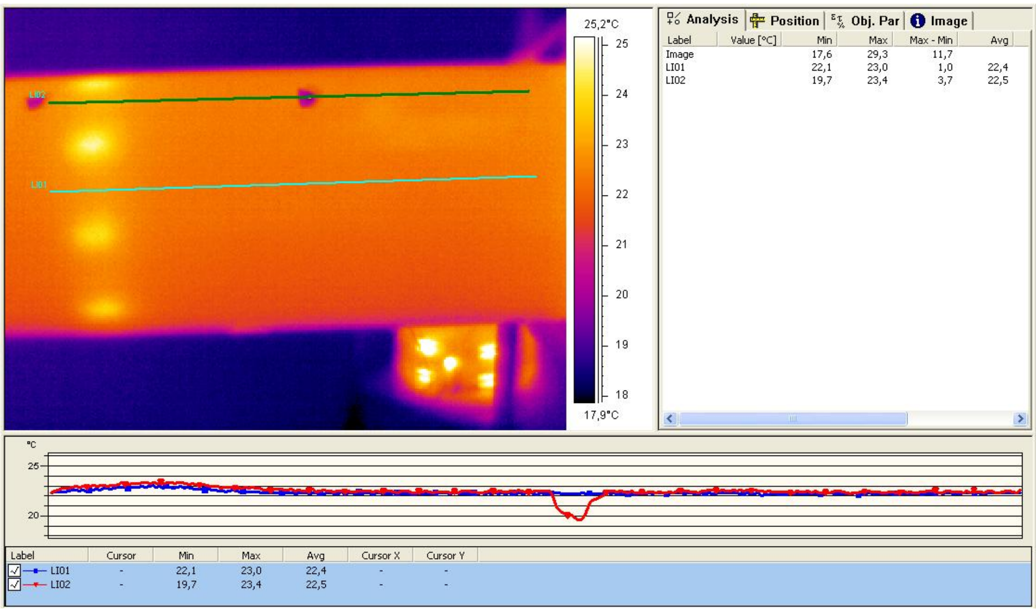

Figure 9. Thermogram of testing pipe I

Figure 10. Photo of testing pipe I

3.4.2 Testing pipe II

Inside temperature of service pipe: 84,4 °C (stationary state)
Average temperature on outer casing surface: 24,25 °C (measured by thermography)
Ambient temperature: 22,8 °C
Input power: 45,02 W
Casing diameters: D_{C4} = 492,4 mm; D_{C3} = 484,4 mm
Service pipe diameter D_{S2} = 324,4 mm; D_{S1} = 314,4 mm
Thermal conductivity: λ_c =0,4 W/(mK), λ_s = 50 W/(mK)
Length: L = 2,11 m

Using equations (1) to (4) we obtain:
λ_i = 0,0231 W/(mK)
T_3 = 24,39 °C
T_2 = 84,39 °C
T_m = 54,3 °C

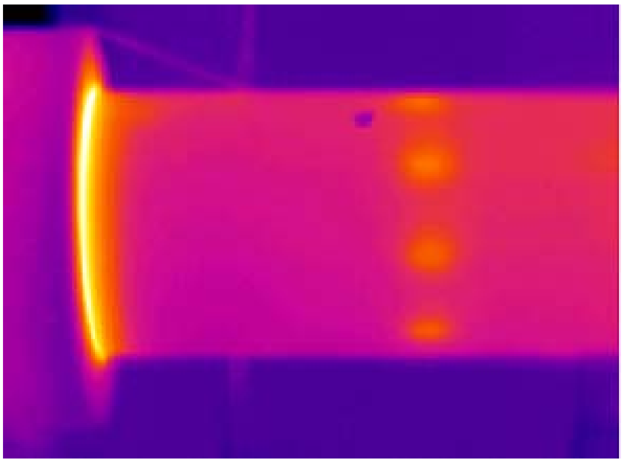

Figure 11. Thermogram of testing pipe II

Figure 12. Photo of testing pipe II

4. Conclusion

Thermography can be successfully used not only for determining the thermal conductivity of insulating sandwich panels and prefabricated insulated pipe-in-pipe assemblies according to the requirements of existing standard but also for determination of non-uniformities between insulation and casing as well as for testing the quality of panels and pipes during production and in situ before being built in or buried.

References

1. ISO 8302:1998. Thermal insulation-Determination of steady state thermal resistance and related properties-Guarded hot plate apparatus.
2. EN ISO 8497:1988. Thermal insulation-Determination of steady state thermal transmission properties of thermal insulation for circular pipes.
3. EN 253:2003, District heating pipes-Preinsulated bonded pipe systems for directly buried hot water networks-Pipe assembly of steel service pipe, polyurethane thermal insulation and outer casing of polypropylene.
4. Gerald C. Holst, Common sense approach to thermal imaging, SPIE Optical engineering press, Bellingham, Washington USA, 2000.
5. S. Švaić, I. Boras, M. Suša: The estimation of state of building using infrared thermography and numerical method, Ensayos no destructivos y estructurales, International congress, Neuquén, Patagonia, Argentina, 2005.