Testing Laboratory OBRC SPEC S.A. in Warsaw

Thermal Conductivity Coefficient of new Preinsulated Pipes

The results of investigations conducted by Laboratory of District Heating Research and Development Center of Warsaw Municipal Heating Company (OBRC SPEC S.A.) concerning ground load for pre-insulated joints and thermal conductivity coefficient from preinsulated pipes disassembled after period of operation were presented in *EuroHeat&Power* II/2010. This article includes the results of researches concerning thermal conductivity coefficient from new pre-insulated pipes.

Influence of how to determine the Surface Temperature of Line Pipes on the Thermal Conductivity Coefficient

The thermal conductivity coefficient of cylindrical insulation depends basically on the insulation properties – its structure, its density, and its constitution. It appears that the method of how to determine the mean value of temperature at the surface of the pipe is equally important.

The value of thermal conductivity coefficient is determined based on heat flux measurements as well as on measurements of the temperature at the surface of casing and line pipe (testing pipe). For cylindrical insulation it is determined using a pipe apparatus. In the laboratory of OBRC it is an apparatus construction equipped with a casing cylinder (*figure 1*), as described in EN ISO 8497 [1] [1]. Inside the pipe, in the centre, a main heating coil is located made of resistance tapes. At the end of the pipe, 6 auxiliary heating coils are installed in order to compensate the axial heat flux between pipe ends and clamping installation at the test facility. In order to achieve an equal temperature distribution at the pipe surface, a vacuum is created inside the pipe during the measurement process. This prevent the convective heat transfer between resistance tapes of heating coils and the pipe's walls. During the test process a constant air temperature is realised arround the test pipe. The stabilization of temperature ensures a thermostatic chamber, which keeps the air temperature accurate to ±1 K. The measurement of line pipe temperature is realised by 16 thermoelements located at pipe perimeter, in every 90° in four sections (*figure 2*).

In *figures 2* and *3* the possible distribution of the thermoelements are presented for laboratory practice, *table 1* shows how the temperature of the pipe is determined.

To determe the mean temperature of the pipe surface the following measurement methods may be applied:

- 16 thermoelements located in 4 sections of pipe, in every 90° at perimeter – method I, applied in OBRC (*figure 2*),
- 4 thermoelements spiral located along measuring pipe segment, in equal distances on perimeter, in the centre of every of 4 segments resulting from division of tested segment to at least 4 equal parts – method II,

[1] The Standard permits other constructions of testing apparatus – with calibrated or calculated pipe ends.

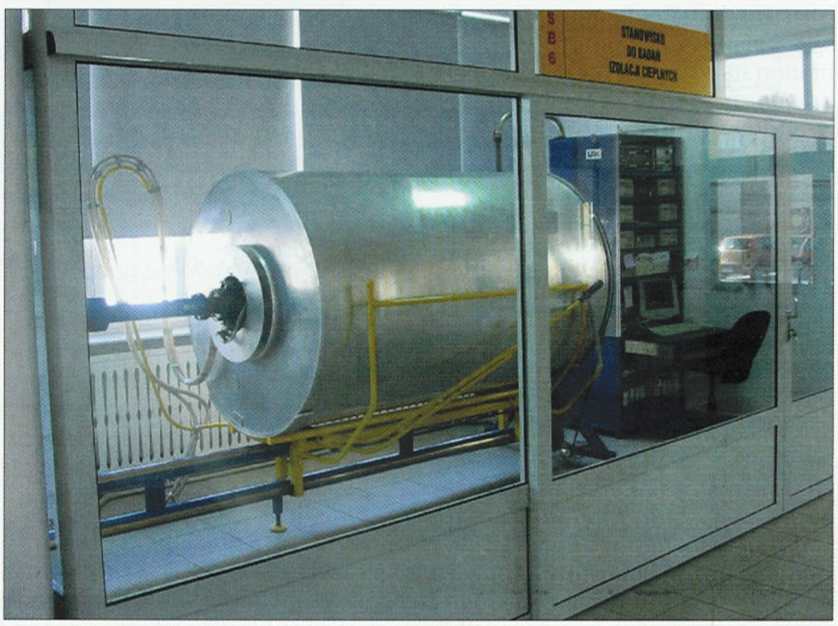

Figure 1. Pipe apparatus in Testing Laboratory OBRC SPEC S.A. in Warsaw

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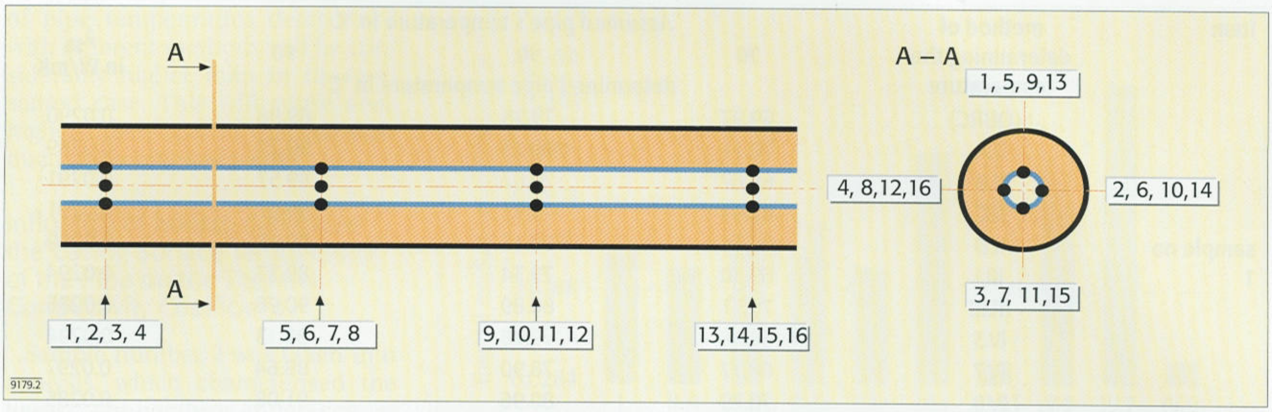

Figure 2. *Location of 16 thermoelements for measurement temperature of pipe with the usage of pipe apparatus*

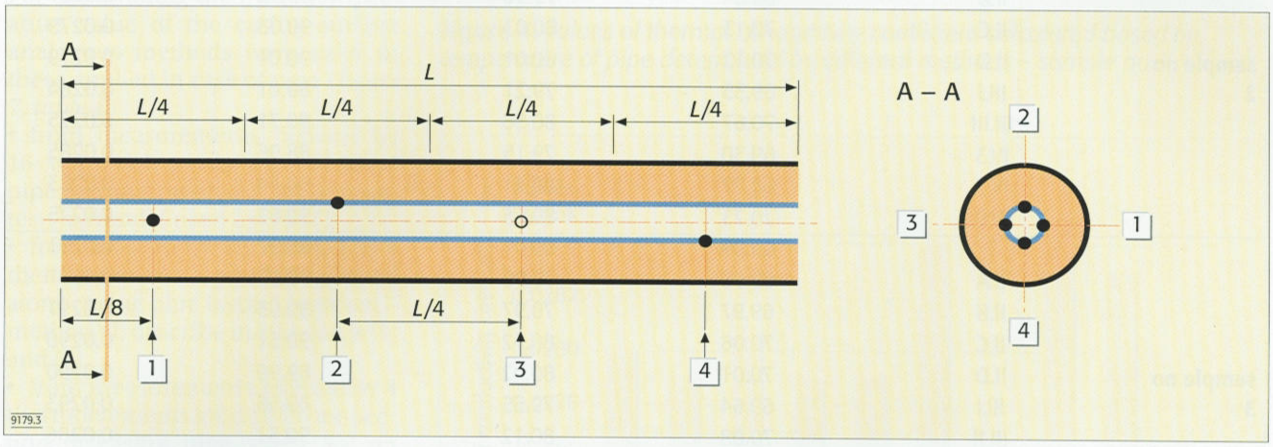

Figure 3. *An example of thermoelements distribution for pipe temperature measurement, according to standard EN ISO 8497:1996 (1 – front; 2 – up, 3 – back; 4 – bottom)*

recommended in EN 253 [2] and EN ISO 8497,

- 4 thermoelements located in one pipe section, every 90° at perimeter – method III,
- using of only one thermoelement – method IV.

Three samples of different pipe producers were analysed (pre-insulated pipe segments DN 50), with thermal insulation made of different raw materials systems. Temperature measurements were performed in three measuring cycles for each sample, with assumed pipe temperatures of 70 °C, 80 °C and 90 °C. Each cycle consisted of a series of measurements with half hour intervals between every series. Each measuring series consisted of measurings with every 10 minutes intervals between each series.

method of determining the temperature		number of thermoelements	marking of thermoelements
I (OBRC)	-	16	1-16
II (spiral, according to standard	A	4	1 - 6 - 11 - 16
	B	4	2 - 7 - 12 - 13
	C	4	3 - 8 - 9 - 14
	D	4	4 - 5 - 10 - 15
III (in one section)	I	4	1 - 2 - 3 - 4
	II	4	5 - 6 - 7 - 8
	III	4	9 - 10 - 11 - 12
	IV	4	13 - 14 - 15 - 16
IV (in one point)	n	1	n

Table 1. *The method of pipe temperature measurement*

Table 2 presents the temperature of pipe surface determined by method I, II, III and IV, in measuring cycles 70 °C, 80 °C and 90 °C for samples marked with numbers 1, 2 and 3 and the insulation thermal conductivity coefficient λ_{50}, calculated based on these temperatures.

The thermal conductivity coefficients λ_{50} were determined with assumption of equal mean temperatures at the casing pipe surface in particular measuring cycles for every sample (*table 3*), determined based on measurements realised by 16 thermoelements located at the perimeter of pipe, every 90° in four sections.

Figures 1 to *3* present the thermal conductivity coefficients λ_{50} in W/(m·K) of three tested samples, calculated based on the mean tem-

Item	method of determining the temperature	Assumed pipe's temperature in °C			λ_{50} in W/mK
		70	80	90	
		determined pipe temperature in °C			
sample no 1	I (OBRC)	69.97	79.98	89.98	0.0290
	II.A	70.11	80.13	90.27	0.0289
	II.B	69.67	79.67	89.57	0.0291
	II.C	69.94	79.95	89.91	0.0291
	II.D	70.14	80.17	90.15	0.0289
	III.I	69.50	79.34	89.37	0.0294
	III.III	70.71	80.89	90.98	0.0285
	IV.3	69.46	79.28	89.13	0.0294
	IV.7	68.77	78.90	88.64	0.0297
	IV.9	70.79	80.96	91.08	0.0285
sample no 2	I	69.99	79.99	89.98	0.0280
	II.A	70.08	79.97	89.96	0.0279
	II.B	69.64	79.96	89.93	0.0281
	II.C	70.13	80.03	90.03	0.0279
	II.D	70.12	80.01	90.01	0.0279
	III.I	69.35	79.21	89.01	0.0284
	III.III	70.67	80.56	90.71	0.0275
	IV.3	69.30	79.15	88.96	0.0285
	IV.7	68.77	80.41	90.44	0.0283
	IV.9	70.73	80.65	90.82	0.0275
sample no 3	I	69.99	80.01	89.97	0.0291
	II.A	69.98	79.99	89.97	0.0291
	II.B	69.97	79.97	89.93	0.0291
	II.C	70.08	80.12	90.51	0.0290
	II.D	70.01	80.02	89.99	0.0290
	III.I	69.64	79.55	89.56	0.0293
	III.II	70.08	80.12	90.51	0.0286
	IV.3	69.57	79.47	89.46	0.0294
	IV.5	70.52	80.63	91.37	0.0287
	IV.8	70.58	80.71	91.45	0.0286

Table 2. *Temperature of pipe, determined with different method and thermal conductivity coefficient λ_{50} calculated based on it*

sample number	assumed pipe temperature in °C		
	70	80	90
	determined temperature on casing surface on pipe j in °C		
sample no 1	24.26	25.15	26.16
sample no 2	23.85	24.60	25.59
sample no 3	24.19	24.98	25.86

Table 3. *Mean temperatures at casing surface of pipe*

peratures of pipes determined by method I to IV.

The method of determining temperature of pipe influences its value and determined on its basis thermal conductivity coefficient. And that is why the method of determining the line pipe temperature is not optional.

Comparing the mean value of line pipe temperature determined by method I (OBRC) and II (according to standard), depending on sample and assumed temperature of line pipe, the maximum difference between the results is $\Delta T = 0.7$ K. It has small influence on the value of insulation thermal conductivity coefficient, causing its maximum change of 0.0002 W/(m·K). It means that accuracy of both (OBRC and according to standard) is comparable, and their precision is very high.

The mean temperature of pipe determined by method III (in one section) and IV (one point measurement) in considered cases, differs depending on sample and assumed temperature of testing pipe by a maximum of $\Delta T = 2.44$ K. This influences the results of the determined thermal conductivity coefficient, with a maximum deviation of $\Delta\lambda_{50} = 0.0009$ W/(m·K) concerning method III and a maximum deviation of $\Delta\lambda_{50} = 0.0012$ W/(m·K) concerning method IV.

In case of test stands where the line pipe is heated by air or oil, when the testing segments of pipe are long or the axial heat flux compensation is improper, the differences of pipe temperatures determined with different methods will be considerably higher than in the presented case. This will cause even higher differences in thermal conductivity coefficient values.

Influence of how to determine the Casing Surface Temperature of the Pipe on the Thermal Conductivity Coefficient

Sample number 2 was taken into analysis, which characterised the lowest temperature difference at surface of pipe in the three measuring cycles 70 °C, 80 °C, and 90 °C. For determining the mean temperature value of the casing surface analogous methods were used to these applied in case of pipe (*figure 7, table 4*).

- from measurements realised by 16 thermoelements located in 4 pipe sections, every 90° on perimeter – method V, used by OBRC,
- from measurements realised by 4 thermoelements spiral distributed along casing pipe testing segment – method VI, describe in standards [1] and [2],
- from measurements realised by 4 thermoelements located in one section of casing pipe, every 90° on perimeter – method VII,
- from measurement realised by only 1 thermoelement – method VIII.

The temperatures of the pipe surface determined by methods I, II, III and IV, the temperatures of the casing surface determined by method V, VI, VII and VIII measured in measuring cycles 70 °C, 80 °C, and 90 °C as well as the thermal conductivity coefficients λ_{50} for selected configurations is presented in *table 5*.

Figure 8 shows values of the thermal conductivity coefficients λ_{50} in W/(m·K), calculated for different configuration methods of measuring the pipe's surface and casing temperature for sample number 2.

The method of measuring the casing surface temperature similarly to surface of line pipe temperature influences on the achieved mean value of temperature and determined based on it thermal conductivity coefficient. For this reason the selection of method of determining mean value of casing surface is not optional.

From comparison of values of mean temperatures of casing, determined for sample number 2 with method V (OBRC) and VI (according

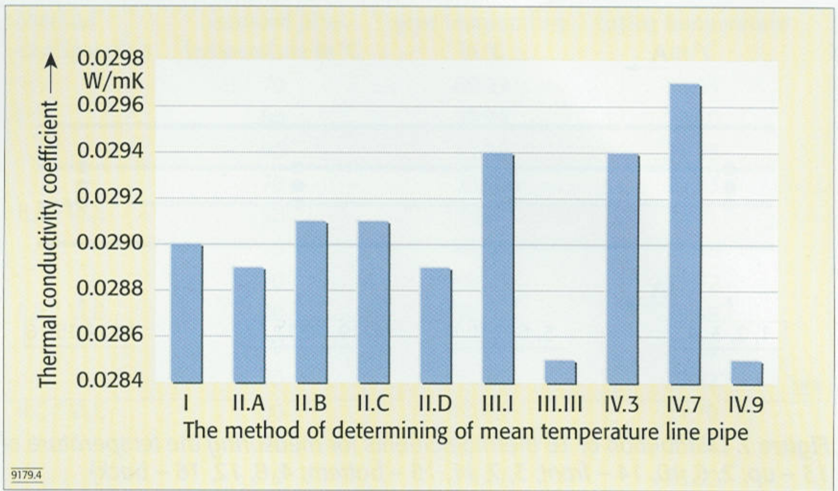

Figure 4. *Values of thermal conductivity coefficient calculated based on temperature of pipe determined by different methods – sample no 1*

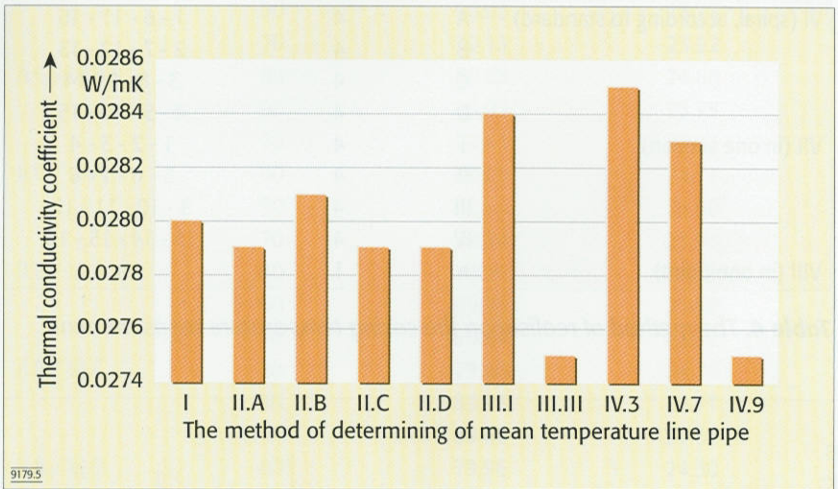

Figure 5. *Values of thermal conductivity coefficient calculated based on temperature of pipe determined by different methods – sample no 2*

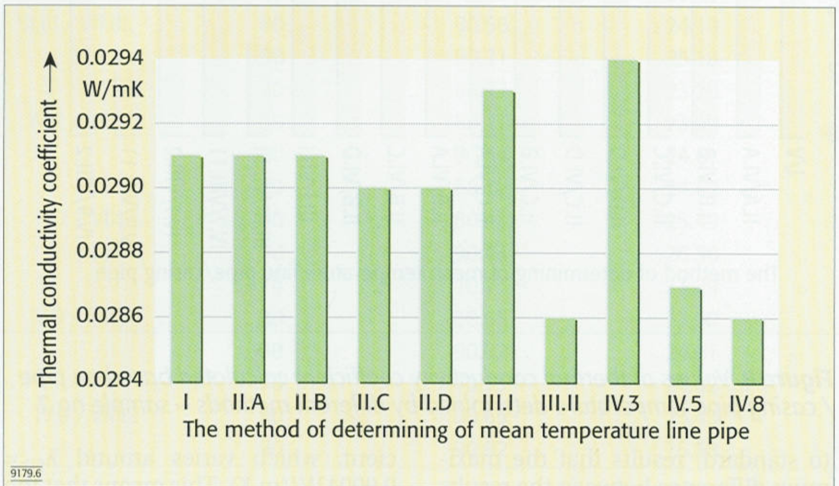

Figure 6. *Values of thermal conductivity coefficient calculated based on pipe's temperature determined by different methods – sample no 3*

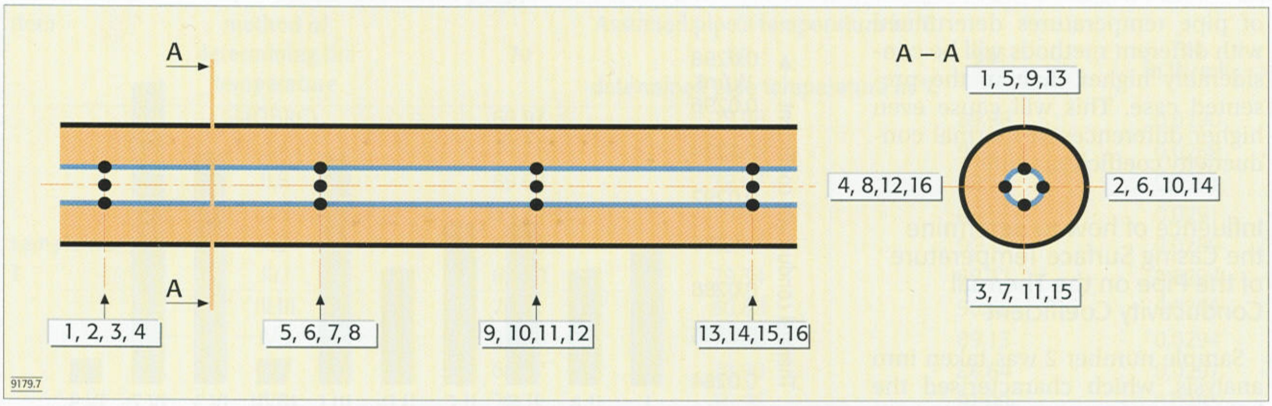

Figure 7. Distribution of 16 thermoelements for measuring the temperature of casing pipe applied in OBRC (1, 5, 9, 13 – up; 2, 6, 10, 14 – front; 3, 7, 11, 15 – bottom; 4, 8, 12, 16 – back)

method of determining the temperature		number of thermoelements	marking of thermoelements
V (OBRC)		16	1-16
VI (spiral, according to standard)	A	4	1 - 6 - 11 - 16
	B	4	2 - 7 - 12 - 13
	C	4	3 - 8 - 9 - 14
	D	4	4 - 5 - 10 - 15
VII (in one section)	I	4	1 - 2 - 3 - 4
	II	4	5 - 6 - 7 - 8
	III	4	9 - 10 - 11 - 12
	IV	4	13 - 14 - 15 - 16
VIII (in one point)	n	1	n

Table 4. The method of realisation the casing temperature measurement

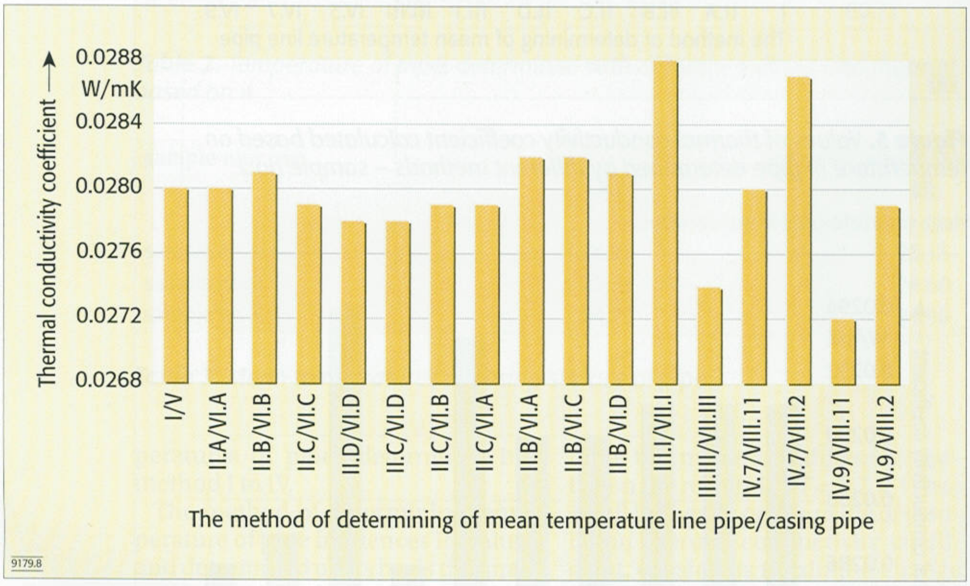

Figure 8. Values of thermal conductivity coefficient calculated based on pipe / casing pipe temperature determined by different methods – sample no 2

to standard) results that the maximum difference between the results is $\Delta T = 0.52$ K, which does not highly influence the value of determined on its basis thermal conductivity coefficient, which varies around $\lambda_{50} = 0.0004$ W/(m·K). This means that the accuracy of both methods (OBRC and according to standard) is comparable and their precision is high.

Mean temperature of casing pipe determined by method VII (in one section) and VIII (one point measurement) in considered case differs depending on assumed temperature of tested pipe of about $\Delta T = 1.97$ K, which results in a maximum deviation of the thermal conductivity coefficient of $\Delta\lambda_{50} = 0.0012$ W/(m·K) concerning method VII and a maximum deviation of $\Delta\lambda_{50} = 0.0015$ W/(m·K) concerning method VIII.

In case of heterogeneity of insulation structure, cavities presence and empty places in PUR foam, large (>±5 %) dispersion of insulation apparent density, pipe's and casing's misalignment, and variability of external temperature during sample testing ($\Delta T > 1$ K), the differences will be higher than in the analysed case. It will cause even higher differences of thermal conductivity coefficient values determined for that same sample.

Summary

During determining the insulation thermal conductivity coefficient, the method of specifying the mean temperature of the pipe surface and the mean temperature of the casing is extremely important. The measurement must be performed with a minimum of 8 thermoelements located on the whole sample's measuring segment length, distributed spiral on perimeter of both surfaces. In order to increase of accuracy of measurement it is advisable to increase the number of thermoelements during investigation, for example the method conducted by OBRC. It is inadmissible to use temperature measurement in one sample section and point measurement.

Divergence between the values of insulation thermal conductivity coefficients made of the same material system and with close mean apparent density, determined according to requirements of standard EN ISO 8497 and EN 253 may testify of for example: insulation heterogeneity or misalingnment of casing and line pipe.

Up to now the researches performed in OBRC concerning thermal conductivity of pipe unit segment were done for insulation with casing jacket after previous removing them from pipe and mounting on specially prepared testing pipes, fulfilling the role of line pipes. Thanks to modernization of research stand, form this year OBRC performs the investigations concerning thermal conductivity coefficient of preinsulated elements according to standard EN 253:2009, so using fully prefabricated product without the necessity of removing insulation.

References

[1] EN ISO 8497:1996: Thermal insulation – Determination of steady-state thermal transmission properties of thermal insulation for circular pipes.

[2] EN 253:2009: 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 polyethylene.

[3] *Wisniewski, S.; Wisniewski, T. S.*: Heat transfer, WNT, 2000.

[4] *Furmanski, P.; Wisniewski, T. S.; Banaszek, J.*: Thermal insulations. Heat transfer mechanisms, thelmar propertis and their measurments, Institute of Heat Engineering Warsaw University of Technology, 2006.

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Method configuration	assumed pipe temperature in °C	pipe temperature in °C	casing temperature in °C	λ_{50} in W/(m·K)
	70	69.99	23.85	
I / V	80	79.99	24.60	0.0280
	90	89.98	25.59	
	70	70.08	23.93	
II.A / VI.A	80	79.97	24.71	0.0280
	90	89.96	25.68	
	70	69.64	23.92	
II.B / VI.B	80	79.96	24.68	0.0281
	90	89.93	25.75	
	70	70.13	23.92	
II.C / VI.C	80	80.03	24.70	0.0279
	90	90.03	25.71	
	70	70.12	23.62	
II.D / VI.D	80	80.01	24.30	0.0278
	90	90.01	25.23	
	70	70.13	23.62	
II.C / VI.D	80	80.03	24.30	0.0278
	90	90.03	25.23	
	70	70.13	23.92	
II.C / VI.B	80	80.03	24.68	0.0279
	90	90.03	25.75	
	70	70.13	23.93	
II.C / VI.A	80	80.03	24.71	0.0279
	90	90.03	25.68	
	70	69.64	23.93	
II.B / VI.A	80	79.96	24.71	0.0282
	90	89.93	25.68	
	70	69.64	23.92	
II.B / VI.C	80	79.96	24.70	0.0282
	90	89.93	25.71	
	70	69.64	23.62	
II.B / VI.D	80	79.96	24.30	0.0281
	90	89.93	25.23	
	70	69.35	24.48	
III.I / VII.I	80	79.21	25.32	0.0288
	90	89.01	26.42	
	70	70.67	23.47	
III.III / VII.III	80	80.56	24.18	0.0274
	90	90.71	25.18	
	70	68.77	23.29	
IV.7 / VIII.11	80	80.41	23.90	0.0280
	90	90.44	24.61	
	70	68.77	24.62	
IV.7 / VIII.2	80	80.41	25.49	0.0287
	90	90.44	26.58	
	70	70.73	23.29	
IV.9 / VIII.11	80	80.65	23.90	0.0272
	90	90.82	24.61	
	70	70.73	24.62	
IV.9 / VIII.2	80	80.65	25.49	0.0279
	90	90.82	26.58	

Table 5. *The temperature of pipe and casing determined with different method and thermal conductivity coefficients Ï50 calculated for different method configuration*