# MEASUREMENT OF LINEAR THERMAL RESISTANCE
## OF PRE-INSULATED FLEXIBLE PIPES

**Evgeniy Devyatkin, Igor Gvozdev, Dmitriy Gvozdev**

Provision of data on the heat insulating properties of pre-insulated flexible pipe systems is required by EN 15632-1:2009 (E) [1] and TU 2248-001-48532278-2013 [2]. According to EN ISO 8497:1996 [3], measurements of linear thermal resistance are conducted in steady-state thermal conditions, usually on relatively short pipe samples, and requires minimisation or measurement of the heating flow in an axial direction. If the sample is sufficiently long, heat flow through its ends can be neglected. A simpler method for calculation of overall heat loss is based on measurements of average velocity of heat transferring fluid in the long pipe and the temperature at the pipe ends. The measurements are performed on an experimental setup of coiled ISOPROFLEX pipe under steady-state convection and radiation heat transfer conditions to the ambient air modelling pipe service conditions in the crawlway. Papers [4, 5] describe the method of measuring temperature dependence of the thermal conductivity coefficient using 18 metre pre-insulated pipe in 1.8 m diameter coils, conditioned in a water thermostat at about 17°C. Measurements were made in unsteady temperature conditions and one measurement was conducted within 10 hours.

**Pic. 1. General view of the experimental setup**

The general view of the experimental setup is shown in Pic. 1. It includes a closed circuit with circulating water; a section of the pipe without thermal insulation is placed in the thermal chamber and a section of the thermal insulated pipe is placed in the laboratory outside the chamber at room temperature.

Circulation of water is induced by a Grundfos UP 20-30 pump. Its volume flow is controlled by a KROHNE VA 40 flow meter and the temperature of the water is measured using K type submerged thermocouples M8 (chromel/alumel). 20 metres of pre-insulated ISOPROFLEX 25/63 pipe is used for testing, coiled into a 1.6 m diameter with a space between the loops of 0.1 m. The ambient temperature is measured using two thermometers placed at the top and bottom loop of the coil.

From consideration of the energy balance in the long pipe placed in air, the following equation for temperature of heat transferring fluid at the outlet of the pipe $t_l$ can be derived (see e.g. [6]):

$$t_l = t_{air} + (t_0 - t_{air}) \cdot \exp\left(-\frac{l}{g\rho CR}\right) \qquad (1)$$

where $t_0$ – temperature of fluid at the inlet, $t_{air}$ – ambient temperature, $R$ – overall linear thermal resistance (value opposite to the heat transfer coefficient), $g$ – volume flow of the heat transferring fluid, $\rho$ and $C$ – density and heat capacity respectively.

It was assumed in deriving the equation that $R, \rho, C$ values don't depend on the temperature.

In case of practical interest $l/(g\rho CR) << 1$ temperature distribution of heat transferring fluid along the pipeline can be considered to be linear and the temperature drop in it $\Delta t$ insignificant:

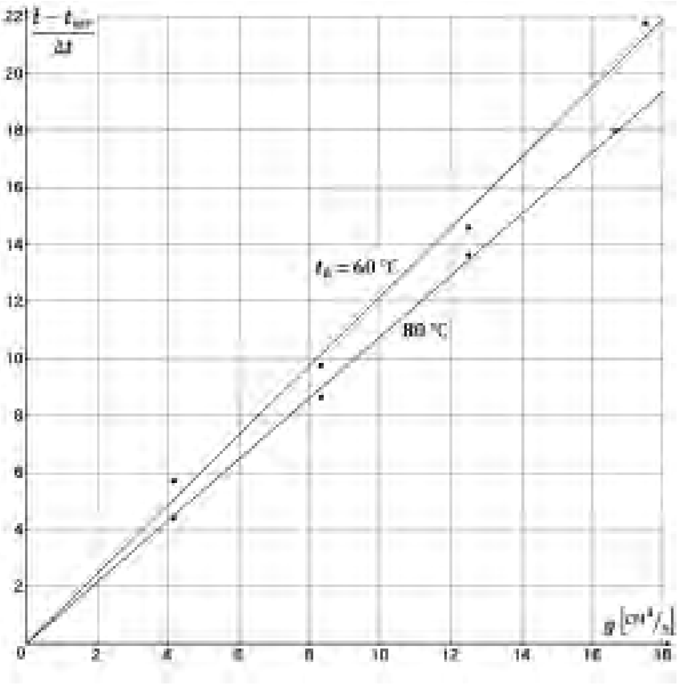
$$\Delta t = t_0 - t_l \approx (t_0 - t_{air}) \frac{l}{g\rho CR} \ll t_0$$

In this case, from the equation (1) we can derive the following approximate equation:

$$\frac{\bar{t} - t_{air}}{\Delta t} = \frac{\rho C R}{l} g \qquad \left(\bar{t} = \frac{t_0 + t_l}{2}\right) \qquad (2)$$

Therefore, experimental data represented in coordinates g and $(\bar{t} - t_{air})/\Delta t$, are described in linear dependence (2) beyond the immediate vicinity to the origin of the coordinates. This dependence can be achieved by equating the following two values for heat energy lost in the pipeline per second (heat flow rate) – $g\rho C\Delta t$ and $(\bar{t} - t_{air})l/R$, with the last expression being true for linear distribution of the heat transferring fluid temperature.

**Pic. 2. Measurement results for two temperature conditions in the thermal chamber $t_h$ = 60°C and 80°C**



The results of measurements and calculations conducted for two temperature conditions $t_h$ = 60°C and 80°C and 80°C at four values of heat transferring fluid flow are shown in pic. 2. The correlation coefficient for the obtained straight lines (their slope a is calculated using the least square method) equals 0.9993 for measurements at $t_h$ = 80°C and 0,996 for $t_h$ = 60°C. Overall thermal resistance is calculated using the following equation:

$$R = \frac{al}{\rho C} \qquad (3)$$

The above assumption about non-dependency of $\rho$ and $C$ from the temperature for the present tests is true as at the maximum observed heat transferring fluid temperature drop $\Delta t$ = 10°C, the corresponding reduction in its volumetric heat capacity $\rho C$ is only 0,4% (data on temperature dependences of $\rho$ and $C$ for water see, e. g., in [7]).

The results of calculating $R$ at $l$ = 20 m and $\rho C = 4{,}1 \cdot 10^6$ J/(m³ · K) are shown in the table. Now we can calculate overall linear thermal resistance of pre-insulated pipe $R_{pipe}$ and the average value of thermal conductivity of the insulation material in it, assuming that value $R$ is known. Thermal resistance on the inner surface of the carrier pipe is usually ignored during pipelines thermal design calculations [8, 9]. Then, taking into account thermal resistances of the insulation $R_i$, carrier pipe $R_f$, casing $R_c$ and resistance on the outer surface of the casing $R_e$, we have

$$R = R_{pipe} + R_e\,, \qquad R_{pipe} = R_i + R_f + R_c \qquad (4)$$

The above mentioned resistances are [8, 9]:

$$R_i = \frac{1}{2\pi\lambda_i} \ln\frac{D_{PUR}}{d_0}\,, \qquad R_f = \frac{1}{2\pi\lambda_f} \ln\frac{d_0}{d_0 - 2e}$$

$$R_c = \frac{1}{2\pi\lambda_c} \ln\frac{D_c}{D_{PUR}}\,, \qquad R_e = \frac{1}{\pi D_c \alpha_e} \qquad (5)$$

where $D_c$, $D_{PUR}$, $d_0$ – are outer diameters of casing, the insulation and the carrier pipe, respectively, e is the wall thickness of the carrier pipe, $\lambda_i$, $\lambda_f$, $\lambda_c$ – are thermal conductivities of insulation, carrier pipe and casing materials, $\alpha_e$ is the heat transfer coefficient at casing outer surface.

As opposed to small longitudinal thermal gradient and temperature changes in pipelines in a steady-state, radial gradient and changes are great and, generally, require taking into account the temperature dependence of thermal conductivity when calculating thermal resistance of layers of pre-insulated pipes.

The heat insulating layer mainly contributes to the overall thermal resistance of pipes insulated with polymeric foams ($R_i >> R_{f,c}$, for ISOPROFLEX 25/63 it is about 98%) and in the first approximation we can assume that practically all temperature drop in the pipe takes place in this layer. Therefore, here and hereinafter $\lambda_i$ is assumed to be a value averaged in the corresponding temperature range.

From equations (4) and (5) we get:

$$\lambda_i = \frac{\ln\frac{D_{PUR}}{d_0}}{2\pi(R_{pipe} - R_f - R_c)} \qquad (R_{pipe} = R - R_e) \qquad (6)$$

For ISOPROFLEX 25/63 we have $d_0$ = 25 mm, $e$ = 2,3 mm and average values of the outer diameter of the insulation and casing are $D_{PUR}$ = 59 mm and $D_c$ = 63 mm

[10, 11]. For numerical calculations we take $\lambda_f$ = 0,38 W/(m ·K) for PEX carrier pipe, $\lambda_c$ = 0,43 W (m · K) for LDPE casing [11], $\alpha_e$= 10 W/(m$^2$ · K) for a horizontal pipeline in an indoor environment and casing material with a high radiation heat transfer coefficient [9]. Thermal resistance values calculated from Equation (5) equal $R_f + R_c$ = 0,11 m ·K/W and $R_e$ = 0,51 m · K/W whereas the corresponding values of $R_{pipe}$ and $\lambda_i$ got from Equations (6) are represented in the table.

Values $\lambda_i$ given in the table are close to the corresponding average values of thermal conductivity determined previously from the results of measuring the temperature dependence of PU foam using an IZOMET 2114 thermal properties analyser with a measuring probe IPN 1100; at an average temperature of thermal insulation layer $t_i$ = 40 °C the difference from the average value for tested samples of PU foam is about 7%, and at $t_i$ = 46 °C it is practically the same. The table also gives absolute error estimates of indirect measurements of PU foam thermal conductivity $\Delta\lambda_i$ at confidence probability 0.95.

Thus, the proximity of calculated PU foam thermal conductivity values to those previously measured using IZOMET 2114 shows the possibility of measuring thermal resistance of coiled pre-insulated pipes at ambient temperature in a steady-state condition.

**The results of calculations of linear thermal resistance R, Rpipe and thermal conductivity of PU foam λi for pre-insulated flexible pipe ISOPROFLEX 25/63**

| $t_h$, °C | $\tilde{t}$, °C | $\tilde{t}_i$, °C | α · 10$^{-6}$, c/m$^3$ | R, m ·°C/W | $R_{pipe}$, м ·°C/W | $\lambda_i$, W/(m · °C) | $\Delta\lambda_i$, W/(m · °C) |
|---|---|---|---|---|---|---|---|
| 60 | 53 | 40 | 1,22 | 5,95 | 5,44 | 0,026 | 0,002 |
| 80 | 67 | 46 | 1,08 | 5,27 | 4,76 | 0,029 | 0,001 |

## References

1. EN 15632-1:2009 (E) District heating pipes – Pre-insulated flexible pipe systems – Part 1: Classification, general requirements and test methods.
2. TU 2248-001-48532278-2013 ISOPROFLEX-115A with PU foam insulation in corrugated PE layer.
3. EN ISO 8497:1996 Thermal insulation – Determination of steady-state thermal transmission properties of thermal insulation for circular pipes.
4. Reidhav C., Claesson J. A transient method to determine temperature-dependent thermal conductivity of polyurethane foam in district heating pipes. The 8th Nordic symp. on building physics, Copenhagen, Denmark, 2008.
5. Reidhav C., Claesson J. Transient thermal conductivity of flexible district heating twin pipes. The 12th Int. symp. on district heating and cooling, Tallinn, Estonia, 2010.
6. Kopko V. Thermal insulation of heating pipelines. Minsk, Tekhnoprint, 2002.
7. Volkov A., Zharskiy I. Great chemical reference book. Minsk: Modern School, 2005.
8. Ionin A., Khlybov B., Bratenkov V., Tereletskaya E. Heating supply, M.: Stroyizdat, 1982.
9. SP 61.13330.2012 Thermal insulation of equipment and pipelines.
10. TU 2248-021-40270293-2005 ISOPROFLEX and ISOPROFLEX-A PEX with PU foam thermal insulation in PU corrugated layer.
11. ISOPROFLEX. Technical specification. Flexible pre-insulated pipes for district heating and hot water supply. POLYMERTEPLO Group 2007.