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RAPPORT

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Hot Pipe Coating

Thermal conductivity

Report 2006/20 (1)

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1. Introduction

On November 8, 2006, the Superior Products NV company demanded the Laboratory of Building Physics at the K.U.Leuven to measure the thermal conductivity of ‘Hot Pipe Coating’.

This report describes the measuring method, gives the results of the measurements and contains a short discussion on accuracy and values to use.

2. Thermal conductivity of Hot Pipe Coating

2.1 Samples

The laboratory received 4 samples, composed of a substrate board of 4 mm, finished with ‘Hot Pipe Coating’. Characteristics:

Sample	Thickness M	Weight G
1	0.0372	1152
2	0.0376	1181
3	0.0175	647
4	0.0175	652

2.2 Measurements

2.2.1 Method

Thermal resistance of the 4 samples was measured with the heat flow meter apparatus for samples 30x30 cm, as described in the standard ISO 8302 (figure 1). The apparatus consists of a central hot plate with a cold plate above and below. That way, two samples can be tested at the same time. Round heat flow meters with a diameter of 10 cm are positioned centrally at the underside of the top plate, at both sides of the central plate and at the upside of the lower plate. These heat flow meters are embedded in a neoprene layer with the same thickness as the meters and as large as the area of the plates. In the centre of each plate side, extremely thin Cu/Co thermocouples are glued against the heat flow meters. The samples are then mounted between the top plate and the central plate and between the lower plate and the central plate. The whole is finally packed in a thermally isolating box as to create close to adiabatic conditions around the set-up. Before the measurements started, the heat flow meters were recalibrated using the reference samples of the EU's BCR.

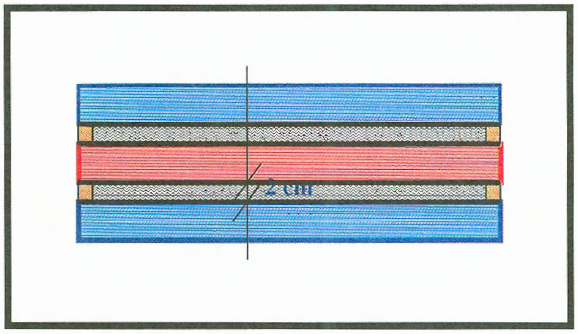

Figure 1 The experimental set-up. The central plate is coloured in red, the top and bottom plate in blue. The thick black line around the set-up coincides with the borders of the insulated box, which should create a near adiabatic border between the set-up and the environment. The thinner black lines against the plates represent the neoprene layers with embedded heat flow meters

Temperature difference between the thermostatic bath that keeps the top and lower cold plate on temperature and the thermostatic bath that keeps the central warm plate on temperature is set at 10°C. As soon as the temperatures and the heat fluxes at both surfaces of the samples turn constant, all data are logged at a time interval of 10" and stored on hard disk. All further calculations are done in Excel: transforming the 10" values in averages spanning three hours and calculating thermal resistance with the following equation:

$$R = \frac{2\Delta\theta}{C_1E_1 + C_2E_2} \qquad (\mathrm{m^2.K/W}) \qquad [1]$$

with:	C_1, C_2	Calibration constants of the heat flow meters in W/(m².mV))
	E_1, E_2	Measured electrical voltage difference over the heat flow meters in mV
	$\Delta\theta$	Temperature difference over the samples in K (measured with the Cu/Co thermocouples)

2.2.2 Measured results

Sample	Thickness m	Vol. moisture ratio $\%\,m^3/m^3$	Mean temperature °C	Temp. Difference °C	Thermal resistance (1) m².K/W
1	0.0372	0	1.5	9.0	0.60^2
			11.5	9.2	0.58^7
			21.4	9.2	0.58^0
			31.3	9.3	0.57^2
			41.2	9.2	0.56^0
2	0.0376	0	1.6	8.9	0.60^7
			11.6	9.1	0.59^0
			21.5	9.2	0.58^0
			31.4	9.2	0.57^2
			41.3	9.2	0.56^2
3	0.0175	0	1.6	8.4	0.26^8
			11.6	8.7	0.26^2
			21.4	8.6	0.25^9
			31.4	8.6	0.25^3
			41.3	8.6	0.25^2
4	0.0175	0	1.8	8.3	0.27^4
			11.7	8.6	0.26^9
			21.5	8.6	0.26^5
			31.5	8.6	0.26^1
			41.4	8.6	0.25^8

(1) The last number in superscript is unsure

2.2.3 Measuring accuracy

The maximum uncertainty on the measured data is given by:

$$\left|\frac{\partial R}{R}\right| \le \left|\frac{\partial q}{q}\right| + \left|\frac{\partial \theta}{\theta}\right| + \left|\frac{qR_n}{\Delta\theta}\right| \tag*{[2]}$$

with q heat flux in W/m². The term $\left|\frac{qR_n}{\Delta\theta}\right|$ represents a systematic failure, the consequence of a kind of zero thickness thermal resistance between the plates and the samples in between (in m².K/W). In the case being, its value does not pass 0.006 m².K/W.

As most probable uncertainty, one has:

$$\frac{\partial R}{R} \le \pm\sqrt{\left|\frac{\partial q}{q}\right|^2 + \left|\frac{\partial \theta}{\theta}\right|^2} \pm \left|\frac{qR_n}{\Delta\theta}\right| \tag*{[3]}$$

Results:

Sample	$\left\|\frac{\partial q}{q}\right\|$ %	$\left\|\frac{\partial \theta}{\theta}\right\|$ %	$\left\|\frac{qR_n}{\Delta\theta}\right\|$ %	**Maximum uncertainty** %	**Most probable uncertainty** %
1	1.5	0.55	1	3.1	1.9
2	1.5	0.55	1	3.1	1.9
3	1.5	0.55	2.2	4.4	2.8
4	1.5	0.55	2.2	4.4	2.8

2.2.4 Discussion

2.2.4.1 Thermal permeance versus mean temperature

- The measured data allow constructing the relationship between thermal permeance of the samples and the mean temperature in the samples. A least square analysis gives:

  In general

  $$P = \frac{1}{R} = a_\theta + b_\theta \bar{\theta}$$

  with P thermal permeance in W/(m².K) (is the inverse of thermal resistance) and $\bar{\theta}$ average temperature in °C

  Samples 1 and 2

  $a_\theta = 1.656 \quad b_\theta = 0.00308$

  $\sigma_a = 0.0041 \quad \sigma_b = 0.00016$

  $r^2 = 0.979 \quad F = 366$

  10 values

  Samples 3 and 4

  $a_\theta = 3.692 \quad b_\theta = 0.00584$

  $\sigma_a = 0.0032 \quad \sigma_b = 0.00127$ [4][5]

  $r^2 = 0.727 \quad F = 21.3$

  10 values

  See also the figures 2 and 3.

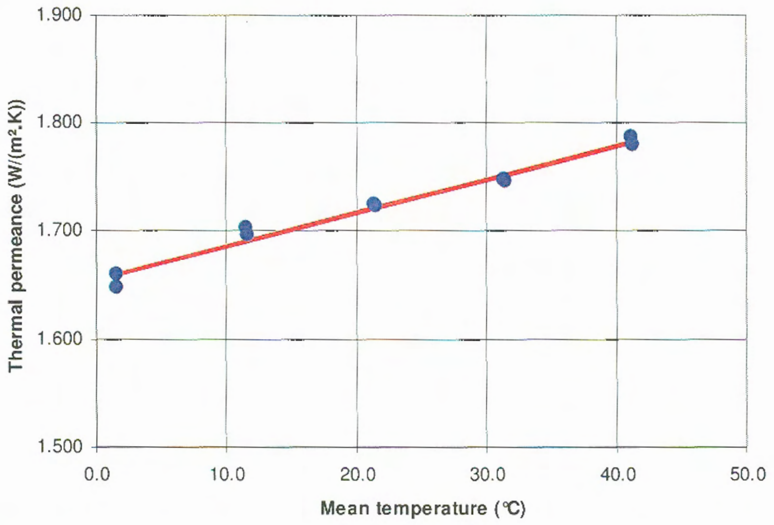

Figure 2 Samples 1 and 2, relationship between thermal permeance and mean temperature in the material

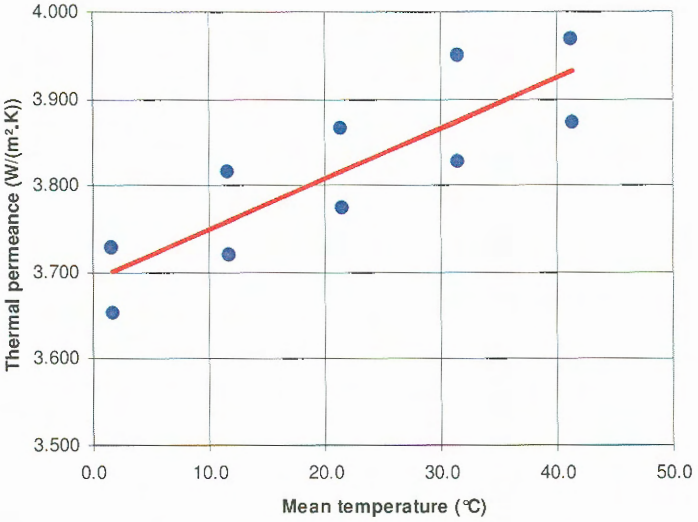

Figure 3 Samples 3 and 4, relationship between thermal permeance and mean temperature in the material

2.2.4.2 Thermal conductivity of Hot Pipe Coating

The samples 1, 2 3 en 4 are composed of a 4 mm thick substrate board finished with Hot Pipe Coating. With other words, the samples 1 and 2 contain 33.16 mm, respectively 33.56 mm of ceramic paste, while the samples 3 and 4 contain 13.53 mm, respectively 13.46 mm of ceramic paste. If we call the thermal resistance of the substrate board R_o, then at each mean temperature, we may write:

$$R = \frac{d_{hpc}}{\lambda_{hpc}} + R_o$$

That gives four equations per temperature step with two unknown: λ_{hpc} en R_o. These equations have been solved statistically, resulting in a thermal resistance R_o for the substrate board of 0.045 m².K/W, while the thermal conductivity of the ceramic paste became:

Mean temperature °C	**Thermal conductivity W/(m.K)**
1.6	0.059^6
11.6	0.061^5
21.5	0.062^5
31.4	0.063^1
41.3	0.065^0

In a formula:

$$\lambda = 0.059^8 + 0.000115\bar{\theta}$$

$a_\theta = 0.00045 \quad b_\theta = 2.25\,10^{-5}$

$r^2 = 0.929 \quad F = 26.2$

5 values

Also see figure 4. Uncertainty: a maximum of ±6.3% and a most probable value of ±3.5%.

Thermal conductivity at a mean temperature of 10°C:

$$\lambda=0.061 \pm 0.002$$

i.e. a rather high value. The reason is the quite high density of Hot Pipe Coating: not less than 299 ±3.3 kg/m^3.

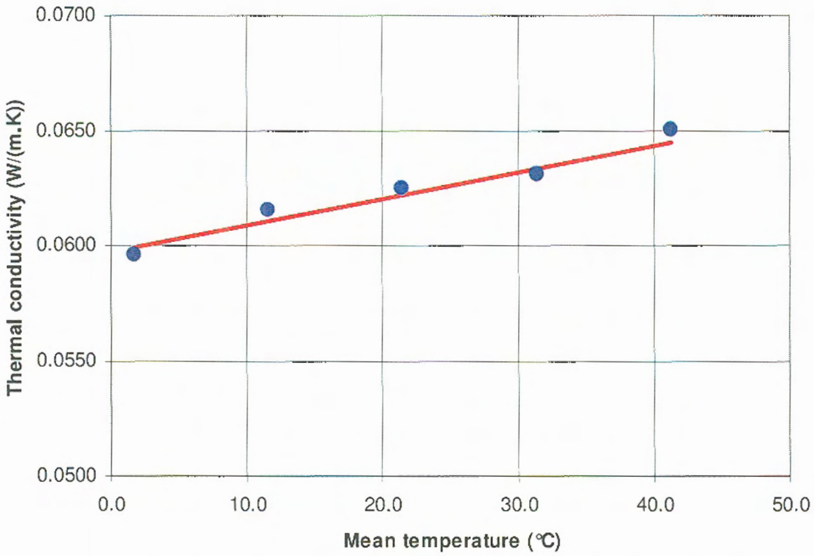

Figure 4 Relation between the thermal conductivity of Hot Pipe Coating and its average temperature

2.2.4.3 Thermal conductivity at different mean temperatures

These are given in the following table:

Mean temperature °C	**Thermal conductivity W/(m.K)**
-10	0.059
0	0.060
10	0.061
20	0.062
30	0.063
50	0.066
100	0.071
200	0.083
300	0.094
400	0.106
500	0.117

As all insulating materials, Hot Pipe Coating performs the best at low temperatures. Above a mean temperature of 350°C, its thermal conductivity passes 0.1 W/(m.K). The effect on the surface temperature and the heat loss of 1 meter run steel pipe thus depends on the temperature of the fluid in the pipe, de insulation thickness applied, the diameter of the pipe and the fact of the pipe hangs inside or outside. Only to illustrate the effect of Hot Pipe Coating, we calculated the reduction in heat loss per meter run for a steel pipe with an exterior diameter of 10 cm, hung in an environment with an effective temperature of 20°C. The pipe transports a 350°C hot fluid and is insulated with a 1 cm thick layer of Hot Pipe Coating. Without coating, the heat loss touches 3409 W/m. With Hot Pipe Coating it diminishes to 776 W/m, i.e. a decrease with 77.3%. The average thermal conductivity in the coating then reaches 0.088 W/(m.K).

Leuven, 4/7/2007

H. Hens
Professor

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HOT PIPE COATING

Conductivity Testing and Results

1. **Conduction Testing via ASTM C-177 Method:**
   Thermal conductivity over three tests: 0.560 BTU
   To find the Lambda Value or K (0.560 X 0.144 = 0.0806 k value
   Average 600 mils (14mm)
   Convert k 0.0806 X0.5778 (Heat Conversion Handbook Pg. 506) to K for sq.m = 0.0466.
   Whereas R = 1/K = 21.46

2. **Conduction Testing via the ASTM FLASH METHOD (E 1269 and E 1461-92)**
   K value average is 0.1083
   0.1083 X 0.5778 = 0.063K for sq.m
   R-1/K – 15.87
   Average 38 mils (.90 mm)