VERIFICATION OF HEAT LOSS MEASUREMENTS

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ABSTRACT

Heat loss tests are performed on different samples of the Thermaflex Flexalen 600 series and one ST-PUR-PE sample with the Thermaflex heat loss equipment and at two recognized test facilities, both using different test methods. The results of the institute using the same, guarded end method comply with the Thermaflex heat loss equipment's results. The results of the institute using the calculated end method differ considerably from the Thermaflex results. In this paper a comparison of these methods and results and a verification of the Thermaflex heat loss equipment is given.

INTRODUCTION

Last year Liandon developed test equipment for Thermaflex to measure the heat loss of insulated plastic piping systems. With this test equipment it is possible for Thermaflex to test their pre-insulated, semi flexible pipes in various diameters.

To verify the test results, the results of the Thermaflex heat loss equipment are compared to the test results of two recognized institutes. For this paper two institutes are chosen, since they both carry out measurements in compliance with the European standard EN 15632 [1], however with different methods as described in this paper. In order to give a comparison, knowledge of the test methods of both systems is required. In this paper the testing methods of all three systems are covered, together with the comparison of the test-results. Since the test facilities use two different methods, the comparison refers to the test methods as well as the test results.

The objective of this paper is to compare the test methods and test results of the two acknowledged test institutes for the Thermaflex heat loss equipment and verify the outcome. As in *"Heat loss of flexible plastic pipe systems analysis and optimization" (E. van der Ven et Al.)* [4] and *"Performance of pre insulated pipes" (I. Smits et Al.)* [6] the Thermaflex heat loss equipment's results are used to compare different sizes of the Flexalen 600 series and competitive products to each other.

NOVELTY AND MAIN CONTRIBUTION

The Thermaflex test-rig is newly developed and is used for research into the heat loss of pre-insulated pipes.

The novelty of this system is its ability to measure the overall heat loss of different samples under similar conditions, as defined by the European standard [1]. The ability to conduct equally based heat loss measurement result in an objective comparison of different types of (semi) flexible piping systems, thereby providing the opportunity to highlight strengths and weaknesses of (competitive) piping systems. Furthermore, in contrast to most heat loss tests, the test time in the Thermaflex test-rig is only a few hours, so the test can be performed while production is in progress. This provides the opportunity to optimize the production process real-time and measure the heat loss of the product several times during a production run. This guarantees the quality of the produced batch. In addition, the handling of the equipment is made easy, so no specially trained staff is needed for testing, making it possible for operators to carry out the tests. Furthermore a comparison with two other, recognized institutes is made to validate the Thermaflex heat loss equipment.

EUROPEAN STANDARD METHOD DESCRIPTION

The European standard EN 15632 [1] allows two different methods of heat loss or thermal conduction testing. These methods both state the same on internal heating of the service pipe but vary on the method of compensation for heat loss in the axial direction.

The first method, the guarded end method, states no axial heat transfer is permitted. This should be accomplished by the use of end guards, an extra pair of heating elements at both ends of the service pipe as shown in Figure 1. By heating the ends separately to the same temperature as the middle test section no heat transfer will take place to the ends of the service pipe. In this case a theoretical compensation is not required since the test section only has losses in the radial direction. This method is used in the Thermaflex heat loss equipment and at test institute 2.

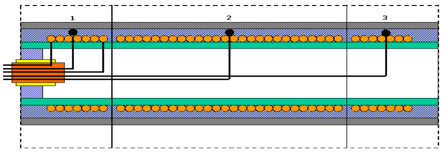


Figure 1, Longitudinal section guarded end heating probe

The second method described for compensating for axial heat loss is the calibrated or calculated end method. Since only the calculated end method is used for comparison the calibrated end method will not be covered in this paper.

The calculated end method states the ends of the service pipe shall be insulated with a known thermal conductivity as shown in Figure 2.

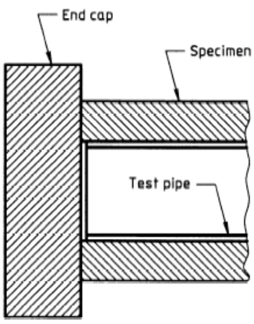


Figure 2, Configuration calculated end cap

The service pipe is heated, using a heating element with only one section. During the tests a thermal profile is made of the outer casing of the sample, showing lower values at the ends. After testing the heat loss is compensated for the end loss with the van Rinsum or Nukiyama theory. For this investigation only the van Rinsum theory is used and therefore described. According to the van Rinsum theory, the axial heat loss causes a decrease in temperature not only towards the ends of the service pipe, but in the test section as well. With the use of the equations (1), (2) and (3) this temperature decrease, in the test section, can be calculated and added to the measured value, compensating the end loss. This corrected temperature is used in equation (4) to calculate the overall thermal conductivity. This method is used by one of the institutes.

$$(\lambda_{calc}) := \frac{\phi \cdot \ln\left(\frac{D_2}{D_0}\right)}{2\cdot\pi\cdot L\cdot\left(T_{0m} - T_2\right)} \qquad (1)$$

$$c := \frac{2\cdot\pi\cdot\lambda_{calc}}{\left(A_1\cdot\lambda_1 + A_2\cdot\lambda_2\right)\cdot\ln\left(\frac{D_2}{D_0}\right)} \qquad (2)$$

$$\Delta T_{0m} := \frac{T_{0m} - T_{0X}}{\cosh\left(X\cdot\sqrt{c}\right)} \qquad (3)$$

$$\lambda := \frac{\phi \cdot \ln\left(\frac{D_2}{D_0}\right)}{2\cdot\pi\cdot L\cdot\left(T_{0m} + \Delta T_{0m} - T_2\right)} \qquad (4)$$

- λ_{calc}: approximate value of thermal conductivity
- D_2/D_0: outer/inner diameters of casing and service pipe
- A_1, A_2: areas of the heating probe, inner service pipe
- λ_1, λ_2, λ: thermal conductivity of heating probe, thermal conductivity of the service pipe, thermal conductivity total test sample.
- X, L: distance to next measuring point from the middle, sample length
- T_{0m},T_{0X},ΔT_{0m},T_2: pipe temperature at the middle of the test section, temperature at distance X of the middle, temperature correction, temperature at insulation surface.

VERIFICATION OF SAMPLES

To verify the outcome of the Thermaflex heat loss equipment and the laboratory tests, three samples of the Flexalen 600 piping system are tested for heat loss. These samples consist of 2 or 3 m of the pre-insulated piping system. More information about the Flexalen 600 system can be found in *"Heat loss of flexible plastic pipe systems analysis and optimization" (E. van der Ven et Al.)* [4]. Furthermore, method comparison tests are performed on competitive pre-insulated piping systems, a comparison of the products themselves is given in *"Performance of pre insulated pipes" (I. Smits et Al.)* [6].

The tests on the Flexalen 600 products are performed by Thermaflex and by one of the recognized institutes, using the different methods. To ensure the effect of ageing in the Flexalen 600 system is the same during all tests, the Flexalen 600 samples are tested simultaneously. To exclude effects of the production process both tested samples are half of a 6 metre stick.

For the Flexalen 50A25 and competitive product samples the same sample is tested at the different test facilities.

The comparison of the results is based on the outcome of heat loss per metre calculated as described in the European standard [1]. This loss per metre is only conclusive for the piping and not for the entire system. Therefore the complete Flexalen 600 system will be covered in paper *"Heat loss system optimisation" (J. Korsman et Al.)* [3] and "*New economical connection solutions for flexible piping systems" (C. Engel et Al.)* [5].

In this report the following diameters of the Flexalen 600 piping systems are used for comparison of the measurements:

Flexalen 600:

- 50A25, two guarded end tests and calculated end test.
- 160A90, one guarded end test and calculated end test.
- 200A110, one guarded end test and calculated end test.

Competitive products:

- Sample 1 two guarded end tests
- Sample 2 two guarded end tests

THERMAFLEX HEAT LOSS EQUIPMENT 600

The Thermaflex heat loss equipment is designed for testing the Thermaflex Flexalen 600 series. One of the major design goals was to develop a fast and easy-to-use test rig with the accuracy of a laboratory test. These goals have resulted in a test rig that is able to measure heat loss in a few hours, allowing direct optimization during the production process, and is operable by the production staff.

Physical test facility

The physical part of the Thermaflex heat loss equipment consists of three segments.

The first is the water cooled compartment in which all tests are performed. This compartment is kept at a constant temperature, (23°C), during each measurement. Furthermore it is possible to perform the heat loss test at lower temperatures. This provides the possibility to test at the same temperatures that occur in the buried state.

The second is a heat source, for which heating probes are used. These heating probes are custom made by equipping a two meter Thermaflex piping segment, of all available diameters, with three heating coils, as shown in Figure 1.

The third part of the heat loss equipment is the control unit, which powers the heating coils, regulates the temperature and reads out the temperature and power values. By using custom-made software all desired readings can be done. The final output is the actual heat loss in W/m through the entire pre-insulated Flexalen pipe, consisting of the service pipe, insulation and outer casing.

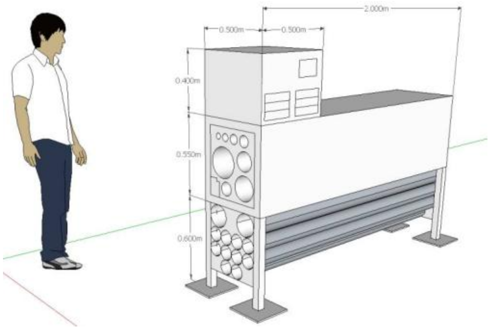


Figure 3, Thermaflex heat loss equipment

Measurement principle Thermaflex

The Thermaflex test rig has been designed in compliance with the European standard [1] and the tests are carried out according to ISO 8497 and EN 15632. In the design of the heating probes the guarded end method is used. According to this method the heating probes are equipped with three heating coils with separate power supply. As shown in Figure 1 the end guards consisting of 400 mm heating coils are located at each end of the probe. These two end guards provide thermal insulation at both ends of the 1000 mm test section in the middle since all three are kept under uniform temperature, eliminating axial heat loss. With this method it is possible to measure the heat loss by measuring the power needed to maintain a constant temperature of the test sample. In contrast to the measurements at the test institutes, the Thermaflex heating probes temperature is regulated by PID controlled power supplies. In the test results Graph 2 shows the power consumption versus test time. With this variable power supply it is possible to heat the probes in a short period of time, shortening waiting times considerably. Furthermore the use of the actual pipe material as a heating probe increases the accuracy. Moreover it eliminates all additional heat loss by convection that will be present with the use of smaller, not inner service pipe connecting heating probes.

For testing competitive products with different diameters these advantages are lost. However, by the use of thermal compartments in the service pipe the test results can be guaranteed.

Thermaflex test method

For testing, the heating probe with the appropriate diameter is inserted in the insulation with outer casing, and inserted in the cooled test section. After connecting the probe to the control unit the measurement can be started. Different testing conditions can be entered at this point such as the inner pipe temperature. When the test is started the heating coils heat the inner side of the probe until the desired temperature is reached.

When the inner temperature is constant and uniform throughout the three heating coils, the actual measurement is started. To ensure a constant temperature in the probe, a waiting time is built in the software that will reset the measurement if the temperature exceeds preset temperature values. The heat loss measurement is done by measuring the energy required to keep the probe at a constant temperature, by measuring the current at constant voltage in the heating coils, and calculating the power consumption. Since the middle/testing coil is exactly one metre in length the required energy represents the exact heat loss through one metre of piping and insulation in W/m. Since the actual piping material is used during the measurement, there are no other losses, nor advantages, than there will be in practice, ensuring an objective measurement. Furthermore a realistic fit of the insulation material is guaranteed. As stated in the foregoing paragraph these advantages are lost for different diameters. However during this investigation the probes have proven suitable.

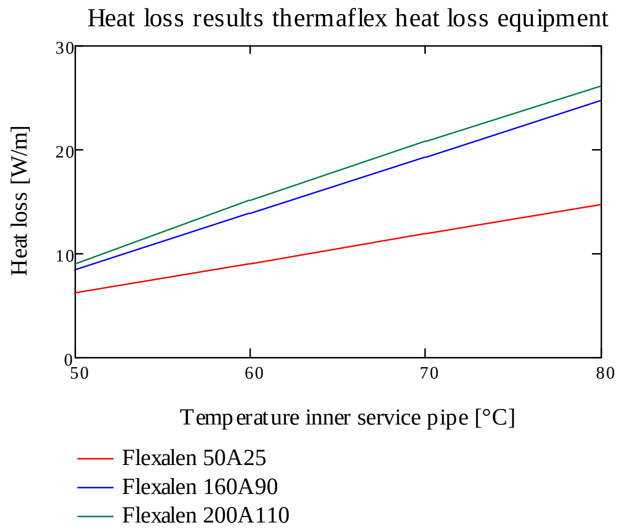
Test results Thermaflex heat loss equipment

In this paragraph the test results are presented for the tests carried out with the Thermaflex heat loss equipment. For this study four different types of the Flexalen 600 series were tested. The tests for the Flexalen 600 series took place at three different temperatures, 60, 70 and 80°C. The values at lower temperatures are calculated using the linearization method described in the European standard EN 15632 [1]. In the following tables and graphs the test results of the Thermaflex heat loss equipment are presented. The power usage during the testing cycle is shown in Graph 2. In this graph the first 40 minutes represent the heating and stabilisation time for the heating probe and insulation, whereas the last 30 minutes is the actual test time. Since, as the figure shows, the temperature is constant, the power usage equals the heat loss through the piping system in the radial direction during the last 30 minutes. The results, as given in Table 1, are calculated by using the mean of the power consumption during the last 30 minutes of the heat loss test. The results in Table 1 are also displayed in

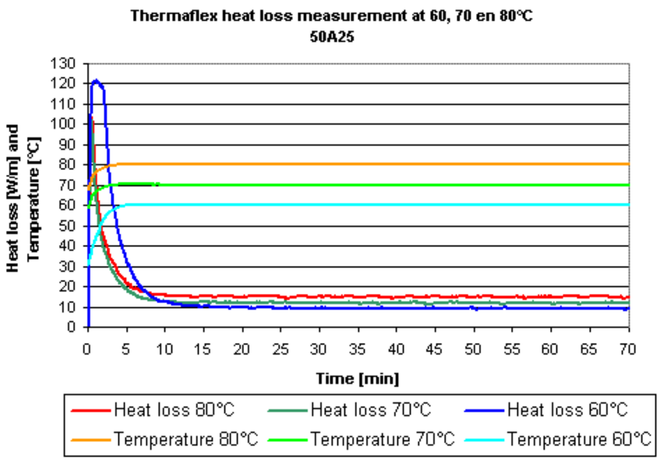
Graph 1 for the three tested samples.

Heat loss of the Flexalen 600 series in W/m tested on the Thermaflex heat loss equipment				
Product	50 °C	60 °C	70 °C	80 °C
50A25	6.2	9.1	11.9	14.8
160A90	8.5	13.9	19.3	24.7
200A110	9.0	15.2	20.9	26.1

Table 1, Results Thermaflex heat loss equipment



Graph 1, Results heat loss equipment Flexalen 600 products



Graph 2, Power and temperature of the heating probe

Outcome Competitive products for comparison of testing method:

For the comparison with test institute two, two samples of competitive products are tested. As these samples are ST-PUR-PE system, a correction has been made for using the PB heating probe using the Wallentén [2] method. First the thermal conductivity of the insulation is determined by using equation (5). Afterwards the heat loss is recalculated without the heating probe, using the temperature of the inner service pipe in equation (6). The results are presented in Table 2 and Graph 3.

$$\lambda_i := \frac{\ln\left(\frac{d_3}{d_2}\right)}{2\pi\cdot\frac{(T_p - T_c)}{\phi_{probe}} - \frac{1}{\lambda_{st}}\cdot\ln\left(\frac{d_2}{d_1}\right) - \frac{1}{\lambda_p}\cdot\ln\left(\frac{d_6}{d_5}\right) - \frac{1}{\lambda_c}\cdot\ln\left(\frac{d_4}{d_3}\right)} \qquad \frac{W}{m\cdot K} \qquad (5)$$

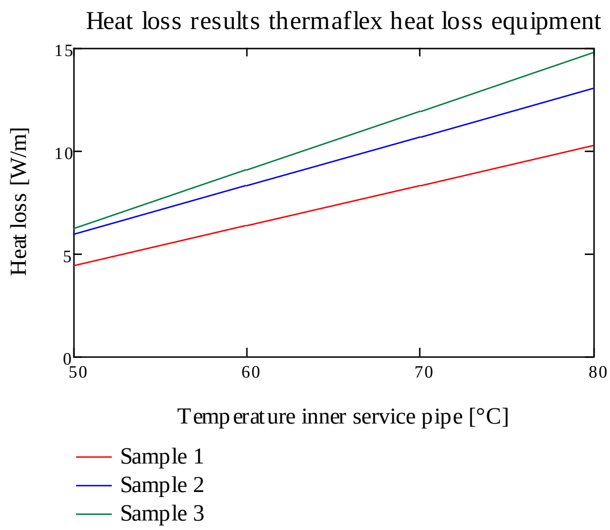
$$\phi_{corrected} := \frac{2\pi\cdot(T_{st} - T_c)}{\frac{1}{\lambda_{st}}\cdot\ln\left(\frac{d_2}{d_1}\right) + \frac{1}{\lambda_i}\cdot\ln\left(\frac{d_3}{d_2}\right) + \frac{1}{\lambda_c}\cdot\ln\left(\frac{d_4}{d_3}\right)} \qquad \frac{W}{m} \qquad (6)$$

Where:

- T_p, T_c, T_{st}=Probe, Casing and Steel pipe temperature
- d_1 to d_6 = inner/outer diameters of service pipe, casing and heatingprobe
- λ_{st}, λ_i, λ_c, λ_p = heat coefficient of service pipe, insulation, casing and probe
- Φ_{probe}, $\Phi_{corrected}$ =probe power and corrected heat loss.

Heat loss of competitive products in W/m tested on the Thermaflex heat loss equipment				
Sample	50°C	60°C	70°C	80°C
Sample 1	4.5	6.4	8.4	10.3
Sample 2	6.0	8.3	10.7	13.0
Sample 3	6.2	9.1	11.9	14.8

Table 2, Results heat loss equipment competitive products



Graph 3, Results heat loss equipment competitive products

TEST INSTITUTE 1

This institute is specialized in measuring heat loss in different types of insulation. The test facility used for the Flexalen 600 system is designed for measuring the heat loss of (pre-) insulated piping systems. This means the facility is designed to measure all different types and diameters.

Measurement principle institute 1

The measurements are all based on the calculated end apparatus, using the van Rinsum theory as correction, as described in the paragraph European standard [1] method description of this paper.

Physical test facility

The physical part of the test facility is similar to the Thermaflex test rig and also consists of the three elements: A temperature controlled compartment where the tests are carried out at a constant temperature of 23°C. Test institute 1 also uses heating probes as a heat source but, since it is not designed for the Flexalen 600 system, they are made to fit all systems. To ensure the fit of the probes in all different systems the diameters are smaller, and for durability made of metal. Furthermore no heat guards are used. This means the outer ends of the piping system are insulated and the heat loss is corrected with a calculated value. In the paragraph "European standard method description" a more detailed description is given. As can be seen in Figure 4 the heat distribution in this case is not uniform along the test specimen, proving the need for the van Rinsum correction.

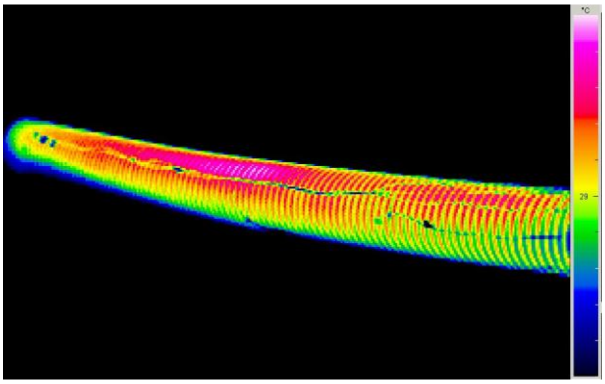


Figure 4, Thermal image of the sample at institute 1

In contradiction to the Thermaflex test rig, no integrated computer controlled power supply system is used. The power for the heating probe is first theoretically calculated and manually set to this value. For the temperature measurement thermocouples and a data logger with computer link are used.

Method of testing

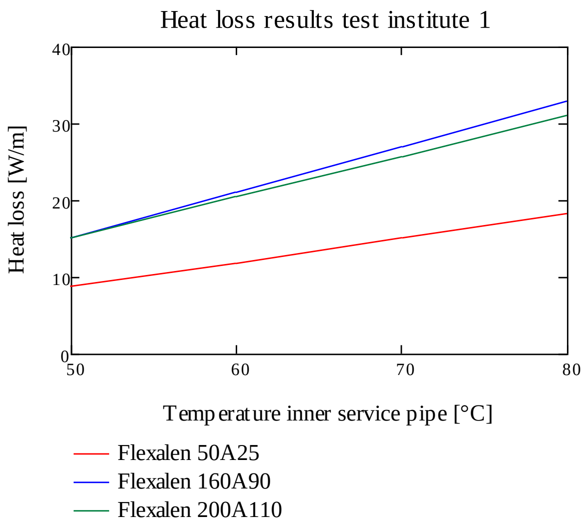
The heating probe is positioned in the centre of the test pipe with positioning foam in three sections of the pipe. On these foam blocks four thermocouples are placed in 0, 90, 180 and 270 degrees on the inner surface of the service pipe. For the outcome of the pipe inner temperature the mean of the four values is used. To measure the temperature on the outside casing of the insulation, five groups of four thermocouples are used in the same configuration as the inner pipe. The difference being that the thermocouples are placed both on and in between the corrugations of the casing. The test sample, with the heating probe, is placed in the conditioned container, after which the test can be started. The power supply of the heater is turned on by setting the voltage and current of the power unit to a fixed value so the electrical power equals the calculated heat loss. Depending on the diameter of the test sample and the test temperature the waiting time for the heating of the sample is five to eight hours due to the low, fixed power input. After a constant temperature of the outer casing is achieved the actual test cycles start. Each test cycle consists of a measurement of 30 min in which the outer casing temperature is to be constant. If not, the cycle has to be restarted. In total ten cycles will be performed on each sample. After the test the values are corrected for axial heat loss, and the thermal conductivity, thermal resistance and overall heat loss are calculated.

Test results institute 1

As the actual measurement data are not available due to the correction factor, only the calculated values can be discussed in this paragraph. As soon as the actual measurements become available this section will be updated. Furthermore, the results are not given for exactly 60, 70 and 80°C due to the fixed power supply with no temperature set point. The displayed results are calculated heat loss values at the set temperatures to make the data more interpretive. For this calculation the linearization method described in the European standard [1] is used. In Graph 4 the data from Table 3 is presented as a graph.

Heat loss of the Flexalen 600 series in W/m tested at test institute 1				
Product	50 °C	60 °C	70 °C	80 °C
50A25	8,8	11.9	15.1	18.3
160A90	15.1	21.1	27.1	33.0
200A110	15.1	20.5	25.8	31.2

Table 3, Results test institute 1



Graph 4, Results test institute 1

TEST INSTITUTE 2

For the second test institute in this research, an institute using the same guarded end method is chosen. This makes it possible to provide a correct comparison between the test results and not only the testing method. The tests carried out by test institute 2 at the time of writing are of competitive products only, as the facility was already running on full capacity. An update to this paper will be made as soon as the Flexalen 600 results become available.

Testing method institute 2

The method used by this institute is generally the same as the method used by Thermaflex; however the test facility itself is different.

Physical test facility

The testing facility at institute 2 consists of a temperature controlled room, kept at the prescribed 23°C. As a heat source a heating probe, consisting of a 2 m test section and two 50 cm end guards, is used.

Method of testing

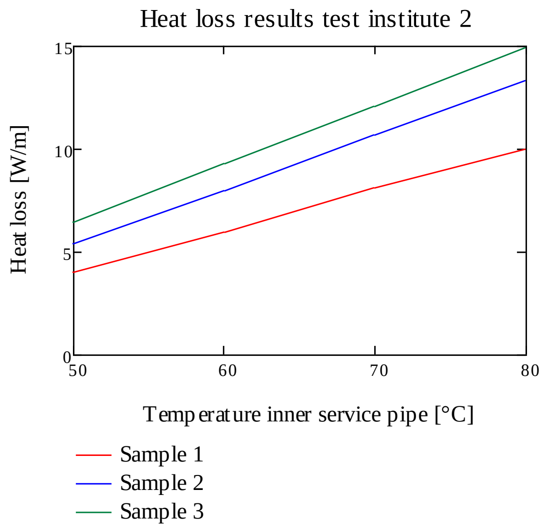
Prior to testing, the sample is prepared by placing thermocouples in various locations on the inner service pipe and outer casing. Subsequently the sample is placed in the temperature controlled room and the heating probe is inserted. By setting the power supply to a calculated value for all three heating coils the heating process of the sample is started. Because of the low fixed value of the power supply, this heating will take approximately 5 to 8 hours. After the desired temperature is reached at the test section as well as at the guarded ends, the actual test is performed. The test consists of a power reading during a 30 min cycle where the temperature of the test section and guarded ends may not exceed the limit of a yet unknown bandwidth.

Test results test institute 2

The test results of institute 2 are given in Table 4 and Graph 5.

Heat loss of competitive products in W/m tested at test institute 2				
Sample	50°C	60°C	70°C	80°C
Sample 1	4.00	6.02	8.06	10.09
Sample 2	5.44	8.05	10.67	13.27
Sample 3	6.4	9.3	12.1	15.0

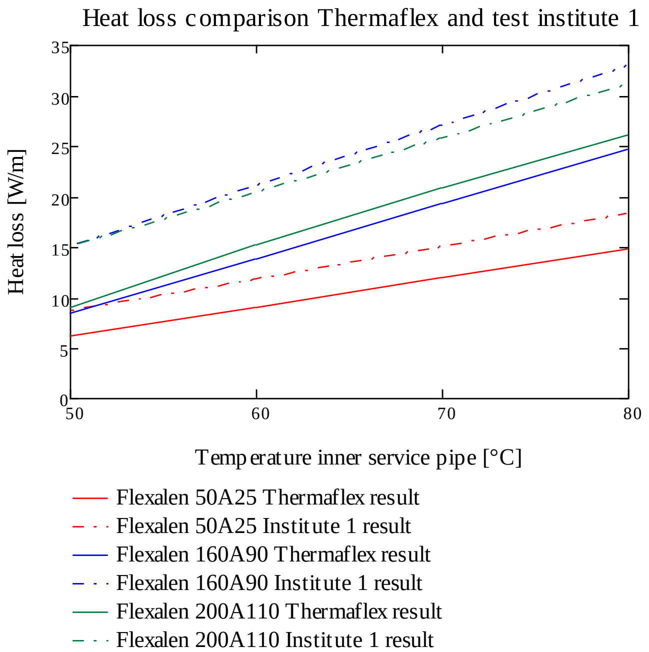
Table 4, Results test institute 2 for the competitive products



Graph 5, Results test institute 2 for the competitive products

COMPARISON OF THE TEST RESULTS

Comparison of the Thermaflex flexalen 600 series: Although both methods, guarded end and calculated end, are approved and described in the European standard [1], the difference between the results is substantial as displayed in Graph 6. Moreover, all results vary more as the temperature difference increases. This can be explained by the use of the calculated end caps that conduct more energy at higher temperature differences. As these end cap losses increase, the corrected thermal conduction for the sample also increases, resulting in a higher calculated heat-loss.



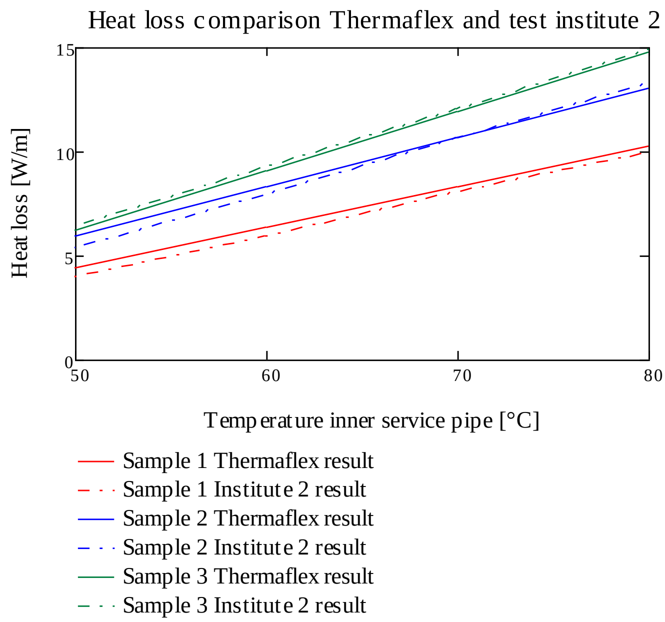
Graph 6, Comparison results of the heat loss equipment and test institute 1

Comparison of competitive products:

Although the Thermaflex heat loss equipment is designed for the Flexalen series, test results on competitive products show consistency with test institute 2 as well as the results of the Flexalen sample, as shown in Graph 7. The heat loss equipment values for the competitive products are just a little higher, which can be explained by the need to cut the sample in order to place the heating probe with thermocouples in the right position. For the Flexalen sample the results from institute 2 are higher, because in this case they had to use a cut sample.

The difference between the results of the test on sample 1 is 0.39 and 0.22 W/m at an inner service pipe temperature of 60 and 80 °C respectively. For sample 2 these differences are 0.28 and 0.24 W/m. For sample 3 the differences in the results are 0.20 and 0.17 W/m at 60 and 80 °C. These values are well within the combined accuracy range of both facilities. This comparison proves the worthiness of the Thermaflex heat loss equipment and that measurements are carried out according to the European standard [1].

Graph 7, Comparison results of the heat loss equipment and test institute 2



CONCLUSION

During this research it has become clear that the European standard [1] tolerates differences in heat loss test results by allowing different testing methods. The results of the tests indicate that the results of the guarded end method differ substantially from the results of the calculated end cap method. These differences can lead to problems with the choice of product or heat loss calculations for district heating networks.

However both methods are according to the European standard [1], the guarded end method seems the most accurate since no compensating calculations have to be performed after testing.

Further research into the accuracy of the use of the calculated end cap method, or van Rinsum theory, in combination with plastic piping systems is recommended.

The comparison of the results from test institute 2 and the Thermaflex heat loss equipment concludes that the results of the heat loss equipment comply with the European standard [1]. This validation makes the results of the Thermaflex heat loss equipment valid for not only in-house testing but also for publication as done in *"Heat loss of flexible plastic pipe systems analysis and optimization" (E. van der Ven et Al.)* [4] and *"Performance of pre-insulated pipes" (I. Smits et Al.)* [6].

FURTHER INFORMATION

Questions concerning the paper can be addressed to:

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