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**Accuracy of surface mounted
temperature sensors in
different applications**

Abstract

Accuracy of surface mounted temperature sensors in different applications

Surface mounted temperature sensors have more frequently been used in district heat metering during the last years. The accuracy of these sensors has been investigated and compared to the requirements in the Swedish regulation SPKB 1986:18. The most important parameters that influence the surface sensors and their accuracy are the efficiency of the insulation and the heat transfer from pipe to sensor. The influence on the accuracy also depends on the construction of the sensor.

The dominant source of error is deficiency in the insulation of the sensor. The insulation must consequently be carefully mounted. Furthermore it is of great importance that the mounting of the two sensors is as identical as possible so that the loss of heat to the surroundings is equal and the thermal contact with the pipe is uniform.

Keywords: Temperature sensor, Surface sensor

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Acknowledgement

The authors are indebted to the manufacturers of the two different surface sensors for their consent to use their sensors in this study.

Summary

The most important parameters that influence the surface sensors and their accuracy are the efficiency of the insulation and the heat transfer from pipe to sensor. The influence on the accuracy also depends on the construction of the sensor. The insulation must be carefully mounted. Furthermore, it is of great importance that the mounting of the two sensors is as identical as possible so that the loss of heat to the surroundings is equal and the thermal contact with the pipe is uniform. To get a satisfactory mounting the following steps should be observed.

Insulation

To get the insulation as proper as possible around the surface sensor, the insulation must be carved in those places where the sensor and the mounting clips are situated. If not carved, isolated air spaces and chimney effects might develop and this will result in loss of heat for both sensors.

To avoid heat dissipation through the wall of the pipe it is also important to insulate around the location of the sensor. The attachment of the clips shall be opposite the sensor, which gives a better homogeneity of the insulation around the pipe.

Thermal contact

To get a proper thermal contact the pipe must be cleaned and oxidation and paint has to be removed. The use of a paste will improve the thermal contact for some of the sensor constructions.

Sealing

The insulation around the sensor must be sealed to prevent the hot spot sensor from an increased loss of heat through diminished amount of insulation. The sealing can consist of special tape.

General

The sensors must be protected from draught and located so that the surrounding temperature is equivalent.

The rules for approval of surface sensors are presented in an annexe.

Page 6 : missing

Background

Surface mounted temperature sensors have more frequently been used in district heat metering during the last years.

The principle of measuring the temperature of a liquid circulating in the pipe system by putting a sensor outside the pipe surface will create a lot of problems compared to an ordinary sensor immersed in the pipe. Some of the problems could be identified as the velocity of the liquid, the thickness of the walls, the thermal conductivity of the walls, the geometry and the mass of the sensor, insulation to the surroundings etc. See figure 1.

The mountings and the locations of the sensors are consequently very important in order to achieve an acceptable accuracy of temperature measurements.

SP has investigated a new measuring method to be able to perform type approval testing of surface sensors. For this purpose a measuring circuit (described below) has been built. The circuit has been used to make comparative testings between sensors in different applications.

The investigations have resulted in a better understanding of the importance of correct mounting for proper measurements.

Measuring equipment

The measuring circuit consists of a temperature stabilized water bath, a circuit of pipes, a pump, a water meter and two reference thermometers. See figure 2 and the specification below.

One part of the circuit is an open section A-A where different pipes or heat meter configurations can be mounted.

The flow of the system is adjusted to $0,7 \text{ m}^3/\text{h}$ and the temperature is stabilized within 5 mK.

Water bath	Heto, type KB 21
Pump	Grundfos, type UPS 15-35
Water meter	Valmet, type MT2.5A
Reference thermometers	Pentronic P1100 1/10 DIN B
Contact paste	Wacker P12
Circuit pipes	Steel $\phi=25 \text{ mm}$

Dependent on the size of the mounted pipe turbulent flow might arise in the A-A region. With proper water velocity and a good temperature control the turbulence will not affect the assumption of linearity.

In section A-A the following different types of pipes are used for measuring:

15 x 1.0 mm	copper pipe
28 x 1.2 mm	copper pipe
15 x 1.5 mm	steel pipe
32 x 2.6 mm	steel pipe

The decrease in temperature along section A-A is registered by the two reference thermometers and is supposed to be linear. Therefore, the temperature is calculated to the location of every single surface sensor.

The specification of the circuit is:

Measurement of temperature	$\pm 4 \text{ mK}$
Measurement of resistance	$\pm 1 \text{ m}\Omega$
Stability of temperature	$\pm 5 \text{ mK}$
Stability of flow rate	$\pm 5 \%$

Surface sensors

The surface sensors are mounted with clips to the pipe and are properly insulated with 30 mm mineral insulation. See figures 3 and 4.

The surface sensors investigated are Pt100 sensors from Sonceboz and ICM. Depending on construction every sensor has different thermal behaviour. The following specific qualities are to be notified.

Sonceboz (Hydrometer) The Pt100-sensor is enclosed in a thin copper envelope protected with a plastic cover. This construction is insusceptible for different types of insulation. The side of the envelope towards the pipe has a fixed radius which means that the sensor is supposed to be less accurate without contact paste.

ICM In this sensor the Pt100 element is put into a rectangular metal body. Each side of the metal piece has different radius to fit different pipe dimensions. The sensor is supposed to be more sensitive regarding choice of insulation but will probably give a better thermal contact using contact paste or not.

Measuring state and calculations

The characteristics of the surface sensors are calculated from the values measured with the sensors mounted in the circuit with flowing water.

For every single sensor the resistance value was measured at about 1 °C, 32 °C, 64 °C and 97 °C. The flow velocity is constantly 0.7 m³/h.

On the basis of measured values the adaption of the resistance function was made

$$R = R_0 (1 + A \cdot T + B \cdot T^2)$$

where

- R = the actual resistance
- R₀ = the resistance of the sensor at 0 °C
- T = the actual temperature
- A, B = specific constants of the sensor

The pair of sensors is compared to DIN 43760, October 1980. The error of the displayed energy caused by the difference between the resistance of a pair of sensors compared to the accurate DIN-sensors is calculated according to the function

$$\text{Error \%} = 100 \left(\frac{R_1 - R_2}{R_{\text{DIN1}} - R_{\text{DIN2}}} - 1 \right)$$

where

- R₁ = resistance of the forward pipe thermometer
- R₂ = resistance of the return pipe thermometer
- R_{DIN1} = resistance for the accurate DIN thermometer in the forward pipe
- R_{DIN2} = resistance for the accurate DIN thermometer in the return pipe

Calculation of the error is performed with the two possible locations of the sensor in the forward or return pipe. The presented error limits are transferred from the Swedish regulation for heat meters. The calculation of those limits was done according to the following formula and statement.

$$\text{Error \%} = \pm 100 [0.004 + 0.1/\Delta T]$$

Maximum error limit = ± 4 %

where ΔT = the actual difference of temperature.

Result

The results for every pair of sensors are presented in two diagrams.

The upper diagram is a comparison with DIN 43760 for both detectors in the pair. The deviation in milliohm is presented for temperatures in the range 0 °C to 120 °C.

The lower diagram shows the error of displayed energy caused by the difference measurement. The error is presented for temperature differences of 0 °C to 45 °C. Both location alternatives are presented. In this diagram the cold temperature is set to 75 °C while the hot temperature varies between 76 °C and 120 °C. The dashed lines indicate the demands of the Swedish regulation for heat meters.

Conclusions

The following comments are given on the results.

1 In case 1 (ICM, water bath) the difference to DIN increases with increasing temperature. Compared to case 2 (ICM) the sensors are mounted on 15 mm copper pipe with full insulation and this gives a curve with almost constant deviation from the DIN curve.

2 No changes of the sensor function are observed in cases 2-5. This means that material and dimension of pipes are of less importance.

In case 5 the density value of the insulation was found to be somewhat lower compared to the insulation in the other cases. The reason is probably inferior insulation.

3 In case 6 where the sensors were not insulated at all, the Sonceboz (Hydrometer) sensors are in accordance with the demands while the ICM sensors exceed the limits.

It should be noticed that in the laboratory there was a minimum of draught or temperature gradients. Such conditions do not often occur in practice.

Furthermore, it should be stressed that if the insulation is less efficient it is more probable that the sensor pair will create a negative error in the energy measurement.

4 In case 7 both sensors are measured without contact paste. Both sensor types fulfill the demands in the Swedish regulations but the Sonceboz (Hydrometer) sensors are more sensible than the ICM sensors.

5 In case 8, mounting one sensor insulated and the other without insulation, the importance of a homogene insulation is shown. The error calculated exceeds the limits.

6 In case 9, mounting one sensor without contact paste, the error just exceeds the limit values. This shows once more the importance of equivalent mounting of both sensors.

7 Cases 10-12 show that the type of pipe used for the application is of less importance. The inferior insulation in case 11 results in errors which exceed the limits.

References

German Industrial Standard DIN 43760

Swedish regulation for heat meters SPKB 1986:18

Requirements for type approval of surface sensors in Sweden

As there are certain limitations in the use of surface sensors when measuring temperature for heat meters the following requirements are proposed for sensors tested for type approval.

First we emphasize the importance of a Swedish manual for mounting..

- The maximum dimension of the pipe must not exceed 32 x 2.6 mm.
- The hot and cold sensor must be mounted on the same type of pipe and with the same insulation.
- The minimum thickness of insulation around the sensor and the pipe must be 30 mm.
- The pipe must be cleaned and the oxidation and the paint must be removed to get a proper thermal contact . Contact paste will improve the heat transfer for some constructions.
- The pipe must be insulated for a distance of 0.5 m and with a thickness of 30 mm on both sides of the sensor . It must be possible to seal the insulation.
- There must be a manual for mounting to every sensor pair. Except the paragraphs above the manual comprises the following points:

Text and drawings giving complete information on mounting and sealing.

Information about dimensions and allowed materials for pipes and recommended type of insulation.

Identification for reference to the approval certificate.

Approval is only valid if the mounting instructions are followed.

Depending on the construction of the sensors further requirements and limitations might be introduced.

In addition to these requirements the demands according to SPKB 1986:18 are valid.

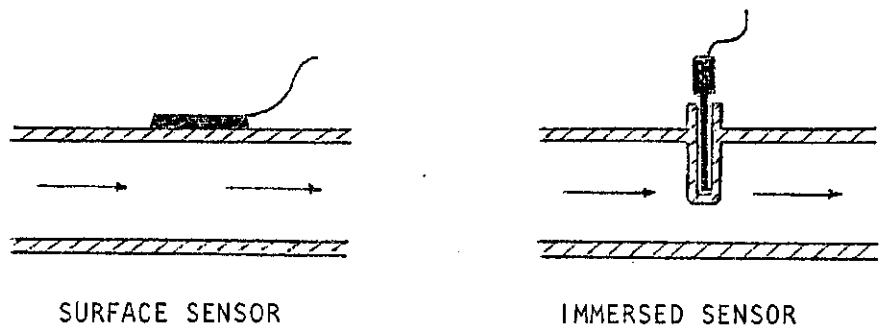


FIGURE 1 : TEMPERATURE SENSORS FOR HEAT METERING.

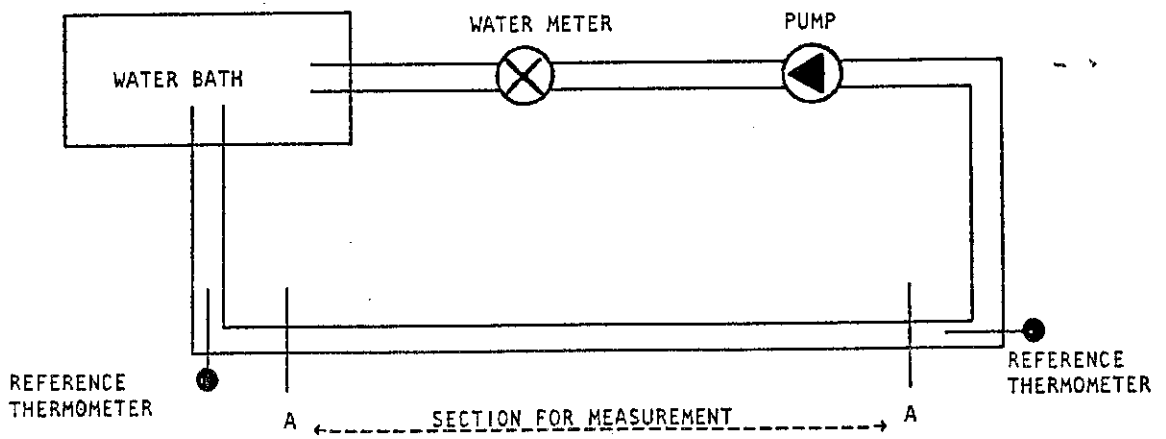


FIGURE 2 : THE MEASURING CIRCUIT.

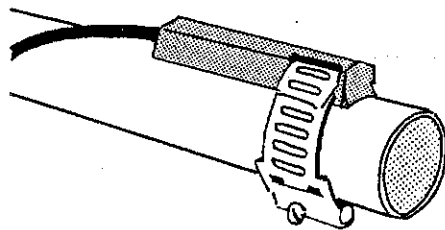
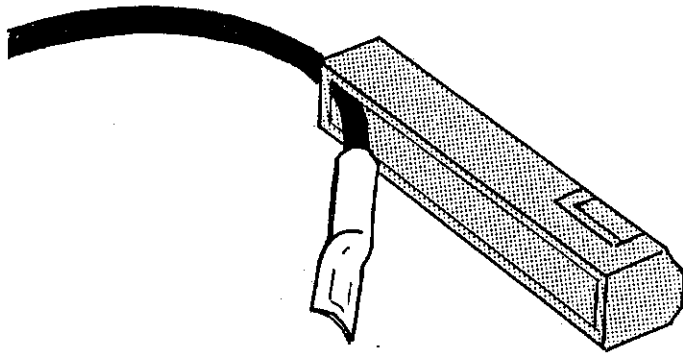


FIGURE 3 : SURFACE SENSOR SONCEBOZ (Hydrometer)

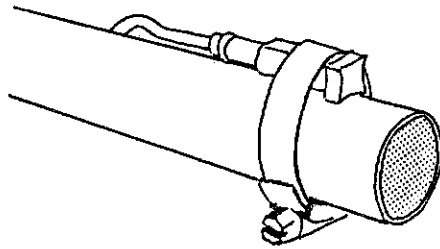
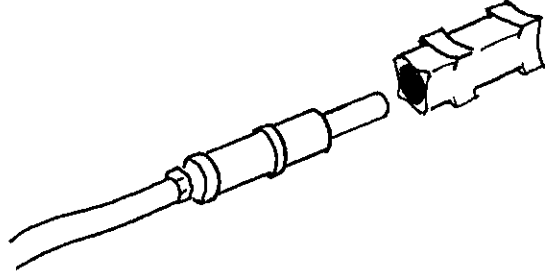
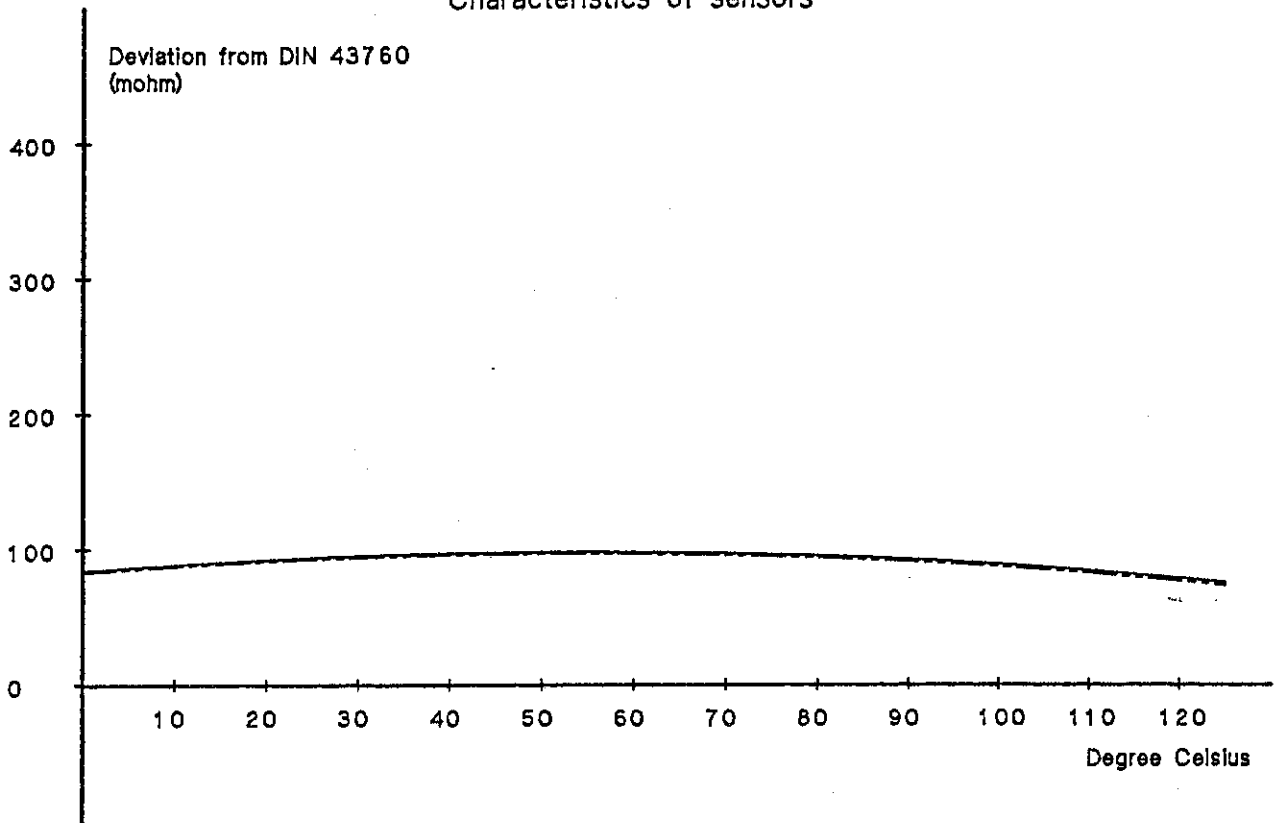


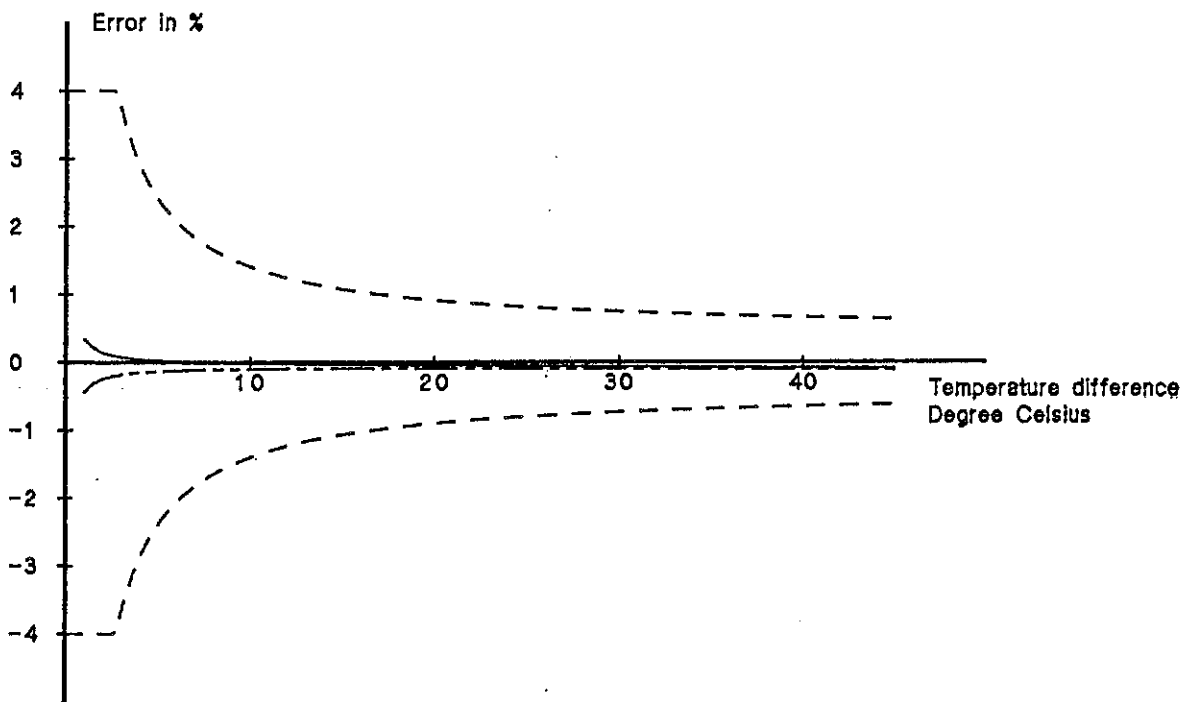
FIGURE 4 : SURFACE SENSOR ICM

Case No 1
Sensors immersed in waterbath
(Hydrometer)

Characteristics of sensors



Error in energy due to sensor pair

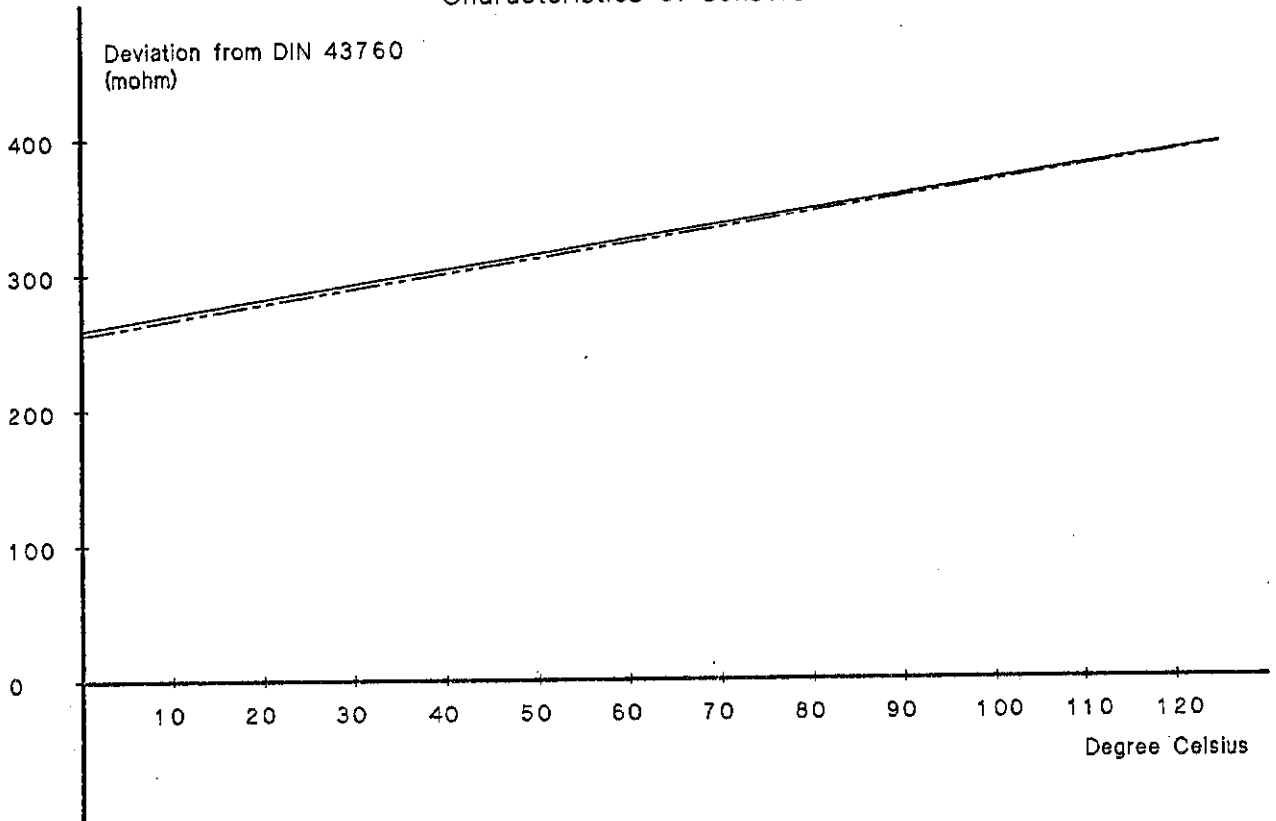


Case No 1

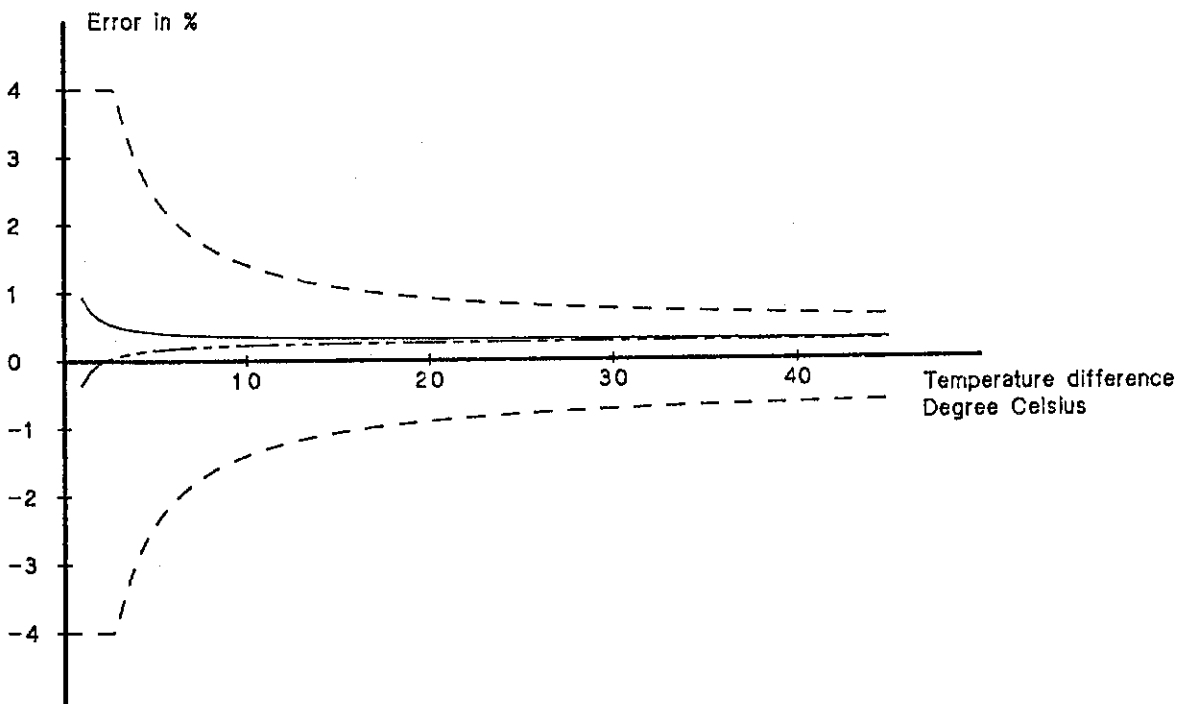
Sensors immersed in waterbath

(ICM)

Characteristics of sensors



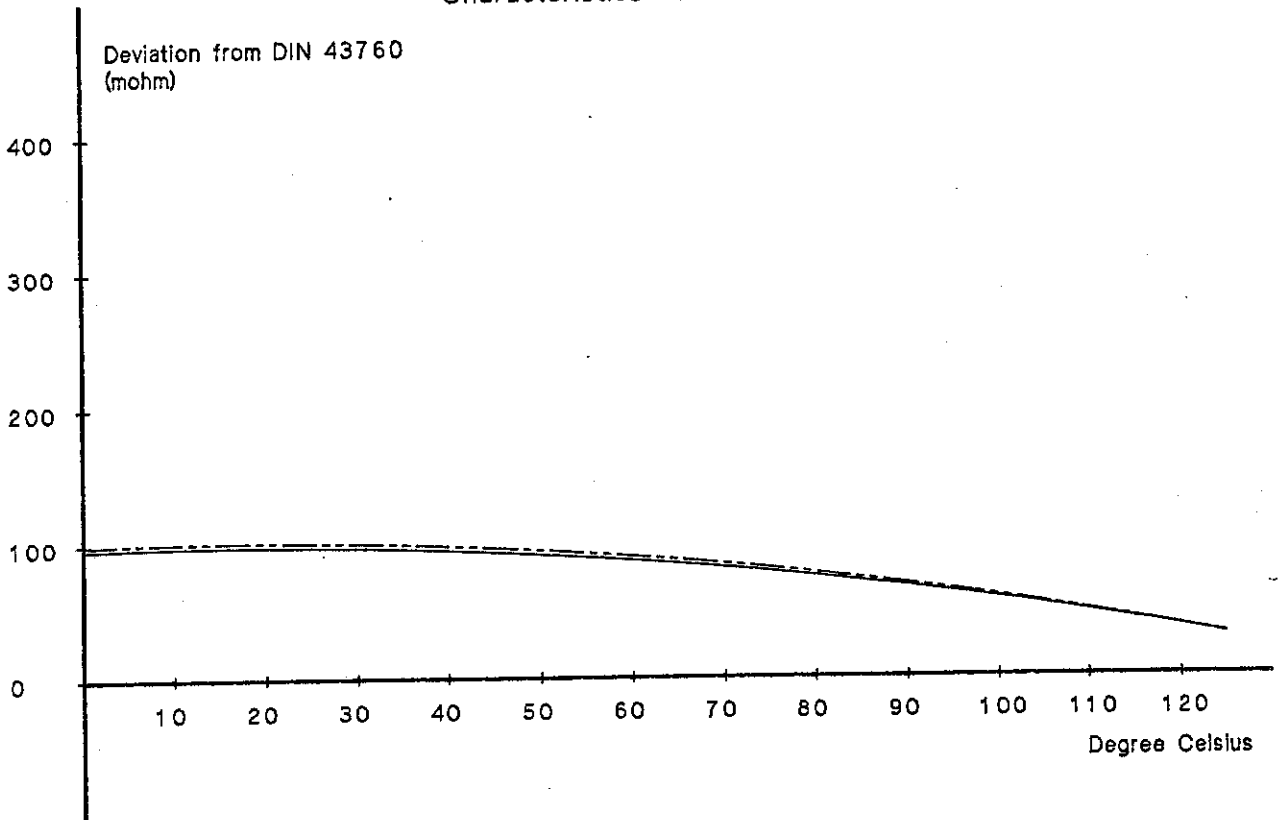
Error in energy due to sensor pair



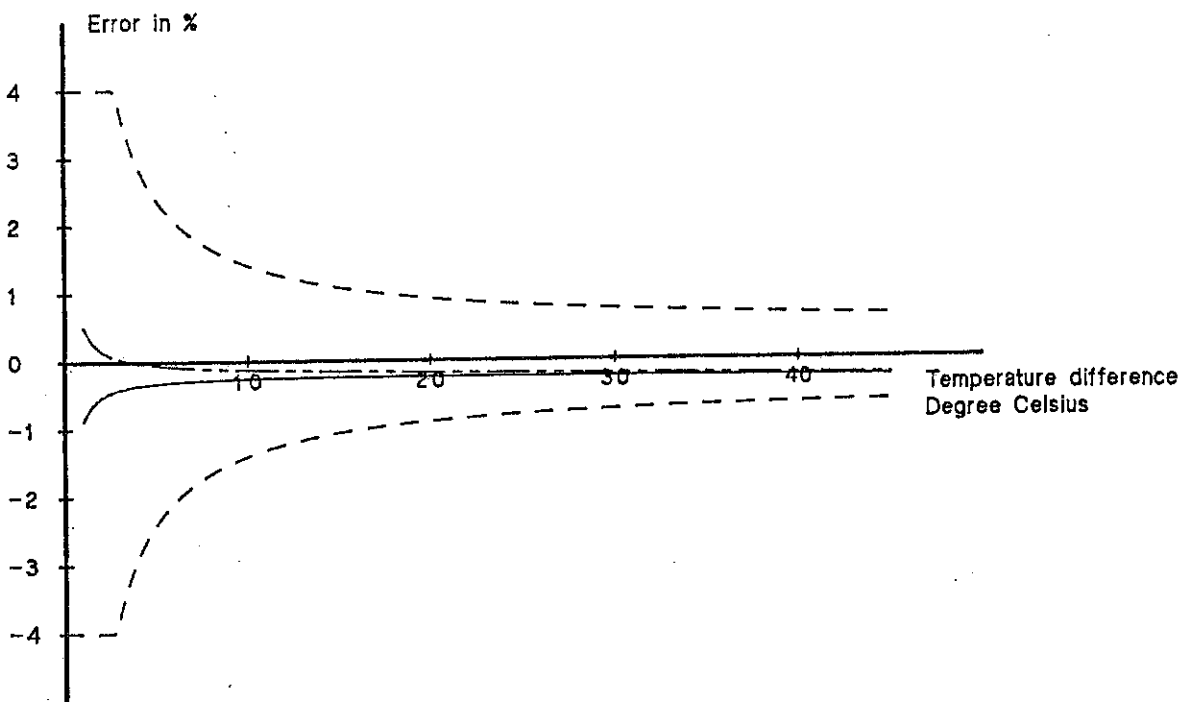
Case No 2

Sensors mounted on copper pipe 15 mm with insulation and with contact paste
(Hydrometer)

Characteristics of sensors



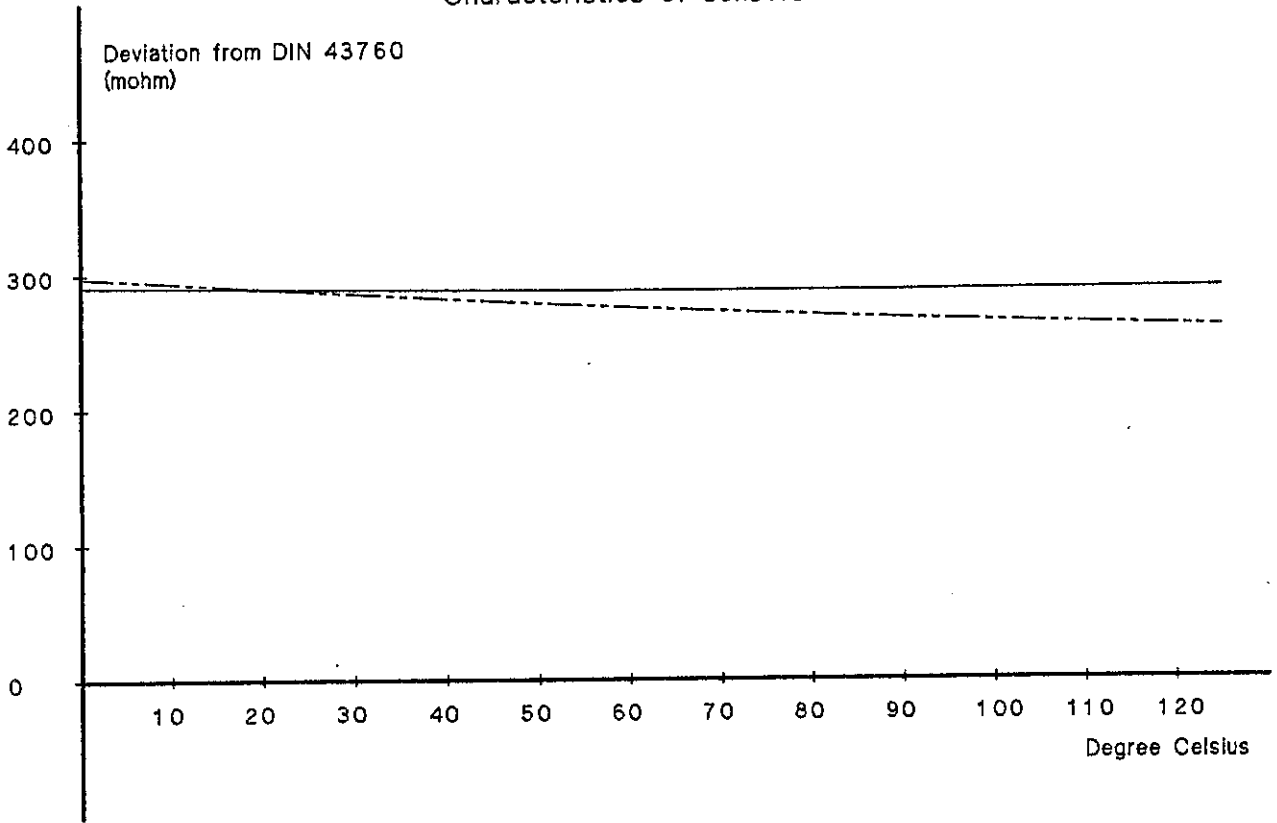
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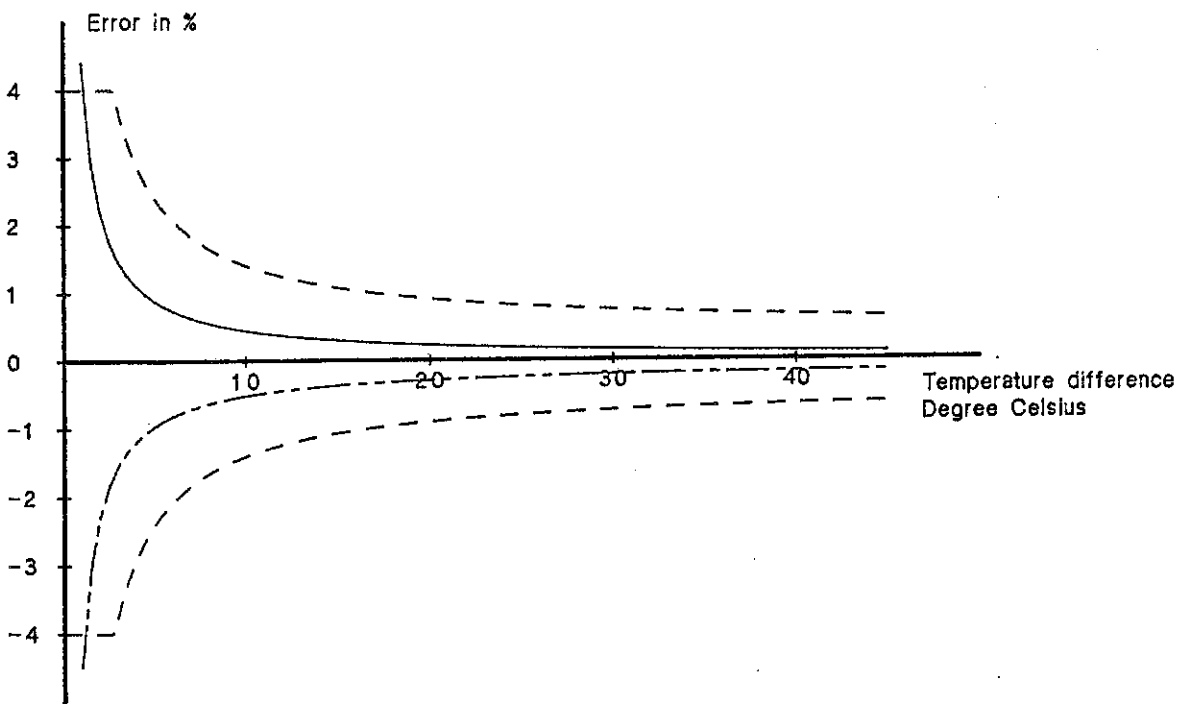
Case No 2

Sensors mounted on copper pipe 15 mm with insulation and with contact paste (ICM)

Characteristics of sensors



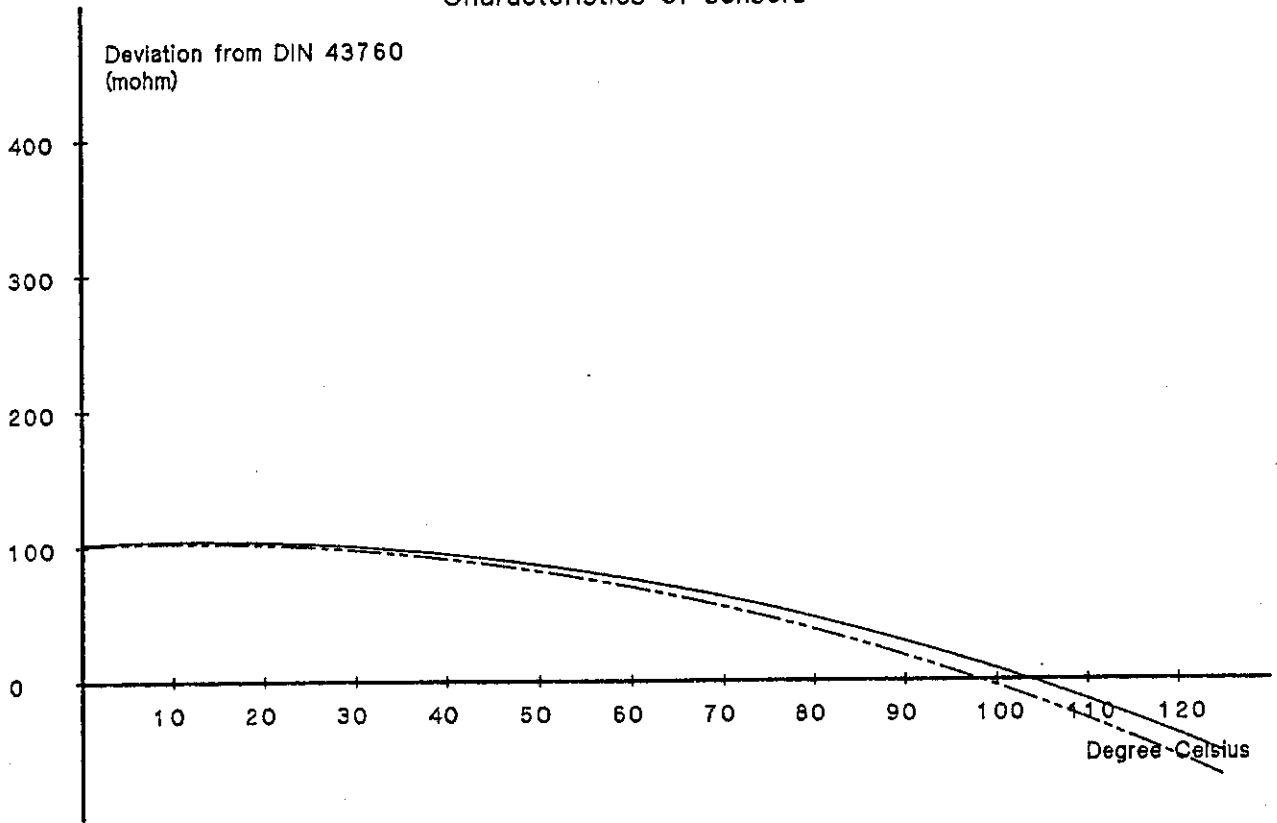
Error in energy due to sensor pair



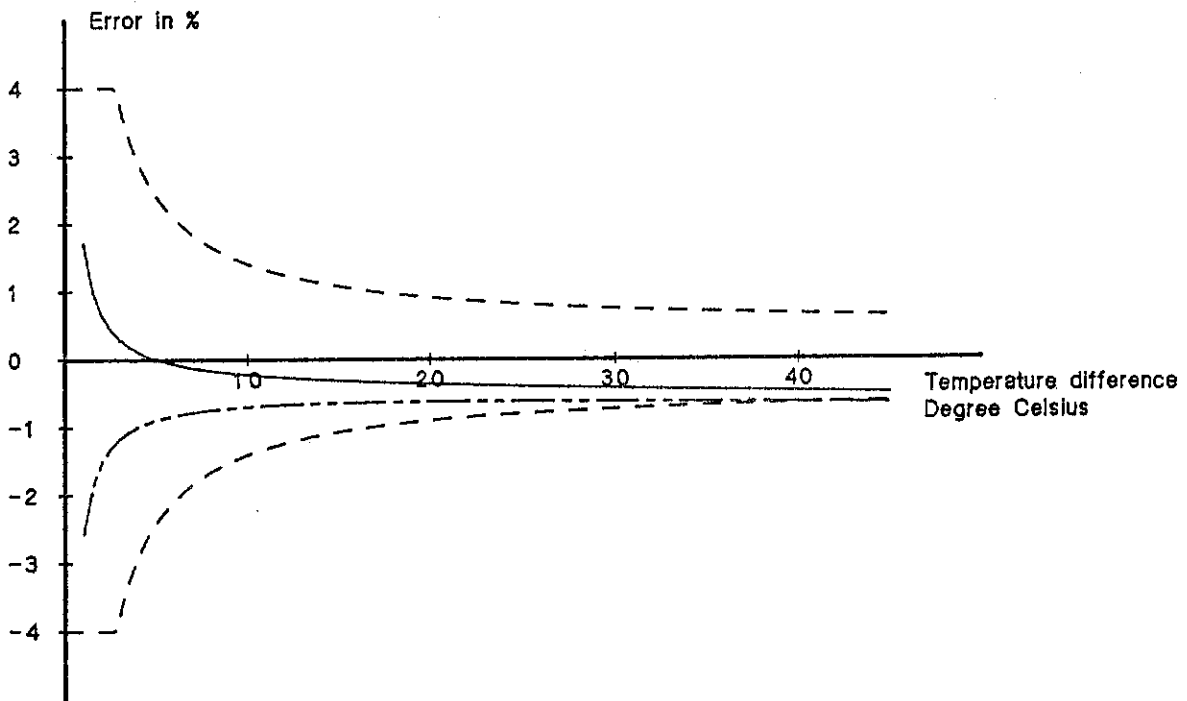
Case No 3

Sensors mounted on copper pipe 28 mm with insulation and with contact paste (Hydrometer)

Characteristics of sensors



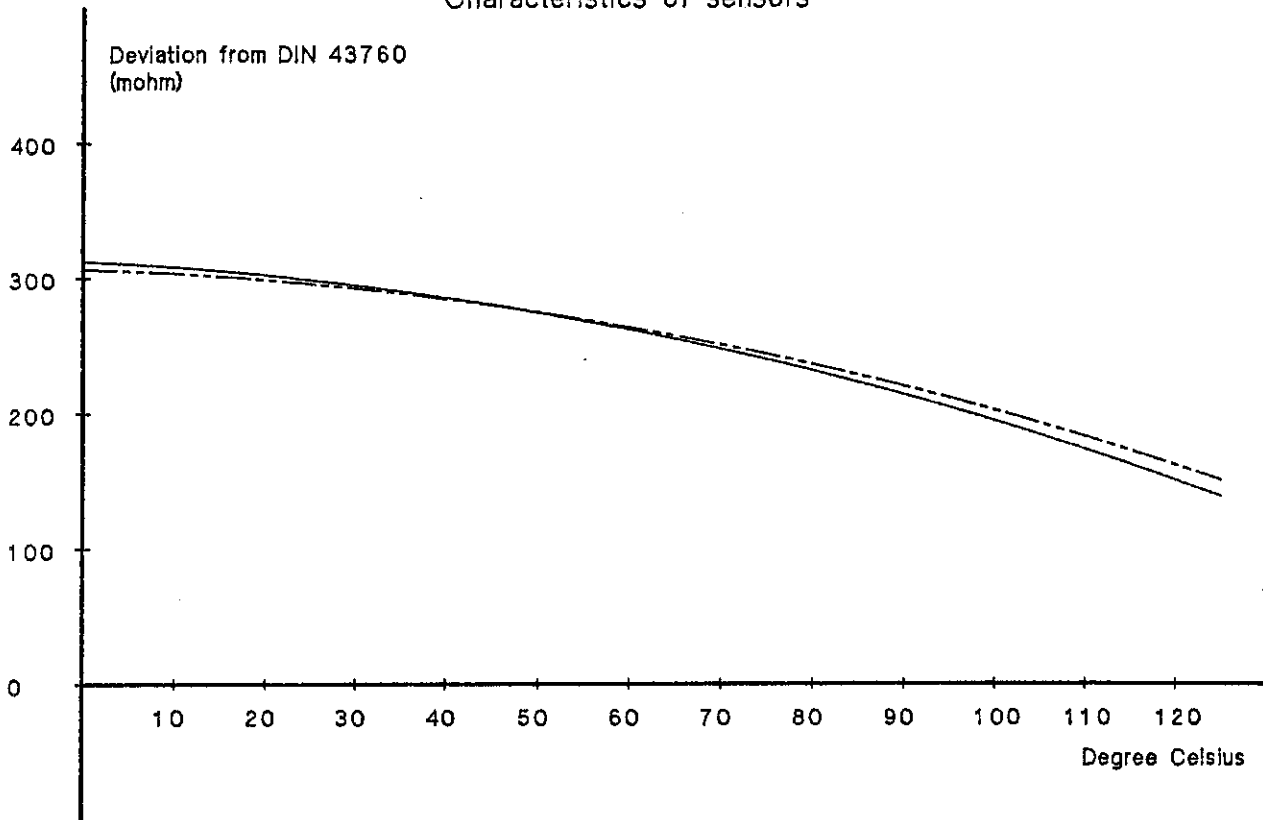
Error in energy due to sensor pair



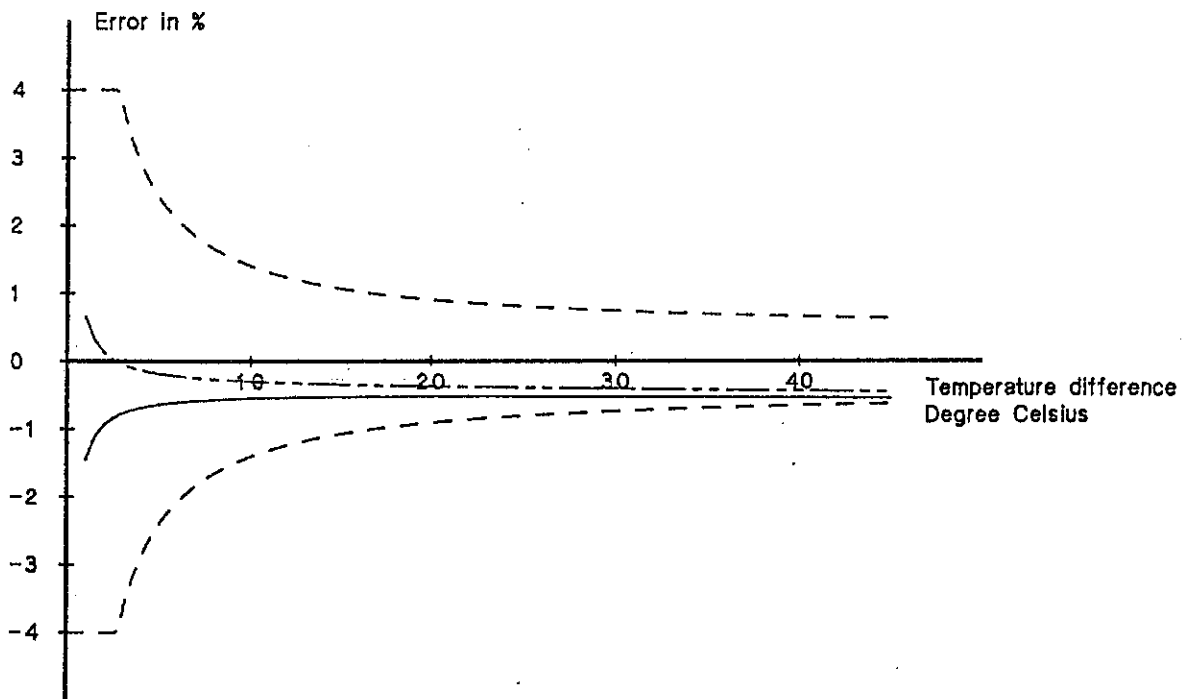
Case No 3

Sensors mounted on copper pipe 28 mm with insulation and with contact paste (ICM)

Characteristics of sensors



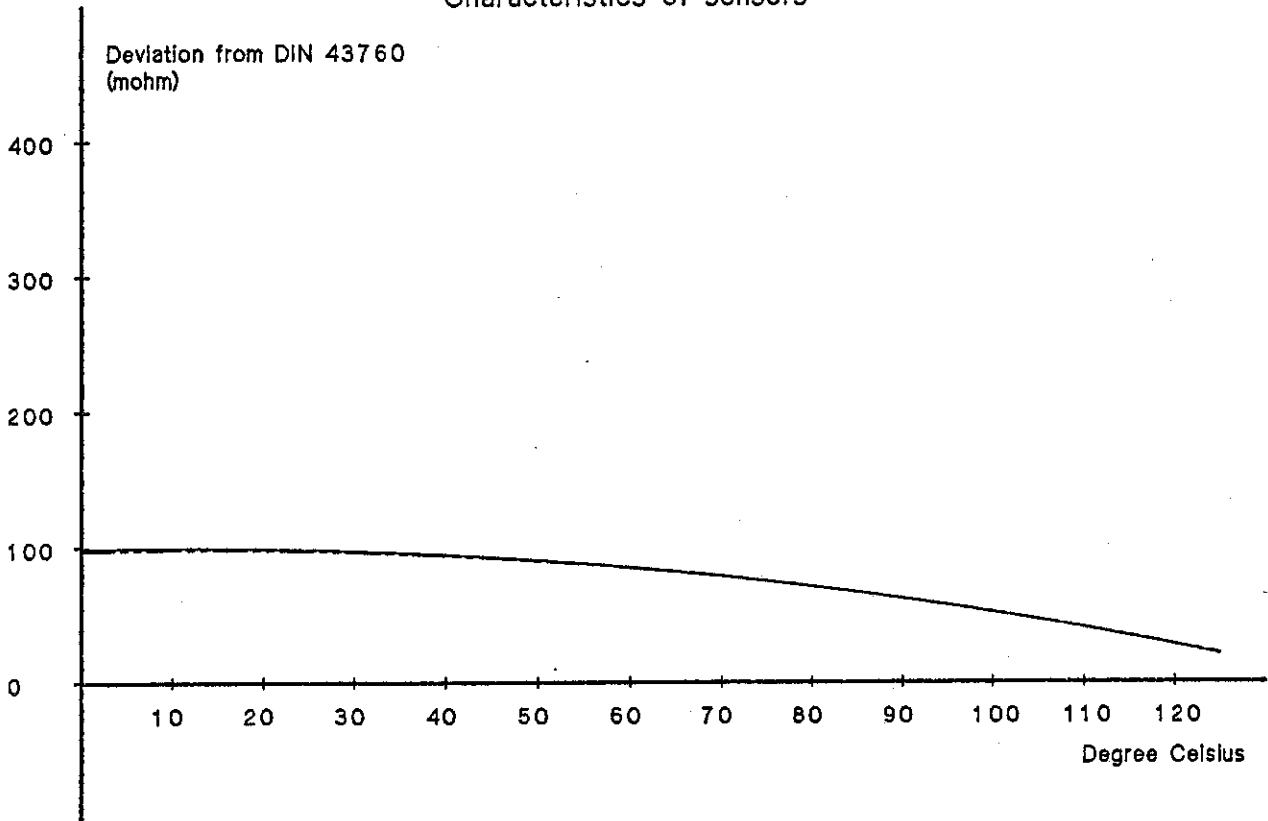
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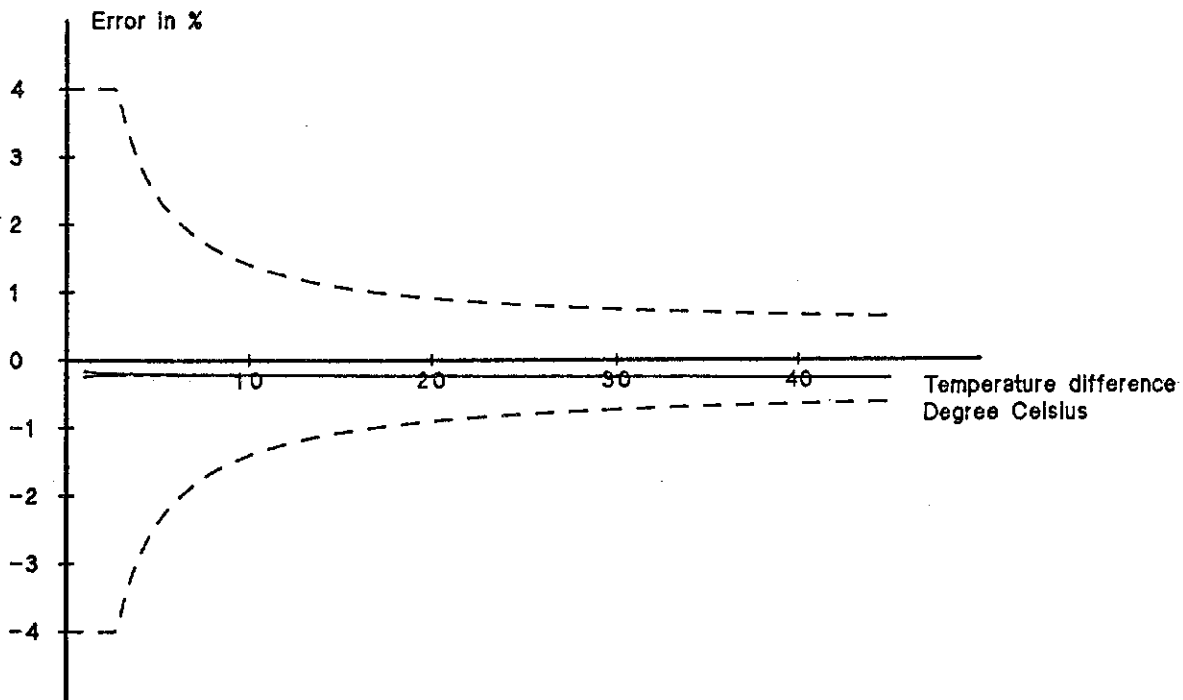
Case No 4

Sensors mounted on steel pipe 15 mm with insulation and with contact paste (Hydrometer)

Characteristics of sensors



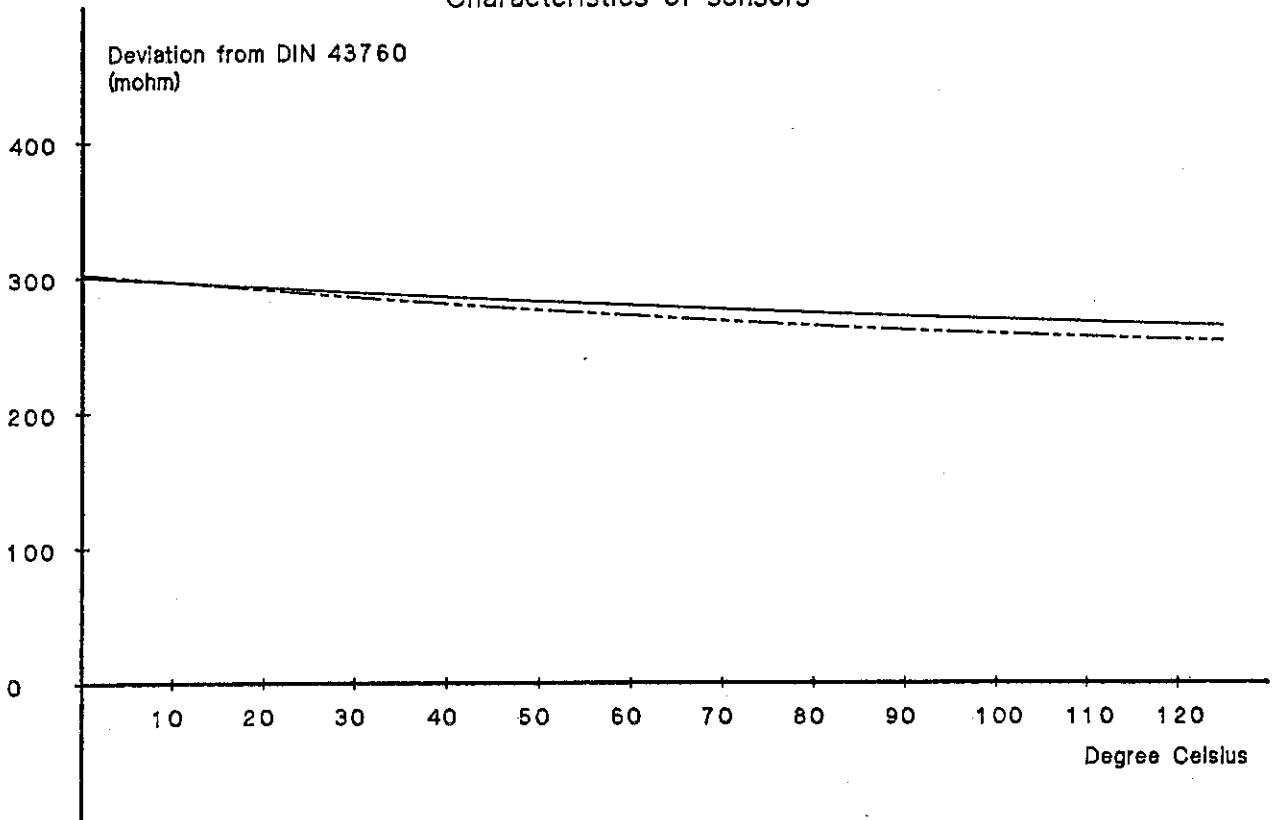
Error in energy due to sensor pair



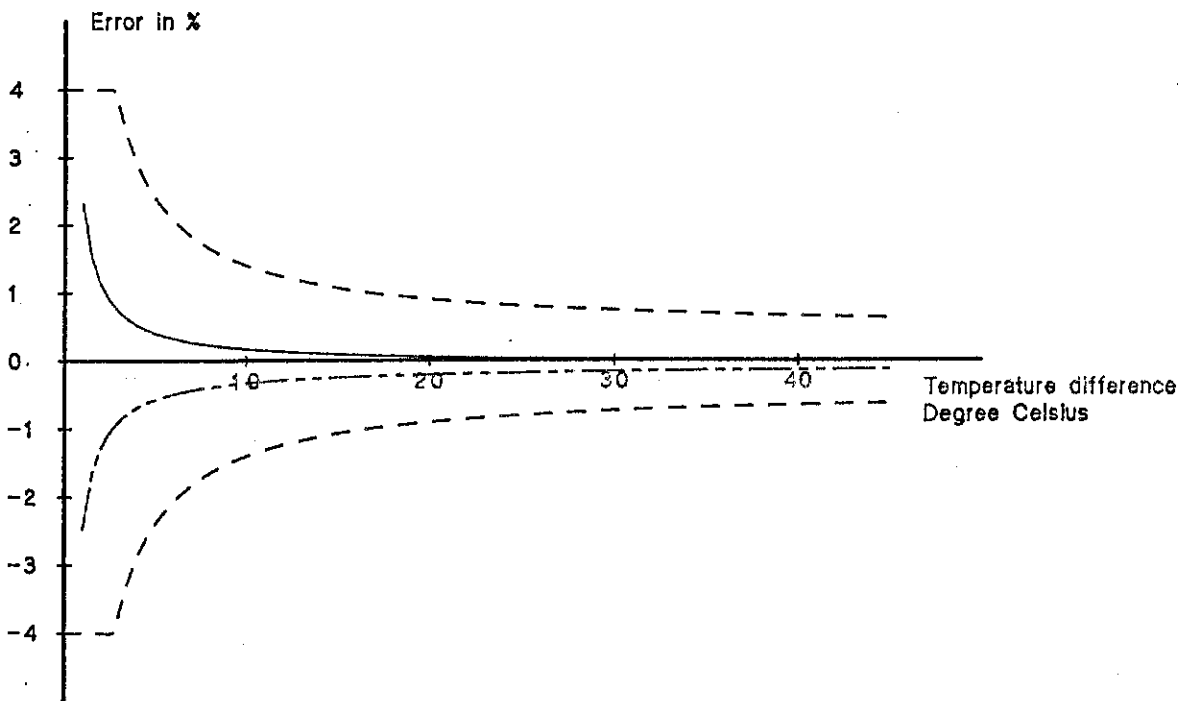
Case No 4

Sensors mounted on steel pipe 15 mm with insulation and with contact paste (ICM)

Characteristics of sensors



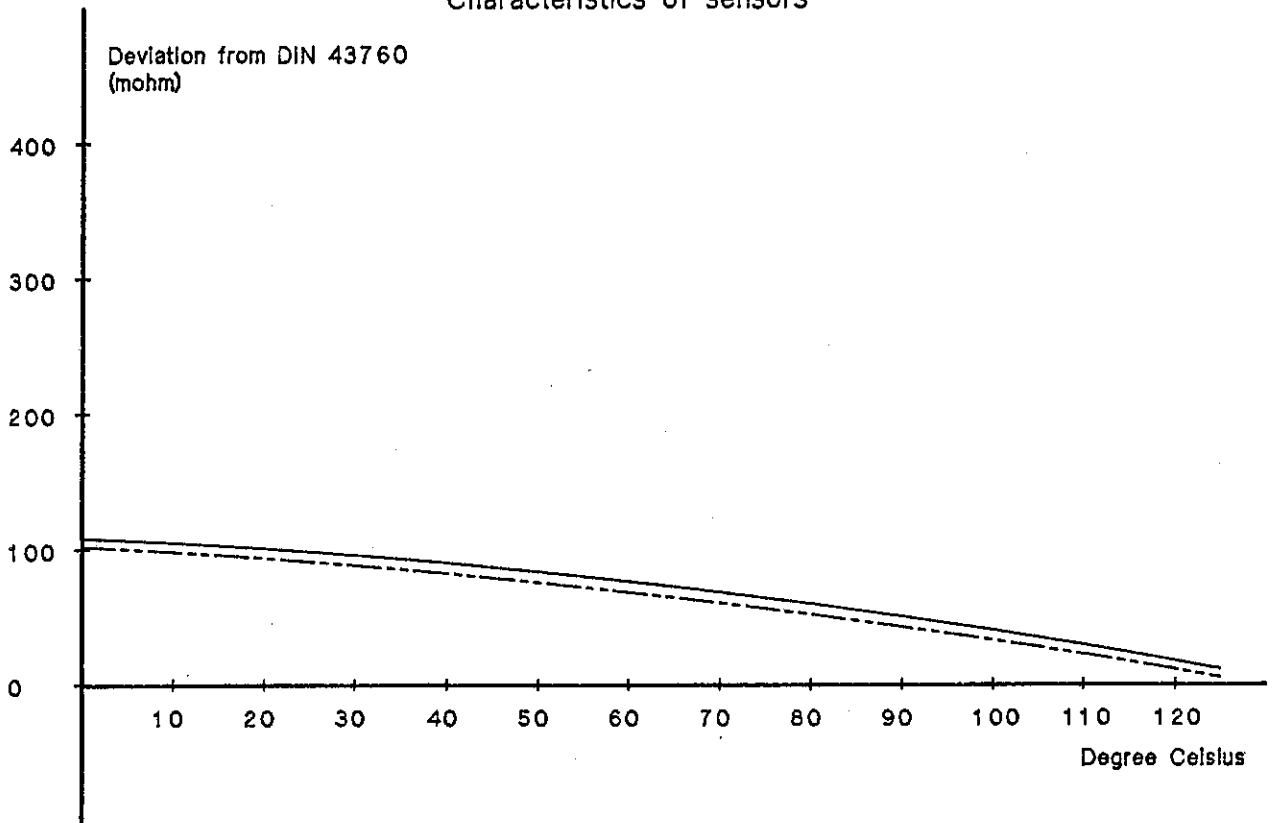
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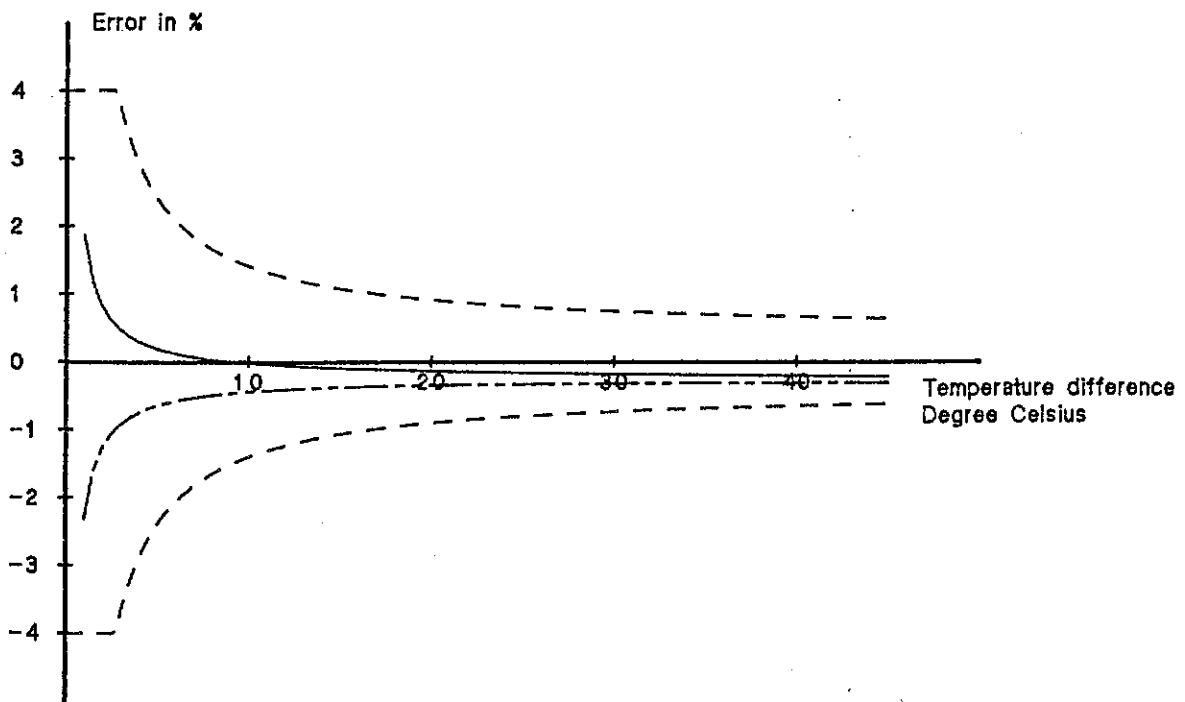
Case No 5

Sensors mounted on steel pipe 32 mm with insulation and with contact paste (Hydrometer)

Characteristics of sensors



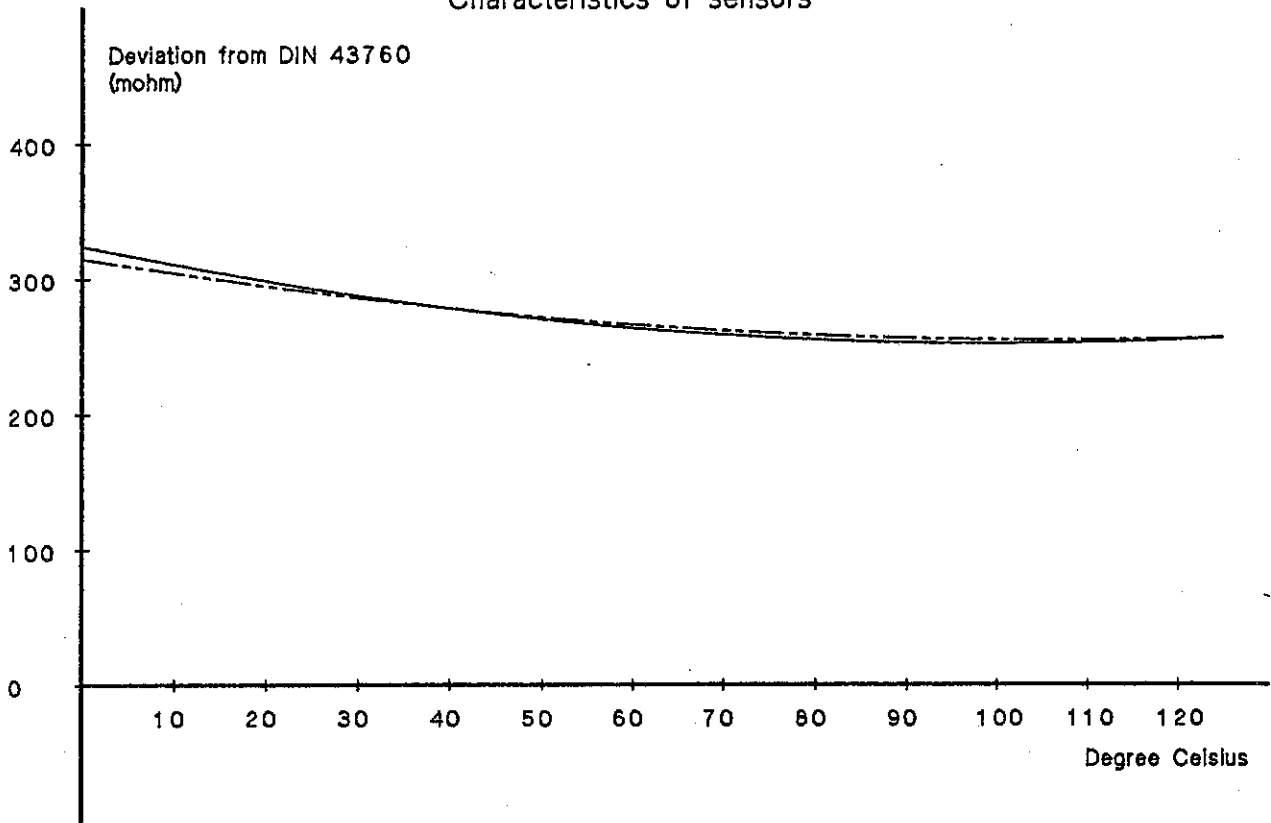
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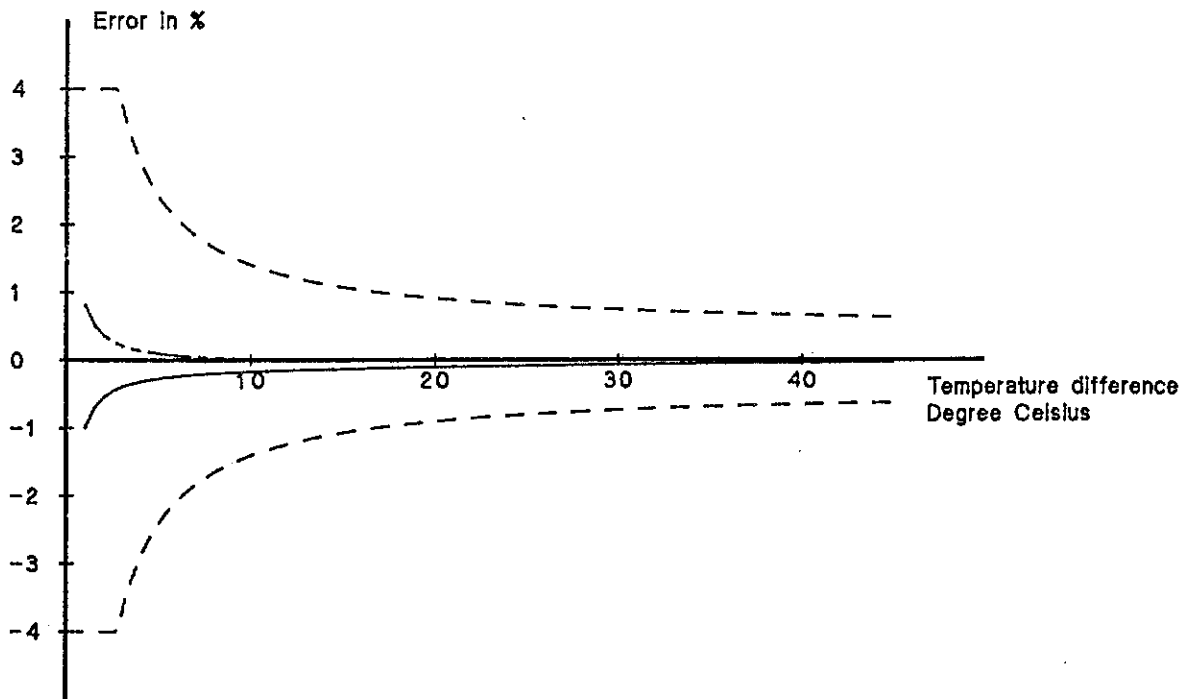
Case No 5

Sensors mounted on steel pipe 32 mm with insulation and with contact paste (ICM)

Characteristics of sensors



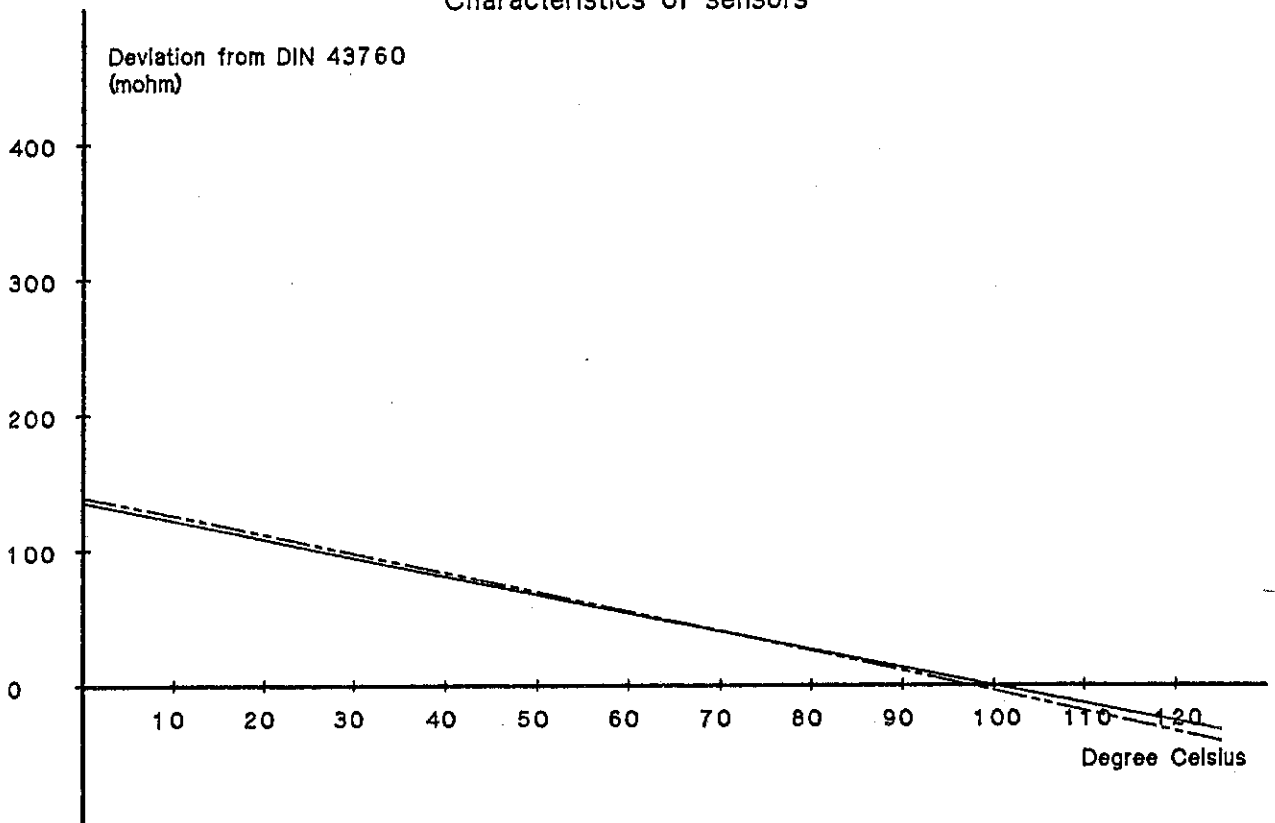
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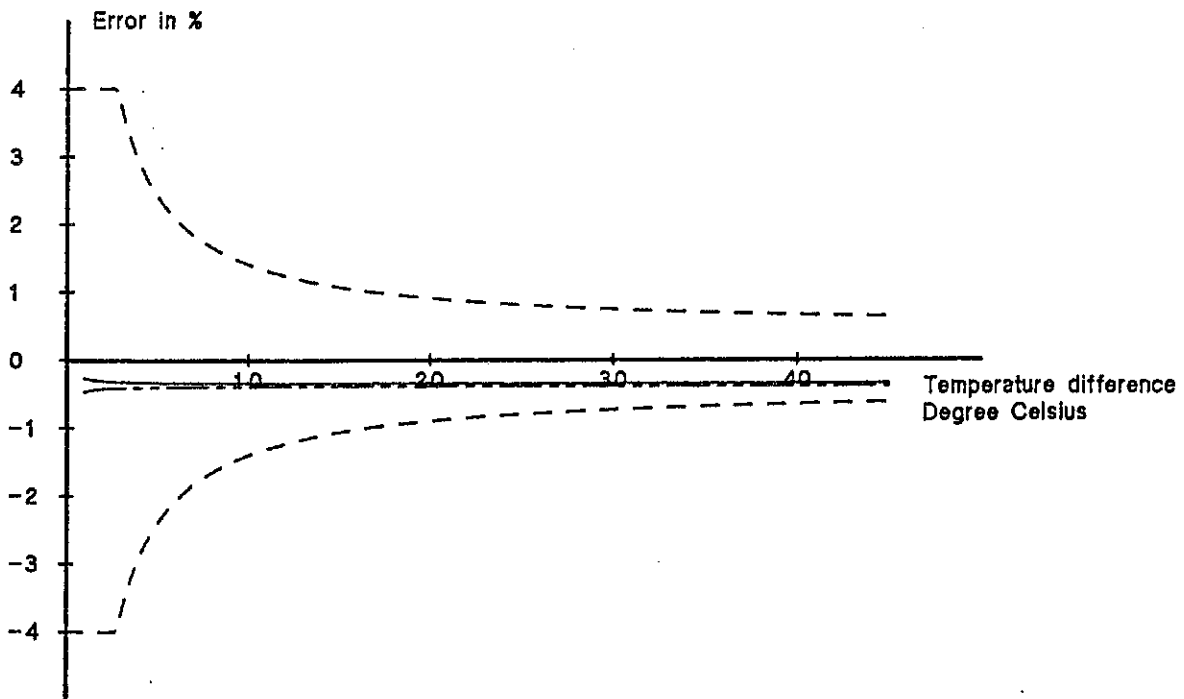
Case No 6

Sensors mounted on copper pipe 15 mm without insulation and with contact paste (Hydrometer)

Characteristics of sensors



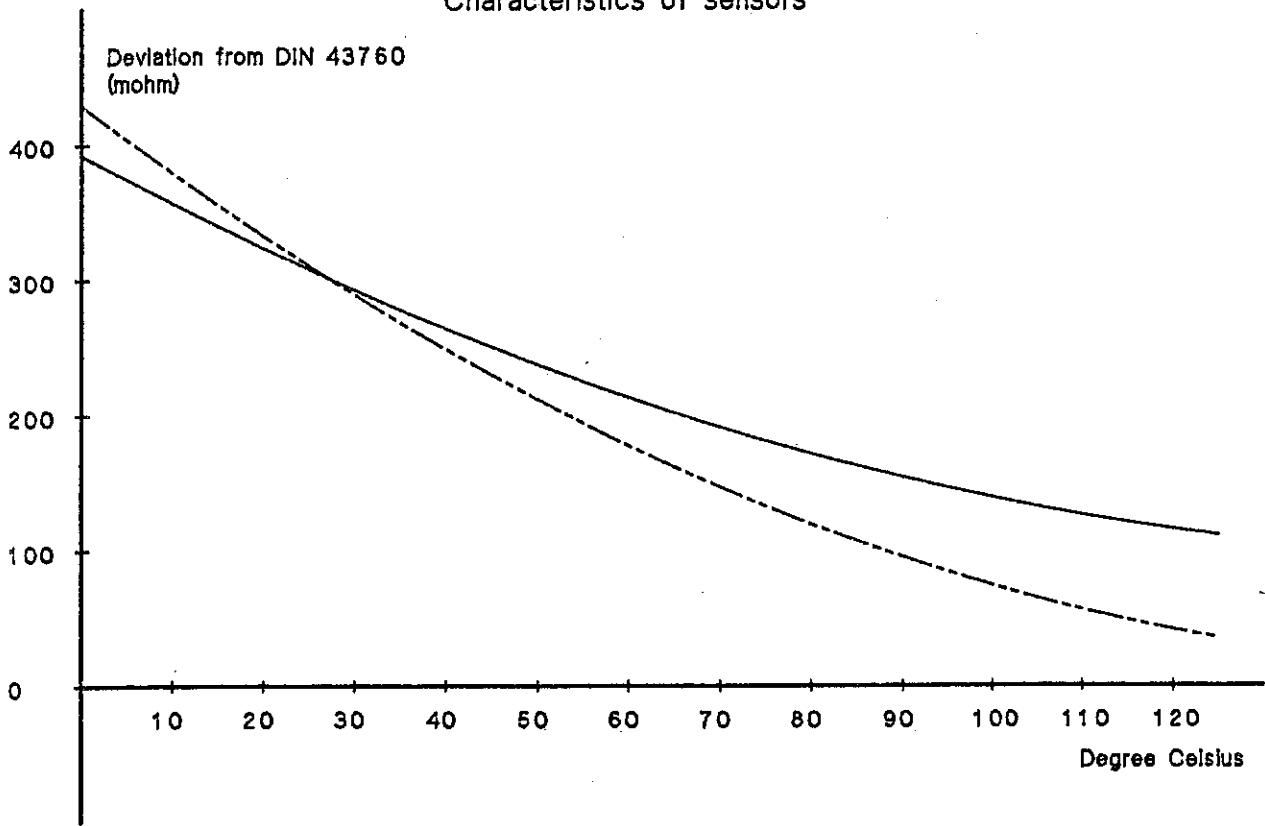
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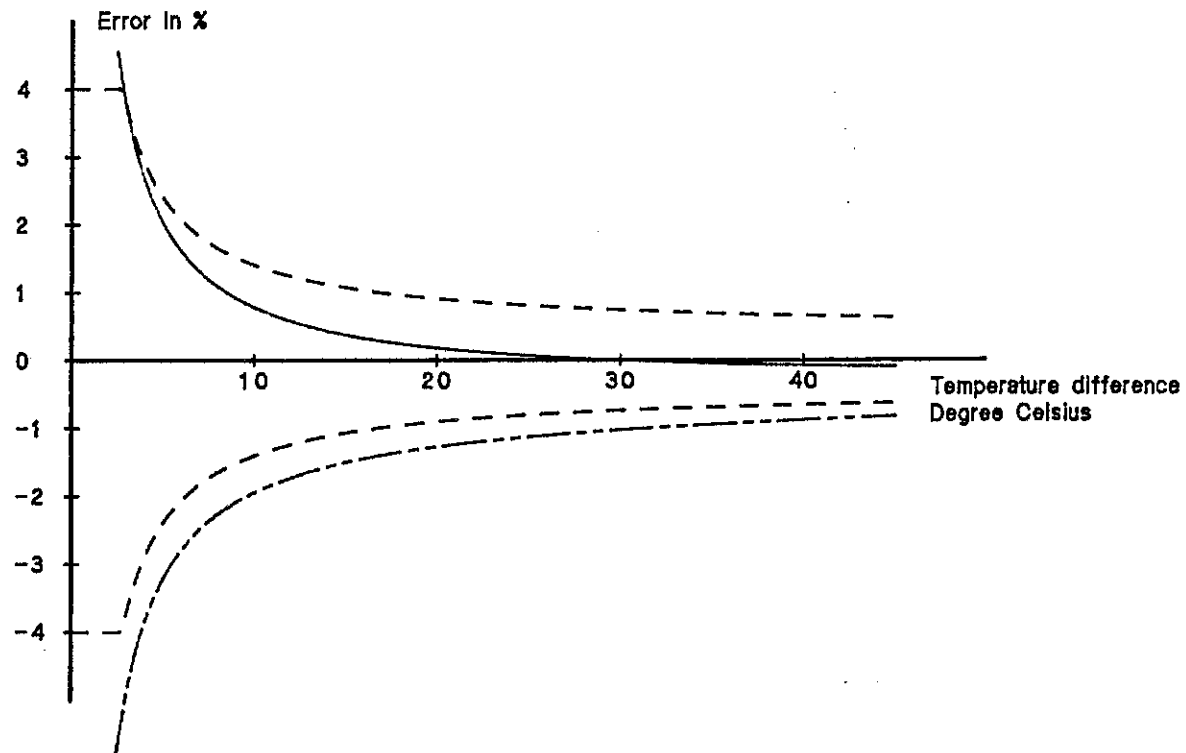
Case No 6

Sensors mounted on copper pipe 15 mm without insulation and with contact paste (CM)

Characteristics of sensors



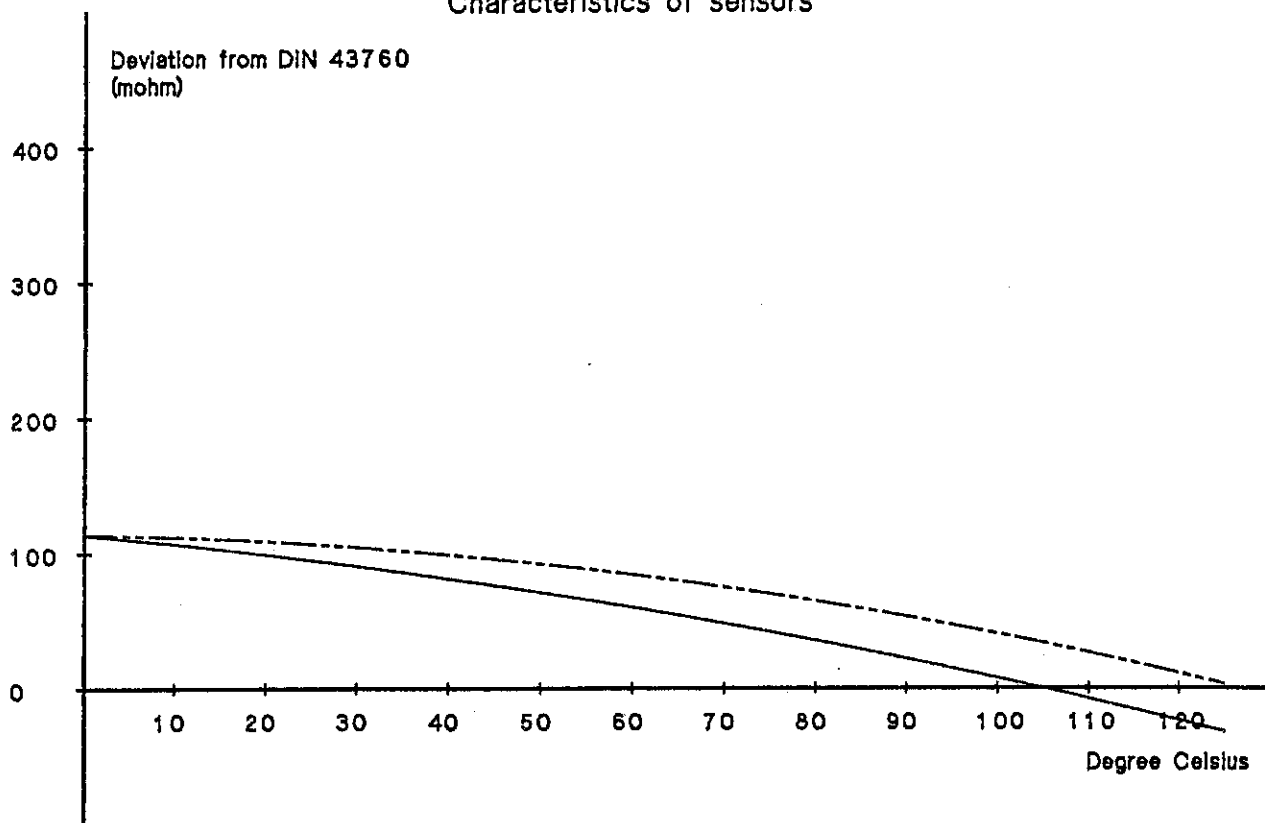
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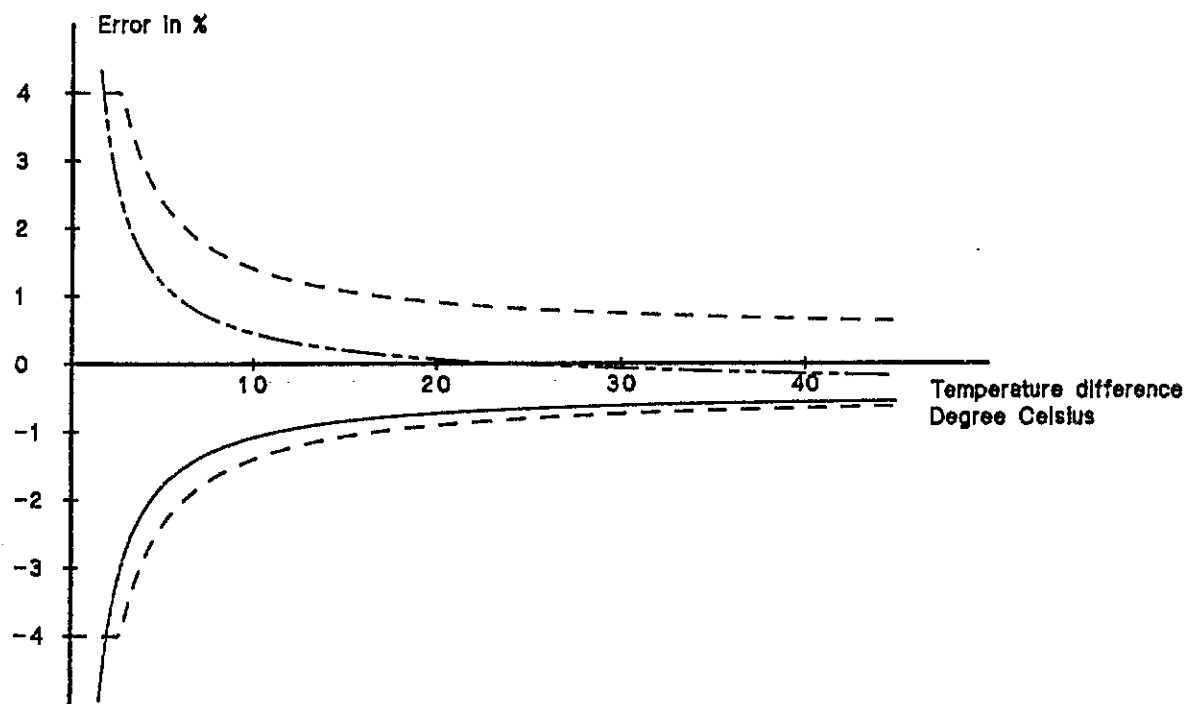
Case No 7

Sensors mounted on copper pipe 15 mm with insulation and without contact paste
(Hydrometer)

Characteristics of sensors



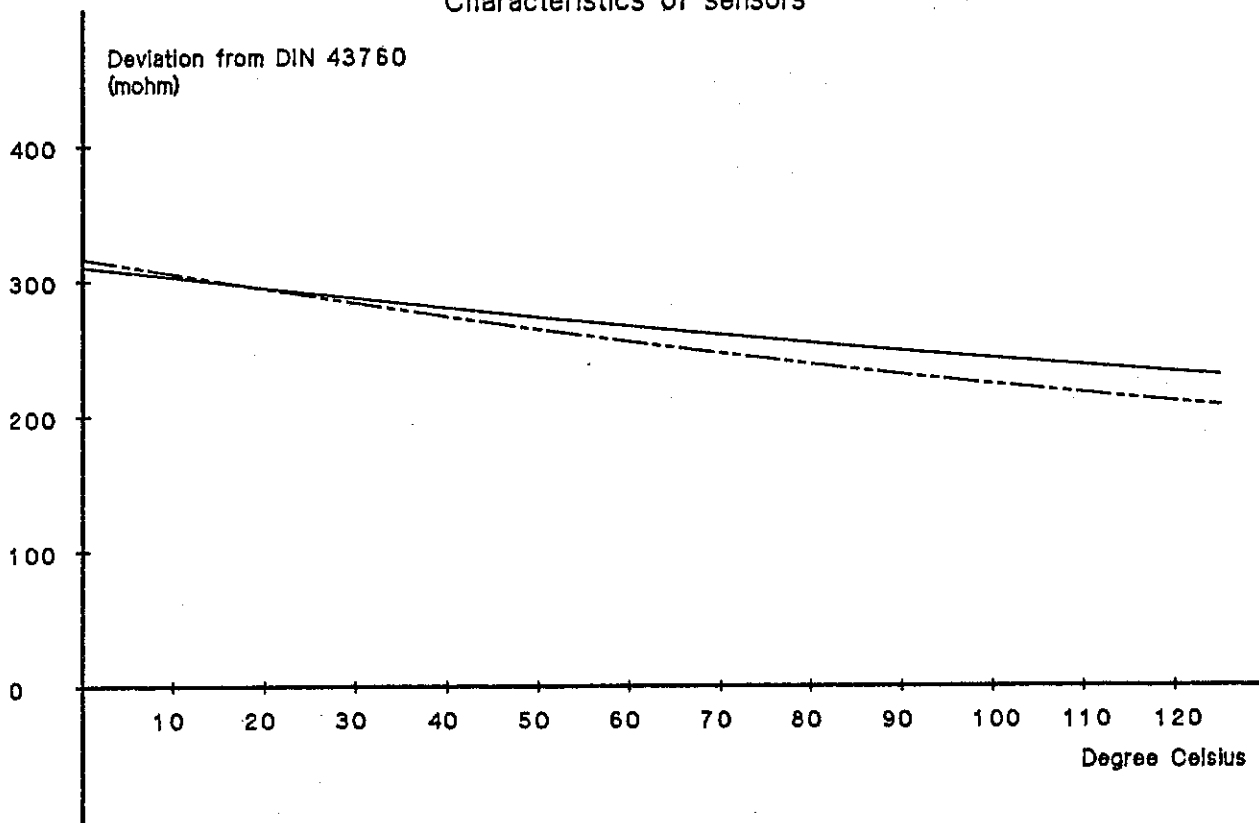
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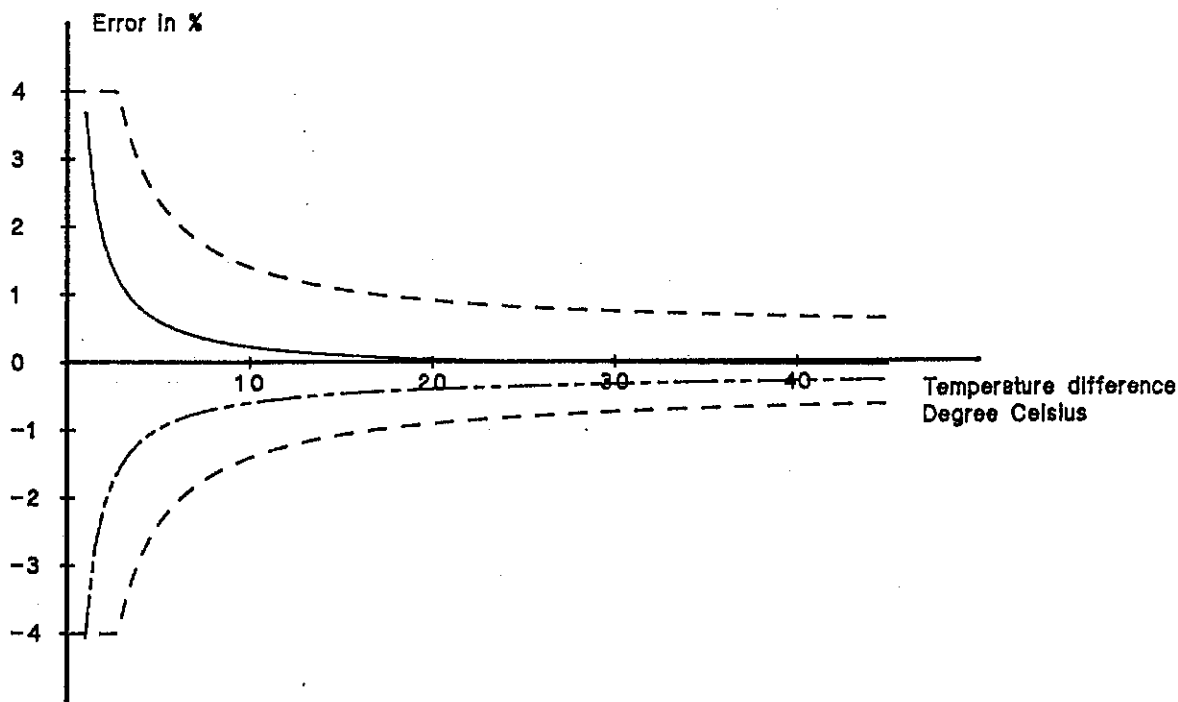
Case No 7

Sensors mounted on copper pipe 15 mm with insulation and without contact paste (ICM)

Characteristics of sensors



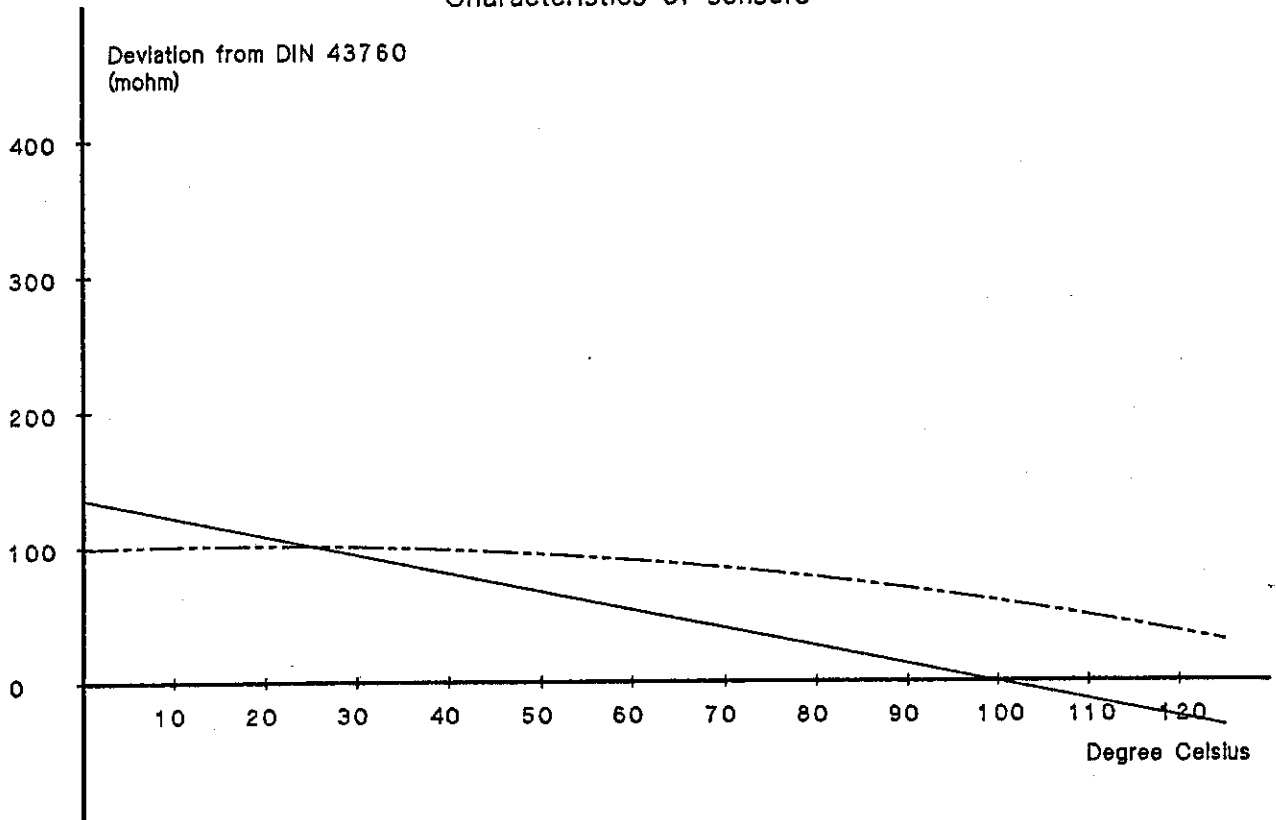
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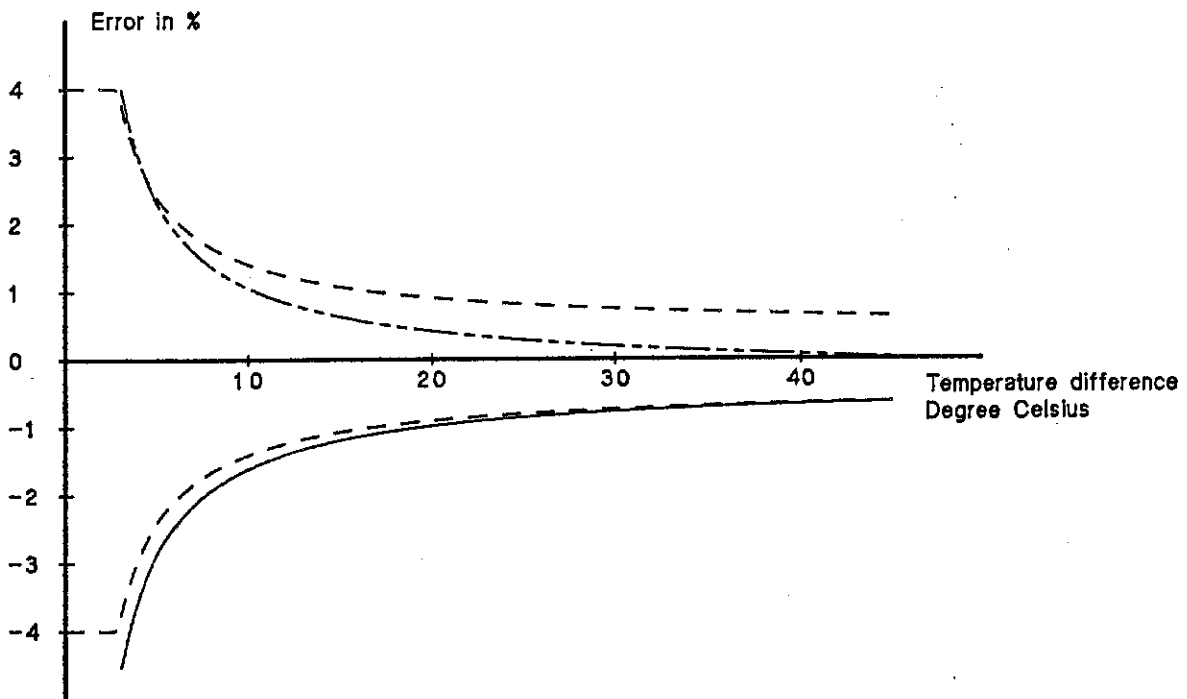
Case No 8

Sensors mounted on copper pipe 15 mm with and without insulation
(Hydrometer)

Characteristics of sensors



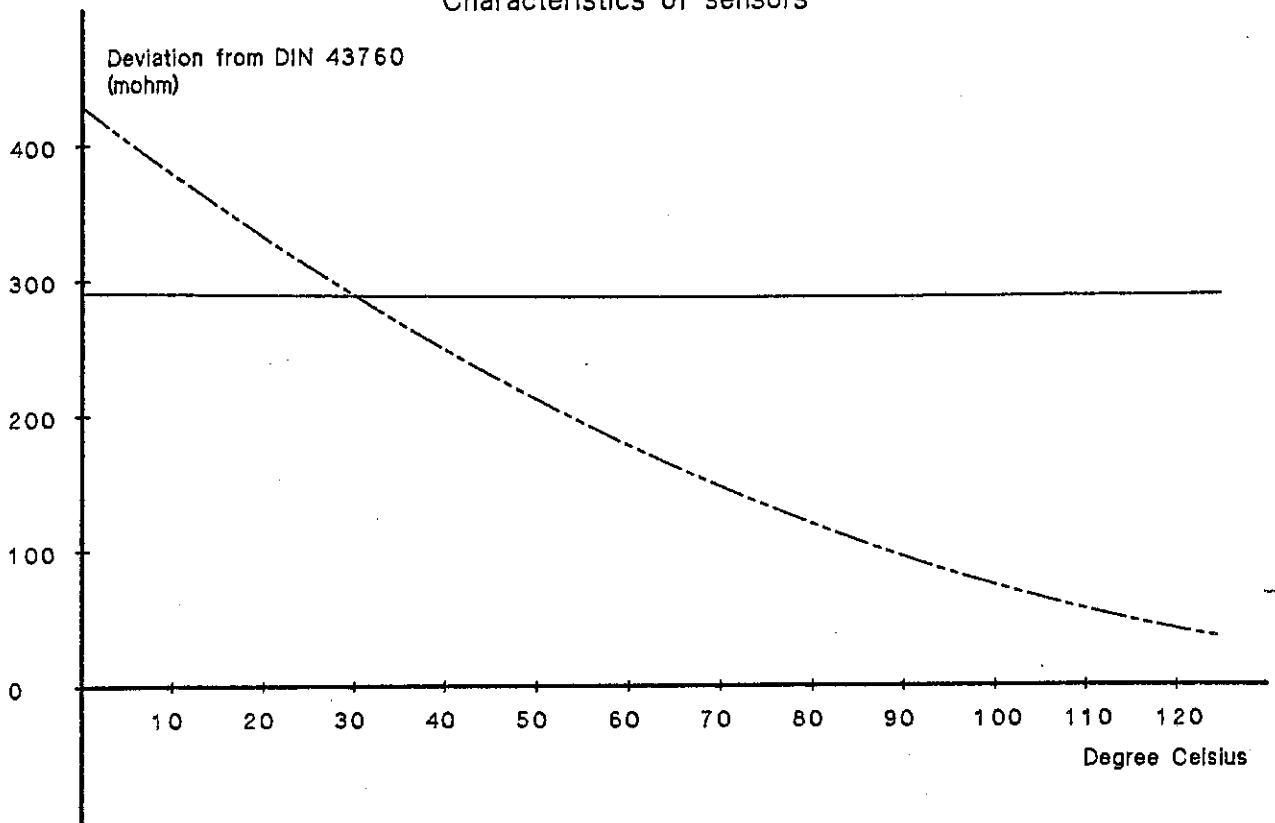
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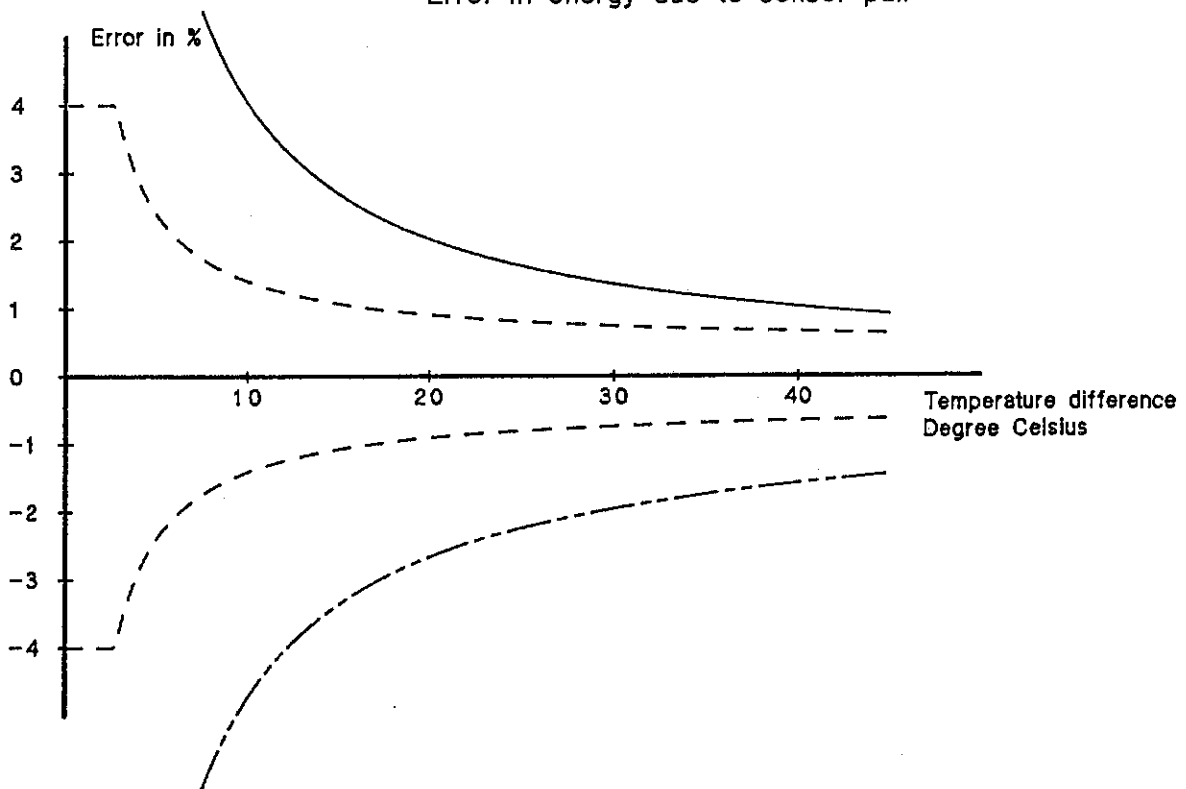
Case No 8

Sensors mounted on copper pipe 15 mm with and without insulation (ICM)

Characteristics of sensors



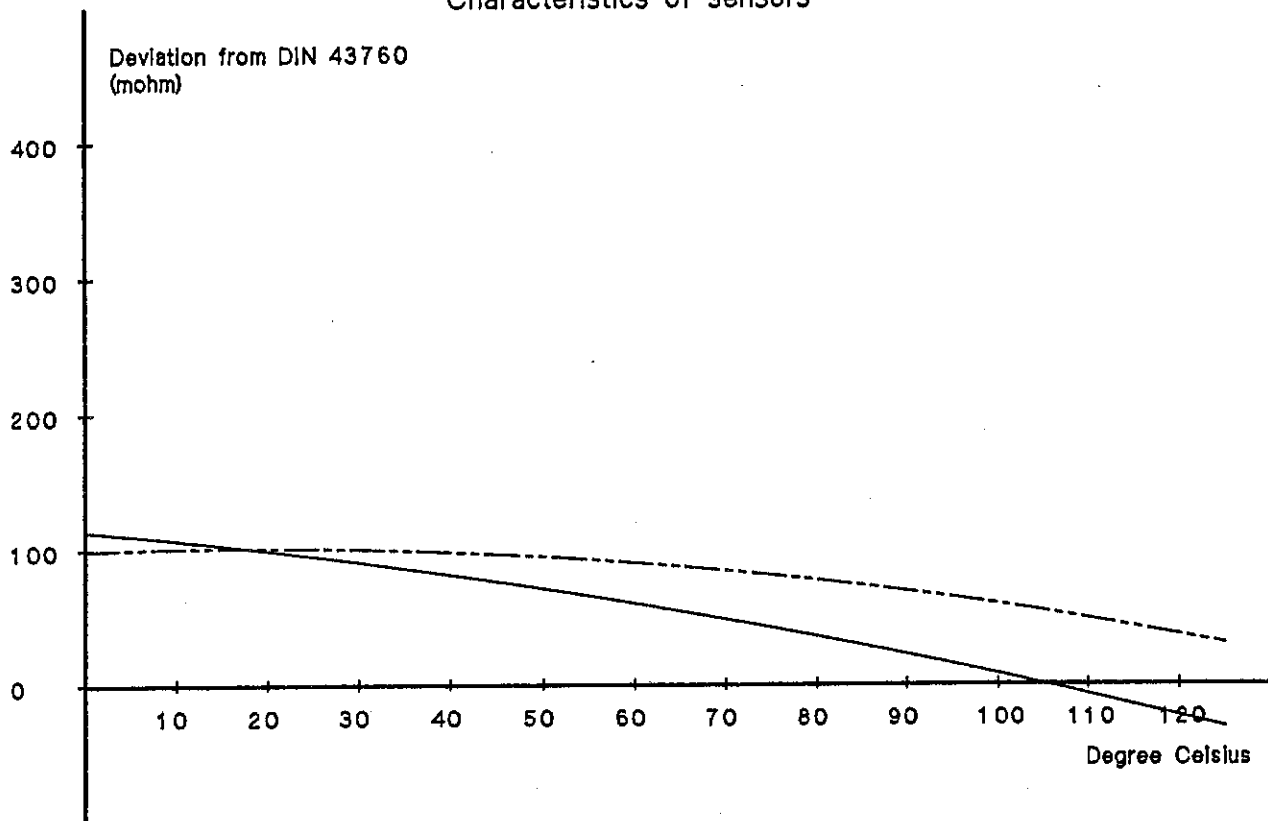
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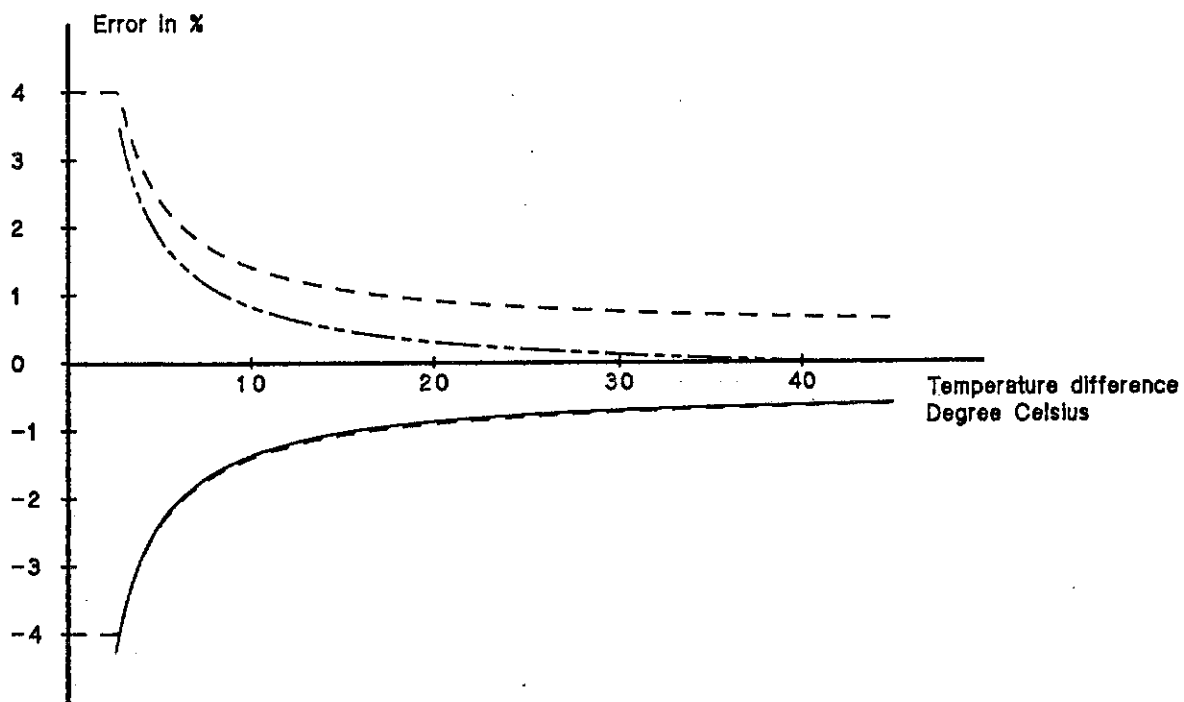
Case No 9

Sensors mounted on copper pipe 15 mm with and without contact paste
(Hydrometer)

Characteristics of sensors



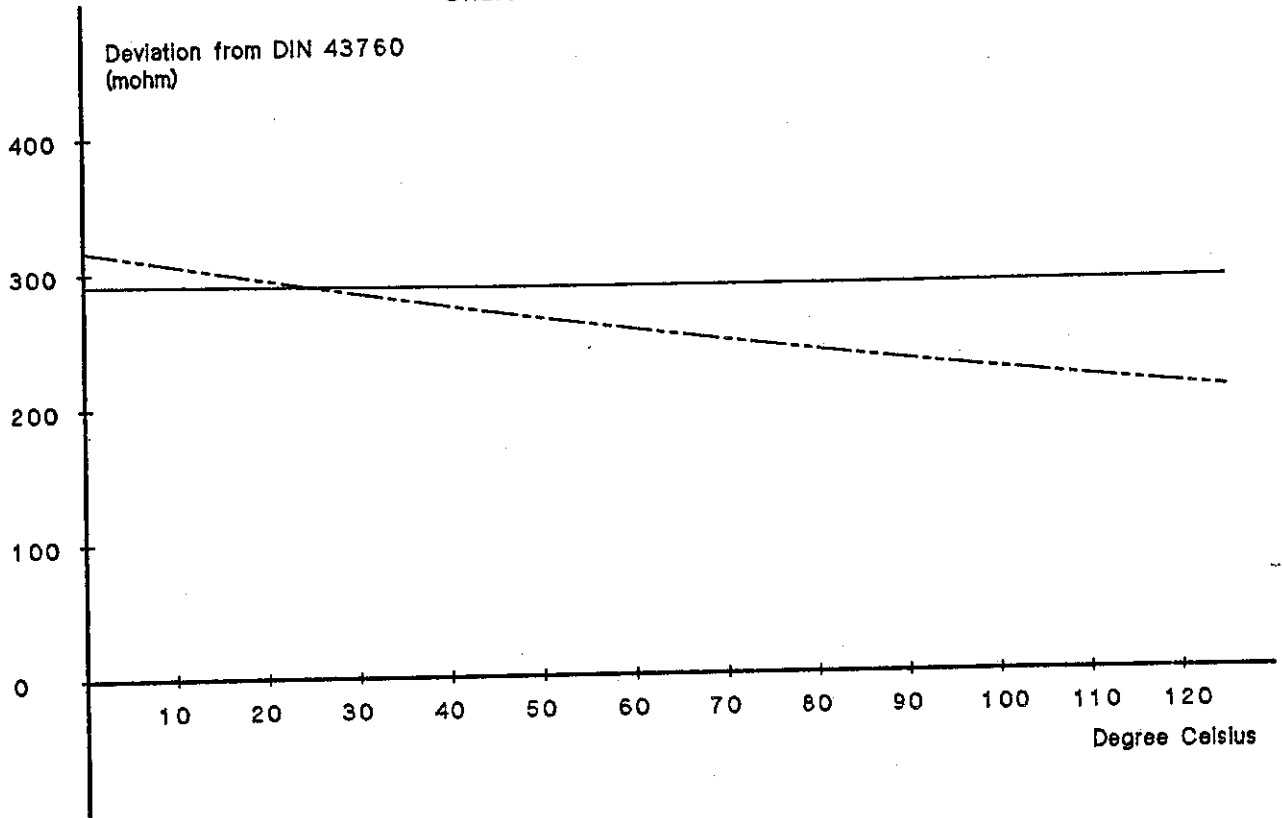
Error in energy due to sensor pair



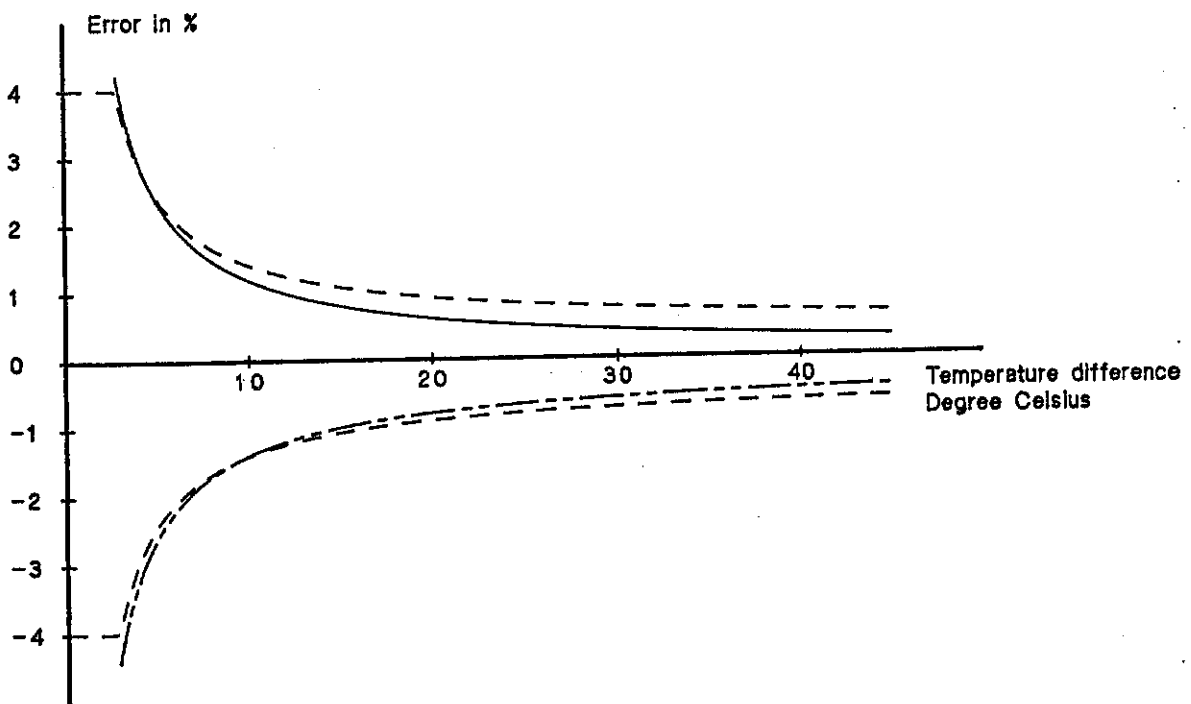
Case No 9

Sensors mounted on copper pipe 15 mm with and without contact paste (ICM)

Characteristics of sensors



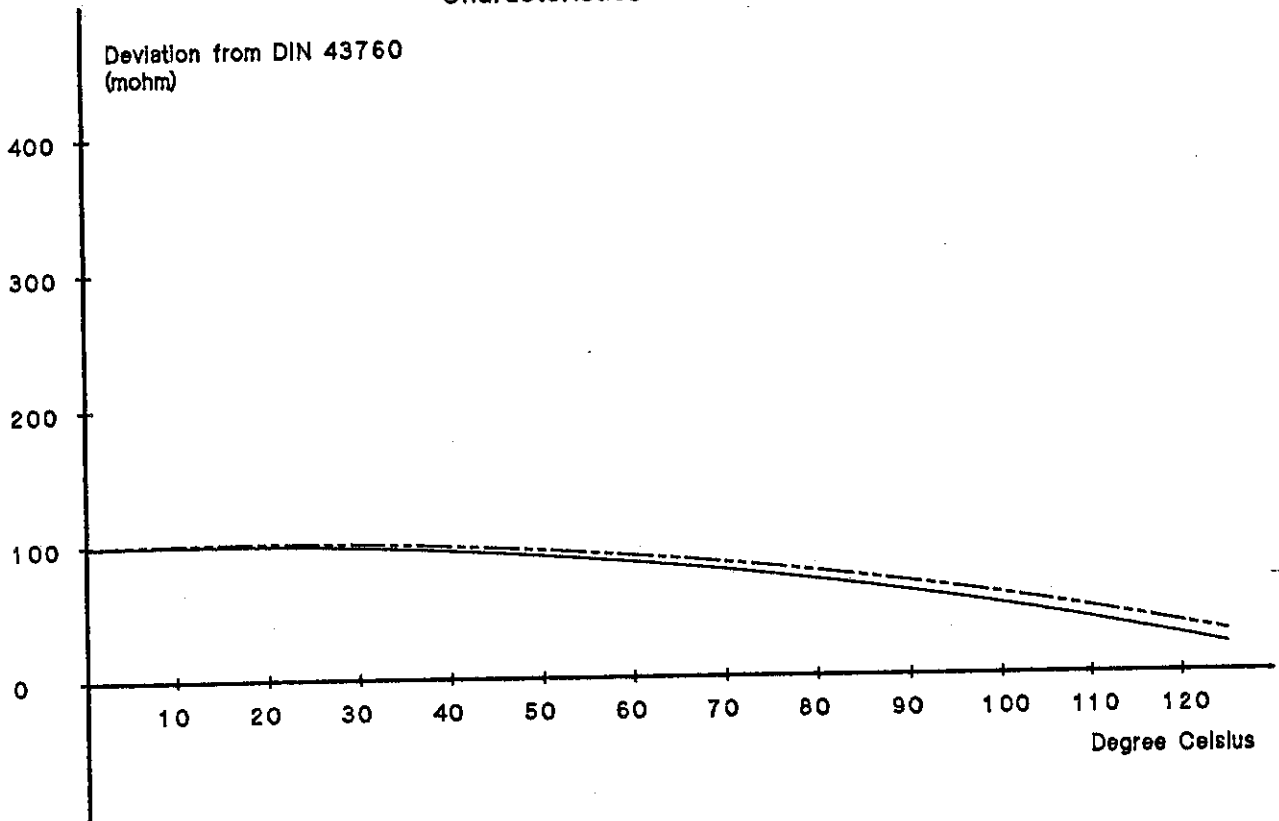
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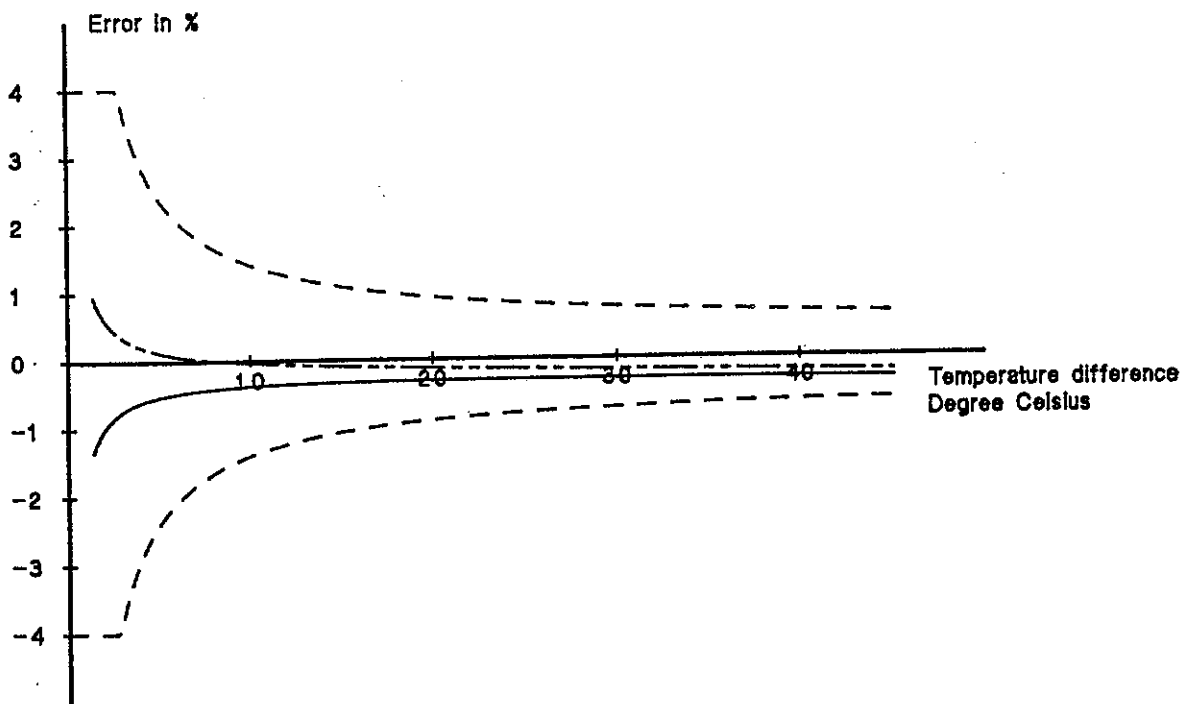
Case No 10

Sensors mounted on copper pipe 15 mm and on steel pipe 15 mm
(Hydrometer)

Characteristics of sensors



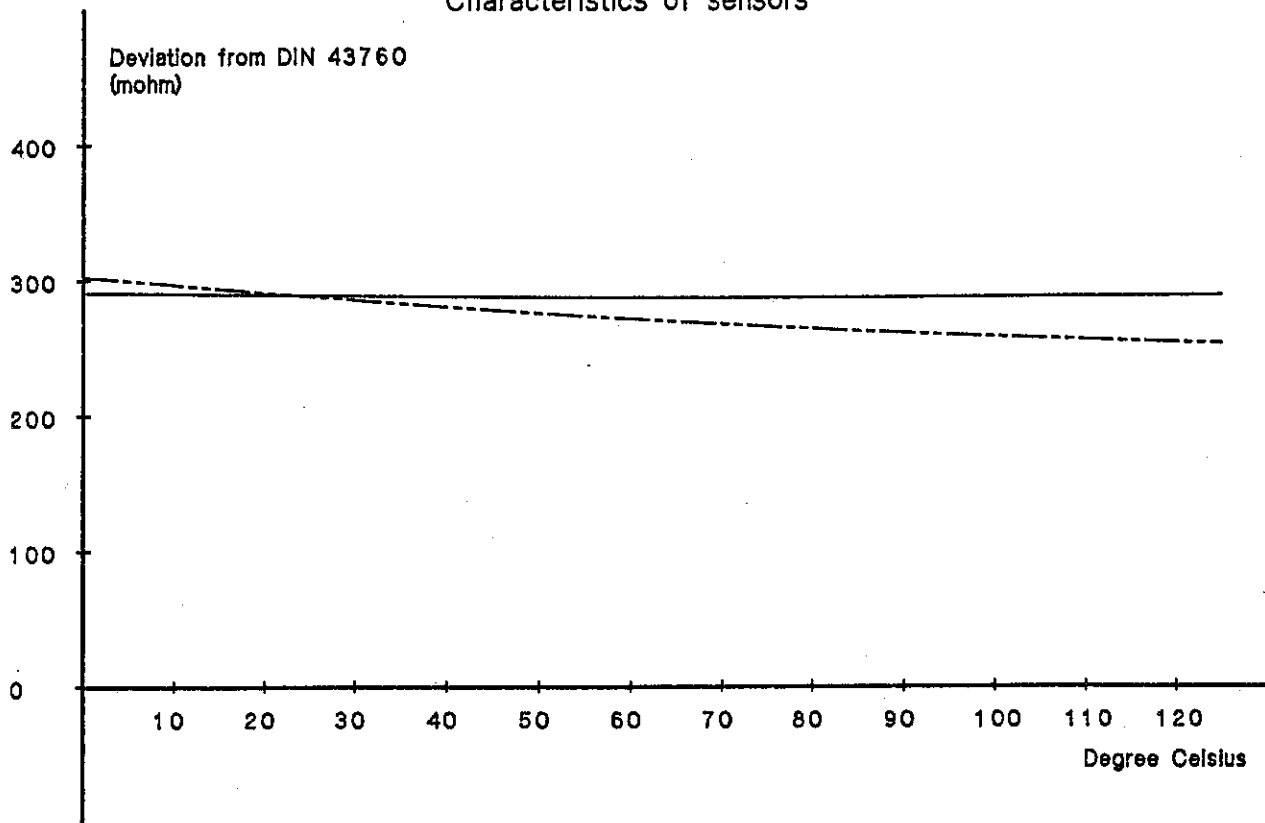
Error in energy due to sensor pair



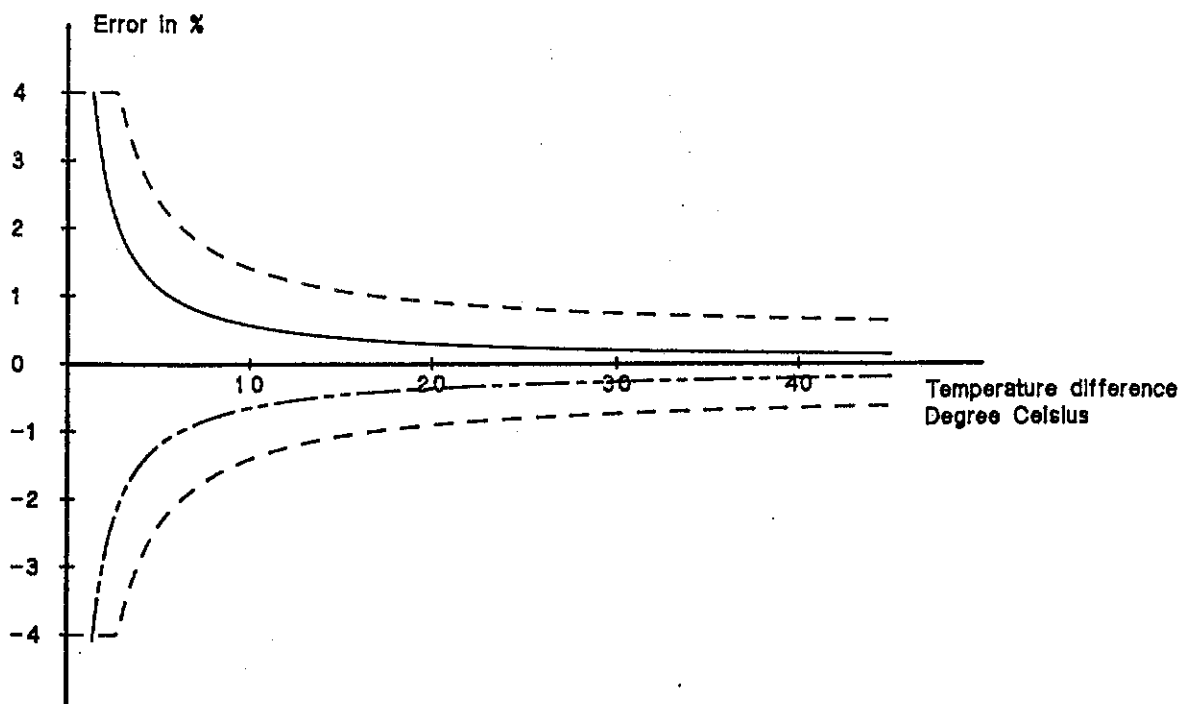
Case No 10

Sensors mounted on copper pipe 15 mm and on steel pipe 15 mm
(ICM)

Characteristics of sensors



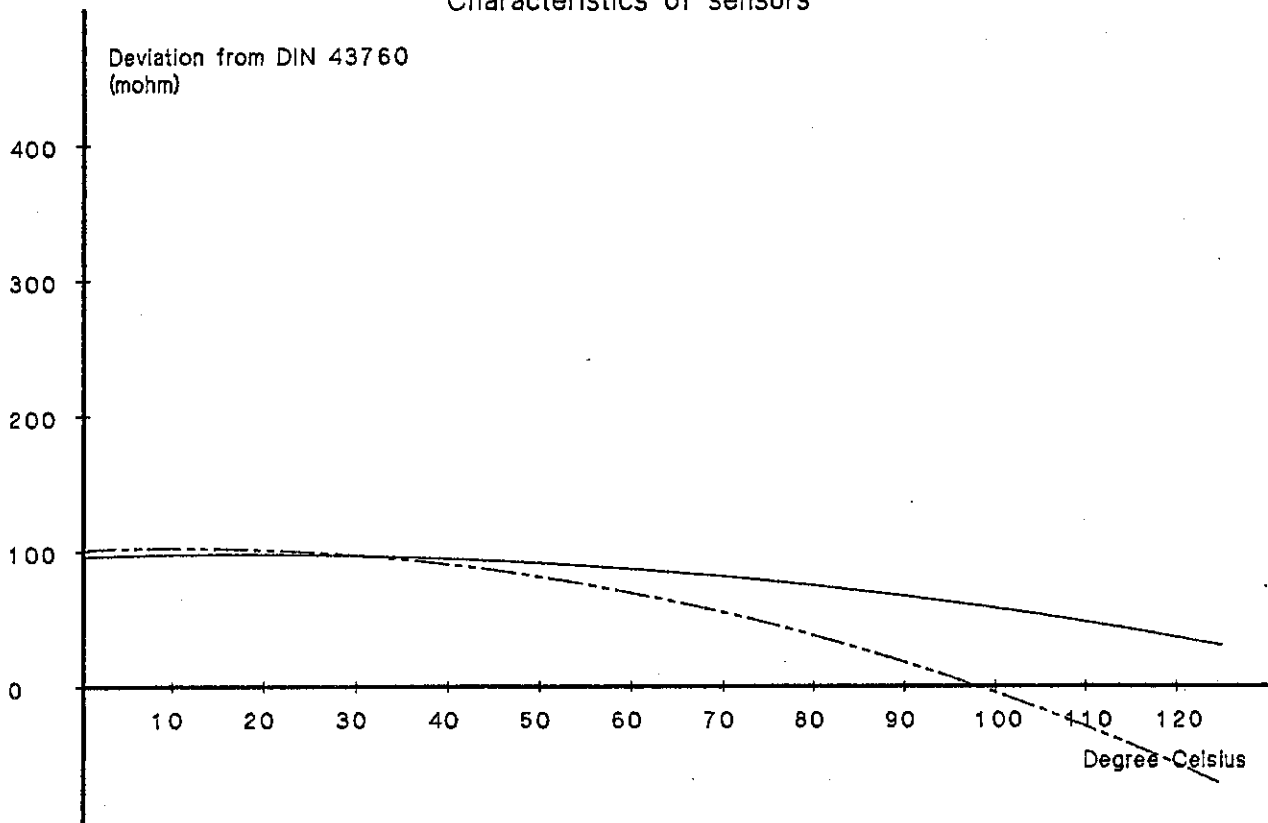
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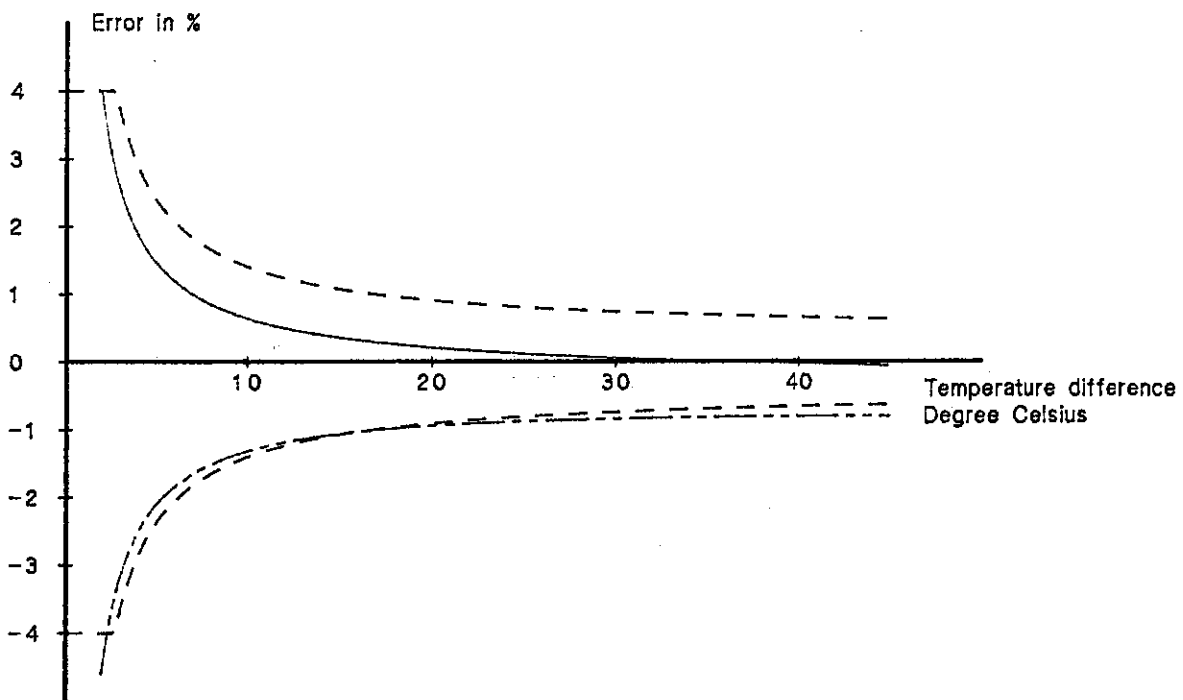
Case No 11

Sensors mounted on copper pipe 15 mm and on copper pipe 28 mm
(Hydrometer)

Characteristics of sensors



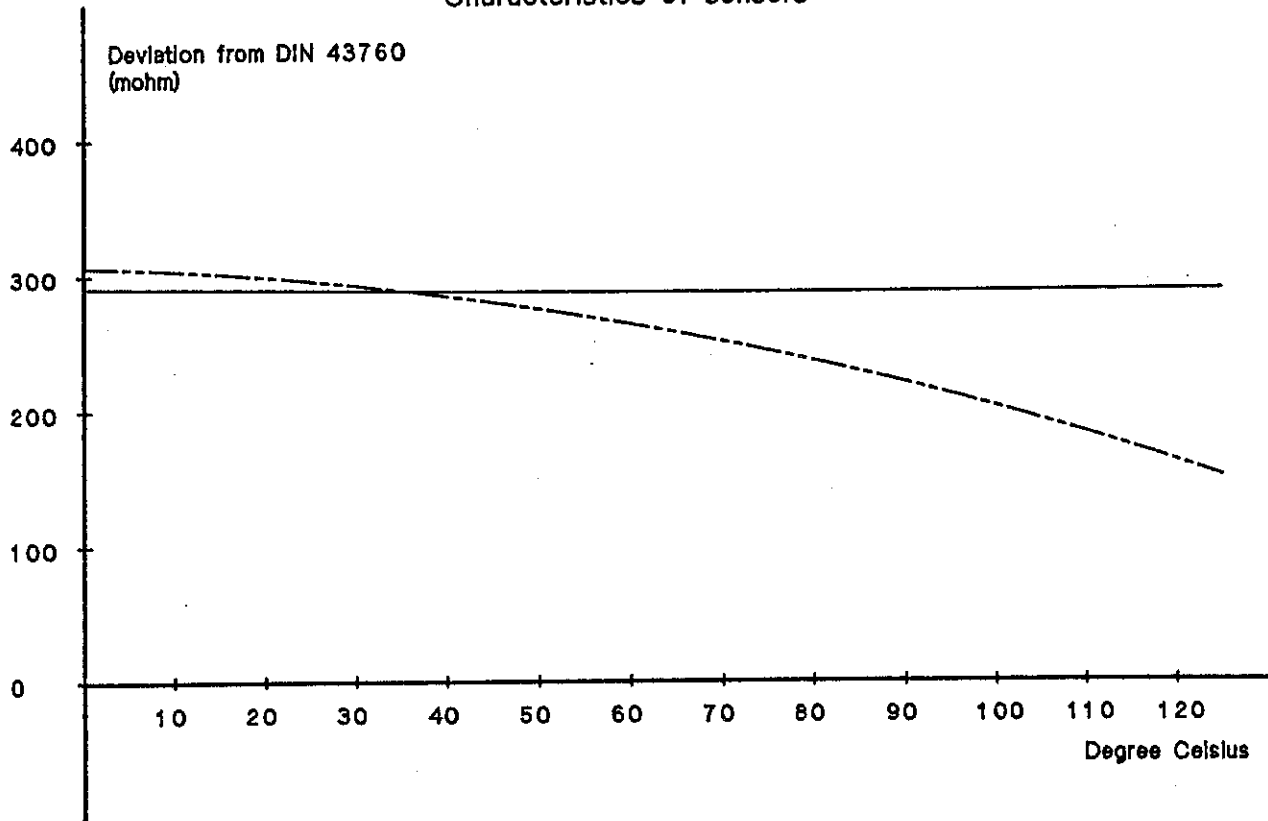
Error in energy due to sensor pair



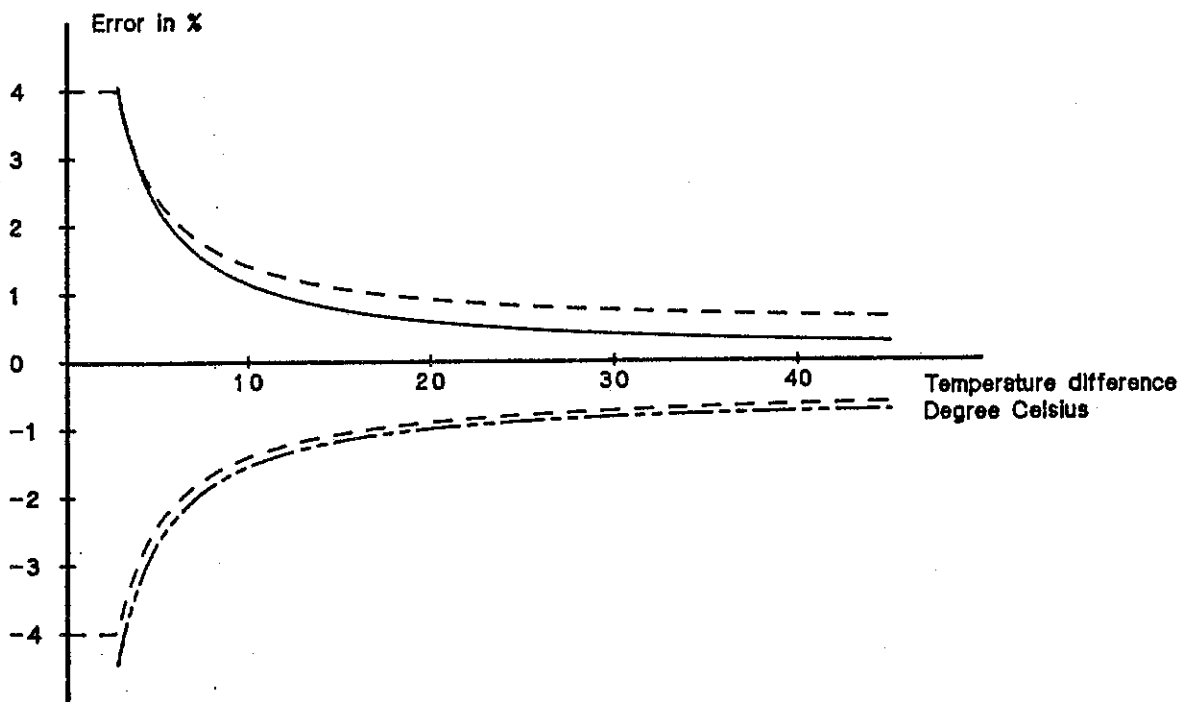
Case No 11

Sensors mounted on copper pipe 15 mm and on copper pipe 28 mm
(ICM)

Characteristics of sensors



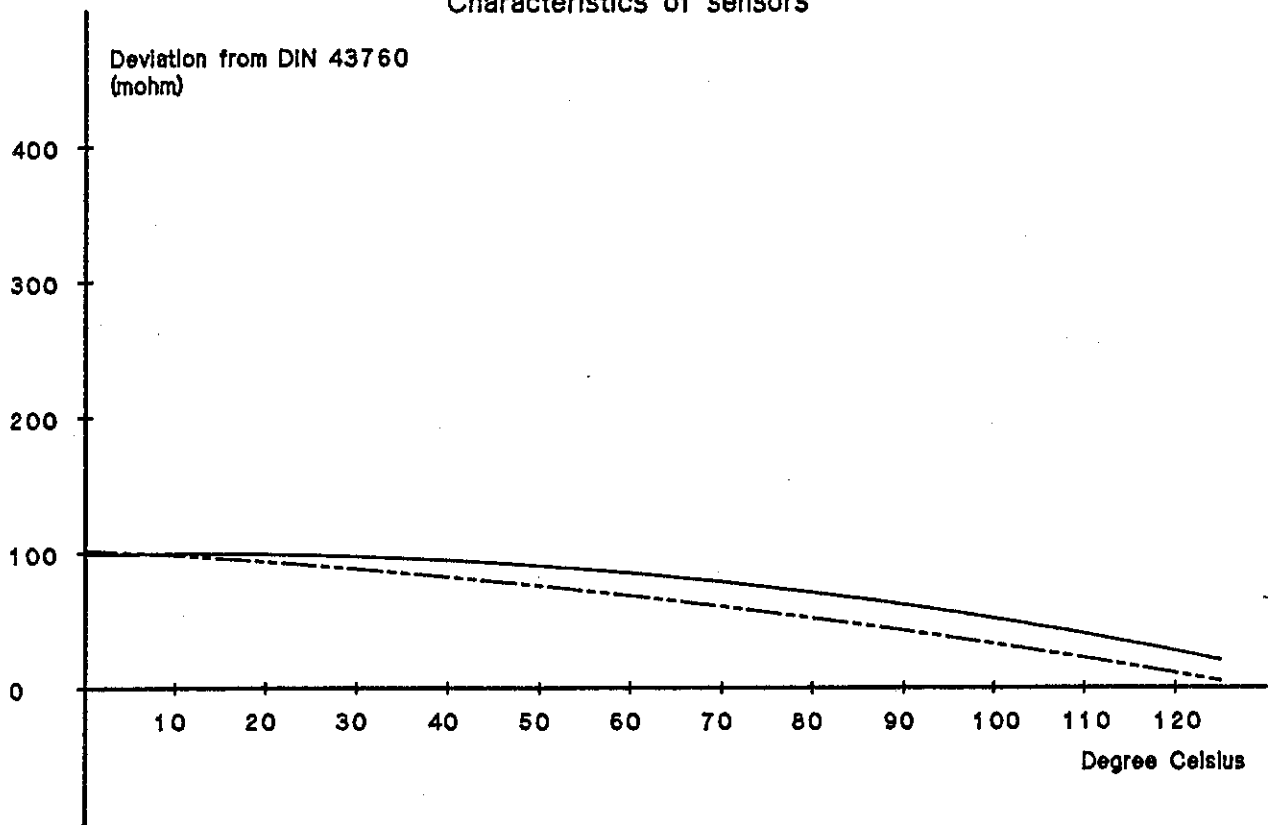
Error in energy due to sensor pair



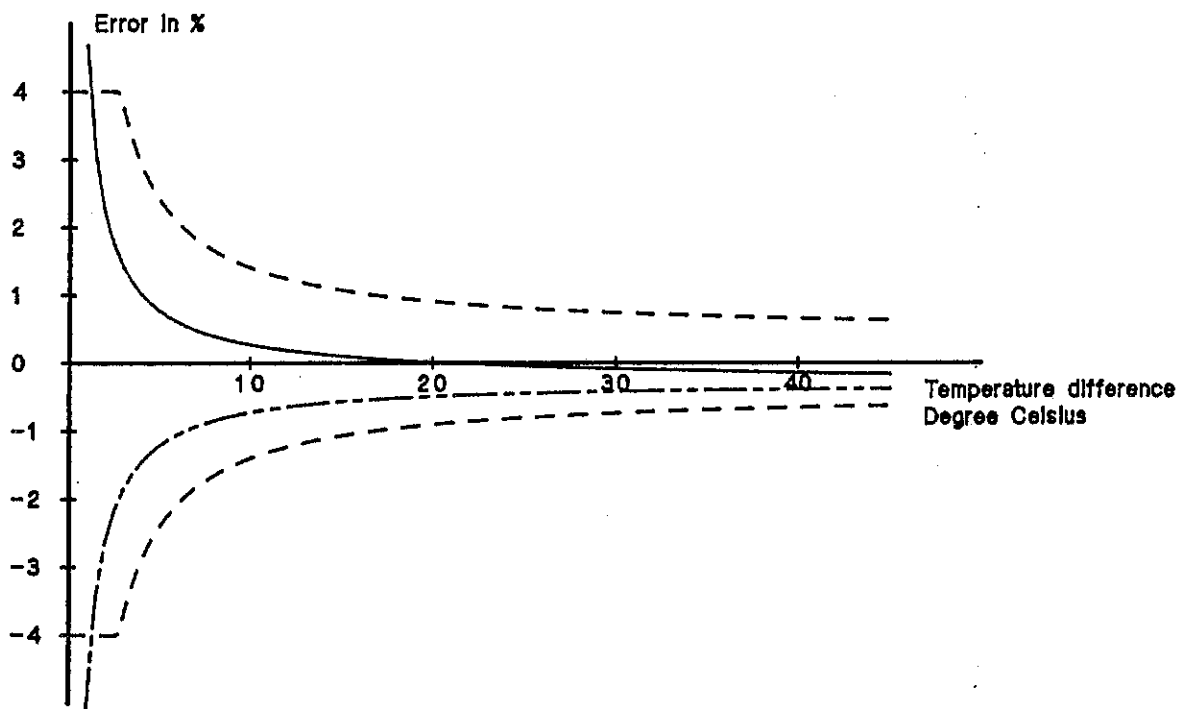
Case No 12

Sensors mounted on steel pipe 15 mm and on steel pipe 32 mm
(Hydrometer)

Characteristics of sensors



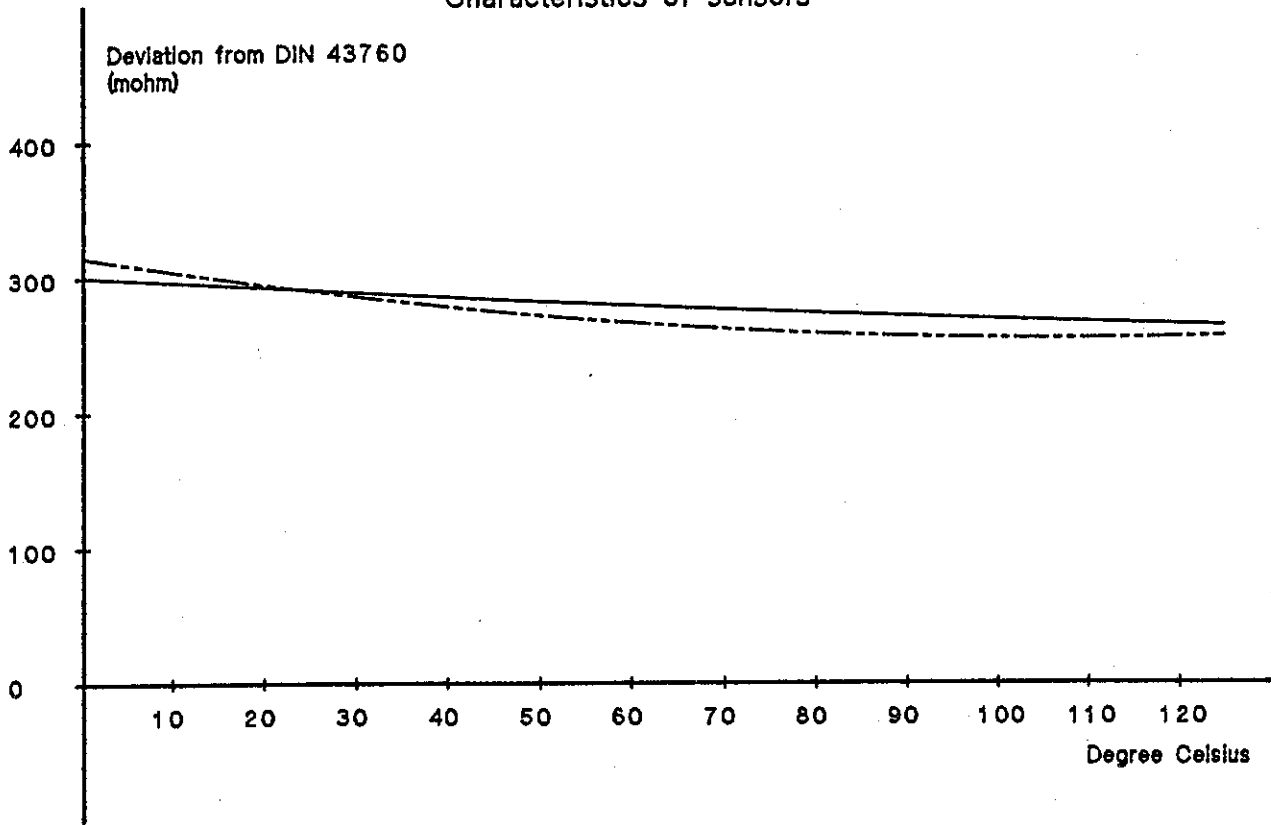
Error in energy due to sensor pair



Case No 12

Sensors mounted on steel pipe 15 mm and on steel pipe 32 mm
(CM)

Characteristics of sensors



Error in energy due to sensor pair

