UPON SOME ASPECTS OF TEMPERATURE MEASUREMENTS

Gh. Dragan
GDF-DATA BANKS srl
str. Abrud 25, Bucharest 011315, ROMANIA
www.gdfdatabanks.ro

Résumé

La plupart des mesures d’étalonnage thermométrique ignore les différences du température autour les thermomètres étalon et du mesure en immersion dans le même bain. Dans ceux conditions les valeurs indiquées par les deux thermomètres peuvent être incorrectes ou sans un incertitude bien définie. Les circuits d’énergie associés au systèmes calorimetriques peuvent être modelés d’après les principes topoénergetiques en considérant toutes les éléments lesquels contribuent à l’incertitude du mesure. Ces modèles permettent d’évaluer et/ou d’optimiser cette incertitude. Ils sont présentés deux types patentés de systèmes d’étalonnage thermométriques dans la séries ISOCALT® en utilisant ces principes lesquels permettent aussi d’optimiser l’incertitude du mesure pour les autres quantités.

Abstract

Almost all calibration measurements ignore temperature gradients around the standard and under test thermometers as immersed in the same bath. In these conditions the compared values may be incorrect or have a undefined uncertainty. The energy circuits associated to these calorimetric systems can be modeled according to the topoenergetic principles taking into account all elements contributing in the final uncertainty of measurement. These models allow to evaluate and/or to optimize this uncertainty. Two types of temperature calibrators in the series of ISOCALT® are presented by using these working principles as patented solutions. Topological principles can be extended to any other measurements in view to establish and optimize the measurement uncertainty.

Immersion in an isothermal bath (IB)

Figure 1 represents the basic disposition used for calibration of a measuring thermometer (TM) immersed in a homogeneous and isothermal bath (IB) maintained at a constant temperature T. In the same bath a standard thermometer (not represented) is immersed in view to compare the readings of the two thermometers (TM and TS, respectively) at equilibrium (steady state).

Both in a fluid and in a solid (dry) IB, the practical conditions show that there are always temperature gradients between the two immersed thermometers. In fact, there are immersed only the sensitive elements (sensors, SE) of the two thermometers, but inevitably they are thermally connected to the ambient temperature (TA) by specific conversion links to the external measuring instruments. On the other hand, temperature of IB is maintained by heating and/or cooling sinks localized in a restricted area, so that its thermal dissipative property essentially contributes to these temperature gradients.

Calorimetry is based just on the existence of temperature gradients between two or many specimens, because heat flows result according to Fourier law. Topenergetic principles [1] were used for calorimetric systems [2] and developed to a large variety of measuring systems [3-11]. They represent an extension of general rules from electric circuits to thermal and to any kind of energy circuits composed by components with elementary behavior: potentials, dissipative, capacitive, inductive, energy flow,

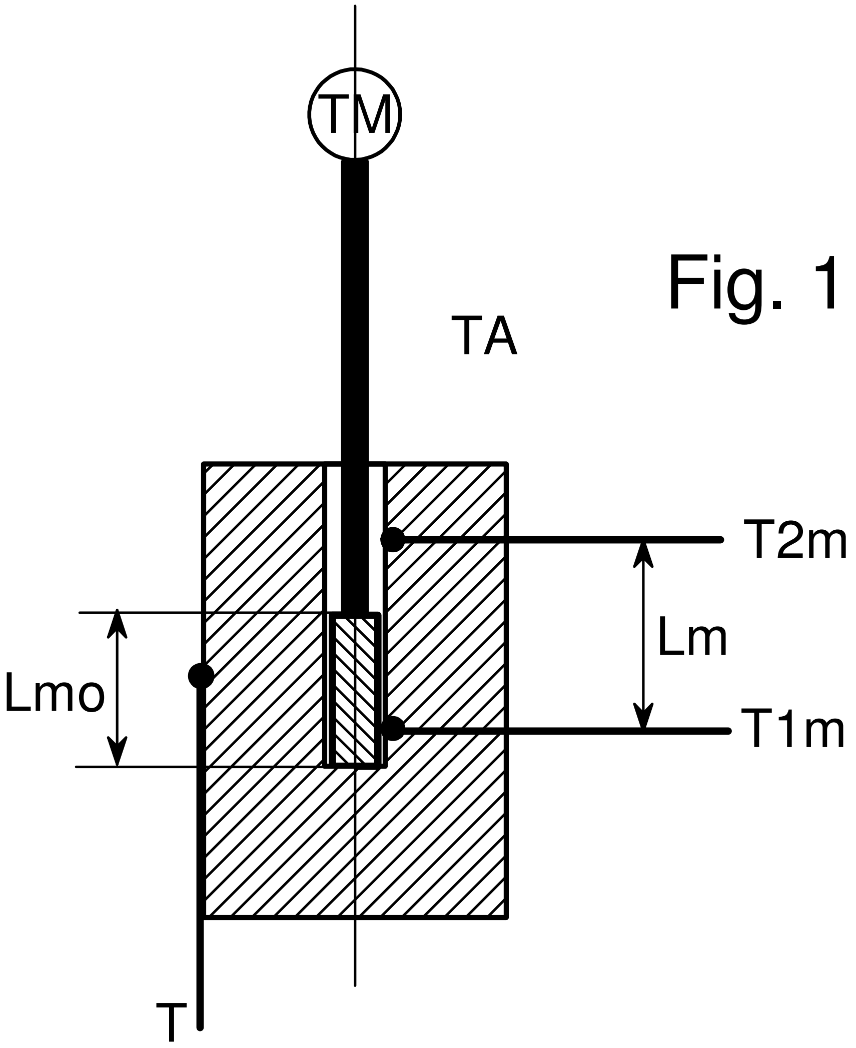
TM
TA
T2m
Lm
Lmo
T1m
T

Fig. 1

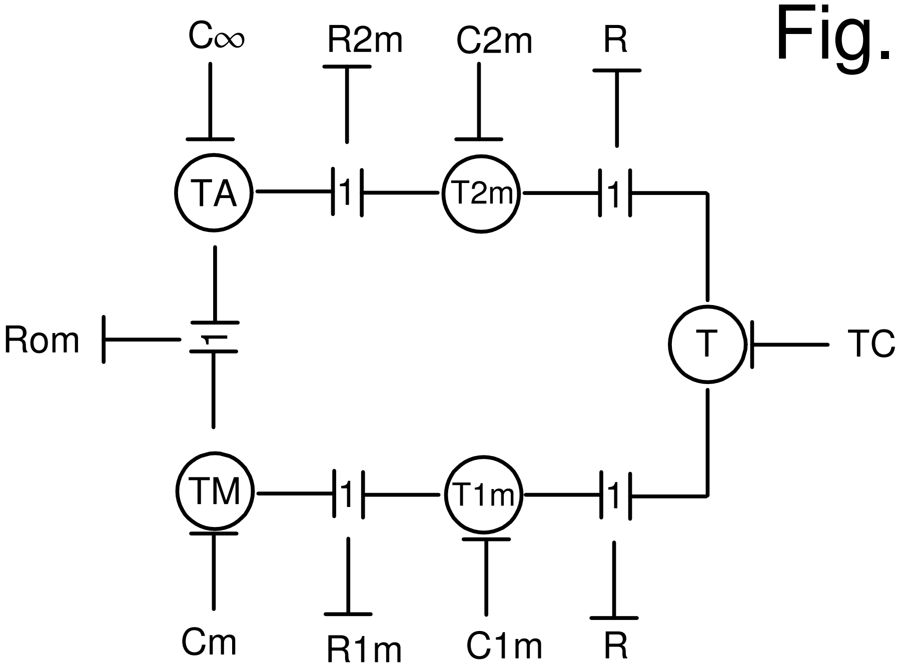
C∞
R2m
C2m
R
TA
1
T2m
1
Rom
1
T
TC
TM
1
T1m
1
Cm
R1m
C1m
R

Fig. 2

etc. These principles substantiated the new vision on the calibration of thermometers [12].

Figure 2 shows the bond diagram of the thermal (energy) circuit associated to TM branch (Figure 1) for which the following quantities are introduced:

R = thermal resistivity of IB (= 1/thermal conductivity of IB, in K*s/J);
R1m = thermal resistivity between SE and IB;
R2m = thermal resitivity between SE of T2m and TA;
C1m, C2m = heat capacity of IB parts establishing T1m and T2m, respectively;
Rom = thermal resistivity of connection rod of SE of TM and TA.
C∞ = the infinity heat capacity of the ambient.

For the branch of standard thermometer, the quantities with index s are defined in similar manner.

At equilibrium of temperatures and temperature gradients (steady state) we can express the thermal flow, w1 (J/s), passing through Rom, R1m and R by the following relationships:

$$w1 = (T1m-TM)/R1m = \\ =(TM-TA)/Rom = (T-T1m)/R \qquad (1)$$

so that:

$$TM = TA + (Rom/R)*(T-T1m) \qquad (2)$$

$$TM = (Rom/(Rom + R1m))*T1m + \\ + (R1m/(Rom + R1m))*TA \qquad (3)$$

As an immediate result we may observe that TM is more close to T1 (not to T !), i.e. the measurement of T1 by TM thermometer is more correct in the given experimental conditions described by all above defined quantities, if

$$R, R1m << R2m, Rom \qquad (4)$$

so that

$$Rom/(Rom + R1m) \rightarrow 1 \qquad (5)$$
$$R1m/(Rom + R1m) \rightarrow 0$$
$$Rom/R1m >> 1$$

We must notice once again the following important aspects:

- T is not a reference value; it is only an orientating value which can be maintained experimentally as constant with high accuracy;
- T1m and T2m are values measured with small SE with negligible external connections in view to avoid perturbation of TM, TS and T. These conditions are specific for differential measurements characterized by high accuracy and stability on a large temperature interval.

In practical cases we must take into consideration TM and TS and the following temperature gradients as independent contributions:

$$\Delta Ts = (T1s-T2s)/Ls \text{ , in K/m} \qquad (6)$$
$$\Delta Tm = (T1m - T2m)/Lm \text{ , in K/m}$$
$$\Delta T1 = (T1m - T1s) \text{ , in K}$$

so that the composed uncertainty of comparison of the two readings becomes [12]:

$$uc = \qquad (7)$$

$$((\Delta Ts*Lso)^2 + (\Delta Tm*Lmo)^2 + \Delta T1^2)^{0.5}$$

It is important to notice that this estimation is valid only in the conditions (4) or (5) for both TM and TS branches.

Calibration disposition with three equipotent surfaces (TES)

Figure 3 shows another calibration system using three equipotent surfaces [14]. The two SE are connected to the ambient (TA) by Rm and Rs, respectively. They are separately enclosed in first equipotent surfaces measuring Tm and Ts, respectively and separated from the second surface maintained at T1 by R1. T1 consists in two separated cavities in view to avoid direct heat transfer between the two SE. The third surface is maintained at T2 and is connected to second surface by R2. S1 and S2 are the thermal sinks at which the surface T1 and T2 are connected, respectively.

Figure 4 shows the associated bond of this calibration disposition for which the uncertainty of comparison of readings TM and TS can be simply expressed by the difference:

$$\Delta T = Tm - Ts \approx R1*(wm - ws) \qquad (8)$$

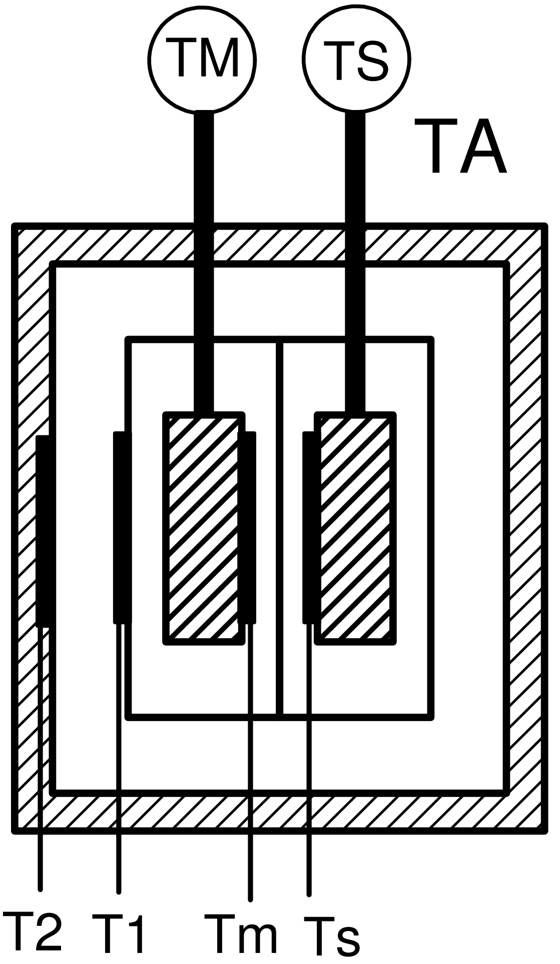
TM
TS
TA
T2
T1
Tm
Ts

Fig.3

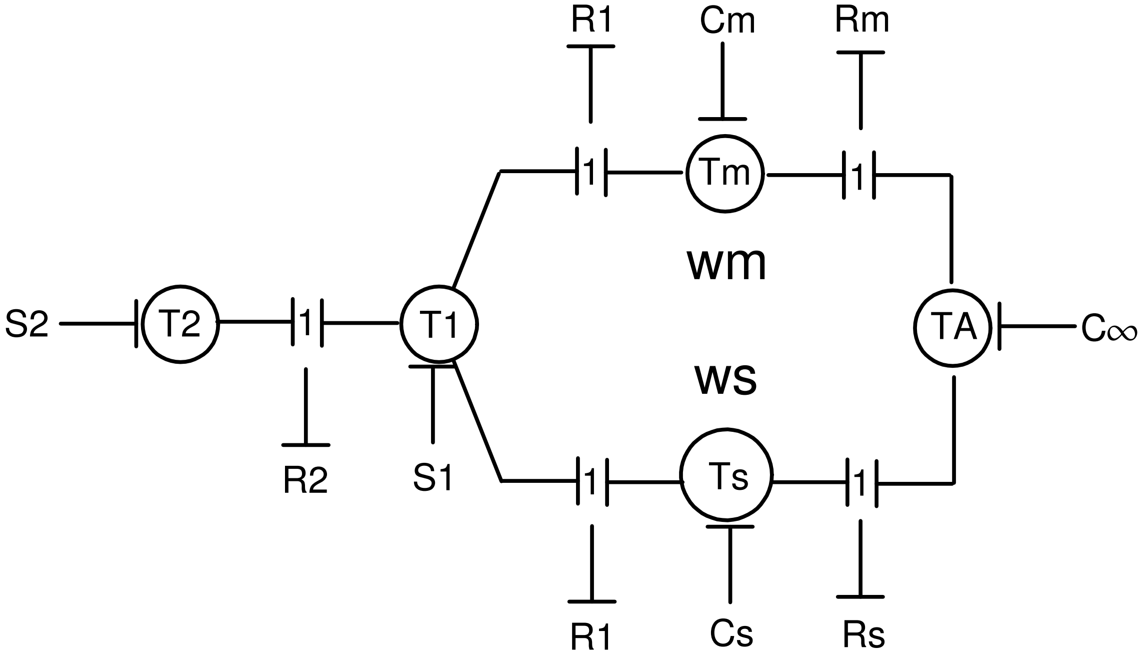
R1
Cm
Rm
Tm
1
1
1
wm
S2
T2
1
T1
TA
C∞
ws
R2
S1
1
Ts
1
R1
Cs
Rs

Fig.4

at steady state, so that $\Delta T \rightarrow 0$ for wm ≈ ws.

Concluding remarks

1. Topoenergetic principles allow optimizing measurements and calibration of any quantity by optimizing the associated energy circuit of measuring system and by establishing the exact contribution to the final uncertainty of measurement.
2. Topoenergetic principles impose additional measurements of constitutive components of energy circuits. In particular case of temperature measurements, these are in the first stage the dissipative elements between SE and IB, SE and TA, etc. and in the second stage the temperature gradients.
3. ISOCALT® represents an original series of calibration thermostats using these working principles. Their main advantages consist in: small volumes, measurement of temperature gradients with high accuracy (up to 0.003 ^{0}C for dry IB (each orifice has 2 or 3 sensors for temperature gradients) and under 0.001 for TES disposition) , low power for maintaining constant temperature for long time (approximately 100 Watts @ +500 ^{0}C), high accuracy of constant temperature in steady state (under 0.01 ^{0}C at least for 1 hour), no moving component, high reliability (continuous work for several months @ +500 ^{0}C). For details visit our web site.

References

[1] G.F.Oster and D.M.Auslander, “Topological representations of thermodynamic systems.I. Basic concepts.” J.Franklin Inst., Vol 292, pp. 1-7 (1971).

[2] Gh.Dragan, “Topological aspects of differential thermal analysis”, J.Thermal Anal., Vol. 9, pp. 405-414 (1976).

[3] Gh.Dragan, “Topological model of the crystalline morphology in polyethylene with grafted defects”, J.Polymer Sci., Polymer Symposium, Vol. 64, 99. 141-148 (1978).

[4] Gh.Dragan, “Amorphous-crystalline coupling in polyethylene. VII. Study of the crystallization kinetics in the approximation of the purely thermal dissipative coupling”, Rev.Roumaine Chim., Vol. 23, pp. 629-635 (1978).

[5] Gh. Dragan and Felicia Stoenescu, “Purely dissipative coupling model applied to the curing reaction of an epoxide system” Rev.Roumaine Chim., Vol. 24, pp. 55-57 (1979).

[6] Gh.Dragan, “Amorphous-crystalline coupling in polyethylene. IX. Study of the transforming branches by step calorimetric system.” Rev.Roumaine Chim., Vol.28, pp. 1315-1326 (1981).

[7] Gh.Dragan, “Topoenergetic aspects of solid-solid transitions in SnCl2(H2O)x(D2O)(2-x) system”, Rev. Roumaine Phys., Vol. 27, pp.297-309 (1981).

[8] Gh.Dragan, “Polarity of the transformation processes in thermal measuring systems”, J.Thermal Anal., Vol.23, pp.173-193 (1982).

[9] Gh.Dragan, “Inductive effects in topological thermodynamics”, Revista de Chimie (Bucharest), Vol. 29, pp. 214-217 (1978).

[10] Gh.Dragan and Gabriela Banica, “Mechanical stability of polystyrene and polystyrene-based compounds defined by topoenergetic study of ductile-to-brittle transition”, Phys.Chem Mechanics (Sofia), Vol. 10, pp. 41-44 (1983).

[11] Gh. Dragan, “Topoenergetic aspects of quenching processes of atomic and molecular excited species in rarefied gases”, Rev. Roumaine Phys., Vo. 28, pp. 389-402 (1983).

[12] GDF, “New vision on the calibration of thermometers: ISOCALT®”, TN1-2001, GDF Databanks Bull., Vol. 5, No. 2 (2001); “Report on metrological tests”, TN1-2002, GDF Databanks Bull., Vol. 6, No. 3 (2002).

[13] GDF, “Calibration of thermometers using ISOCALT® 2/70/21 thermostats. TN1-2004”, GDF Databanks Bull., Vol. 8, No. 1 (2004).

[14] GDF, “Calibration of thermometers using ISOCALT® 2.2R thermostats. TN2-2004”, GDF Databanks Bull., Vol. 8, No. 1 (2004).

ISOCALT® 21/70/2

GDF-DATA BANKS srl
str.Abrud 25, Bucuresti
gdfdatabanks@rdslink.ro
www.gdfdatabanks.ro