MICROTHERMOCOUPLE PSYCHROMETER DESIGN AND CHARACTERIZATION

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Résumé

Cet article présente la conception et les performances d'un psychromètre à microthermocouple. Le principe de fonctionnement repose sur le refroidissement d'une jonction de thermocouple par effet Peltier pour la détection de condensat. L'objectif principal est de déterminer un compromis entre le type de thermocouple, le diamètre des fils et le courant injecté afin d'obtenir la baisse de température la plus importante. Le dispositif est constitué de deux microthermocouples collés et isolés entre eux électriquement. Le premier, représentant l'élément actif, est refroidi par injection de courant (effet Peltier). Le second est utilisé pour mesurer les variations de température. L'ensemble du dispositif est testé dans différents taux d'humidité relative (11 % - 97 %).

Summary

This paper presents the design and the performances of microthermocouple psychrometer. The operating principle is based on the cooling of a thermocouple junction by Peltier effect to detect condensation. The main objective is to determine a compromise between thermoelectrical couple, wires diameters, and injected current in order to obtain the largest temperature drop. A psychrometer device is made of two microthermocouples glued together and electrically isolated from each other. The first one excited by a current will cool down due to the Peltier effect. The second one microthermocouple is used to measure the temperature variations of the system. The whole system is tested at different relative humidities (11%-97%).

Introduction

Temperature and humidity are among the most frequently measured quantities in physics today. When the static and dynamic temperature measurement can nowadays be done with a high degree of accuracy, the humidity measurement appears much more complex [1]. The multitudes techniques for measuring humidity [2] reflects the complexity of the problem owing to the fact that no solution can provide all requirements and all conditions such as stability, measuring range, response time and hysteresis at the same time [3, 4]. Characteristics of a moist air could be determined by the simultaneous measurement of two parameters only such as wet bulb and dry temperatures [5]. The others characteristics like moisture constant, enthalpy, relative humidity and dew point temperatures will be deduced. Usually the psychrometer accuracy is typically estimated to be better than 2% on relative humidity [6, 7].

Physical principle

In a psychrometrics thermocouple three thermoelectric effects (Seebeck, Joule and Peltier) take place [8]. The Peltier effect (table 1) is the release or absorption of a heat at a junction of two different conductors when an electric current is passing through them [9].

Materials	Peltier Coefficient (mV)	Thomson Coefficient (μV K^{-1})
Chromel	6.5	5.9
Iron	3.9	-7.9
Nicrosil	3.5	5.6
Copper	0.6	1.8
Platinum	-1.4	-9.1
Nisil	-4.3	-4.7
Alumel	-5.3	-6.7
Nickel	-5.7	-16
Constantan	-11	-2

Table 1: Peltier and Thomson Coefficients.[11]

The purpose is to create a significantly temperature drop at the thermocouple junction using electrical current injection. In specific conditions a condensate appears at the junction. The moist air parameters can be easily deduced by simultaneous dry and wet bulb or dew point temperature measurements [10].

Experimental setup and methods

This section presents the microthermocouples setup and the experimental device. The main objective is to obtain the optimal configuration giving the largest temperature drop. The device is made of two microthermocouples glued together and electrically isolated from each other. The first one is cooled by Peltier effect when a current is injected and the second one measures continuously the temperature variation generated by the Peltier effect. The cooling effect being dependant on the current intensity, the thermocouple type and the wires diameter we try to determine a compromise between these three parameters.

Several devices have been tested. We crossed the thermocouple type: E-type (Constantan - Chromel), J-type (Constantan - Iron), K-type (Chromel - Alumel) and three different diameters 80 µm, 125 µm, and 250 µm. we obtained nine devices (table 2) junctions are welded with a microburner. A smaller microthermocouple (K-type, 25.4 µm welded by capacitive discharge) is glued on the junction and is used to measure the temperature variations of the whole system (figure 1).

The study is divided in two parts. At first we determined the best configuration in terms of diameter, current intensity and thermocouple type in order to obtain the largest temperature drop. Then we tested the ability of these thermocouples to be used as micro psychrometer.

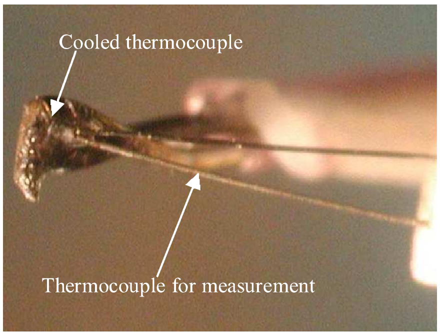

Fig 1: small one used for measurement and a bigger one cooled down by current injection

The following table gives characteristics of different devices tested the (lengths diameters and resistance):

Types	Wires diameter (µm)	Wires length (mm)	Resistance (Ω)
E	80 25	1000 1000	240 50
E	125 25	1000 1000	110 50
E	250 25	1000 1000	36 59
J	80 25	1000 1000	244 60
J	125 25	1000 1000	80 70
J	250 25	1000 1000	26 70
K	80 25	1000 1000	240 50
K	125 25	1000 1000	94 65
K	250 25	1000 1000	37 59

Table 2: List of devices.

Test bench consists of a National Instruments CompactDAQ managed by LabVIEW software. It can measure the temperature variations and control the current injection (square signal). The OPA 548 amplifier is connected as a follower circuit and the current limit is adjusted with a resistor.

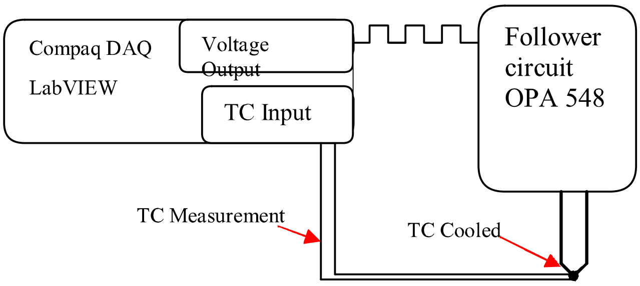

Fig 2: Test bench and electrical diagram.

To perform experiments at fixed relative humidities the thermocouples were inserted above oversaturated salt solutions in sealed glasses (figure 3). The type of brine sets the relative humidity as shown on the table 3

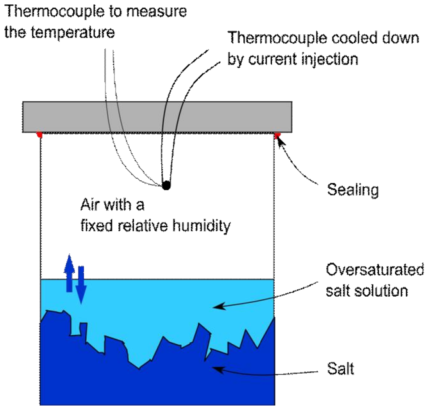

Fig 3: Sealed glass for psychrometric tests.

Type of salt	Relative humidity at 20°C
LiCl	11.1 %-12.6 %
$CaCl_2$	33±0.5 %
NaCl	75.5±0.1 %
KCl	85.1±0.3 %
K_2SO_4	97.6±0.5 %

Table 3: Relative humidity rate for saline solutions. [12]

Results

The first part of tests was performed in a thermostatic bath, the temperature is 20 °C and the ambient relative humidity is about 45%. The frequency must be changed to obtain steady state temperature measurement at each half-period. Therefore it is 0.002 Hz for a current below 50 mA and 0.0015 Hz above. The duty cycle of the square is 50%. The injected current to cool down the microthermocouple junction takes values between 0.5 and 120 mA.

The second part of the tests concerns the psychometric device. Once the optimal configuration defined the device is placed above (1.2 cm) the over salt solution than we measure the temperature drop.

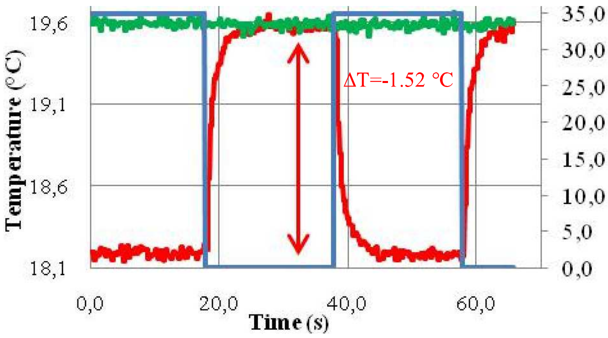

Fig 4: Temperature variation of E type thermocouple (125 µm). (— temperature measurement. —Temperature reference). The signal current about 35 mA is presented on the right axis (—).

The first graph shows the temperature variation recorded by the microthermocouple measurement (K type 25.4 µm), glued on E type microthermocouple 125 µm. For a current of 35 mA we measured a temperature drop of -1.52 °C when there is a current flow.

Similar results were obtained for all the devices tested and the following graphs summarize the results of all tests (temperature variation for each device according to the current and diameter of the wires).

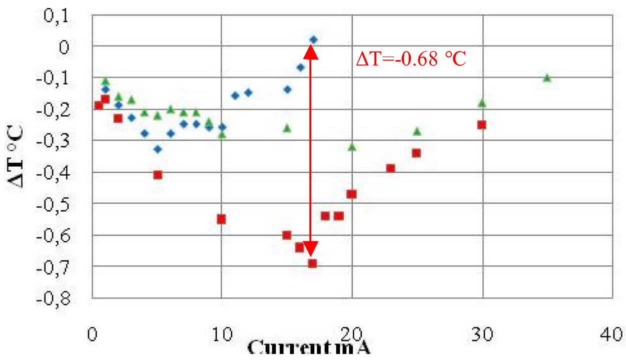

Fig 5: Results for a diameter of 80 µm. Each point corresponds to a steady state temperature.
(■ E type. ◆J type. ▲K type).

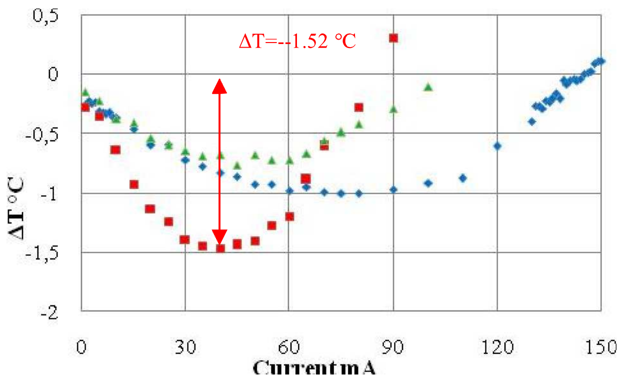

Fig 6: Results for a diameter of 125 µm.
(■ E type. ◆ J type. ▲ K type).

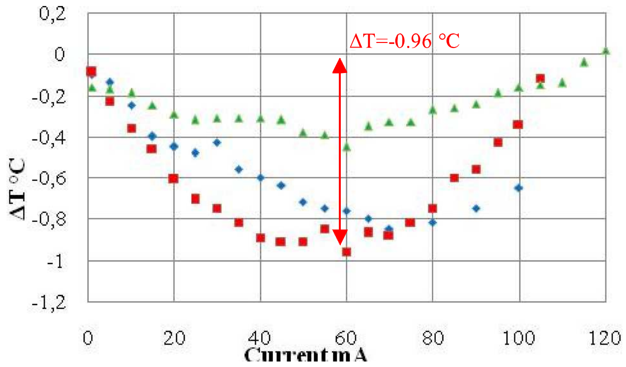

Fig 7: Results for diameter of 250 µm.
(■ E type. ◆ J type. ▲ K type).

From the results obtained for the three diameters (80, 125, and 250 µm) the largest temperature drop (-0.68 °C, -1.52 °C and -0.96 °C) is given by the E type with a current of 17, 36 and 60 mA respectively.

According to figures 5 to 7 we notice almost no cooling effect at low level of current. As the current intensity increases the temperature drop increases too until an optimal value specific for each kind of thermocouple (diameters and types). At a certain value of the current the Joule effect takes over the Peltier one and the thermocouple heats up. Therefore the measured temperature drop becomes smaller.

Psychrometric mode

The maximum temperature drop is obtained with the E type thermocouple of 125 µm for a current range from 0 to 100 mA. All the psychrometric tests will be done with this specific – optimal - configuration.

Now that the optimal configuration is defined, the devices are tested in different relative humidities. The aim is to determine the influence of the relative humidity on the temperature variations.

The following graph shows the results obtained.

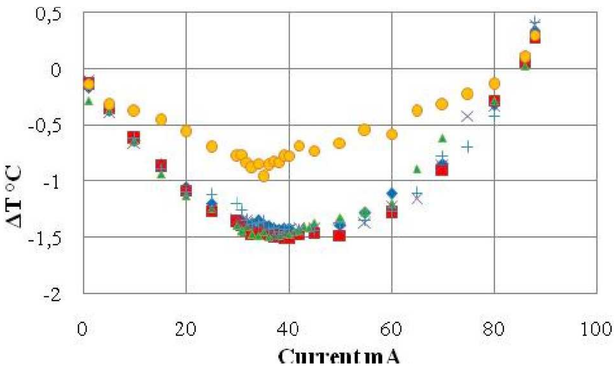

Fig 8: Relative humidity effect on temperature drop.
(◆ 12%. ■ 33%. ▲ 45%. × 75.5%. + 85.1%. ● 97.6%).

For all relative humidities the maximum temperature drop (-1.5 °C) is obtained around 40 mA. The results are similar on a relative humidity range from 11.5% to 85.1%. In fact the humid air surrounding the probe is not sufficiently cooled to condense as expected by the psychrometric diagram. The table 4 sums up the temperature drop that we should theoretically assess to reach the dew point for each relative humidity.

RH %	11.5	33	45	75.5	85.1	97.6
ΔT °C	-30.1	-16.66	-12.24	-4.44	-2.8	-0.38

Table 4: temperature drop ΔT = T_{dry}-T_{dew} to reach dew point for some relative humidities

On the other hand for 97.6% we can observe that the general trend is different and the maximum temperature drop is only of -1 °C. For this particular value of relative humidity the difference between the dry and the dew point temperature can be calculated with the standard psychometric relationships. From table 4 temperatures drop of -0.38 °C is necessary to condense which corresponds to an intensity of 10 mA according to figure 8. Above 10 mA the measured temperature can be regarded neither as the wet bulb nor the dew point temperature. In fact in this area it corresponds to an overcooled condensate.

In order to study the influence of condensation on the temperature measurement we compare the temperature drop variations through time for two relative humidities (85.1 % and 97.6 %) and for a current of 20 mA (figure 9).The signal response of the sensor may be divided into two parts (figure 9).

The first one (a) concerns the cooling step. A current is injected during ~4 min and the temperature decreases. Both curves exhibit the same dynamic behaviour during the cooling phase. They do not reach the same temperature due to condensation for the experiment at a high relative humidity level (97.6 %).

The second part (b) concerns the relaxation phase without current flow. Both temperatures increase by heat exchange between the probe and its surroundings. The delay observed between the two experiments is due to the evaporation of a liquid film on the junction (red curve at 97.6 %). Even after 240 seconds of relaxation the both temperatures are not equal to the reference (*i.e.* ΔT=0°C). So some condensate remain on the junction.

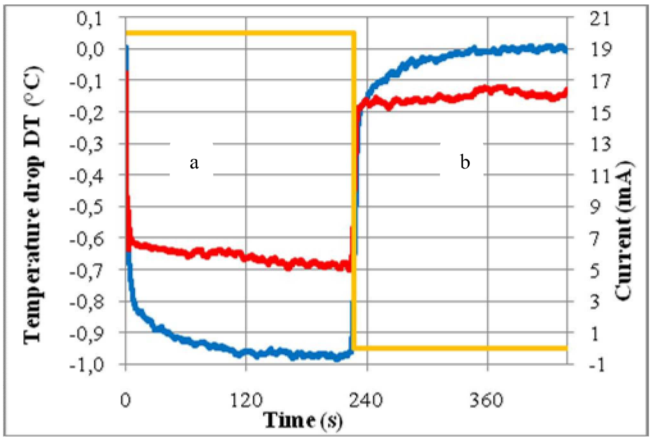

Fig 9: Temperature drop variation of E type thermocouple (125 µm) (— temperature drop at 97.6%. — temperature drop at 85.1%.). The signal current about 20 mA is presented on the right axis (—).

Conclusion

We studied in this work a device able to measure continuously the temperature drop of a microthermocouple cooled by Peltier effect. At first three parameters should be determined to obtain the largest temperature drop at the thermocouple junction: (i) the type thermocouple, the (ii) diameter wires and (iii) the injected current.

In fact the temperature drop depends on (i) the Peltier coefficient (ii) the geometric parameters which have an impact on the electrical resistance and the mass of the junction and (iii) the Joule effect driven by the injected current value. The maximum of temperature drop (-1.52°C) is obtained by a E-type thermocouple 125 µm in diameter and an injected current of 35 mA.

In the second part of the study we tried to use it as a psychrometer. After 10 seconds of current injection a steady state is reached and the temperature drop remains constant (figure 4).

Unfortunately the relative humidity has no impact on the final temperature drop except for the extreme value (97.6%) (figure 8). In fact the cooling promotes condensation on the junction.

On the other hand the dynamic behaviour (figure 9) is slightly affected by a high relative humidity level (97.6%) especially during the relaxation phase where the condensate should be evaporated.

In further studies a detailed thermal model will be developed to predict the temperature drop through time. This would be the first step to a dynamic characterization of such system.

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