Development of a gas flow independent coulometric trace humidity sensor for aerospace and industry

Andreas Lorek[1], Alexander Koncz[1] und Roland Wernecke[2]
[1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) Berlin-Adlershof
[2]dr.wernecke Feuchtemesstechnik GmbH

KURZFASSUNG: Im vorliegenden Beitrag erfolgt am Beispiel des Transquerprojektes HUMITRACE eine kurze Darstellung, wie Erkenntnisse aus der Weltraumforschung am DLR in Kooperation mit Industriepartnern zu konkurrenzfähigen Produkten für die industrielle Anwendung weiterentwickelt werden. Im Projekt wird ein coulometrischer Spurenfeuchtesensor, der für in-situ Messungen auf dem Mars im Feuchtebereich -40 °C Frostpunkt bis -75 °C Frostpunkt vorgesehen ist, durch schrittweise Modifikation seiner Sensorparameter optimiert und sein Einsatzbereich auf industrielle und labortechnische Anwendungen erweitert.

ABSTRACT: The technology transfer project HUMITRACE exemplarily demonstrates successful transfer of space-technique applications via appropriate modification to competitive products. These are finally based on technical developments for scientific space experiments at DLR-PF (DLR Institute of planetary research), and have correspondingly been modified and manufactured in cooperation with an industrial partner.

In the project, a coulometric trace humidity sensor developed for in-situ measurements on Mars, is being optimized by successive modification of his sensor parameters. This development led to an enhancement of potential applications of this coulometric principle in industry and laboratory.

Schlagwörter: coulometrisch, Feuchte, Sensor, HUMITRACE

1. Introduction

Water is a key factor for physical, chemical and biological phenomena on Earth, but also on Mars. Images from recent years indicate current rheological activity on Mars, such as sediment deposition, gullies, and downslope flows on polar dune slopes. These phenomena indicate the action of a liquid like water bounded on solid surfaces and in brines [1].

The first millimeter of the martian surface is of particular interest [2] because it interacts directly with the atmosphere. The atmospheric boundary layer adsorbs and desorbs water in dependence on diurnally varying temperature and relative humidity (RH) of the atmosphere. Therefore, the soil permanently changes its water content and its solid (minerals, ice) and liquid (brines) components [3]. This varying water content could be a reason of observed rheological phenomena.

A trace humidity sensor (MiniHUM) has been developed at DLR-PF for in-situ measurements of the near-surface martian atmosphere - as part of the scientific Humboldt payload (HPL) of ESA ExoMars program with launch in 2013. The measurements were planned to deliver information about interactions between the shallow subsurface and the Martian atmosphere.

The sensors were designed for Martian conditions with a humidity range from -55 °C frost point* (FP) [4] to -75 °C FP [5] and temperatures in a range from 0 °C to -100 °C [6].

* The Frost Point of a moist air sample is the temperature to which the sample must be cooled to reach saturation with respect to ice.

The technical requirements for the ExoMars mission, e.g. low mass and power consumption led to the decision to use humidity sensors and no spectrometers.

However, to better cover the expected humidity, three sensors based on different principles have been used for MiniHUM. The first sensor is an atmospheric saturation sensor which measures the temperature of a thin copper plate during condensation of water. The sensor is used for the night hours with 100 % relative humidity (RH). The second sensor is a capacitive probe with a measurement range from 3 %RH to 98 %RH. This is expected to be reached in the colder evening- and morning hours on Mars when temperatures are below -50 °C. The last sensor is based on the coulometric principle and measures trace humidity contents below 3 %RH. Therefore, it is mainly used during the day time.

For measuring traces of water vapour the principle is the most appropriate. It is small, lightweight, has almost no cross sensitivity to other gases, a fast response to humidity changes and beside a dew point mirror it is the only principle which is able to measure the absolute humidity at that low water vapour concentrations.

This principle was described first in 1959 by Keidel [7] and is in theory a moisture trap and an electrolytic cell. The function principle of the electrolytic sensor is based on the absorption of water vapor from the atmosphere by the extremely hygroscopic phosphoric pentoxide (P_2O_5), which is located on the sensor between two platinum electrodes. A potential of minimum of 2 V across the electrodes is needed to start electrolysis of the trapped water. The phosphoric acid, produced by the absorption of water vapor, will be electrolyzed and by emission of two electrons P_2O_5 will be formed again. The current resulting from the electrolysis is a direct measure of the amount of water trapped by the agent [8]. Further the P_2O_5 stay always dry as a result of this electrolysis and is ready to absorb new amounts of water.

For a precise determination of the humidity, the exact amount of water being delivered to the sensor per unit mass of carrier gas must be known (Diagram 1). Our industrial partner the SMB dr.wernecke Feuchtemesstechnik GmbH, have been used this technique successfully in industry (process gases, pharmaceutical industry) and laboratory applications for many years.

For industrial and aerospace applications, the realization of a constant gas flow over the sensor can be disadvantageous because additional “mass- and power consuming” equipment, such as mass flow meter and pump or the implementation of a bypass is necessary (Figure 1).

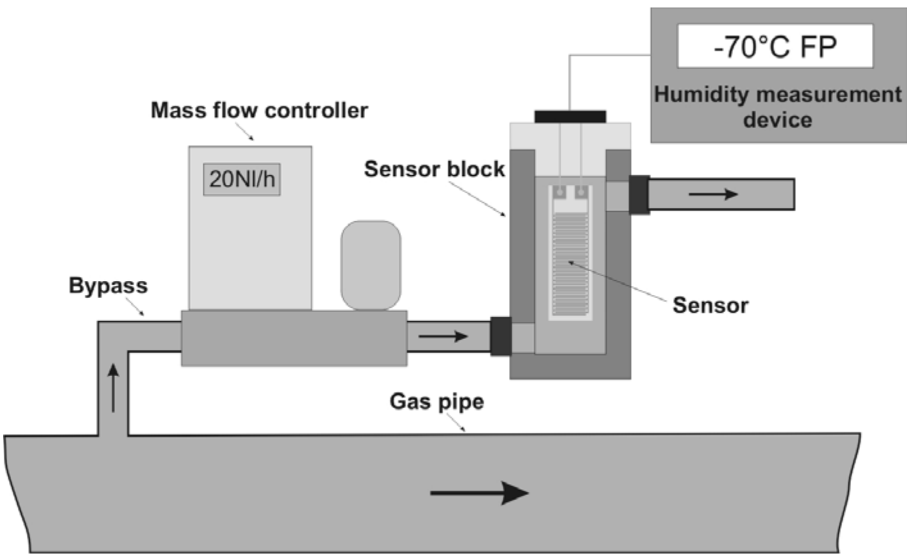

Figure 1: Measurement unit (State of the art)

One of the major disadvantages of the coulometric moisture sensor for space applications is the need of mass flow meter and a pump for providing a constant volume flow to the sensor. This will lead to high mass, less reliability and in a worst case to a possible single point of failure. Therefore one of the major aims of the DLR - MiniHUM project was to improve the sensor significantly regarding mass, reliability and size. For the Martian application the sensor was being miniaturized by using a porous membrane [9]. The permanent electrolysis of water will cause the P_2O_5 to maintain a low water vapour partial pressure and therefore the sensor to be acting as a moisture sink.

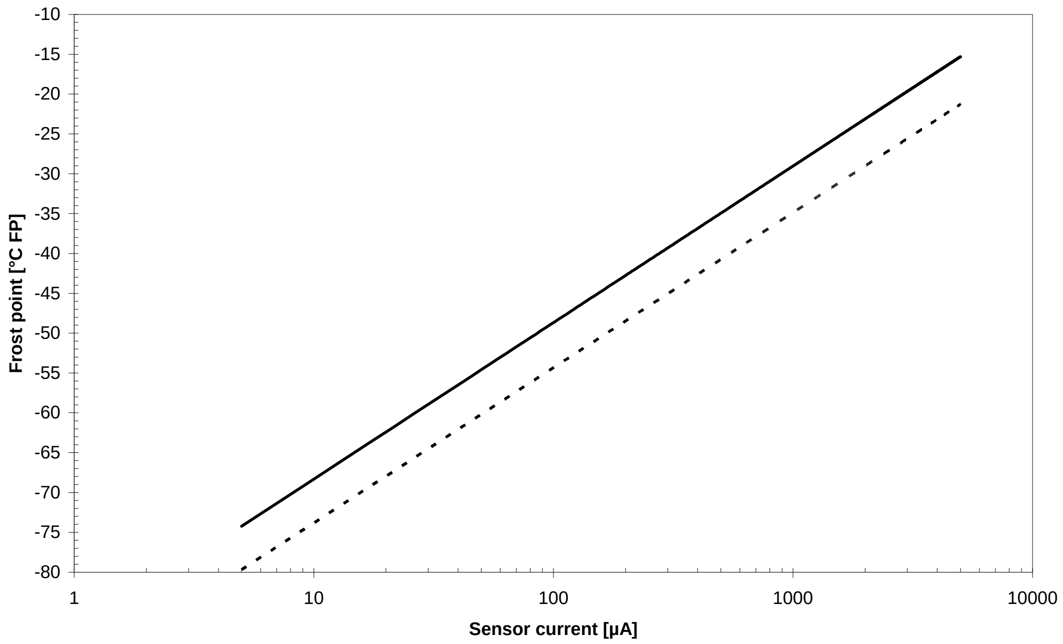

Diagram 1: Characteristic curves of an industrial sensor for 20 norm-litre / hour (Nl/h) (solid line) and 100 Nl/h (dotted line) – difference ca. 5 °C FP

Thus, water vapour diffuses through the membrane as a result of the emerging concentration gradient between membrane top and bottom. The use of a membrane will led to a membrane specific volume flow depending on their parameters.

The ExoMars mission was subject of constant changes due to financial but also political consideration. In 2009 ESA and NASA agreed a Mars Joint Exploration Program altering the financial and technical setting of the mission. The original mission was split into two parts, an exploration rover in 2018 and a lander/orbiter in 2016. Since the latter one is only planed to be a demonstrator, all scientific payload of the former lander was cancelled and will be tendered again in the fall of 2010.

2. Further development of the coulometric measurement principle and the sensor at DLR in the technology transfer project HUMITRACE

Our long-standing industry partner, dr. Wernecke Feuchtemesstechnik GmbH have a particular interest to use the spin-off of the coulometric principle for an optimized , gas flow independent humidity transmitter for industrial applications. Therefore, the DLR and the industrial partner have founded the technology transfer project HUMITRACE. The aim of the project is to develop a humidity transmitter family for the humidity range -10 °C to -75 °C FP with a precision better than +/- 2 °C FP. It is a remarkable advantage that this sensor can also be used in corrosive gases.

Different kinds of sensor layouts have been tested. Those are planar sensor prototypes (Figure 2) but also different types of glass rod sensors. The test results described below were made by using a sensor block similar to those in Figure 1 were additionally the sensor was covered by a porous membrane (Figure 3). These experiments were performed with membranes of different porosities.

The results obtained from the test show that the porosity of the membrane significantly affects the response time to a change of humidity as well as the response to different flow rates. Thus, for the remaining tests a membrane was used which provide the best results for an independent mass flow and a fast response to the sensor.

The results described below were performed using this membrane at room temperature and atmospheric pressure. The S8000 dew point mirror from Michell has been used as reference onto the measured humidity.

Most of the modifications made to improve the original sensor concept are protected company know-how and could not be discussed in detail in the following sections.

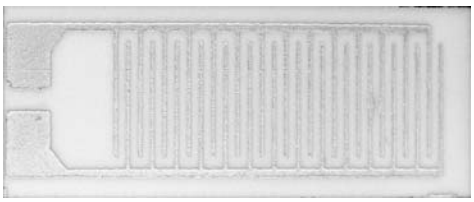

Figure 2: planar sensor with comb-shaped electrodes on a ceramic substrate (30x10x1mm)

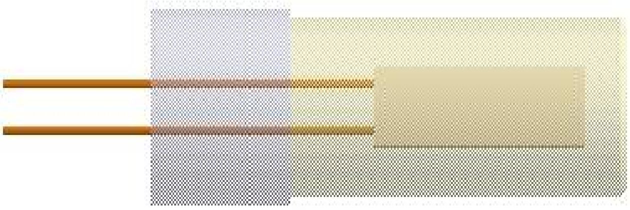

Figure 3: Planar sensor with porous cylindrical PTFE-membrane

The diagram 2 illustrates the sensor characteristic (sensor current – humidity dependence) at different volume flows of 5 Nl/h, 20N l/h, 35 Nl/h and 100 Nl/h. It is seen that the sensor signal is nearly flow independent at volumes higher than 20 Nl/h, whereas variations are within the expected accuracy of the sensor.

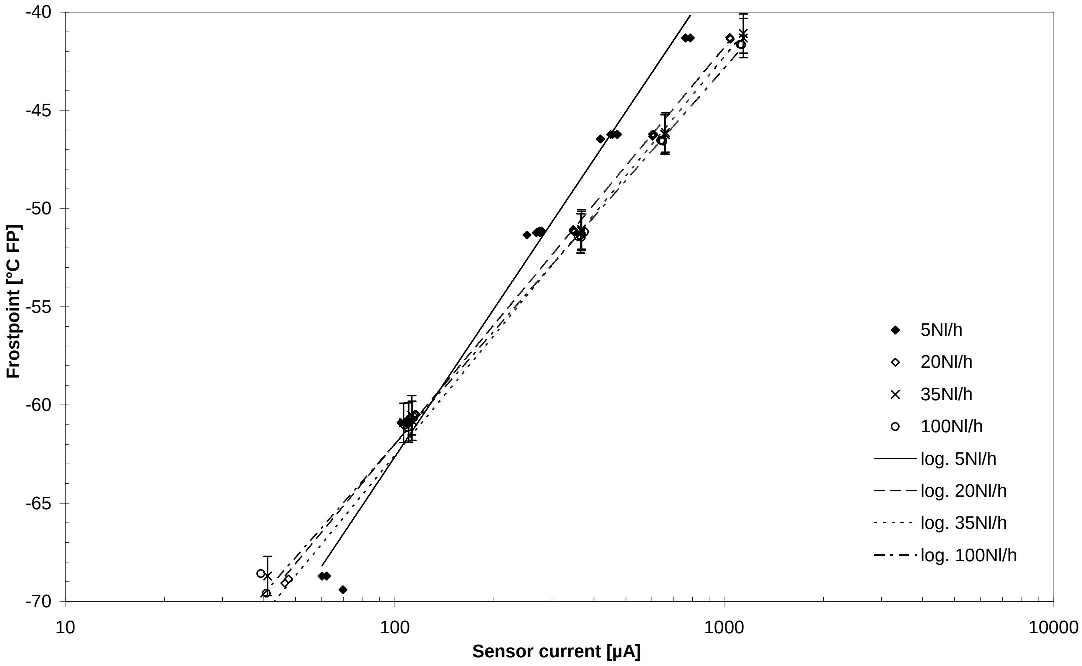

Diagram 2: Dependence of the characteristic curve on volume flow around the membrane at different volume flows

One of the major problems of planar as well as the glass sensor is shown in Diagram 3. The sensor drifts towards lower signals while humidity is kept constant. This phenomenon was already observed during the MiniHUM project whereas the shift for the planar sensor is lower than for the glass sensor.

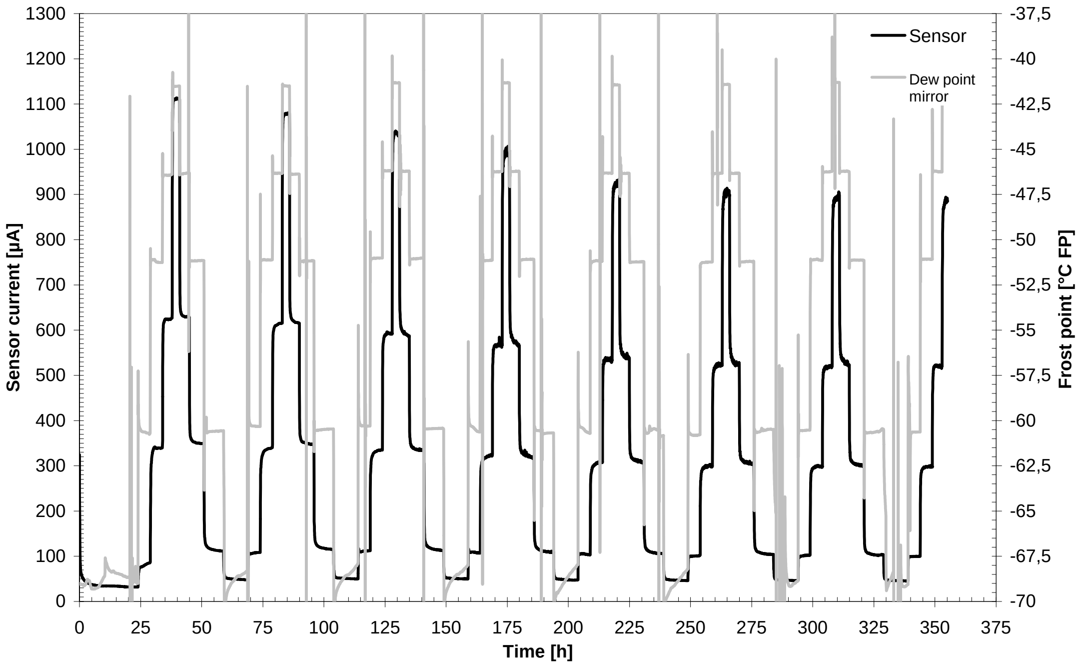

Diagram 3: Signal drift of a planar sensor towards lower values at a gas flow of 20 Nl/h

The signal drift (Diagram 3) causing a deviation of approx. 2 °C FP in 350 hours of operation (Diagram 4).

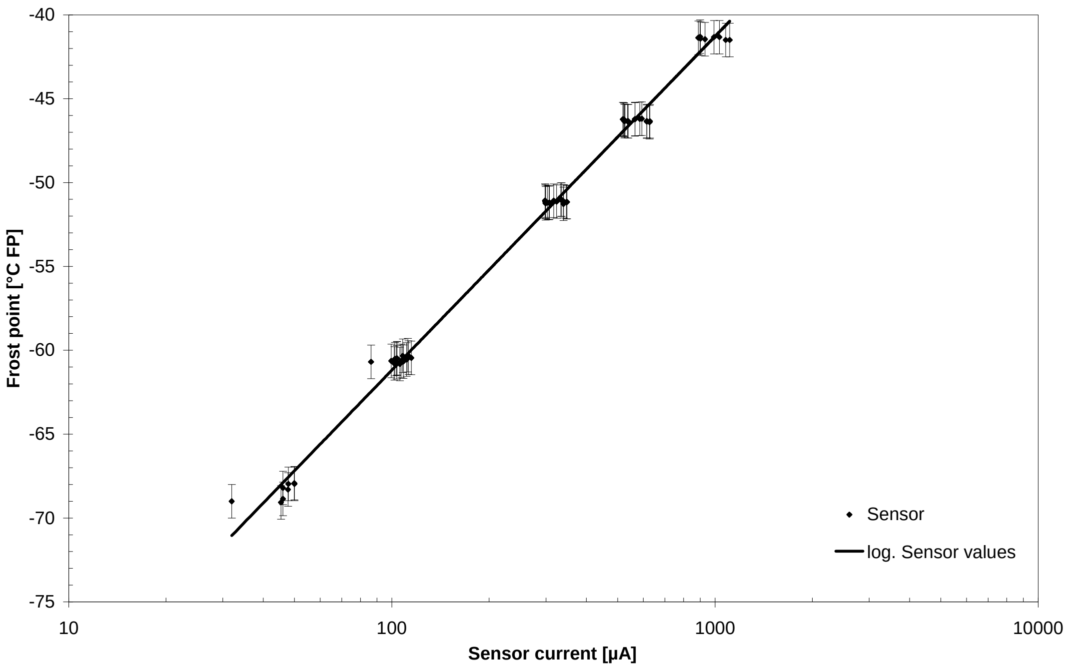

Diagram 4: Sensor current vs. reference frost point temperature obtained by the same sensor used in Diagram 3. The drift of the sensor signal is indicated by error bars.

An identified possible reason for the drift can be the observed material accumulation on the anode (Figure 4). This material is probably P2O5. The P_2O_5 seems not to participate anymore at the electrolytic procesess. This could be the reason for the drift observed as mentioned above.

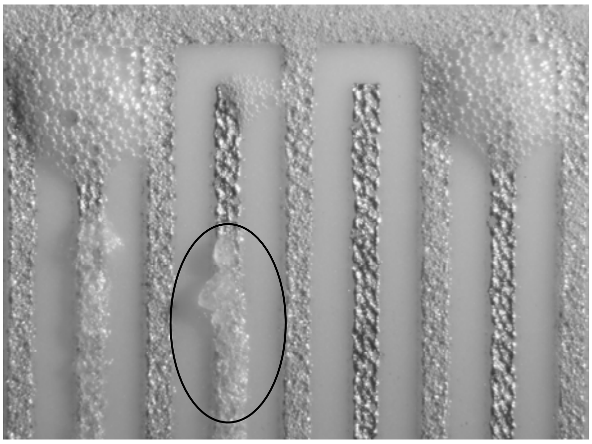

Figure 4: active coulometric sensor with accumulation of P_2O_5 on the anode (marked area)

As a result of MiniHUM but also based on findings made during this project, the coating of the sensor was changed as well as how the sensor is being operated (Figure 5). These changes support the hypothesis and a new procedure has been developed to avoid the drift phenomenon (Diagram 5).

Experiments with different electrode spacing have shown that a smaller electrode spacing between anode and cathode lead to faster response times.

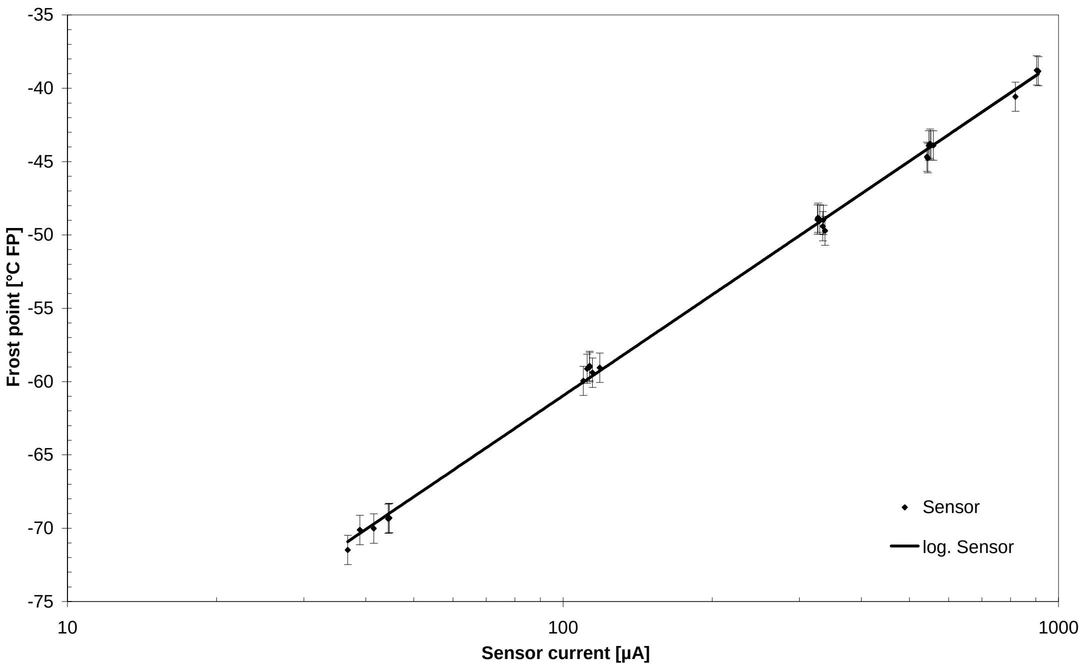

Diagram 5: Sensor signal of a planar sensor at 20 Nl/h; drift is not observable with respect to Diagram 4

Diagram 6 illustrates the sensor characteristic of two different sensors for a change in humidity from -60 °C FP to -50 °C FP. Here, sensor one (S1 – solid line) have a smaller electrode spacing than sensor two (S2 – doted line). The vertical line in Diagram 6 marks the point when each sensor is within 1 °C of his final value. It is seen that sensor 1 reaches this point within 35 minutes after humidity has changed whereas the second sensor needs almost 60 minutes.

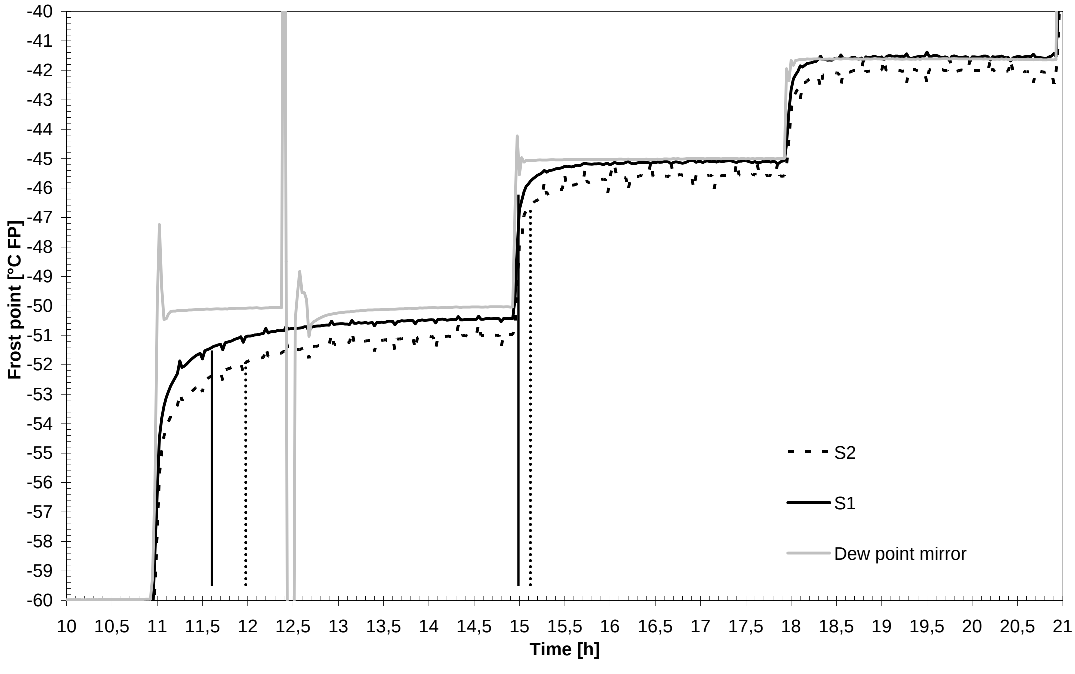

Diagram 6: Response time of planar sensors with different electrode spacing (vertical solid and dotted lines mark the point, when each sensor is within 1 °C of his final value)

3. Summary and outlook

The present paper illustrates on the example of the technology transfer project HUMITRACE, how spin-offs from space research in cooperation with an industrial partner can lead to marketable products for sophisticated and specific industrial applications.

The extreme requirements for spacecraft instruments, such as accuracy, reliability and weight have led to a stepwise modification of the current coulometric sensor. The current prototypes surpass the previous industrial coulometric glass rod sensor in terms of gas flow independence, response time, repeatability and precision. Also the number of components has been reduced.

The experiments show that gas flow independence could be achieved by using a porous membrane. Thus allows the sensor to be used directly in pipelines without being operated in a bypass. The current sensor also outperformed the commonly used capacitive sensors for trace humidity applications.

In the ongoing project, the parameters such as sensor design and coating are further optimized to increase the stability of the sensor. Next, the electronics developed by the industry partner will be adapted and finally, the entire transmitter will be reviewed in view of its operational capability.

References

[1] Möhlmann D., Kereszturi, A., The Viscous liquid film flow on dune slopes of Mars, Icarus, 207, 2010, S. 654–658

[2] Möhlmann D., The influence of van der Waals forces on the state of water in the shallow subsurface of Mars, Icarus, 195, 2008, S. 131–139

[3] Möhlmann D., The The three types of liquid water in the surface of present Mars, International Journal of Astrobiology, 9 (1), 2010, S. 45–49

[4] Hudson T. L., Zent A., Hecht M. H., Wood S., Cobos D., Near-Surface Humidity at the Phoenix Landing Site as Measured by the Thermal and Electrical Conductivity Probe (TECP)., 40th Lunar and Planetary Science Conference (2009)

[5] Ryan J. A., Sharman R. D., H2O Frost Point detection on Mars?, J. Geophys. Res., 86, No. C1, 1981, S. 503-511

[6] Smith Michael D., Interannual variability in TES atmospheric observations of Mars during 1999–2003, Icarus 167 (2004) 148–165

[7] Keidel, F. A., Determination of Water by Direct Amperometric Measurement,Journal Anal. Chem. 31 (1959), S. 2043–2048

[8] Wernecke, R., Industrielle Feuchtemessung - Grundlagen, Messmethoden, technischeAnwendungen, Weinheim, Wiley-VCH GmBH & Co. KGaA, 2003. – 567 S. – ISBN 3–527–30285–9

[9] Koncz, A.: Diplomarbeit "Grundlagen und Entwicklung eine auf dem coulometrischen Messprinzip basierenden miniaturisierten in-situ Feuchtemessgerätes für den Marseinsatz" Universität Stuttgart, 01.2007

Kontakt: Dr. Roland Wernecke, dr. wernecke Feuchtemesstechnik GmbH; Gerlachstr. 41; D-14480 Potsdam; Germany; Phone: + 49-331-5056858; Fax: + 49-331-613269; E-mail: info@dr-wernecke.de