

MEASUREMENT PRINCIPLE AND EQUIPMENT FOR MEASURING HUMIDITY CONTENTS IN THE UPPER MARTIAN SURFACE AND SUBSURFACE

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ABSTRACT

In-situ measurements of the water vapour content in atmosphere and surface are required for the better understanding of the physical, chemical, and possibly also exobiological processes in the upper Martian surface.

The method measures the water vapour content coulometrically in the range between saturation and dew point temperatures less than -90°C_d . The typical sensor characteristics are: low energy consumption, low data rates, very small dimensions by miniaturization, less weight, very robust packaging. A chamber simulates time profiles of humidity and temperature. Therefore the measuring system includes generators for humidity, temperature, gas contents and pressures, a gasdryer and –mixer, a regulated freezing box and a possibility for the creation of underpressure within the freezing box. The measuring capabilities are kept universal for the planned experiments to reach a maximum of suitability for the desired hardware configuration. A specific electronic managing and logging system has been developed and manufactured. It permits high integration possibilities into other existing measurement systems.

1. INTRODUCTION

Measurement possibilities for very less humidity contents as they are expected in Martian ground and atmosphere must be chosen in view of many different aspects. The Martian “atmosphere-ground-water” system helps to explain why the measurement task is so complicated. By considering several possible measurement principles the conclusion follows that the coulometric principle has many advantages. The company deka Sensor & Technology has a lot of know-how because of its long time industrial, science and medical experiences. We also have knowledge and experiences in the sector of trace humidity measurement equipment by the use of such a coulometric principle. The principle, seizing, dimensions and technical data seem to fit best into the afforded missionary requests. A combinatorial measuring head where such a coulometric sensor will be included seems to be a good solution to measure under Martian conditions in a very wide humidity area. This combinatorial measuring head could find a place

in further missions. It is also possible to include this head into a penetrator. For the development of such a measuring head special equipment is needed. A “humidity laboratory” is under development at the DLR Berlin. It will be possible to calibrate sensors, make referenced measurements and perform other biological or chemical experiments there. A special electronics system with the main task to glue the electronic signals of all equipment within one device to perform the controlling of the whole measurement place was developed. The basically planned configuration of the “humidity laboratory” will show how to simulate and measure under Martian conditions mainly concerning pressure, temperature and humidity as the most important influences on the water content in soil or other Martian similar sample probes.

2. WATER IN SOIL AND ATMOSPHERE

By taking a look to the expected Martian water allocation as recorded by mars ODYSSEY (Fig. 1) you can see that water measurements in the middle and lower latitudes are very interesting to learn more about the water and not only the hydrogen content.

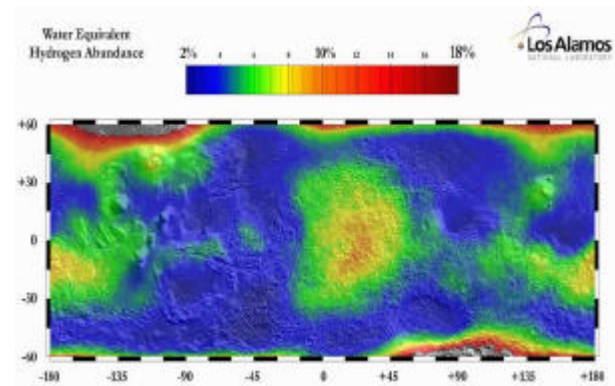


Fig. 1, Global Water allocation

All the states the water can have within its different states of aggregate in combination with other particles and other gas components are shown in Fig. 2. This system is very similar to the earth’s ones but there are other concentrations because of atmospheric

components and especially underpressure and temperature. The water appears in all three states of aggregate in Martian ground and atmosphere, dependent on day/night temperature cycles or seasonal conditions. The interactions of the particle bounded water which will also appear under Martian conditions are very interesting for the true water content on mars.

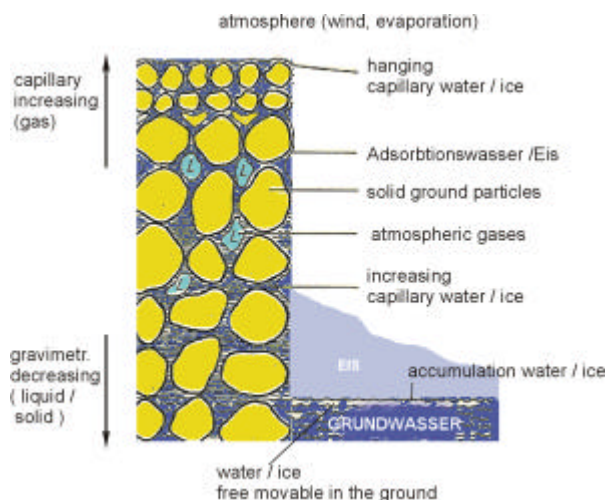


Fig. 2, Martian „ground-atmosphere-water“-system

There exist many known measurement principles for those less water concentrations which are in use by typically industrial applications. But not all of them seem to be suitable for Martian conditions. A summary of the principles which may be taken into consideration is given in Tab 1.

Meas. method	physical principle	Meas. range (% vol)
neutron probe	attenuation of neutrons	0...100
optical meas.	infrared, ultraviolet (Krypton, Lyman-Alpha line)	3...100
high frequency	changing of permittivity TDR, FDR, multifrequency	3...98
equilibrium humidity	polymer-sensor, psychrometre, metal oxide sensor, dewpoint mirror, coulometric sensor (Keidel Cell)	0,5...4 0...1
microbalance tensiometre	quartz crystal oscillator tensiometric soil pressure	0...10 3...100
thermo-gravimetric	thermal drying	0...100
thermal conduct	thermal transport in soil	5...80
microwave indicator/array	resonance/absorption Variation in color and mechanical size	3...50 0,5...40

Tab. 1, measurement methods for soil moisture and low gases humidity (tracer)

When you consider spectroscopy principles where it is surely possible to detect water you have to pay attention to the chemical components the water is made from. Those principles also detect free radicals or other hydrogen atoms. The frequency and time domain principles basically measure the dielectric and permittivity behaviours of a sample probe. Water has a very interesting dielectric constant which depends on temperature and its state of aggregate in a very wide area. So measurements in those less areas can't be possible. Many principles also seem to fail for the requested measurement task. The principles listed under equilibrium humidity are the only suitable ones. By the assembly of two of these principles into one combinatorial measuring head we have enough capabilities to measure in a very wide humidity range.

2.1 Measurement tasks

The main task to fulfil is to measure the absolute humidity content in the near of the Martian ground atmosphere. Therefore many facts have to be considered. Because of the day/ night temperature cycles and the seasonal dependent appearance of water in its different states and concentrations an important measuring task should be the registration of the water vapour content of the martian atmosphere. Therefore we have to consider fog phases which may appear in the near of the ground by the decreasing of the temperature. Next task is to detect very less traces of water in liquid and solid states within the martian soil where the water is bounded at particles. For the choice of a suitable physical measurement principle with the aim to detect those water in its different binding forms three points must be fulfilled. First we need a wide measurement area within the gaseous phase of the water. Second a high accuracy even at the detection of very less humidity contents. And third best selectivity to water in all three states of aggregation.

The measurement principle and the used equipment will have to resist extreme missionary requests. The application time should be ca. two years within the martian ground. The measurement cycle should be once an hour for a day cycle to reduce redundant informations. The design concept must be highly shock resistant for the start, landing and digging of the penetrator as a possible carrier for such a transmitter. Therefore the dimensions should not exceed a length of 30 cm with a diameter of 3cm. The energy and data transmissions have to be done by a cable to the lander where the electronics for the supply and the telemetry are included.

3. THE COULOMETRIC HUMIDITY SENSOR

The functional principle of such a sensor is comparatively simple. Platinum electrodes on a substrate with a thin film of phosphorpent oxide builds the sensitive surface (Fig. 3). As a gas flow contacts this surface, the phosphorpent oxide will react with the water content of the gas stream.

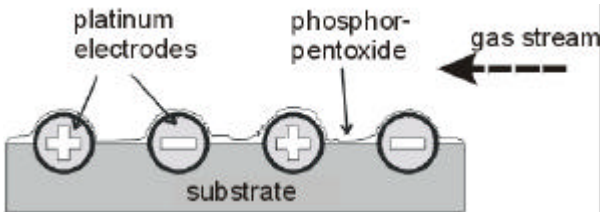
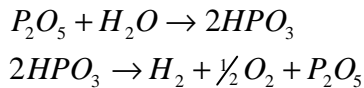


Fig. 3, schematic structure of a coulometric sensor

The total and partial reaction seems to be similar to a dissociation. This only happens in the presence of water. So it is possible to measure within hydrochloric acid, corrosive gases, sulphur combinations and other aggressive mediums.



By creating a constant electrical field at the electrodes, a measurable electric current will appear. This current is directly dependent on the amount of the reacted water which flushes over the whole sensitive surface. While keeping the voltages at the electrodes constant, the sensor can be seen as a variable resistor.

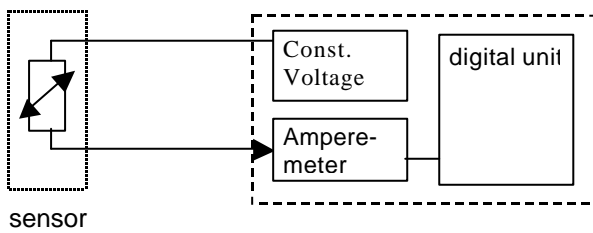


Fig. 4, equipment for the coulometric sensor

The typically used equipment for a simple electronic data processing unit is shown in Fig. 4. It consists of a twelve volt dc regulated power supply, a high precision ampere-meter and a micro-controller unit with special functions which are important for service-times. The current appears at a maximum of ca. 15 mA in this typically industrial application where the platinum electrodes are rolled around a cylindrical glass-tube substrate.

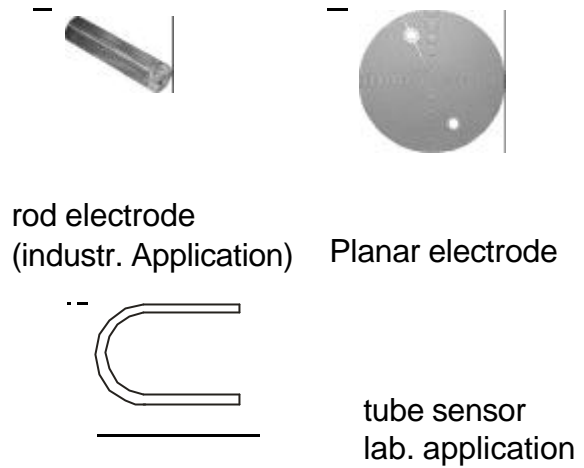


Fig. 5, electrode arrays

Such an industrial sensor cannot be sent to any mission because of many reasons. The current would be too high to make real measurements. Through varying the structure of the electrodes the substrate or the voltage it became known that the current can be set down to several mA by using planar technology and a power supply of ca. two volt.



Fig. 6, coulometric planar sensor

The extreme dimension differences between a typical industrial sensor with a cylindrical body and the planar sensor are shown in Fig. 6. The electrodes are arranged on a plane ceramic substrate. There is also the capability for the implementation of other sensors like for pressure or temperature.

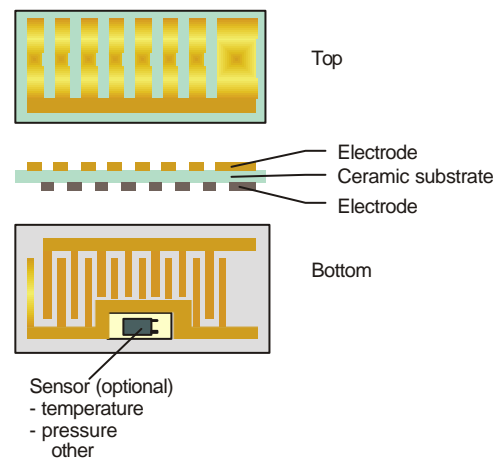


Fig. 7, detailed view of electrode array

As mentioned before, the combination of two humidity sensors into one combinatorial measuring head brings many advantages. The planar coulometric and a capacitive polymer sensor would give the best results. Thus a very wide measurement area especially in view of the operation temperature follows.

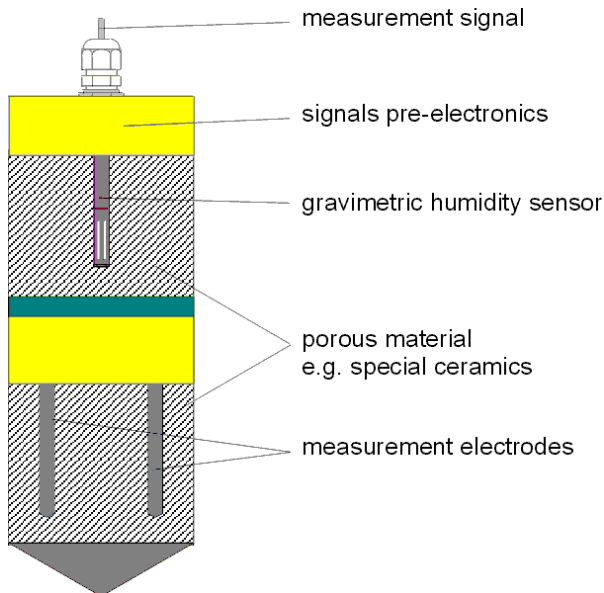


Fig. 8, combinatorial measuring head

The combined head has two chambers, each with another sensor (Fig. 8). The upper chamber includes a low range humidity sensor like the coulometric planar, for example. The other chamber could be an array of measurement electrodes for higher humidity contents. The signals-pre-electronic is included within the connection pieces. In view of a possible mounting of such a measuring head in a cylindrical penetrator, it is recommended to have the sensor within a cylindrical body of porous ceramics, here drawn as the grey hatched. The complete mass is expected to be less than 50 g.

4. SIMULATION CHAMBER

Especially for calibration tasks of the coulometric planar sensor we started the development of a special humidity measurement place at the institute of planetary research in Berlin. The main target of this place is to perform a lot of different long time experiments concerning humidity dependent interactions in not only, but especially Martian similar soil samples to become more known about martian's soil sorbent isothermal lines and to perform calibration possibilities for new humidity transmitters. The humidity content of the absorbed water within a sample mainly depends on pressure and temperature. As everybody knows, mars has a typical underpressure of ca. 6 mbar with a temperature day/night cycle of ca.

minus 90 up to 20 degrees. The humidity content in the martian soil is supposed to be in the area of 10^{-3} molecules per cube-meter. This is would be a very less absolute humidity content under earth's conditions, but for mars you can say it is relatively much because of the underpressure and the temperature range. By seeing these afforded conditions it will be clear that there are many problems to solve. The less absolute humidity causes a very cost-intensive apparatus because of expensive measurement equipment like a dew point mirror but also because of the therefore needed polished pipe lines to reject water residues which might fail the measurement. Also the diameters of the pipe lines are very important. Frozen carbon dioxide could appear at temperature areas less than ca. minus 70 °C which might overlap sensitive surfaces of sensors. However, before starting a measurement, the pipe lines and apparatus pipes have to be cleared from rested water. By taking nitrogen as an initial gas it is possible to reduce the water content to the afforded level. To measure the absorbent isothermal lines of a soil sample other problems will appear. Because it is necessary to measure the mass of the probe within a sample in the inner of the test chamber you need a micro balance which is able to operate at a temperature of ca. minus 90 °C and an under-pressure of ca. 6 mbar. There is no known product on the open market which fulfils this demand. A solution might be a lower-graded trend balance within the sample container to detect at least the saturation of the sample probe. Next the original measurement has to be made external from the test chamber where the next problem occurs. This has to be done very fast to reject any water absorption of the sample probe by the air.

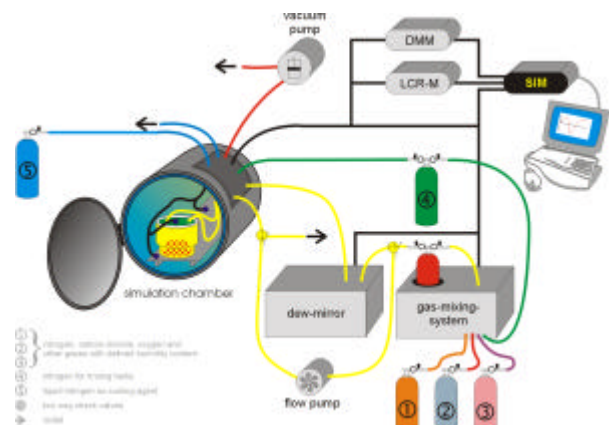


Fig. 9, typical measurement place configuration

The standard configuration consists of a digital multimeter for the phase of the development of the coulometric planar sensor, an LCR-Meter for other sensor technologies in view of referenced measurements, a dew-point mirror for very exactly gas humidity measurements, a gas-mixing-system to simulate Martian atmosphere, several gas bottles,

mainly nitrogen and carbon dioxide and each a flow and vacuum pump to perform pressure dependent experiments. For easy data handling a so called SIM (signal interface module) was developed which can be seen as an interface between the personal computer and the whole measurement place in its electrical signals. All experiments have to be done in a special test chamber.

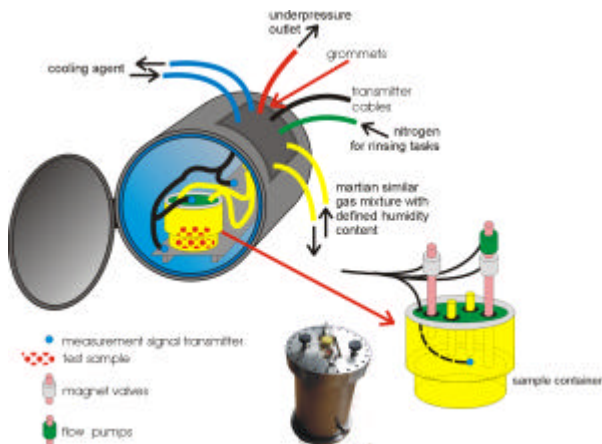


Fig. 10, test chamber and sample container

Because of small sample probes there is no need to use the whole simulation chamber for the experiments. The used container is highly resistant concerning pressure, temperature and grommets. So the best suitability for martian similar experiments is given. You can see schematics to attach small magnet valves and a flow pump directly to the in- and outlets of the container (Fig. 10). This is thought to perform faster measurements in view of rinsing and cooling in the initial phase of a measurement run.

4.1 Signal and data handling

A short trip to the developed electronic system as seen in the figures with the name SIM will show the problems and tasks of the measurement place in view of easy data handling. This device is a 19 inch case including analogue and digital electronic components. The SIM is a micro-controller based logger and generator with special functions and many different interfaces. The number of in- and output channels by its interface types can be taken from Fig. 11. The task of this device is to control and log the whole connected equipment of the measurement place. Connection capabilities for higher graded measurement equipment are also given. The device is portable and supplied with a storage battery. The data's and signal values which are taken from the SIM device are shown directly under EXCEL where the controlling and managing of many input/output schemes are accessible.

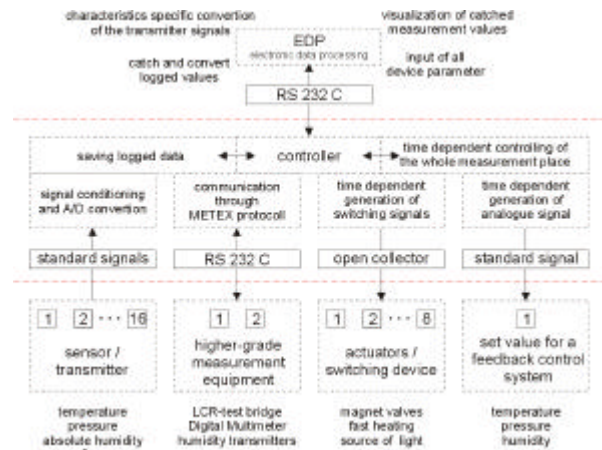


Fig. 11, tasks and canalization of hard- and software

The complete evaluation and controlling software bases upon a visual basic for applications script with an own user mask. Excel has many advantages for those tasks because of its mathematical operations. Especially sensor converting characteristics can easily be set and tested by non-engineering laboratory assistants with standard computer know-how.

5. SUMMARY

It is very important to measure the real water content in the Martian surface because of the remarkable consequences for physical, chemical and possibly also exobiological processes. The coulometric principle is highly recommendable because of its long application time in extreme rough industrial conditions.

→ **Water in the upper (m-scale) Martian surface at mid- and low latitudes is sorption water (physisorbed/adsorption water and chemisorbed)**

→ **Bulk water and ice did not survive until present in the upper meters of the Martian surface at mid- and low latitudes**

→ **Adsorption water is „unfrozen“ or „liquid-like“**

Remarkable consequences for physical, chemical and possibly also biological processes.

THERE IS THE URGENT AND CHALLENGING NEED TO MEASURE IN-SITU THE WATER CONTENT OF THE UPPER MARTIAN SURFACE

→ **coulometrical humidity sensor is applicable under extreme rough industrial conditions**

→ **the coulometric sensor (Keidel Cell) is most appropriate for humidity measurements at and in martian soil**

Fig. 12, summary

When the development phases of the humidity laboratory ends, the following measurements may be very interesting for many different sciences. But the necessary to make real and not simulated in-situ measurements requires a further co-operation with DLR and esa/estec to develop appropriate techniques to measure the water content of the upper martian surface. The key role of deka Sensor and Technology in this co-operation could be to influence the development with new technological possibilities and the long time engineering experience at the field of coulometric measurement principles and humidity behaviours.

6. SAMPLE REFERENCES

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