METER
ENVIRONMENT

User Manual

T5/T5x

Pressure Transducer Tensiometer

Art.Nr. T5
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Table of content

1 Introduction

1.1 Safety instructions and warnings

Electrical installations must comply with the safety and EMC requirements of the country in which the system is to be used.
Please note that any damages caused by handling errors are out of our control and therefore are not covered by guarantee.
Tensiometers are instruments for measuring the soil water tension, soil water pressure and soil temperature and are designed for this purpose only.

Please pay attention to the following possible causes of risk:

- Lightning: Long cables act as antennas and might conduct surge voltage in case of lightning stroke – this might damage sensors and instruments.
- Frost: Tensiometers are filled with water and therefore are sensitive to frost! Protect Tensiometers from frost at any time. Never leave Tensiometers over night inside a cabin or car when freezing temperatures might occur!
  Tensiometers normally are not damaged when the cup is installed in a frost free soil horizon (in general below 20 cm).
- Excess pressure: The maximum non destructive pressure is 300 kPa = 3 bar = 3000 hPa. Higher pressure, which might occur for example during insertion in wet clayey soils or during refilling and reassembling, will destroy the pressure sensor!
- Electronic installation: Any electrical installations should only be executed by qualified personnel.
- Ceramic cup: Do not touch the cup with your fingers. Grease, sweat or soap residues will influence the ceramic's hydrophilic performance.

- Do not twist the T5 shaft against the sensor body!

1.2 Content of delivery

The delivery of a **T5** or **T5x** includes:

- Tensiometer, calibrated and filled, with 4-pin plug M12/IP67, with plug cap
- This manual
- Rubber protection cap, filled with water to the half, for keeping the ceramic moist and clean

For available accessories see chapter “Accessories”.

The delivery of a **T5-set** or **T5x-set** includes:

- Blue plastic transport case
- Tensiometer, filled and calibrated, with 4-pin plug M12/IP67, plug with protective cap
- This manual
- Rubber protection cap, filled to the half with water to keep the cup wet and clean
- Pack of paper tissues
- Polyethylene bottle with 250 ml of water
- Evacuation syringe with acrylic adapter for T5 sensor body
- Evacuation syringe for T5 shaft
- Water reservoir syringe for T5 shaft
- Syringe with pipette tip
- Gouge auger, diameter 5 mm, length 200 mm
- Sensor body auger, diameter 18 mm, length 200 mm
- Connecting cable; 1,5 m length

1.3 Foreword

Measuring systems must be reliable and durable and should require a minimum of maintenance to achieve target-oriented results and keep the servicing low. Moreover, the success of any technical system is directly depending on a correct operation.
At the beginning of a measuring task or research project the target, all effective values and the surrounding conditions must be defined. This leads to the demands for the scientific and technical project management which describes all quality related processes and decides on the used methods, the technical and measurement tools, the verification of the results and the modelling.
The continuously optimized correlation of all segments and it's quality assurance are finally decisive for the success of a project.
So please do not hesitate to contact us for further support and information. We wish you good success with your projects.
Yours,
Georg von Unold

1.4 Guarantee

METER gives a guarantee of 12 months against defects in manufacture or materials used. The guarantee does not cover damage through misuse or inexpert servicing or circumstances beyond our control. The guarantee includes substitution or repair and package but excludes shipping expenses. Please contact METER or our representative before returning equipment. Place of fulfilment is Munich, Mettlacher Straße 8!

1.5 Durability

The nominal lifespan for outdoor usage is 10 years, but protection against UV-radiation and frost as well as proper and careful usage extends the lifespan.

1.6 Tensiometer T5 and T5x

1.6.1 Soils and soil water

All water movements in soils are directly depending on the soil water tension as water - in soils as well as on the surface - always will move from a point of higher potential to a point of lower potential.
The majority of soil water flows take place at small water tensions. Only Tensiometers allow the direct and precise measurement of these small tensions.
Naturally embedded soils are heterogeneous. Not only precipitation and evaporation effect the processes, but also texture, particle size distribution, cracks, compaction, roots and cavities. Due to these heterogeneities the soil water tension varies. Thus, it is reasonable to have multiple measuring points at least in soil horizons close to the surface.

1.6.2 Intended use

The intended use of Tensiometers is the measurement of soil water tension respectively of matrix potential. These Tensiometers work from +100 kPa (water pressure/level) to -85 kPa (suction/soil water tension), the T5x even to a lower tension.
If the soil dries out the Tensiometer runs empty and must be refilled as soon as the soil is sufficiently moist again.
Soil water and Tensiometer water have contact through the ceramic which is porous and permeable to water. A wetted porous ceramic creates an ideal pore/water interface. The soil water tension is directly conducted to the pressure transducer which offers a continuous signal.
The atmospheric reference pressure is provided through a membrane on the cable, a distinctive patented method.

The T5 Miniature Tensiometer is specially designed for punctual measurements, e. g. in soil columns, pots or laboratory lysimeters, or when the measurement of a minimal span is desired.
With an active surface of only 0,5 cm^2 and a diameter of 5 mm the ceramic tip has all advantages of small dimensions: little soil disturbance, punctual pick-up and fast response.

1.6.3 Typical applications

Typical applications of the T5 and T5x:

- Punctual measurement of water potential
- Miniature soil column studies, e. g. in combination with micro water samplers and soil temperature probes
- Determination of pF/wc and K/Psi in soil columns, soil cores or soil sampling rings
- Determination of leachate and capillary water movements
- Controlling irrigation
- Pot experiments
- Measurements in the upper soil horizons in the field
- Monitoring with data loggers
- Spot readings with the INFIELD7

For in the field applications it might be recommendable to use T4, T4e or T8 Tensiometers.

1.6.4 Extended measuring range of the T5x

The special version T5x is tested to reach a measuring range of -160 kPa when delivered. To achieve this, the T5x requires an absolutely bubble free filling.
You might notice that your T5x might even go down to -250 kPa before running empty, sometimes even to -450 kPa, but this is an exception and cannot be guaranteed.
The T5x is identical with the T5 but has a different ceramic. The extended measuring range is made possible by the effect called boiling retardation, the special ceramic with smaller pores and, as a necessary condition, an absolutely gas free filling.

- Do not allow the T5x ceramic to dry out by leaving it unprotected in air: by drying out the tension might reach the destructive pressure.
- Due to the finer pores of the ceramic the water conductivity is lower. Therefore the response of a T5x is slower than with a standard T5.
- When the shaft is touched it might warm up. This might cause a short time change of the pressure.

1.6.5 Specific notes

- T5 and T5x are not suitable for dry soils and they are not frost resistant.
- When installed in the field provide sufficient protection.
- The less air is inside the cup and the better the soil's conductivity is, the faster the Tensiometer will respond to tension changes.
- It does not make sense to refill a Tensiometer as long as the soil is dryer than -90 kPa (T5) or - 160 kPa (T5x).
- Using a quartz clay slurry is only recommendable in clayey soils and only if the drilled diameter is larger than the shaft diameter (5 mm). In coarse sand or gravel soil a fine grained slurry paste would act as a water reservoir which would lead to a slower response.
- The T5 can be installed in any position and orientation. Bubbles are easily detectable through the transparent shaft.
- Output signals are standardized.

1.7 Quick installation guide

This chapter is only a summary of following chapters. Please read the complete manual carefully before using the instrument.

T5 are filled and degassed when supplied and are ready for installation. The procedure is the same for T5 and T5x.

In very soft soils the T5 can be inserted directly without drilling a hole. As the shaft is fragile, no force should be applied.

For hard soils a special auger kit for is available as an accessory (art. no. TBT5; included in the T5-set). When the T5 auger is used, slurrying is unnecessary.

Installation procedure:

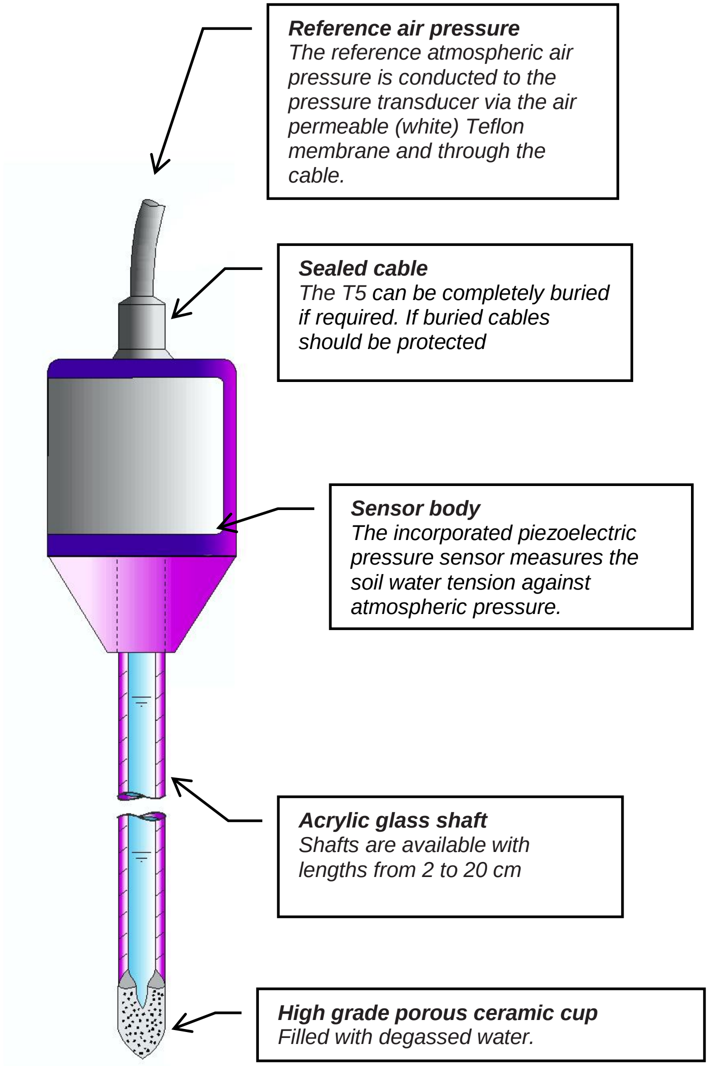
1. Drill a hole with the required diameter and depth. Mark the installation depth on both auger and T5 shaft.

2. Connect the T5 to a readout device, for example a data logger for continuous measurements or the INFIELD7 handheld device for spot readings.

- During the installation the Tensiometer reading has to be controlled at any time. Especially in wet, clayey soils a high pressure might develop while inserting the T5. A pressure of over 3 bar will destroy the pressure transducer. Stop or slow down the insertion to allow pressure relieve.

3. Carefully remove the water filled rubber cover from the tip and gently and steadily insert the T5 down to the mark.

- Never turn the T5 inside the borehole as this might loosen the shaft.
- Put the protection cup on the plug whenever the plug is not connected. Dirt will reduce the water tightness of the plug. Remember to put the protective cap back on the plug after taking spot readings with the INFIELD7.


Reference air pressure
The reference atmospheric air pressure is conducted to the pressure transducer via the air permeable (white) Teflon membrane and through the cable.
Sealed cable
The T5 can be completely buried if required. If buried cables should be protected
Sensor body
The incorporated piezoelectric pressure sensor measures the soil water tension against atmospheric pressure.
Acrylic glass shaft
Shafts are available with lengths from 2 to 20 cm
High grade porous ceramic cup
Filled with degassed water.

2 Sensor description

2.1 Design

2.1.1 Body and shaft

The sensor body is made of acrylic glass and incorporates the pressure transducer and all electronic parts. The corpus is backfilled with resin to hermetically seal the electronics and make the body watertight.

2.1.2 Pressure transducer

The piezoelectric pressure sensor measures the soil water tension against the atmospheric pressure. The atmospheric pressure is conducted through a watertight diaphragm (the white, 2 cm long tube on the cable) and through the cable to the reference side of the pressure sensor.

The non destructive maximum pressure is ±3 bar (300 kPa). Higher pressure will damage the sensor and absolutely must be avoided! High pressures can appear for example when cup and sensor are reassembled, when inserted in wet, clayey soils or in tri-axial vessels.

2.1.3 Reference air pressure

The reference atmospheric air pressure is conducted to the pressure transducer via the air permeable (white) Teflon membrane and through the cable. The membrane does not absorb water. Water will not pass through the membrane into the cable, but moisture inside the cable will leave the cable through the membrane.

The white membrane on the cable must always have contact to air during a measurement and should never be submersed into water.

2.1.4 The ceramic tip

To transfer the soil water tension as a negative pressure into the Tensiometer, a semi-permeable diaphragm is required. This must have good mechanical stability and water-permeability, but also have gas impermeability.
The Tensiometer cup consists of porous ceramic Al_2O_3 sinter material. The special manufacturing process guarantees homogeneous porosity with good water conductivity and very high firmness. Compared to conventional porous ceramic the cup is much more durable.

The bubble point of a T5 cup is about 200 kPa, of a T5x about 500 kPa. If the soil gets dryer than this air passes through so the negative pressure inside the cup decreases and the readings go down to 0 kPa.
With these characteristics this material has outstanding suitability to work as the semi permeable diaphragm for Tensiometers.

❗ Ceramic cup: Do not touch the cup with your fingers. Grease, sweat or soap residues will influence the ceramic's hydrophilic performance.

❗ Do not allow the T5 ceramic to dry out by leaving it unprotected in air: By drying out the bubble point might be reached, the reading will go to 0 kPa and air might enter the cup which requires a refilling.

2.2 Analog output signals

The pressure transducer offers the soil water tension as a linear output signal, with 1 mV corresponding to 1 kPa.
As the pressure transducer is a Wheatstone full bridge, it has to be connected in a certain mode. Please read chapter 3.5.3 and the manual of your display unit or data-logger before connection.

3 Installation

3.1 Scientific measure ideas

3.1.1 Selecting the measuring site

The installation spot should be representative for the soil which should be surveyed. For selection it might be necessary to take soil samples. If the column is refilled care should be taken to achieve the best possible homogenous distribution and evenly compaction. Bear in mind a possible shrinking of backfilled columns when T5 are installed through the cylinder.
On tillage sites (with plants) root spreading and growth during the measuring period should be considered. Fine roots might develop around the ceramic cup as it is a poor but assured water source. Avoid the root zone if possible or replace the Tensiometer from time to time.

3.1.2 Number of Tensiometers per level

The lower the level the less the variations of water potentials are. In sandy or pebbly profundities one Tensiometer per depth is sufficient. Close to the surface about 3 Tensiometers per level are recommendable.

Guiding principle: More heterogeneous sites and soil structures require a higher number of Tensiometers.

3.1.3 Extension of the site

Large distance along with high equidistance between the measuring spots will reduce the influence of sectional heterogeneity.
To determine the water flow according to Darcy two Tensiometers per horizon or required, one each in an upper and lower level of this horizon.
Max. recommendable cable lengths for T5 and T5x are 20 meters:

- Accuracy: long cables cause a reduction of the accuracy.
- Lightning: cables act as antennas and should always be as short as possible.

3.1.4 Ideal conditions for installation

For the installation of Tensiometers, the ideal conditions are:

- Frost-free soil.
- Wet coarse clay or loess.
- Low skeletal structure (gravel).

3.1.5 Documentation

For every measuring spot you should:

- measure the installation spot from 2 reference points (A must for installations below the ground surface).
- Take documenting photos before, during and after installation.
- Save a soil sample.
- Write down installation depth and angle with each sensor identification (serial number).
- Mark all connecting cables with the corresponding sensor identification, serial number or logger channel on each end. Clip-on number rings are available as an accessory.

3.1.6 Selecting the installation angle

An installation position would be ideal if the typical water flow is not disturbed by the Tensiometer. No preferential water flow along the shaft should be created.
If the ceramic cup is positioned higher than the sensor body the first bubble that may appear inside the shaft will block the water exchange and stop the Tensiometer to measure.

3.2 Installation procedure

The following tools are required for installation in the field:

- An auger with diameter 5 mm, preferably the METER Tensiometer auger kit TBT5
- Rule, spirit level, angle gauge, marker pen
- Minute book and camera for documentation of site and soil profile
- Perhaps PE-plastic bags for taking soil samples from the site

1. Drill a hole with the required diameter and depth. Mark the installation depth on both auger and T5 shaft.
2. If the hole's diameter is larger than 5 mm mix a paste of water and grinded soil material.
3. Connect the T5 to a readout device, for example a data logger for continuous measurements or the INFIELD7 handheld device for spot readings.

During the installation the Tensiometer reading has to be controlled at any time. Especially in wet, clayey soils a high pressure might develop while inserting the T5. A pressure of over 2 bar will destroy the pressure transducer. Stop or slow down the insertion to allow pressure relieve.

4. If you use a slurry paste pour it into the hole.
5. Pull off the water filled rubber cap from the shaft. Do not turn the cap as this might unscrew the shaft.
6. Gently and steadily insert the T5 down to the mark while checking the reading.

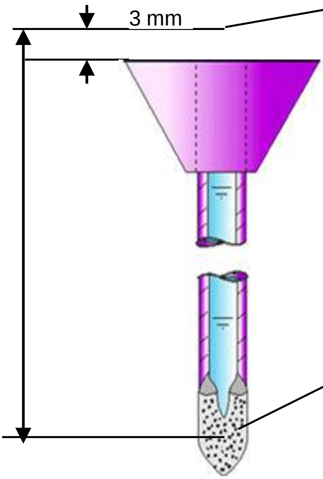
Never turn the T5 inside the borehole as this might loosen the shaft.

The less air is inside the cup and the better the soil's conductivity is, the faster the Tensiometer will respond to tension changes.

7. Put the protection cup on the plug whenever the plug is not connected. Dirt will reduce the water tightness of the plug. Remember to put the protective cap back on the plug after taking spot readings with the INFIELD7.

8. Connect the signal cables as described in the chapter "Connecting the T5 or T5x".
9. Write down the serial number, position, installation angle and depth.
10. Protect the cables against rodent bites. Lead the cables through plastic pipes or use the plastic protection tubes which are available as an accessory.

3.3 Offset correction for non horizontal installations



The pressure transducer is calibrated without a cup. Thus, no compensation is required for horizontal installations.
If a T5 or T5x is installed in a non horizontal position, the vertical water column draws on the pressure sensor and causes an offset shift.

Compensate the offset:
- by calculation,
- by entering the installation angle in the Infield7 for spot readings,
- in the configuration of a data logger by setting an offset.

The deviation is largest for a vertical water column (at 0°). The water column drawing on the pressure transducer is equal to the shaft length, ranging from 2 to 20 cm. The offset is shifted for 0,1 kPa per cm shaft length.
Example: A 5 cm vertical column of water below the pressure sensor will create an 0.5 kPa offset. This means that when the soil water tension is 0 kPa the sensor will indicate -0.5 kPa.
(1 cm water column corresponds to a pressure of -0,983 hPa.)

3.4 Connecting T5 and T5x

3.4.1 Spot readings with the INFIELD7

T5 and T5x are fitted with a 4-pin plug. The plug can be connected directly to an INFIELD7 handheld measuring device for taking spot readings of the soil water tension. The INFIELD7 displays and stores the soil water tension readings. Stored readings can be downloaded with the USB converters tL-8/USB or tL-8/USB-Mini which are available as accessory.

- Remember to put the protective cap back on the plug after taking spot readings with the INFIELD7.

3.4.2 Cables

Connecting and extension cables are required for connecting T5 and T5x to a data logger or other data acquisition device. Find cables in the chapter “Accessories”.

- Cover plugs with the supplied protective cap if not connected.

3.4.3 General requirements

The pressure transducer is a non-amplified bridge circuit which is calibrated for 10.6 VDC and requires a stabilized power supply.
Other supply voltages are possible, but the output signal range has to be recalculated.
In a full-bridge the signal must be measured differentially. This means do not measure only signal plus against common ground, but measure the voltage drop between signal minus against common ground and signal plus against common ground.

- The supply voltage has to be constant and stabilized.
- The supply voltage must not exceed 18 VDC.
- If the Tensiometer is not permanently powered the warm-up before a measurement should be at least 10 seconds. The 99% value is reached after 1/100 seconds.

- If the Tensiometer is supplied with 10.6 VDC the output signal range is around 5.3 VDC. A data logger must have the capability to measure such a signal level, but many loggers cannot do this. In this case use a TV-batt power supply.

3.4.4 TV-batt Tensiometer power supply

The TV-batt power supply is specially designed for Tensiometers T3, T4, T4e and T5. It offers a stabilized 10,6 V power supply, but with supply minus = -5 V and supply plus = +5,6 V. Therefore the output signal will have a logger specific signal level. The Tensiometer signals are in a range of <1 V.
The TV-batt is directly supplied by battery or 12 V mains power.

3.4.5 Connection to a data logger

Some logger types can measure bridge circuits directly, other loggers require certain measures as the Tensiometer signal minus and the supply minus do not have the same ground.

3.4.6 Tensiometer loggers DL6-te or GP1-te

T5 and T5x can be connected directly and without further power supply to the special Tensiometer loggers DL6-te or GP1-te.
The DL6-te is a stand-alone 6-channel logger with six 4-pin sockets. All Tensiometer with 4-pin plug are connected to the DL6-te with *extension cables* EC-4/...
The GP1-te is a stand-alone 2-channel logger with cable glands. All Tensiometer with 4-pin plug are connected to the GP1-te with *connection cables* CC-4/...

4 Service and maintenance

4.1 Refilling

To assure a rapid and reliable measurement of the soil water tension, the cup must be filled possibly bubble-free with degassed water. After dry periods or periods with a large number of wet and drying out successions, Tensiometers must be refilled.

Refilling is the easiest with the refilling tools included in the T5-set or T5-case. A readout device, for example the INFIELD7, is always needed to control the signal.

4.1.1 When do Tensiometers need to be refilled?

Tensiometers need to be refilled:

- the curve of the readings apparently gets flatter (for example a rain event has no sharp peak but is round),
- the maximum of -85 kPa is not reached anymore.

❗ Refilling is only reasonable if the soil is moister than -90 kPa.

If the soil gets dryer than -85 kPa, the readings will remain constant at the vapour pressure of water (i. e. for example 92,7 kPa at 20°C and atmospheric pressure of 95 kPa). By diffusion and slight leakage the reading will slowly drop within months.

If the soil dries out and reaches the bubble point (-200 kPa for T5; -500 kPa forT5x), the tension will decrease rapidly as air will enter the cup.

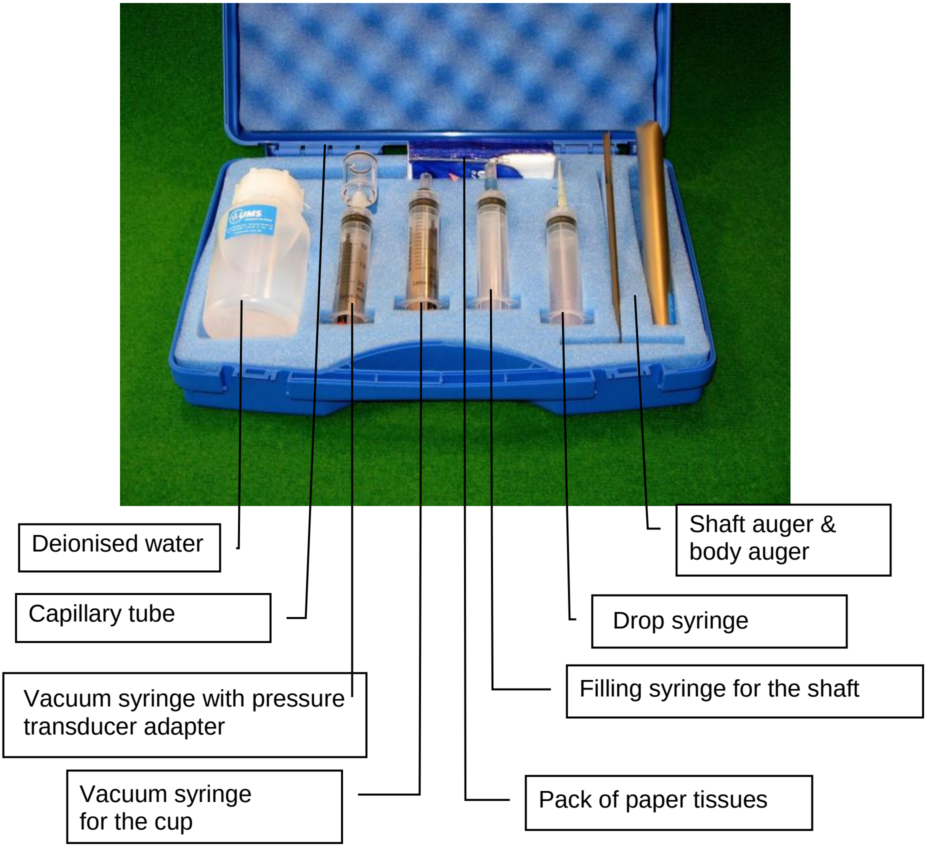
4.1.2 Refilling T5 in lab and field

This chapter describes the refilling of T5 or T5x using the T5-set.
The procedure has 5 steps:

1. Check the T5 Tensiometer
2. Degas cup and shaft
3. Degas sensor
4. Reassemble

5. Function test

The T5-set includes:



Check the T5

1. First, check if the T5 requires a refilling: connect it to an Infield7 or a voltmeter and power supply.

2. Wrap a dry paper towel (kitchen roll) around the cup to dry the ceramic surface.

With short shaft lengths cover the ceramic with a paper towel to avoid contamination.

3. Now wave the T5 tip around in the air. If the reading will rise to -80 kPa within 10 seconds the T5 filling is ok.
If this is not the case the T5 needs to be refilled.

4. To disassemble the shaft hold the sensor body and turn off the shaft counter-clockwise.

The pressure sensor diaphragm is inside the small hole on the pressure sensor body (approx. ∅2 mm). It is very sensitive and must never be touched! It can be destroyed even by slightest contact! No contamination should get on the sealing and gasket.

Degas the cup

If the cup is completely dry just put the shaft in a beaker with deionised or distilled water over night.

Do not fill any water inside the shaft! If water intrudes from inside and outside bubbles are trapped inside the ceramic pores. But if the water only intrudes from the outside and soaks into the inside any air bubbles are pushed out.

1. Take the syringe with the short rubber tube.
Pull up 10 ml of deionised or distilled water.

Take care to avoid bubbles.

2. Remove all air from the syringe.
Now block the tube with your finger and pull up the syringe. This creates vacuum inside the syringe and dissolved gas is released. Turn the still evacuated syringe to collect all bubbles. Hold the syringe upright, unblock the tube and remove all air. Repeat this procedure until no bubbles appear anymore.

3. Insert the ceramic cup into the tube as far as possible with the ceramic pointing inside.
The cup's tip should be close to the syringe nozzle.
Pull up the syringe just a little bit.Hold the syringe down-wards and tap on it to loosen all bubbles.

There should be no air inside the tube around the ceramic. In case fill in some water with the syringe.

4. Take off the tube from the syringe. Leave the shaft inside the tube.
Remove all air from the syringe

5. Put the tube back on the syringe.

6. Now take the vacuum syringe with the 2 black spacers and the O-ring on the tube.
Pull up 10 ml water.

7. Degas the water as described above.

8. Now insert the threaded side of the T5 shaft completely into the tube.
Roll up the O-ring so the shaft is securely fixed: the O-ring should not be in the range of the thread but beyond the end of the thread.

❢ Be careful to keep the parts clean so there will be no leaking when vacuum is applied

9. Now pull up the syringe until both spacers snap in.
Turn the syringe to collect all bubbles, but do not tap on the syringe!
Release the spacers and allow water to flow into the shaft.
Carefully remove the tube from the syringe nozzle and remove all air from the syringe (see 6).

There should be no air inside the tube before inserting the shaft again.

In case fill in some drops of water into the tube with the syringe.
Reattach the syringe and pull it up until the spacers snap in.
Leave the syringes on the shaft.

Degas the sensor body

1. Now take the syringe with the attached sensor body adapter. Pull up the syringe, but not further than shortly before the spacers will snap in.

2. Hold the syringe upwards and remove all air.

3. Insert the sensor body. If you rotate the sensor it will slip in easier.

4. Pull up the syringe a few times. Hold the syringe downwards so bubbles are collected inside the syringe.

5. Take off the tube and remove the air from the syringe.
Leave the sensor inside the adapter.

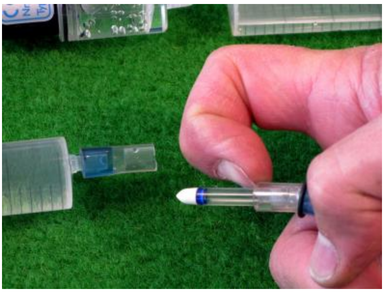
6. Squeeze the tube to remove any air inside while reattaching the syringe.

6. Pull up the syringe until the spacers snap in.
The Tensiometer water now is degassing.

Leave both syringe assemblies for at least 2 hours (the longer the better).

Reassembling

1. Take of the tubes from the shaft.



❗ Taking off the syringe from the sensor body needs care to avoid damage of the pressure transducer!

❗ The piston must not snap in as this might damage the pressure transducer!

2. Hold the syringe and the syringe piston securely. Bear in mind there is still vacuum inside. Press in the spacers and slowly release the piston.

3. Now remove the last remaining bubbles: draw up the syringe once more and release it slowly.
Now take off the syringe and remove the bubble inside.

3. Reattach the sensor body and draw up the syringe again. Tap on the sensor body to release any bubble.

Let the piston release slowly.

5. Now remove the sensor body.

6. Add one drop of water onto the shaft so a bulge of water overlaps the shaft ...

7. … and carefully screw in the shaft into the senor body.

8. Continuously check the pressure with the INFIELD7: the pressure must not exceed 1 bar

You will clearly notice the point when the shaft hits the o-ring inside the sensor body.
From this point do only another quarter turn!

Check the T5

Zero offset:
Place the T5 flat on the table. Put a drop of water on the ceramic cup.
Now the potential is zero and the reading should be between - 3 hPa and + 3 hPa (= -0.3 kPa to +0.3 kPa).

Check the response:
Open the bottle with the water. Dry the ceramic surface with a clean tissue.
Then wave the cup in the air. The reading should rise to -80 kPa within 10 seconds.
If this is the case, the T5 is filled perfectly.

To find out the maximum measuring range of this T5 hold the ceramic tip in the headspace of the bottle over the water.
When you move the ceramic away from the water surface the air gets dryer and the suction rises.
Hold the ceramic as close to the water surface so the tension reading will rise slowly. Depending on the filling quality the value will reach -85 to -450 kPa. Then, the value will rapidly drop to the vapour pressure (around -90 kPa depending on the altitude). Then, immediately put some water on the ceramic and cover the ceramic with the protective bulb which should be filled with water to the half. It will take one day until the Tensiometer will reach its initial value.

4.2 Testing

4.2.1 Calibration

When delivered Tensiometers are calibrated with an offset of 0 kPa (when in horizontal position) and a linear response. The offset of the pressure transducer has a minimal drift over the years. Therefore, we recommend you check sensors once a year and re-calibrate them every two years.
Return the Tensiometers to METER for recalibration, or use the calibration accessories available from METER.

4.2.2 Check the Offset

If there is no pressure difference between the cup interior and the surrounding the signal should be 0 kPa.
There are two ways to check the offset.

1. Connect the Tensiometer to a readout device. Place the T5 in a beaker and fill the beaker with de-ionized water up to the centre of the sensor body (see 3.4.) Wait until the reading is stable. If there are bubbles inside the cup this might take a while.
Now the reading is the approximate offset. The value should be between +0.3 and -0.3 kPa.

2. To check the zero-point more precisely shaft and sensor body need to be disassembled.

- The pressure sensor diaphragm is inside the small hole on the pressure sensor body. It is very sensitive and must never be touched! It can be destroyed even by slightest contact! No contamination should get on the sealing and gasket.
- Before reassembling cup and sensor body carry out the degassing procedure (see chapter "Refilling").

After taking off the shaft shake the pressure sensor to remove water from the pressure transducer hole. The offset is acceptable when the reading is between -0.3 and +0.3 kPa.

4.3 Cleaning

Clean ceramic and sensor body only with a moist towel. If the ceramic is clogged it may be flushed it with Rehalon®.
If the pores are clogged with clay particles saturate the ceramic and then polish the ceramic surface with a wetted, waterproof sandpaper (grain size 150...240).

4.4 Storage

If the T5/T5x should not be used for a year or more then empty shaft and sensor body to avoid algae growth. Store both in a dry place.

5 Protecting the measuring site

5.1 Theft and vandalism

The site should be protected against theft and vandalism as well as against any farming or field work. Therefore, the site should be fenced and signposts could give information about the purpose of the site.

5.2 Cable protection

Outdoors cables should be protected against rodents with plastic protection tubes. METER offers dividable protection tubes as accessory.
In the lab the cables should be fixed so they are not accidentally pulled away and that there is no risk of stumbling.

5.3 Frost

Tensiometers are filled with water and are endangered by frost. T5 and T5x should only be use in frost-free surroundings.

Do not store filled Tensiometer at temperatures below 0°C. Do not leave filled Tensiometers over night in your car, in a measuring hut, etc.

Do not fill the Tensiometers with Ethanol, as this is corrosive for some materials (i. e. PMMA) and will destroy these.

6 Useful notes

6.1 Extended measuring range

The extent of the measuring range of a Tensiometer is influenced by 3 factors:

1. The bubble point
2. The vapour pressure (boiling point)
3. The boiling retardation

6.1.1 The bubble point of the porous cup

The bubble point of a porous, hydrophilic structure is specified by the wetting angle and the pore size. The cups used for METER Tensiometers have a bubble point far beyond the measuring range (8.8 bar). Therefore, the bubble point has no limiting influence.

6.1.2 The vapour pressure of water

At a temperature of 20°C the vapour pressure of water is 2.3 kPa against vacuum. With an atmospheric pressure of 100 kPa and at 20°C the water will start to boil, or vaporize, as soon as the pressure drops below 2.3 kPa against vacuum, i. e. 97.7 kPa pressure difference to an atmospheric pressure of 100 kPa - the Tensiometer drops out.
The measuring range (at 100 kPa/20°C) is limited to -97.7 kPa.

Atmospheric pressures announced by meteorological services are always related to sea level. Thus, the true pressure in a height of 500 meters over sea level is for example only 94.2 kPa although 100 kPa are announced. Then, the measuring range at this height (at 20°C) is even limited to -91.9 kPa.

If the soil gets drier than the maximum possible measuring range the reading will remain at this value and then drop gradually towards zero. If the soil gets as dry as the bubble point a spontaneous equalisation with the atmospheric pressure occurs. Air enters the cup and the reading will rapidly go to zero.

True pressure in heights over sea level at an atmospheric pressure related to sea level as published by meteorological services

Height over sea level (meter)	*Atmospheric pressure (kPa)*	*Max. measuring range at 20°C (kPa)*
0	101.3	-99.0
500	95.5	-93.2
1000	89.9	- 87.6
1500	84.6	- 82.3
2000	79.5	-77.2
2500	74.5	-72.2
3000	70.1	-67.8

6.1.3 Boiling retardation:

Water needs a nucleation site to boil. As our Tensiometers have polished surfaces and a gas-free filling the so called boiling retardation occurs – the Tensiometer keeps on measuring beyond the boiling point. To achieve this the T5(x) must have an absolutely bubble free filling.
Some T5x can go down to -250 kPa before they run dry, occasionally even a range of -450 kPa is achievable. As this is exceptional there is no guarantee for this measuring range.

6.2 Maximum measuring range and data interpretation

The measuring range of Tensiometers is limited by the boiling point of water. At a temperature of 20°C the boiling point is at 2,3 kPa over vacuum. So with 20°C and an atmospheric pressure of 95 kPa the Tensiometer cannot measure a tension below -92,7 kPa, even if the soils gets drier than that. The readings remain at a constant value (fig. 7.1, between day 10 and 16).

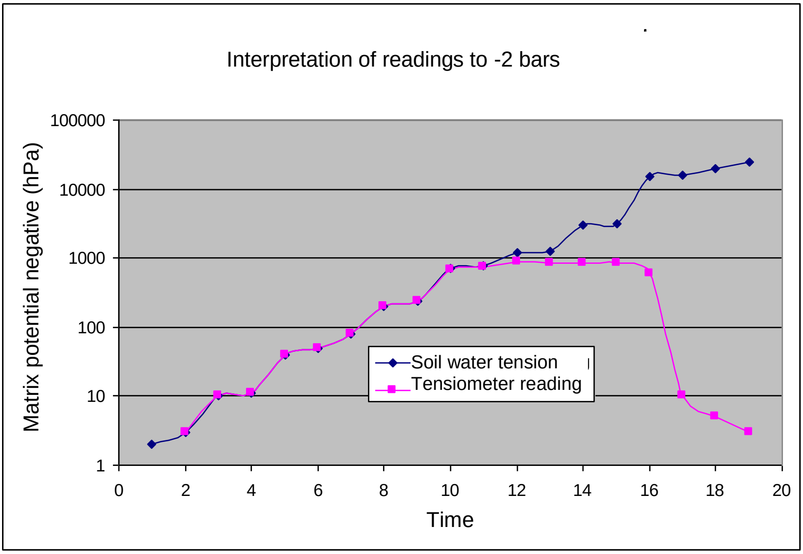


Fig. 7.1: Tensiometer readings with tensions to -2 bar

If the soil will get even drier and reaches -2 bar, the ceramic's bubble point is reached. The cup water will run out quickly and the reading of the air filled cup will go to zero (fig. 7.1, day 16-19)

If there will be rain before the soils reaches -2 bars, the Tensiometer cup will suck up the soil water. However, the soil water includes dissolved gas which will degas as soon as a dry soil again will increase the tension. This will result in a poor response, the signal curve will get flatter and readings will only slowly adapt to the actual soil water tension. Depending on the size of the developed bubble readings will get less close to the maximum (fig. 7.2).

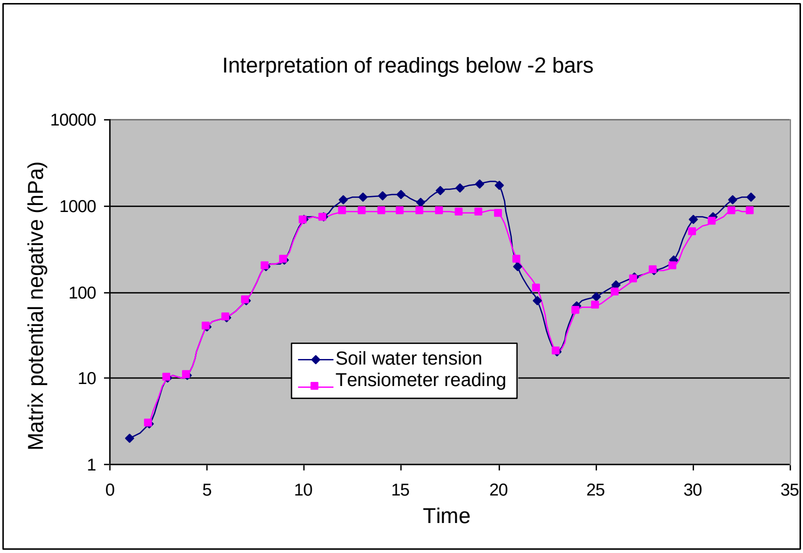


Fig. 7.2 Tensiometer readings with tensions below -2 bar

Soil water tensions normally change only slowly. Therefore, a signal curve with lot of jumps could be an indicator for example for loose contacts, moisture in defective cables or plugs, poor power supply or data logger malfunctions.

6.3 Temperature influences during measurements

If the sensor is not powered continuously the voltage should be switched on 10 seconds before a measurement. In this case, the self heating is negligible.

The correlation of water tension to water content is temperature dependent. The influence is low at tensions of 0 to 10 kPa $\Rightarrow$ 0 … 0,6 kPa/K, but high for tensions over 100 kPa:

$$\boxed{\Psi = \left(\frac{R \cdot T}{M}\right) \cdot \ln\left(\frac{\mathrm{P}}{\mathrm{P}_o}\right)}$$

Ψ = Water tension R = Gas constant (8,31J/mol K)
M = Molecular weight p = Vapour pressure
p_o = Saturation vapour pressure at soil temperature

(from Scheffler/Straub, Grigull)

6.4 Vapour pressure influence on pF/WC

If the temperature of a soil with a constant water content rises from 20°C to 25°C the soil water tension is reduced for about 0,85 kPa due to the increased vapour pressure which antagonizes the water tension.

Temperature in °C	4	10	16	20	25	30	50	70
Pressure change per Kelvin in [hPa]	0,6	0,9	1,2	1,5	1,9	2,5	7,2	14

6.5 Osmotic effect

The ceramic has a pore size of r = 0,3 μm and therefore cannot block ions. Thus, an influence of osmosis on the measurements is negligible because ion concentration differences are equalized quickly. If the T5 cup is dipped into a saturated NaCl solution the reading will be 1 kPa for a short moment, then it will drop to 0 kPa again.

7 Troubleshooting

Please refer to our webpage where you will find a regularly up-dated list of FAQs:

http://www.ums-muc.de/en/support/faq/tensiometer.html

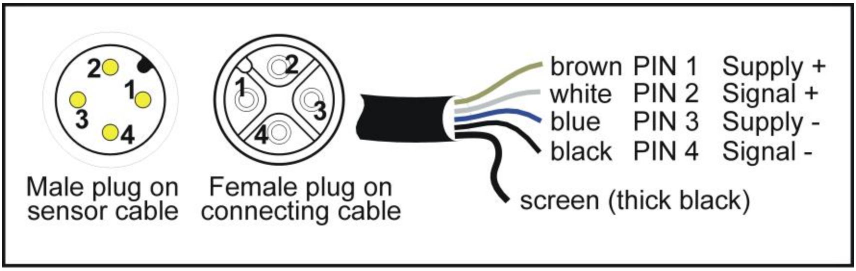
8 Appendix

8.1 Technical specifications

Material and dimensions	
Ceramic material	Al2O3 sinter
Bubble point T5	> 200 kPa
Bubble point T5x	> 500 kPa
Ceramic cup	Length 6 mm, ∅ 5 mm
Sensor body	PMMA, ∅ 20 mm
Shaft material	Impact-proof PMMA, ∅ 20 mm
Sensor cable	
Length	1.5 m
Plug	Male 4-pin, thread M12, IP67
Measuring range	
T5	-85 kPa ... +100 kPa
T5x	min. -160 kPa ... +100 kPa
Water tension	-85 kPa (-160 kPa) … 0 kPa (Tensiometer)
Water level	0 kPa … +100 kPa (Piezometer)
Output signal	
Pressure	160 mV = -160 kPa (T5x) 85 mV = -85 kPa (T5) 0 mV = 0 kPa -100 mV = 100 kPa (water level)
Accuracy	±0,5 kPa
Power supply	
Supply voltage V_{in}	typ. 10,6 VDC by TV-batt (recommended) 5 ... 15 VDC, stabilized
Current consumption	1,3 mA at 10,6 V (TV-batt)
Substance sustainability	
pH range	pH 3 ... pH 10
Limited to substances that do not harm silicon, fluorosilicone, EPDM, PMMA and polyetherimide.	

8.2 Wiring configuration

Configuration of T5 and T5x Tensiometer plug and the 4-wire CC-4 connecting cables:



Pin and wire configuration for UMS connecting cable CC-4

Signal	Wire	Pin	Function
V_{in}	brown	1	Supply plus
V-	blue	3	Supply minus
A-OUT+	white	2	Analog output plus
A-OUT-	black	4	Analog output minus

8.3 Accessories

8.3.1 Connecting and extension cables

Cables must be ordered additionally for each Tensiometer.

METER connecting or extension cables for data logger applications etc.
Connecting cables CC-8/... are fitted with a female plug M12/IP67 and 12 cm wire end sleeves.
Extension cables EC-8/... have one each male and female plug M12/IP67.
Plugs are supplied with protective caps.

Item	Art. no.
4-pin connection cable for T5 and t5x	
Length 1,5 m	**CC-4/1.5**
Length 5 m	**CC-4/5**
Length 10 m	**CC-4/10**
Length 20 m	**CC-4/20**
4-pin extension cable for T5 and T5x	
Length 5 m	**EC-4/5**
Length 10 m	**EC-4/10**
Length 20 m	**EC-4/20**

Additional items	Art. no.
Clip-on cable markers, 30 times numbers 0 ... 9	**KMT**

Plastic protection tube for cables are available with several diameters, also dividable slotted tubes for easy re-fitting.

8.3.2 Handheld measuring device

INFIELD7 handheld measuring device for taking and storing spot readings of soil water tension. Offset correction of water column and installation angle.
Suitable for all METER - Tensiometers. The set comes with refilling tools in small carrying case.
The tL-8/USB-Mini is a USB converter for data readout of the INFIELD7 via PC or laptop USB port, incl. Windows PC software tensioVIEW.

Item	Art. no.
INFIELD7 set	**INFIELD7C**
USB PC adapter for Infield only	**tL-8/USB-Mini**

8.3.3 Tensiometer loggers

6-channel logger DL6-te for Tensiometers T3, T4, T4e, T5 plus 1x counter, 1x temperature, alarm output, 16.000 readings memory, IP68, 4-pin sockets for extension cables EC-4

Data logger GP1-te with channels for 2x Tensiometers, 2x temperature, 2 counters, 1 relay output, IP67

Item	Art. no.
6-channel logger, incl. software and data cable	**DL6-te**
2-channel logger, incl. software and data cable	**GP1-te**

8.3.4 TV-batt power supply

Tensiometer power supply unit for T3, T4, T5, suited in DL2e-logger extension frame (left), or as an open module (right).

Item	**Art. no.**
TV-batt for DL2e logger	**TV-Batt/DL2e**
TV-batt module only	**TV-Batt/module**

8.3.5 T5 auger kit

Auger kit for T5, with shaft auger, length 250 mm length and sensor body auger, length 200 mm.

Item	**Art. no.**
T5-auger kit	**TBT5**

8.3.6 T5-case

Service kit for t5 and T5x (without a T5!), incl. refilling tools (syringes etc.), auger kit, connecting cable CC-4/1.5, all in blue case 35 x 30 x 8 cm.

Item	**Art. no.**
T5 service kit	**T5-case**

8.4 Units for soil water and matrix potentials

	pF	hPa	Cm WS	kPa = J/kg	MPa	bar	psi	%rF
	1	-10	9,8	-1	-0,001	-0,01	-0,1450	99,9993
	2,01	-100	98,1	-10	-0,01	-0,1	-1,4504	99,9926
FK field capacity	2,53	-330	323,6	-33	-0,033	-0,33	-4,9145	99,9756
Standard Tensiometer range	2,93	-851	834,5	-85,1	-0,085	-0,85	-12,345	
	3	-1.000	980,7	-100	-0,1	-1	-14,504	99,9261
	4	-10.000	9806,6	-1.000	-1,0	-10	-145,04	99,2638
Permanent wilting point	4,18	-15.000	14709,9	-1.500	-1,5	-15	-219,52	98,8977
	5	-100.000	98.066,5	-10.000	-10	-100	-1.450,4	92,8772
Air dry, air humidity dependant	6	-1.000.000	980.665	-100.000	-100	-1.000	-14.504	47,7632
oven dry		-10.000.000	9.806.650	-1.000.000	-1.000	-10.000	-145.038	0,0618

8.5 Index

Contact

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Strictly observe rules for disposal of equipment containing electronics.
Within the EU: disposal through municipal waste prohibited - return electronic parts back to METER.

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WEEE-Reg.-Nr. DE 69093488