User Manual

T4/T4e

Pressure Transducer Tensiometer

Art. no. T4, T4e
Version 06/2009
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Table of content

1 Tensiometer T4 and T4e

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, and soil water pressure 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.
- Excess pressure: The maximum non destructive pressure is 300 kPa = 3 bar = 3000 hPa. Higher pressures, which might occur for example during insertion in wet clayey soils, while using of “Triaxialgefäße” or during refilling and reassembling, will destroy the pressure sensor!
- Electronic installation: Any electrical installations must 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.

1.2 Content of delivery

The delivery of a T4 or T4e includes:

- Tensiometer, calibrated and filled, with 4-pin plug M12/IP67 with plug cap
- This manual
- Plastic bottle protecting the ceramic cup (must be filled to half with water to keep the cup wet)
- Rubber shaft water protection disk
- Calibration certificate with each order for conversion of electrical to physical values
- With type T4e: A refilling syringe

T4 and T4e are filled and ready for installation when supplied.

Remark: For available accessories see chapter “Accessories”.

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 modeling.
The continuously optimized correlation of all segments and its quality assurance are finally decisive for the success of a project.
We wish you good success with your projects. Please do not hesitate to contact us for further support and information.
Yours Georg von Unold

1.4 Guarantee

UMS 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 UMS or our representative before returning equipment. Place of fulfillment is Munich, Gmunder Str. 37!

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 substantially extends the lifespan.

1.6 T4 and T4e

1.6.1 Soils and soil water

All water movements in soil 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.

Natural soils (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 especially 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) to -85 kPa (suction / soil water tension).
If the soil gets drier than -85 kPa, the Tensiometer runs dry and must be refilled as soon as the soil is sufficiently moist again (see 5.1).
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.

1.6.3 Types

The T4 is available in 2 versions: the standard **T4** without refilling tubes, and the **T4e** with refilling tubes for refilling the Tensiometer with a syringe.
Within this user manual both versions (T4 and T4e) are described. T4 is used in general for both types and is valid for T4e too. For T4e the refilling process is different and there are special remarks. This is noted within the title of the section.

1.7 Quick start guide

This quick start guide does not replace the user manual. This chapter is only a summary of following chapters. Please read the complete manual carefully before using the instrument!

1. Drilling the borehole
Mark the required drilling depth on auger **and** on Tensiometer shaft.
Note: Installation depth = drilling depth / cos α.

For T4e: For installation from the soil surface, an installation angle of 25° to 65° from the vertical line is ideal for the optimal removal of air from the cup (fig. a). For “horizontal” installation from a manhole the borehole should point upwards in an angle of 5° (fig. b).

2. Slurring the cup is only reasonable in clayey soils and only if the bore hole is larger than the ceramic cup (24 mm). In coarse sand or pebbly soils fine pored slurry might create a water reservoir which slows down the response. With the special Tensiometer gouge auger (article no. TB-25) slurring is unnecessary because of the accurate fitting of the Tensiometer in the soil.

3. Take off the protective plastic bottle from the Tensiometer cup. Tilt and pull the bottle off carefully. If necessary, carefully turn it counter-clockwise!

- Turn the bottle only counter-clockwise when you remove the bottle but also when you reassemble the bottle.

4. Insert the T4 or T4e into the hole to the depth mark with constant gentle pressure and without using force.

- In clayey soils a dangerous overpressure might develop: Check the tensiometer's pressure reading with an Infield measuring device or a data logger!

- Do not turn the tensiometer after it is inserted into the ground - this might loosen the cup.

Note for T4e Tensiometers:

- Pay attention to the engraved black spot on the shaft's top end that marks the position of the exit opening of the external filling inside the cup:

a) *Downwards* installation: If the position of the cup will be lower than the end of the shaft, the black mark must exactly face up! The optimal installation angle is between 25° and 65°.

b) *Upwards* installation: If the position of the cup will be higher than the end of the shaft, the black mark must exactly face down! The optimal installation angle is about 5°.

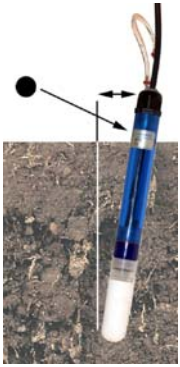


Fig. a) Downwards installation

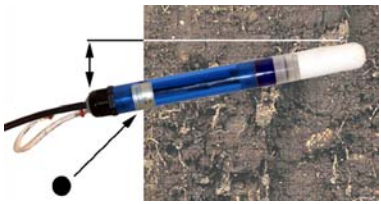


Fig. b) Upwards installation

5. Push down the shaft water retaining disk to a position directly on the soil surface.

6. For T4e: Slide on the thermal insulation tube over the capillary filling tubes.

7. If the plug is not connected right away leave the protective cap on the plug. Dirt will influence the impermeability and Water tightness is only assured when the plug is kept clean.

8. Connect the Tensiometer signal wires as specified (see chapter „Connecting T4")

T4 and T4e can be connected to:

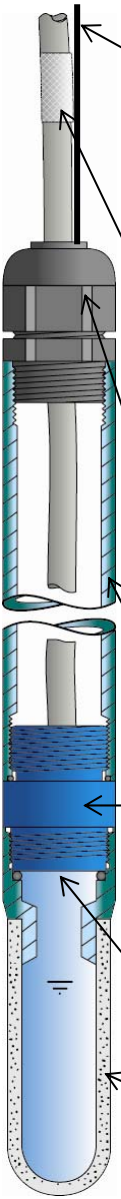
- Data loggers with analog input for recording of analog values
- The INFIELD7 for taking spot readings or for readout of the recorded measured values.

Please note:

Especially in loamy, clayey soils a high pressure can occur just by inserting the T4 or T4e into the borehole. Thus, the pressure values should be continuously observed during installation with an INFIELD7 or a data logger.

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

If the soil is dryer than -90 kPa, it does not make sense to refill the Tensiometer. The refilling procedure will be done best at the time when the Tensiometer installed in the next lower level has reached the value of drying off of the upper Tensiometer.
(Refill the Tensiometer as soon as the Tensiometer that is installed in the next lower level has again reached the reading it had when the upper Tensiometer dried out.)



External syringe refilling (T4e only)
Installed T4e can be refilled or ventilated through the two capillary tubes (stainless steel) without being removed from the soil. The tubes can be extended. With the supplied refilling syringe a measuring range of at least -80 kPa can be assured. With the special Refilling Kit BKTex a range of -85 kPa can be assured.

Reference air pressure
The reference atmospheric air pressure is conducted to the pressure transducer via the water impermeable (white) Teflon membrane and through the cable. The membrane must always have contact to the air and should never be submersed into water.

Cable gland (IP67)
T4 and T4e can be completely buried if required. If buried cables and tubes should be protected. Special cable glands are available for tight connection of a plastic protection tube.

Acrylic glass shaft
One-piece shafts from 10 cm to 200 cm are available. Shafts over 200 cm are divided with threaded adapter and are available up to nearly any length.

Sensor body with electronic
The incorporated piezoelectric pressure sensor measures the soil water tension against atmospheric pressure. Direct connection to the tensiometer power supply unit TV-batt

Pressure transducer
Position of the pressure senor opening, position of the the ventilation tube (T4e only).

High grade porous ceramic cup
Filled with degassed water, with refilling tube (T4e only).

2 Description of T4 and T4e

2.1 Parts

2.1.1 Body and shaft

The pressure transducer is integrated in the sensor body. The electronic is completely sealed and thus well protected against moisture. The shaft is made of blue acrylic glass and has a very high durability and impact resistance.

2.1.2 Pressure sensor

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 conducted through the cable to the reference side of the pressure sensor.

- The non destructive maximum pressure range 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, getting rapidly frozen i.e. on air 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 condensed water inside the cable will leave the cable through the membrane.

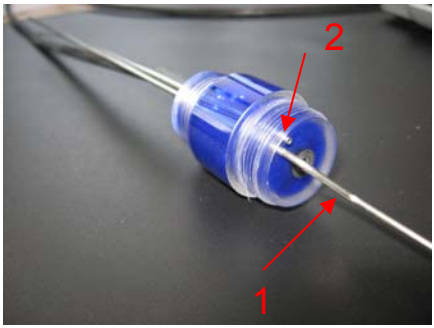
- The white membrane on the cable must always have contact to air and should never be submersed into water.

2.1.4 The ceramic cup

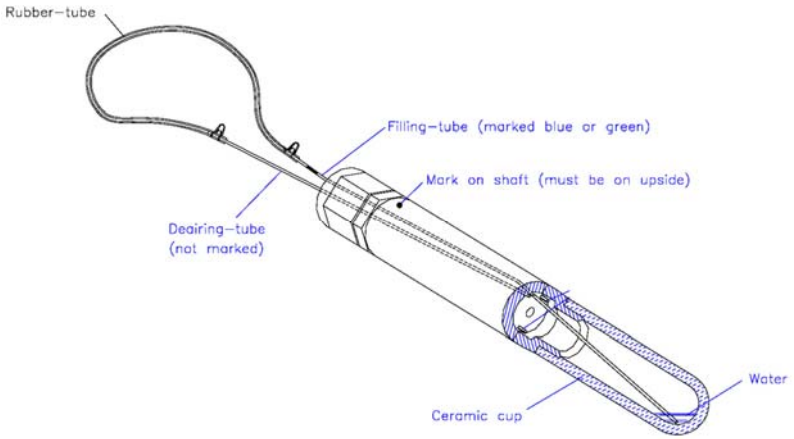
To transfer the soil water tension as a negative pressure into the tensiometer, a semi-permeable diaphragm is required. This must have good mechanical stability and water-permeability, but also have gas impermeability.
The tensiometer cup consists of ceramic Al2O3 sinter material. The special manufacturing 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 is at least 1500 kPa (15 bar). If the soil is dryer than -1500 kPa (-15 bar) 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.

The cup has a lifetime guarantee against breakage.

2.2 External refilling (T4e only)



The T4e is equipped with 2 stainless-steel capillary tubes which are lead through the cable gland and the shaft. Each one has an opening that ends inside the ceramic cup. This allows an easy refilling of the T4e while it remains installed in the ground.
Tube 1 ends at the very tip of the cup, tube 2 ends next to the pressure transducer opening. Outside, both tubes are connected with a short rubber tube.
Any air bubbles will ascend and accumulate either in the ceramic's tip around tube 1 (upwards installation angle) or next to opening 2 (downwards installation angle). Accordingly the air is removed either through tube 1 or 2 (please see chapter 3.2).



2.3 Analog output signals

The pressure transducer offers a linear output signal. As the output signal directly depends on the supply voltage, the supply voltage needs to be constant and stabilized.
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 Advance planning

3.1.1 Selecting the measuring site

The installation spot should be representative for the soil horizon! Therefore, in heterogenic soils, classifying drillings should be made before or during installation.
On farmed sites with vegetation root spreading and root growth during the measuring period must be considered. Fine roots will grow around the Tensiometer cup as this is a poor but still secure source of water. Therefore, avoid the root zone or move the Tensiometer from time to time depending on the root growth.
Disturbing effects like waysides, the rim of a field, slopes or dints must be avoided or considered in the interpretation of the measuring results.

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 obtain a differential description of the soil water situation at least 2 Tensiometers are recommended per horizon, one in the upper and one in the lower level.
Max. recommedable cable lengths for T4 and T4e are 40 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 Protection of refilling tubes (T4e only)

A recent study by Prof. Wolfgang Durner showed that refilling tubes must be protected from heating up and solar radiation.

If a bubble assembles inside a refilling tube, i.e. temperature rises will lead to an expansion of the air resulting in a variation of the reading. Therefore, refilling tubes should be as short as possible and should be thermally protected, either by providing an insulating protection or by burying the tubes.

Thermal effect:
As long as the Tensiometer and its tubes are freshly and completely filled, it will work perfectly. Any air trapped inside the upper parts of the tube will expand when heated up by solar energy. This causes a drop of the water tension and some water will flow from the cup into the ground.
Thus, readings will fluctuate around the actual reading during solar radiation, especially with low water potentials. Furthermore, under permanent solar exposure the tubes get sticky and brownish.

Slide the supplied thermal insulation tube over the shaft end and the refilling tubes as shown in above photo!

3.1.5 Jacket tubes

Jacket tubes are useful with shafts longer than 2 m, in pebbly soils or gravel, and for horizontal installations from inside a well or pit hole. The jacket tube should end 30 to 50 cm away from the cup so leaking or condensation water is not conducted to the cup. The inner diameter of the jacket tube should be at least 35 mm.

3.1.6 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). The more gravel in a soil the more often the drilling has to be repeated to reach the required depth.

3.1.7 Documentation

For every measuring spot you should:

- Measure out the position where the pressure sensor will be placed. (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 together with the 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.

3.2 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. Therefore, Tensiometers are preferably installed at an angle.

3.2.1 "Vertical" with downwards angle (T4e only)

When installed from the surface, an angle of 25° to 65° from the vertical is optimal for refilling. In an absolutely vertical position air bubbles might remain inside the edges of the cup adapter. Still, they could be removed completely with the vacuum refilling kit BKTex. In this position, the refilling tube is the shorter stainless steel tube with the black mark. Into this tube, water is injected for refilling.

- Before inserting the Tensiometer, turn the shaft so the black mark near the shaft end points upwards.
- Do not turn the shaft after it is inserted into the ground as this might loosen the cup.

3.2.2 "Horizontal" or upwards installation anle (T4e only)

When installed horizontally or upwards from inside a well or pit hole, the shaftmark must look downwards! An upward angle of approx. 5° is ideal for refilling. Note that now de-airing and refilling tube are switched: the refilling tube is the longer stainless steel tube without the black mark. Into this tube, water is injected for refilling.

- Before inserting the Tensiometer, turn the shaft so the black mark near the shaft end points downwards.
- Do not turn the shaft after it is inserted into the ground as this might loosen the cup.

3.3 Installation procedure

For the installation of the Tensiometer in the field the following tools are required:

- Tensiometer auger with diameter 25 mm, ideally the UMS gouge auger with shaped blade tip.
- Rule, spirit level, angle gauge, marker pen.
- Minute book, camera for documentation of site and soil profile.
- Perhaps PE-plastic bags for taking soil samples from the site.
- Thermal insulation tubes for installations from soil surface.
- Cable protection tubes.
- Jacket tubes if required (inner diameter > 35 mm).

Please observe the following notes:

- Do not touch the cup with your fingers. The ceramic should not have contact with grease or soap as this will influence the hydrophilic performance.
- Do not leave the cup in air for more than 5 minutes as Tensiometer water will evaporate and the Tensiometer will need to be refilled.

Procedure:

1. Mark the required drilling depth on auger and Tensiometer shaft. The reference point is the center of the cup. Drill a hole with the desired depth on the chosen measuring spot. Auger stepwise and take care when drilling the last 20 cm, remove and save this soil. Water will not run along the shaft if the Tensiometer is installed in an angle because the water will drain into the soil before it reaches the cup.

- Read the chapter "Selecting the installation position" for the best installation angle.

2. When using augers with a diameter of over 25 mm, mix a paste of water and crumbled soil material taken out of the borehole. Fill the paste into the bottom area of the borehole by using a simple pipe with outer diameter about 2 cm.
3. Now take off the protective plastic cap from the Tensiometer cup.

- Important: Do not turn, but pull when taking the bottle off - and also when putting it back on again!
- Save the plastic bottles: Do not store the Tensiometer without the protective plastic bottle filled with a bit of water since the cup drains fast! *Also for storage the bottle must be filled with some water for storage*!

4. Connect the Tensiometer to a readout unit. Carefully insert the T4/T4e into the borehole up to the stop while continuously observing the pressure signal. Using the TB25 auger you feel a light resistance at the last 6 cm indicating proper soil contact of the ceramic.

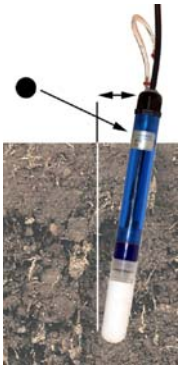
- Do not use any force. Do not hit the Tensiometer - this may damage cup and pressure sensor.
- Especially in clayey soils the pressure reading must be monitored as high pressures might build up! The pressure must not exceed 200 kPa

Note for T4e Tensiometers:

Important: Pay attention to the engraved black spot on the shaft's top end that marks the position of the exit opening of the external filling inside the cup:

a) *Downwards* installation: If the position of the cup will be lower than the end of the shaft, the black mark must exactly face up!

b) *Upwards* installation: If the position of the cup will be higher than the end of the shaft, the black mark must exactly face down!



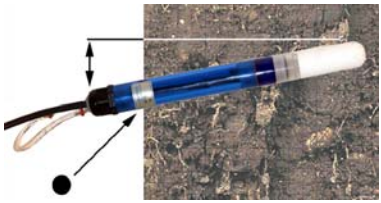
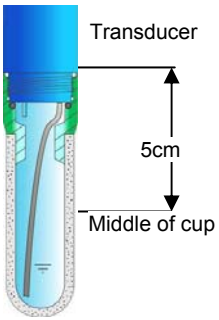


Fig. a) Downwards installation **Fig. b) Upwards installation**

5. Press the soil surface with your boots gently to the shaft to close the gap.
6. Push the shaft water retaining disk down to cover the soil surface. This prevents water from running down into the borehole along the shaft.
7. Leave the protective plastic cap on the plug whenever the plug is not connected!
8. Connect the signal cables as described in the chapter "Connecting the T4 or T4e".
9. The Tensiometer will respond to changes in the soil water tension faster if there is no air inside the system and the soil water conductivity is high.
10. Write down the serial number, position, installation angle and depth.
11. Slide the supplied thermal insulation tube over the shaft end and the refilling tubes. Bend the signal cable and lead it back through the thermal tube.
12. Protect the cables against rodent bites. Lead the cables through plastic pipes or use the plastic protection tubes which are available as an accessory.

3.4 Offset correction for non horizontal installations



The pressure transducer is calibrated without a cup. Thus, no compensation is required for horizontal installations. If a T4 or T4e 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 middle of the cup is regarded to be the measuring level. The correction is largest for a vertical water column (at 0^{o}) and varies as

the cosine of the installation angle, as shown on the table below. In an absolutely horizontal position the offset is zero.

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.

Table showing the offset correction when a 5 cm column of water is tilted at various angles:

Angle to vertical line	**0°**	**10°**	**15°**	**20°**	**25°**	**30°**
Offset correction in [kPa]	+0,5	+0,49	+0,48	+0,47	+0,45	+0,43

Angle to vertical line	**45°**	**60°**	**70°**	**75°**	**80°**	**90°**
Offset correction in [kPa]	+0,35	+0,25	+1,7	+1,3	+0,9	0

The offset is entered as + in your logger if you regard the soil water tension to be a negative pressure (0 ... -85 kPa).

3.5 Connecting T4 and T4e

3.5.1 Spot reading with the INFIELD7

T4 and T4e 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.

3.5.2 Connecting cables

Connecting and extension cables are required for connecting T4 and T4e to a data logger or other data acquisition device. Find cables in the chapter “Accessories”.

Tightly screw together all plugs of connecting cables (CC-4/...) or extension cables (EC-4/...). Do this again after a few minutes as only then the connections will be absolutely water proof.

3.5.3 Connection to a data logger

The pressure transducer is a non-amplified bridge circuit which is calibrated for 10,6 VDC and requires a stabilized power supply.
Some logger types can measure bridge circuits directly, other loggers require certain measures as the signal minus and the supply minus do not have the same ground.
When supplied with just 10,6 V (supply minus = 0 V and supply plus = 10,6 V) the output signal range is between +3,2 V (min.) and +6,8 V (max.) related to power supply minus.
Other supply voltages are possible, but the output signal range has to be recalculated.

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.

Tensiometer loggers DL6-te or GP1-te

T4 and T4e can be connected directly and without further power supply to the special Tensiometer loggers DL6-te or GP1-te.
The DL6-te is a 6-channel logger with six 4-pin sockets. T4 and T4e are connected directy or using extension cables EC-4/... .
The GP1-te is a 2-channel logger with cable glands. T4 and T4e are connected with connecting cables CC-4/...

- The supply voltage has to be constant and stabilized.
- If the Tensiometer is not permanently powered the warm-up before a measurement should be at least 1/100 sec, best 10 seconds.
- The Tensiometer plug should be covered with the supplied protective cap if not connected to a cable.
- The supply voltage must not exceed 18 VDC.

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, the T4 or T4e must be refilled.

The following items are required for all refilling methods:

- Syringe with valve (one supplied with each order)
- Degassed, de-ionized or distilled water
- Measuring device for checking the pressure signal

Simple method to degas water:

The best way to degas water is by using a syringe.

- Draw up water into the syringe until it is 2/3 filled. Close the valve or block the syringe with your finger.
- Now draw up the syringe as far as possible to create a vacuum inside. Rotate the syringe to create one big bubble.
- Take of your finger or open the valve and squeeze out the bubble.

Repeat this procedure a few times.

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 or if a lower level installed Tensiometer shows wetter readings again compared with the time the upper Tensiometer stopped working.

or as soon as a Tensiometer installed in a lower level shows wetter readings than the reading at which the upper Tensiometer stopped working.

If the soil gets dryer than -85 kPa, the readings will remain constant at the vapor 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 more than -1500 kPa (-15 bar), the negative pressure will drop much faster as air will enter the cup.

4.1.2 Refilling in the lab

To reach the optimal measuring range of -90 kPa Tensiometers should be refilled with the BKTex or in the laboratory using the refill kit.

1. Set up the refilling kit and connect the vacuum pump as shown in fig. 4.1. The pump should achieve at least 0,8 kPa against vacuum. Use distilled or de-ionized water which necessarily does not have to be degassed when a pump is used.

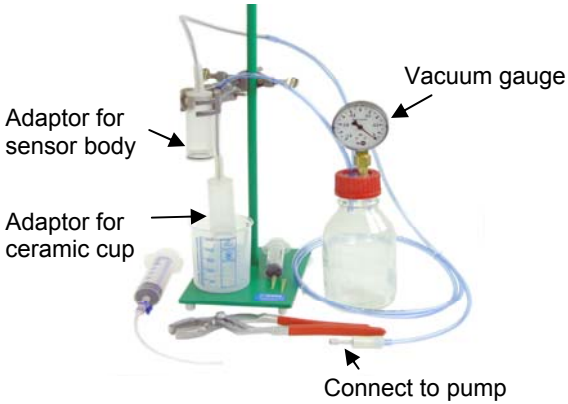


Fig. 4.1: UMS laboratory refill kit BKT468

2. Unscrew the cup in clockwise direction and empty it.

- Do not touch the ceramic cup with your fingers. Wrap a clean towel around the cup!
- The pressure sensor diaphragm is inside the small hole on the pressure sensor body. It is very sensitive and may never be touched! It can be destroyed even by slightest contact!
- No contamination should get on the sealing and gasket.

3. If the cup is dry it should be placed in a beaker filled with distilled water for several hours or overnight. Initially there should be no water inside the cup! Place the empty cup into the beaker in an upright position, with the external water level reaching no higher than 2/3 of the cup.

If the cup is filled with water and water intrudes from both inside and outside cavities of air will be enclosed inside the ceramic.

4. Insert the saturated but empty cup to the adapter and connect it to the degassing device. Place the cup in water in an upright position.
5. Fill the second UMS adapter capsule to the half with water and insert the sensor body. Connect the adapter to the degassing device as well.
6. Now start the vacuum pump. With well-saturated cups, the procedure will take 1 to 2 hours. From time to time knock on cup and sensor body to loosen bubbles. Degassing is complete when no air bubbles ascend from ceramic and body and the cup is completely filled with water.
7. Before screwing together cup and sensor body connect the sensor to a measuring device to observe the pressure signal.

Destructive pressure is 3 bar.

Hold the cup in an upright position, fill it completely and with an overlapping bulge of water. Carefully and slowly screw the cup on the sensor body. Allow the excess water to escape. Make sure that no bubbles are enclosed.

8. Fix the Tensiometer in an angle so the cup is pointing downwards, and the black mark on the shaft is on top.
9. Degas the water in the syringe as described above and connect it to the marked refilling tube. Do not bend the rubber tube. Carefully press water into the refilling tube until no bubbles come out of the de-airing tube. Fill in at least 25 ml. Check the pressure at any time!
10. Remove the syringe and connect the rubber tube to the open refilling tube.

4.1.3 Refilling in the field (T4e only)

T4 or T4e Tensiometers can be refilled with the supplied 50 ml syringe through the stainless steel tubes without removing them from the soil. If the refilling tubes have a total length of 5 meters or more it might be necessary to use the hand-operated vacuum pump – see chapter 4.1.4.
With this method a measuring range of at least -80 kPa can be achieved.

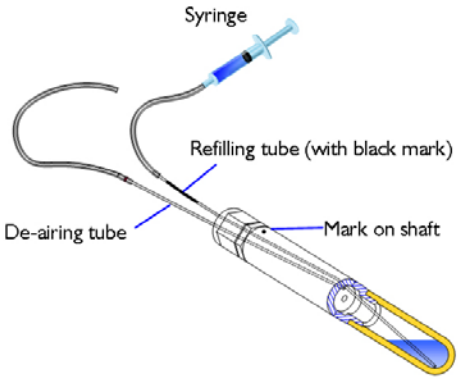


Fig. 4.2 Downwards installation – the marked tube is the refilling tube, the unmarked tube the de-airing tube

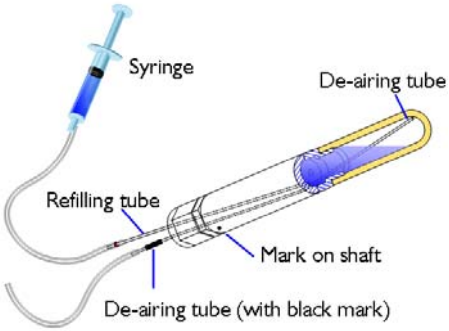


Fig. 4.3 Upwards installation – the marked tube is the de-airing tube, the unmarked tube the refilling tube
Procedure (see fig. 4.2 & 4.3):

1. Connect the T4e to the measuring device and keep an eye on the pressure signal at any time.
2. Two steel capillary tubes come out from the T4e shaft: The refilling tube and the de-airing tube. In a downwards installation the marked tube is the refilling tube, in an upwards installation the not marked tube is the refilling tube. Pull off the rubber tube from the refilling tube.
3. Connect the tube of the water filled syringe to the refilling tube.
4. Carefully inject water into the refilling tube until no bubbles come out of the de-airing tube. Fill in at least 25 ml. Check the pressure at any time!
5. Remove the syringe. Put a drop of water on both rubber and steel tube's end. Connect both.

4.1.4 Refilling with a vacuum pump (T4e only)

To achieve the maximum possible measuring range Tensiometers can be completely degassed using a vacuum pump. This method can be applied for installed Tensiometers in any installation angle as well as for not installed Tensiometers. For refilling tubes longer than 5 meter this method should always be used.

The UMS refill kit **BKTex** includes all required tools: hand-operated vacuum pump, vacuum bottle with tube and syringe with valve.

Procedure (see fig. 4.4 & 4.5):

1. Connect the T4e to the measuring device and keep an eye on the pressure signal all the time.
2. In a downwards installation the marked tube is the refilling tube. In a upwards installation the unmarked tube is the refilling tube. Pull off the rubber tube from the refilling tube.
3. Degas the water inside the syringe as described above. Connect the syringe to the refilling tube and close the valve!
4. Connect vacuum bottle and de-airing tube. With the vacuum pump evacuate the bottle to the maximum possible vacuum. This will enlarge the remaining bubble inside the cup.
5. Now briefly open and close the valve of the syringe for a few times: water is drawn into the Tensiometer while at the same time

the air bubble is sucked into the vacuum bottle. Repeat this 2 or 3 times until no bubbles come out anymore.

6. Close the valve of the vacuum bottle and remove the bottle. Inject 5 ml of water from the syringe into the refilling tube. Remove the syringe. Put a drop of water on both rubber and steel tube's end. Connect both.

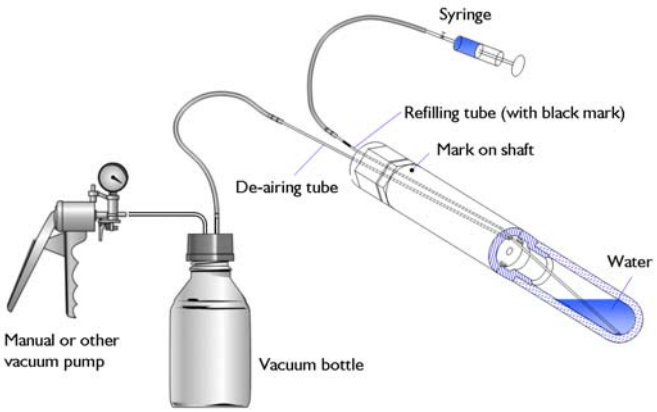


Fig. 4.4 Downwards installation – the marked tube is the refilling tube, the unmarked tube the de-airing tube

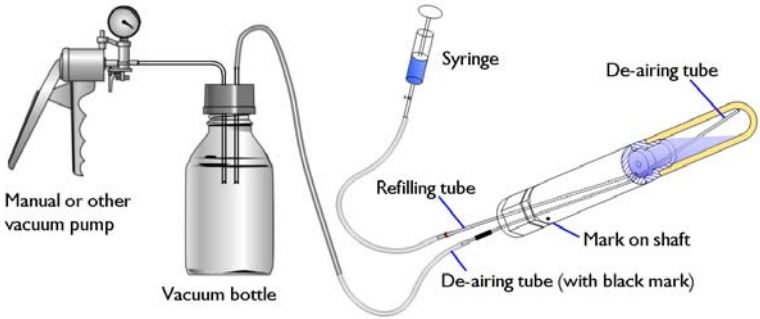


Fig. 4.5 Upwards installation – the marked tube is the de-airing tube, the unmarked tube the refilling tube

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 UMS for recalibration, or use the calibration accessories available from UMS.

4.2.2 Check the Offset

There are two ways to check the offset.

1. Connect the Tensiometer to a readout device. Place the cup in a beaker and fill the beaker with distilled or de-ionized water to a height of 7,5 cm. Wait until the reading is stable. If there are bubbles inside the cup this might take a while. The reading now should be 0 kPa.

2. To check the zero-point more precisely unscrew the cup. Shake the pressure sensor to remove water from the pressure transducer hole. The offset is acceptable when the reading is between -0,5 and +0,5 kPa.

- 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 5.1.2 "Refilling in the lab").

For testing the signal gradient a calibration kit is required.

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

Cables should be protected against rodents with plastic protection tubes. UMS offers dividable protection tubes as accessory. For long term studies we recommend to dig cables a few centimeters below soil surface inside protection tubes.

5.3 Frost

5.3.1 Protection against frost

Tensiometers are filled with water and are endangered by frost.

- Do not store filled Tensiometer at temperatures below -5°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.

Also it is not recommended to fill the Tensiometers with Decalin, mono-ethylene-glycol, di-ethylene-glycol, etc. These could harm any of the materials, destroy the ceramic cup or leak into the soil.

T4 and T4e Tensiometers may remain installed during the winter if the cup is positioned in a depth of at least 20 cm. Then, the frost will ingress the cup slowly without damaging the pressure sensor. The reading will jump to a constant value. After unfreezing the Tensiometer will continue to work.
But as this depends on the clime of your region please contact UMS if you install Tensiometers in extreme temperature zones.

5.3.2 Emptying T4 or T4e

Also read chapter 4.1.

T4e Tensiometers:

1. Remove the connecting rubber tube from the refilling tube. In a downwards installation the refilling tube is the marked tube, in an upwards installation the refilling tube is the not marked tube.
2. Connect the empty syringe to the refilling tube and completely suck out the Tensiometer water.
3. Connect rubber tubes and filing tube.

T4 Tensiometer installed within the depth of frost penetration must be removed and stored in a frost safe place.

5.4 Lightning protection and grounding

In-the-field measuring equipment is always susceptible to electrical surge. UMS sensors and stations are protected against over voltage and false polarity as far as this is technically achievable.
But there never can be total lightning protection. Lighting strikes are unpredictable and vary significantly with region, voltage and destructiveness. A proper lightning protection has to be considered whenever a system with several sensors and loggers is installed.

Passive lightning protection measures would comprise one or more grounding rods, preferably with ground water contact, but without (!) an electrical connection to the measuring system.
With an active lightning protection each sensor and the logger are equipped with an individual grounded surge protection module. Unfortunately, these are very expensive.

Please contact UMS or your UMS dealer for assistance about integrating T4 or T4e into your measurement system.

General recommendations for lightning protection and grounding for stations with battery power	
First step	Measure the voltage drop between sensor positions, data acquisition etc. to get to know the potential levels
Recommendations for lightning protection on masts	2 or 3 meter masts can be equipped with a lightning rod which is installed on top of the mast, and a grounding rod which is clamped to the foot of the mast. This creates a certain protected space in a 45 degree angle around the tip
Recommendations for lightning protection of enclosures	Surge protection devices are installed in one corner inside the measuring enclosure. All lines to and from the surge protection devices should not run parallel.
System protection of stations with enclosure and mast	Lines to equalize drops in the electrical potential between mast and grounding rod are installed 50 cm below the soil surface.
Lightning protection with grounding rods	According to the standards the ground rod (diam. 25 mm) must be inserted into the ground for a minimum of 2,5 meters below the frost level, i. e. in general 3 meters. Cross shaped rods are less advisable for such low depths, but this depends on soil type, moisture or clay content, and distance between soil surface and ground water level.

6 Useful notes

6.1 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 i.e. 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).

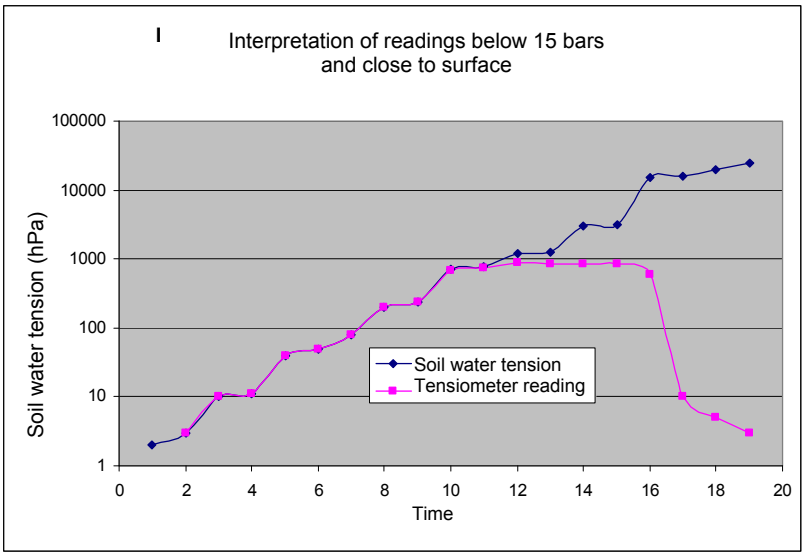


Fig. 7.1: Tensiometer readings with tensions to -15 bars

If the soil will get even drier and reaches -15 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 to 19)

If there will be rain before the soils reaches -15 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, after day 20).

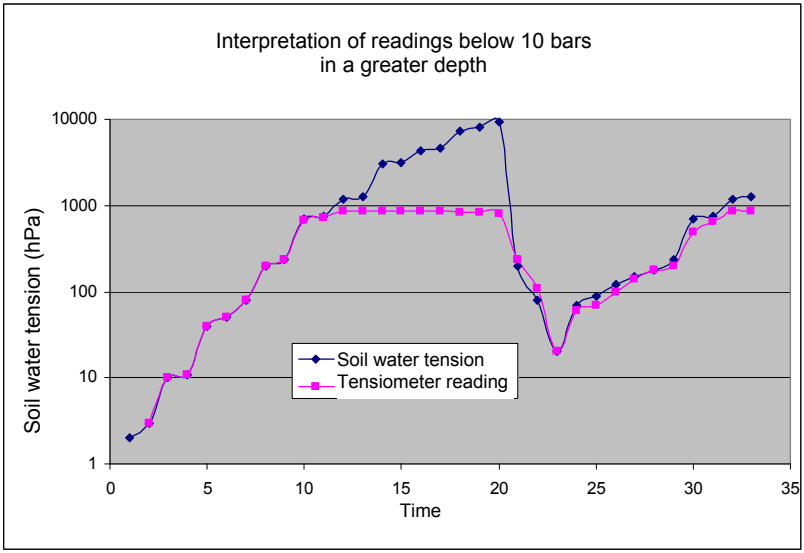


Abb. 7.2 Tensiometer readings with tensions to -10 bars

Other problems that can be recognized by checking the data:
Soil water tension 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 malfunction.
With T8 and T4e Tensiometers, unsteady signals might also be caused by solar radiation on the refilling tubes. This would require the use of thermal isolation - see chapter 3.1.4.

6.2 Temperature influences

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 ⇒ 0 … 0,6 kPa/K, but high for tensions over 100 kPa:

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

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

(from Scheffler/Straub, Grigull)

6.3 Vapor 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 vapor 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

6.4 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 T4 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.

6.5 Using Tensiometers as a piezometer

T4 or T4e can be used as a piezometer for measuring water over pressure. Calculate the height of the water level with:

$$p = p_{H_2O} \cdot g \cdot h \quad [\text{hPa}]$$

and:

$$h = \frac{p}{p_{H_2O} \cdot g}$$

p_{H2O} Density of water at 20°C: 0,998205 kg/dm³, at 4°C: 1,0 kg/dm³. [Pa] = N/m²; [N] = kg*m/s²; [Pa] = kg/(s^2*m).

A water column of 100 cm causes the following pressure:
p [Pa= N/m²] = 998,205 kg/m³ x 9,81 m/s² x 1 m
p = 9792,39 [kg/m³ * m/s² * m] = 9.792 kPa.

Accordingly 10 kPa at 20°C indicate a water column of 102,15 cm.

7 Troubleshooting

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

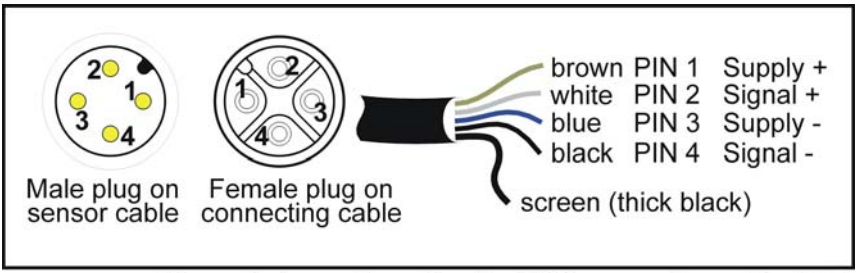
http://www.ums-muc.de/en/support/faq/tensiometer.html

8 Appendix

8.1 Technical specifications

Material and dimensions	
Ceramic material	Al2O3 sinter, bubble point > 15 bar
Ceramic dimensions	Length 60 mm, ∅ 24 mm
Shaft material	Impact-proof PMMA, ∅ 25 mm
Sensor cable	
For shaft lengths < 120 cm	Length 1,5 m from sensor body (effective length = 1,5 m minus shaft length)
For shaft lengths > 121 cm	Length 2,3 m from sensor body (effective length = 2,3 m minus shaft length)
Plug	Male 4-pin, thread M12, IP67
Measuring range	
Pressure transducer	-100 kPa ... +100 kPa (electronically) -85 kPa ... +100 kPa (physically)
Water tension	-85 kPa … 0 kPa (Tensiometer)
Water level	0 kPa … +100 kPa (Piezometer)
Output signal	
Pressure	85 mV = -85 kPa (Tensiometer) 0 mV = 0 kPa -100 mV = 100 kPa (Piezometer)
Accuracy	
Pressure transducer	±0,5 kPa
Power supply	
Supply voltage V_{in}	typ. 10,6 VDC (5 ... 15 VDC), stabilized
Current consumption	1,3 mA at 10,6 VDV
Compatibility of material	
PH range	pH 3 ... pH 10; avoid contact with substances that harm silicon, fluoride silicon, EPDM, PMMA, polyetherimid

8.2 Wiring configuration



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	Signal plus
A-OUT-	black	4	Signal minus

8.3 Accessories

8.3.1 Connecting and extension cables

Cables must be ordered additionally for each Tensiometer.

4-wire connecting cables CC-4/... are fitted with a female plug M12/IP67 and 12 cm wire end sleeves.
Extension cables EC-4/... have one each male and female plug M12/IP67. Plugs are supplied with protective caps.

Item	Art. no.
4-pin connection cables	
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 cables	
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, soil temperature and filling status. Automatic offset correction of water column and installation angle.
Suitable for all UMS - Tensiometers. The set comes with T4/T8 refilling tools in small carrying case.

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 Tensio-meters 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 Tensio-meters, 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 moudle (right).

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

8.3.5 Refill kits (T4e only)

BKTex Refill kit for externally refillable Tensiometers T4e and T8, incl. hand operated vacuum pump, 250 ml bottle, refill syringe, tubes, valves.

BKT468 Laboratory refill kit for Tensiometers T4, T4e & T8, incl. stand, clamps, adapter for T4, T6, T8-sensor bodies, 500 ml bottle, pressure gauge, tubes, beaker, refilling syringe.

Item	Art. no.
Refill kit for external refilling	**BKTex**
Laboratory refill kit	**BKT468**

All vacuum glass bottles are coated and implosion proof.

8.3.6 Tensiometer augers

Tensiometer gouge auger with specially shaped blade. The tip of the blade has the same shape and diameter as the Tensiometer cup, so the Tensiometer fits tightly into the borehole. Thus, no slurrying of the cup is necessary. Set includes gouge auger and handle with hammering head.

Item	Art. no.
Auger with handle	**TB-25**
Extension rod, length 100 cm	**TBE-100**

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

Your addressee at UMS

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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 UMS.

Rücknahme nach Elektro G
WEEE-Reg.-Nr. DE 69093488