Operating Instructions

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ku-pf Apparatus

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Author: Dr. rer. nat. Jürgen Punzel (UGT GmbH)

Co-Author: Jens Berding (TU Cottbus)

1. Measurement principle

The ku-pF apparatus is used to determine the hydraulic conductivity and the pF curve of soil samples in the unsaturated area using the SCHINDLER (1980) measurement method.

To do this soil samples are completely saturated in the sample ring and then sealed basally. The free surface is exposed to evaporation and the gradient of the water movement that ensues is measured and recorded.

Up to 10 soil samples can be examined simultaneously with the ku-pF apparatus, because the sample rings are placed on a star-shaped sample changer and periodically guided across scales at suitable intervals. The volume of water flowing through the sample surface (water movement) at set intervals is determined by this weighing.

The gradient of the soil-moisture tension is calculated in each sample ring by two tensiometers installed 3 cm apart. The readings are recorded with the weighing cycle. The test control and primary data recording is carried out by an integrated process computer. A PC is used for communication with the process computer.

2. Technical data

Soil sample ring volume	250 cm^3
Cross-section of the soil sample rings	41 cm^2
Number of samples	1 - 10
Cyle time of data acquisition	10 - 40 min
Resolution of weighing	0.01 g
Tension range	0 - approx. 90 kPa
Weight of the apparatus	Approx. 40 kp
Dimensions (LxWxH)	Approx. 100x70x40 cm
Power consumption	230V / 1A
PC connection	Serial interface (115200 baud)
Measurement position of the tensiometer	At the weighing position
Memory capacity	210 to 840 days

3. Physical principles

The hydraulic conductivity of the soil samples can be calculated according to DARCY's equation assuming quasi-stationary flow conditions. See **(2)** for the validity of this assumption. This assumes the *hydraulic gradient* of each sample in the sample ring as *constant over the length of the sample*. The gradient is formed from the matrix potential (tensiometer measurement) and the gravitation potential:

$$v_z = k * \frac{\Delta\varphi}{\Delta z}\ (DARCY) \qquad \textbf{(1)}$$

$$\frac{\Delta\varphi}{\Delta z} = \frac{\Psi_t - \Psi_b}{\Delta z} \qquad \textbf{(2)}$$

vz Flow velocity of the water movement

k Hydraulic conductivity

φ Hydraulic potential

z Location coordinates

Ψ_t Tension of the top tensiometers (as positive pressure in the unsaturated area)

Ψ_b Tension of the bottom tensiometer

Δh Gravitation potential as altitude

A flow velocity vt is formed on the free **sample surface** as a result of the evaporation. The basal sealing of the sample causes the flow velocity vb = 0e on the lower interface.

The following can be set for the **sample centre** between the tensiometer positions under quasi-stationary flow conditions:

$$v_m = \frac{1}{2}(v_t - v_b) = \frac{\Delta V}{2 * A * \Delta t} \qquad \textbf{(3)}$$

vm Flow velocity in the sample centre

ΔV The water volume tat evaporates over the time Δt

Δt Measurement interval on individual sample (keying time*10)

A Cross-section of the soil sample ring

In this case the following applies to the soil area between the tensiometers:

$$k = \frac{\Delta V}{2 * A * \Delta t} * \frac{\Delta z}{\Psi_t - \Psi_b - \Delta h} \quad \textbf{(4)}$$

Δz Distance between the tensiometers in the sample ring (=3 cm)

Δh Altitude difference between the tensiometer positions (=3 cm)

The **hydraulic conductivity is a function of the water content** of the sample. To ascertain this, the dry weight of the soil samples must be calculated after the test run. For the **pF curve**, the respective current water content of the sample is assigned to the mean value from both tensiometer readings.

4. ku-pF apparatus DT 04-01

The sample changer constitutes the basic device on the ku-pF apparatus DT 04-01. It consists of a rotating star-shaped carrier with rods to accommodate 10 sample holders. The sample holders each carry a soil sample ring and are each fitted with two tensiometers and an electronic assembly that digitalises the tensiometer readings and sends them to the data logger via a two-wire line.

The connection to the data logger takes place through contacts in the support rods on the rotating carrier. The individual sample holders are guided periodically at selected intervals to the measurement position during the evaporation test in order initially to transmit the tensiometer readings to the data logger.

The scales then receive the “re-zero” command. By lifting the scales, the sample holder is pushed out of its bracket and placed on the scales. In this position the total weight of the sample holder is recorded and transmitted to the data logger. When the scales are lowered the rotating carrier supports the sample holder again and the measurement cycle of a sample is complete.

5. Measurement preparation

Since the bubble point can be exceeded towards the end of the test and as a result of evaporation at the free surface in the case of tensiometers, these should be vented before each further test run and the calibration checked. The same applies if the apparatus has not been used for a long time and the ceramics of the tensiometers have dried out. To bridge such breaks between measurements, it is recommended that tensiometers be stored in the transportation tubes filled with bi-distilled water (supplied on delivery)

5.1. Venting of the tensiometers

The tensiometers are removed from the cup and the venting screw removed. A hose barb fitting is screwed in in its place and a connection established to the manual vacuum pump. If the tensiometer is in a water-filled receptacle, (bi) distilled water can be sucked into a vacuum flask using the vacuum pump, thereby removing the air from the tensiometer. **Caution! No water may be allowed to get into the pump!** Move residual bubbles to the fitting by swinging the tensiometer towards the fitting. After removal of the hose barb fitting, any trapped air is evacuated using the syringe (supplied on delivery) and the connection bore filled with water. The venting screw must then be inserted free from bubbles. **Caution! Twist the screw in slowly and avoid compression!** Insert the tensiometer into the open cups and completely fill these with water.

5.2. **Calibration of the tensiometers**

To calibrate, take the respective sample holder from the support shaft and use the enclosed cable to establish a connection to the ku-pF apparatus DT 04-01.

When connecting, care must be taken to ensure the correct connection position (red marks).

The completely filled tensiometers are inserted into the pressure sleeve, where it is secured and then stored **horizontally**.

Now connect the apparatus to the software

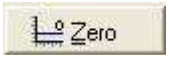
using the 

button.

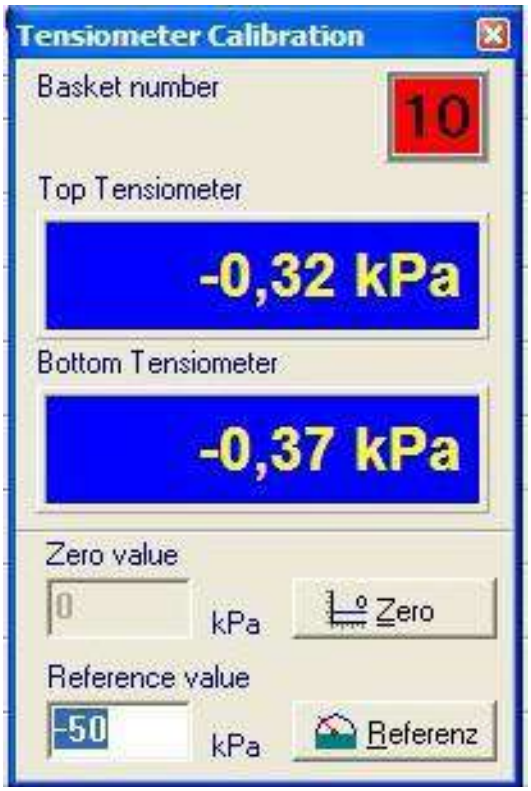
The current tensiometer readings are read online in the calibration menu  , and the complete calibration can be performed using the zero value and reference value.

The red box indicates the number of the current sample holder. As soon as the calibration of the tensiometers has been completed, the background changes from “red” to “green”.

Under relaxed pressure conditions, both tensiometers must display 0 – 0.1 kPa in a horizontal weighing position.

The value can be set to “zero” by acknowledging the 

button.



In the event of deviations from zero, carefully unscrew the filling screw and repeat the calibration process. Measurement against the atmosphere must show the value 0 kPa. If this is not the case the zero point has been incorrectly calibrated, the tensiometer is faulty or there is an electronic fault. Check the gas-free filling or contact UGT GmbH.

To calibrate the reference value, create a vacuum of -50 kPa using a manual pump and compare this to the display in the calibration menu.

If consistent, save the reference value using the 

button.

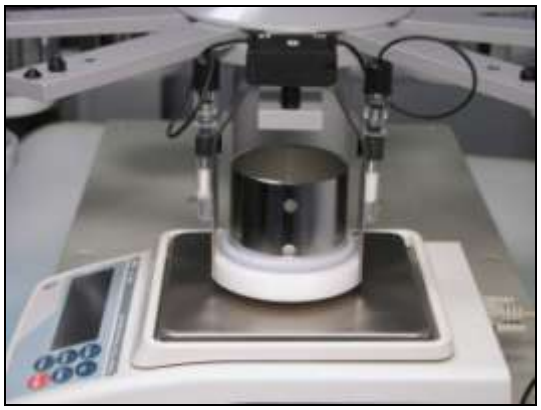
To check calibration, any random pressure value is selected in the adapter sleeve. The online representation must react synchronously and in relation to actuation of the manual pump. After venting the manual pump, the level should fall back to 0 kPa.

The completely filled tensiometers are then standing in the likewise completely filled, open cups ready for installation. In this position a hanging water column of approx. 2 cm is effective on the pressure sensor of the tensiometer. The tolerance range of the displayed readings fluctuates between –0.2 and–0.6 kPa.

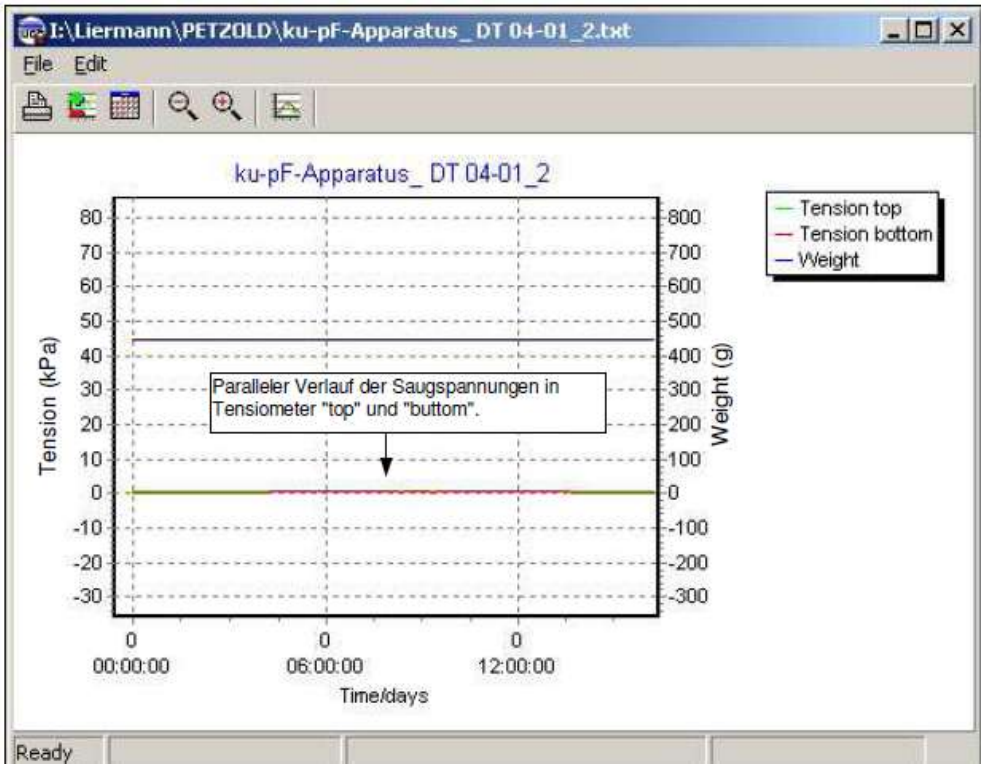
5.3. **Checking the zero point drift**

To prevent incorrect measurements, please check the zero point drift of the tensiometers after the venting and calibration of the tensiometers and before installation of the soil samples. This step can be carried out during the saturation of the soil samples (duration approx. 12 hours).

Place the baskets without soil samples on the rotating carrier and start a new project. The tensiometers are inserted in the transportation tubes filled with (bi) distilled water.



Let the test run for at least 12 hours. With fully functional tensiometers, parallel graphs will result on the zero line.



6. Sample preparation

Sampling takes place in 250 cm³ soil sample rings which each have 2 holes at the side to accommodate the tensiometers. These holes should be sealed with adhesive tape from sampling until saturation. To saturate the sampling rings, place with the cutting edge on the filter plates lined with filter paper.

The holes in the filter plate are filled using a fine jet of water (spray bottle) with forked sample and the samples with partially closed lid then placed in the saturation bath initially up to the top edge of the of the filter plate. After approx. 12 hours, the excess accumulation up to the middle of the sample can be increased for at least a further 12 hours. After at least 24 hours' saturation time, the samples are removed from the water bath and placed to drain on a filter cloth for a few seconds in order to remove surplus water from the filter holes. Once the adhesive tapes have been pulled off, the tensiometer openings are drilled using the drilling jig as far as the corresponding drill will go (tensiometer length). While doing so the lid should be pressed on to prevent the sample escaping. The saturated and drilled samples are weighed with filter plate but without lid and without perforated sheet:

$$M_{si} = sample\ (saturated) + sample\ ring + filter\ plate + filter\ paper\ (wet)$$

i sample number

To insert soil samples, the sample holders are removed and the samples with filter plate pressed into the base plate of the sample holder. The tensiometer openings point inwards here. The soil sample ring lid with perforated sheet is then put on.

Take the tensiometers out of the cups and install them in the holes in the sample rings (top- top; bottom – bottom). It is important to ensure a sufficient capillary connection (possible connection with silt powder). The escape of the soil sample on the top tensiometer can be prevented by pressing the lid on. The tensiometers should be pressed in as far as the sealing ring on the tensiometer shaft can go. If the sealing ring does not reach the sample ring, the gap that remains must be separately sealed (silicon, rubber).

The cups on the tensiometers are removed from the sampler holder (evaporation) and the sample holder mounted according to the numbering.

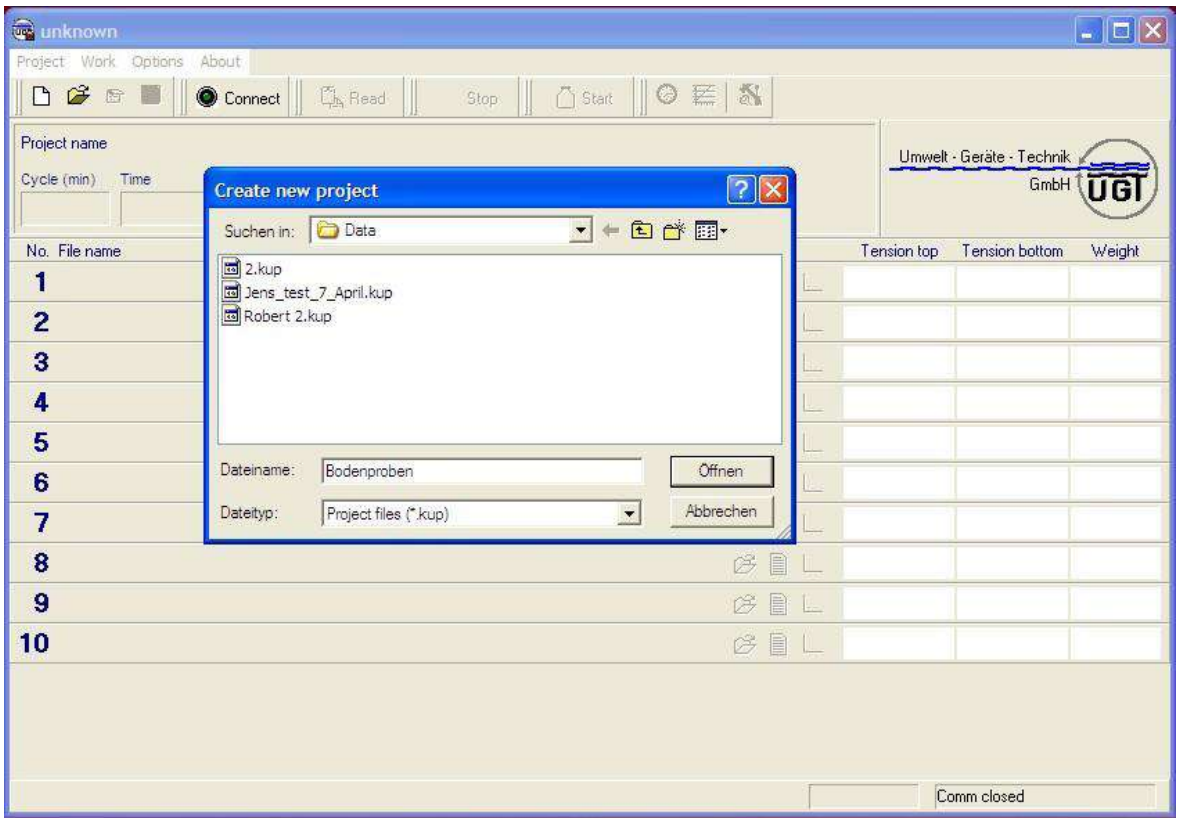
After the samples have been installed, it should be checked that the sample changer can move freely, that no objects can get underneath the lifting table and that the tensiometer cables are not touching the arm of the suspension bracket in the weighing position. A test circle can be controlled using the "TURN" tool.

7. Conducting a test

7.1. Creating a new project

Open the "KupF apparatus" software and create a new project by pressing .

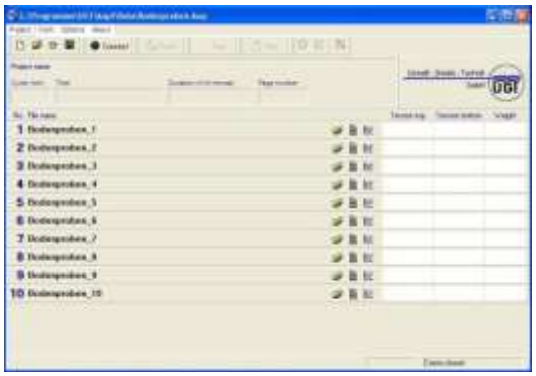
Name your project (here: “Soil samples”) and open the project.



10 files of the type “.TXT” are assigned to the baskets.

Supplementary sample names, site criteria or distinctive features of saturation or the installation of the tensiometers can be entered using the button.

The project can be saved and used later by pressing if you do not wish to begin the measurements immediately.



7.2. **Start measurements**

Using the 

button, connect the software to the apparatus.

You may now be informed that an older project is still present in the apparatus memory. Press “NO” to load the newly created project in the apparatus memory.

If you want to open the existing project (here: "Robert 2.kup") from the memory of the apparatus, press “YES”. You can now save this project by pressing  . After saving, press  to close the already existing object and to disconnect.

Then open  the newly created project and connect software and apparatus again by pressing 

.

In the tool menu  select the cycle time in minutes. Note that the evaporation performance can lead to a different test duration according to the soil type.

- Clay soil (short test duration) – small cycle time
- Sandy soil (medium to long test duration) – average cycle time

Start measurements by pressing 

.

You will be warned that this will overwrite all stored project data. Confirm with “YES”.

A second warning then appears, reminding you to take the tensiometer cups of the out of the baskets. Click on "OK". The measurements will now begin until they are interrupted. The test time starts at “0” again.

You can close the program, as the measurements will also be conducted without the PC connected. If you wish to stop the measurements, press and switch off the ku-pF apparatus on the toggle switch.

7.3. **Functions**

New  Generates a new project.

Open  Opens an existing project and provides the corresponding files. The existing data can be viewed in the graph.

Close  Closes an open project and simultaneously ends the connection to the ku-pF apparatus DT 04-01.

Save  Saves the open project. This has no influence on the files.

Establishes the connection to the ku-pF apparatus DT 04-01. If an ongoing project is running in the ku- pF apparatus DT 04-01 and if no project is open in the software (or if the open project does not correspond to the ongoing project), the ongoing project is searched for in the current directory and in the standard directory.

If it is present, it is opened on request. If it is not present, a message appears with the following options:

- To search for the project yourself
- To generate a new project with the name of the ongoing project.

The connection to the ku-pF apparatus is interrupted. The connection is established again by pressing CONNECT.

All data are read out and written onto a file with the name of the project name +“000n” and the file extension “TMP”. If the reading out proceeds without fault, the data are then written in the data files assigned to the baskets.

You can view the current readings in the  graphs.

Interrupts and ends an ongoing test. The commands CONTINUE, START, CLOCK, CALIBRATION and TOOLS are released. Only stp when the scales have moved down.

The interrupted test is continued.

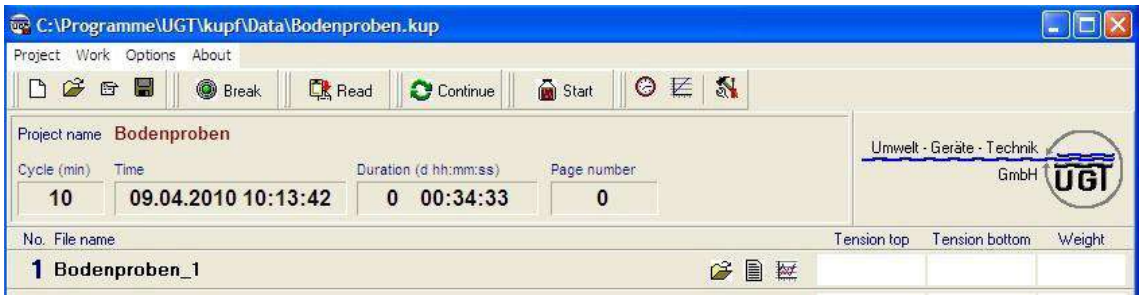
A **new** test is started with the data from the open project. The start time is saved in the project file and use to display the test duration.

Clock  The ku-pF lock is set to the time on the PC.

Calibration  The ku-pF apparatus DT 04-01 is switched to calibration mode and the calibration window is opened.

Tools  The Tools window is opened. The cycle time can be changed, the scales lifted and the rotating carrier turned.

In the main menu three command buttons are assigned to every basket:



Open  Opens a file to store the read data and enables a separate file to be imported in the ".TXT" format.

Caution: importing causes the existing file to be overwritten überschrieben.

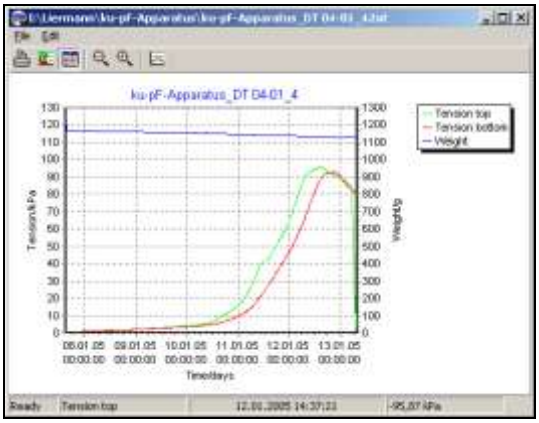
Text  Permits text to be entered for a more detailed description of the sample.

Graph  Displays the data as graph.

Right-clicking on the file name enables the file name (but not the file) to be deleted if the basket is not in use.

7.4. **Graph menu**

Several graph windows can be open at the same time. If data are being read with open window, these will only be displayed after closing the file and opening it again..



Print	Prints the graph. The graph is formatted to the size of the sheet.
Print install	Printer set-up.
Add/Remove	Individual curves can be added to or removed from the graph.
Calendar	The date and time are shown on the X-axis. If the button is not pressed, the test duration is shown on the X-axis.
Undo Zoom	Cancels the enlargement and returns to the levels set in the zoom window.
Zoom	Opens a window to set the display areas.
Points	Shows a small rectangle for each reading.
Copy	Saves a copy of the graph in the clipboard as bitmap or metafile. From there it can be inserted in other programs, e.g. Word.
The following functions can be executed using the mouse:	
Zoom	Click the left mouse button on the top-left corner of the zoom area and hold down to drag a rectangle up to the bottom right-hand corner of the desired zoom area.
Undo Zoom	Click the left mouse button and hold down to drag a window up and to the left.
Horiz. scrolling	Click the right mouse button on the graph and hold down to scroll the graph to the left or right.
Display value	Switch points on and click on the desired reading with the left mouse button. Time and reading appear in the status bar.

7.5. **Tools window**

In addition to actuation of the buttons using the mouse, the following buttons can be used:

S	Set cycle time
T	Turn the rotating carrier
U	Scales up, D scales down
P	Park position
ESC	Close window

Variable sampling rates can be set with the cycle time according to the expected test duration and depending on the type of soil selected.

The park position of the scales platform serves as transport protection and should only be applied for this purpose. On putting into operation for the first time, the scales moves to the measurement position once the “Lift up” button has been actuated twice.

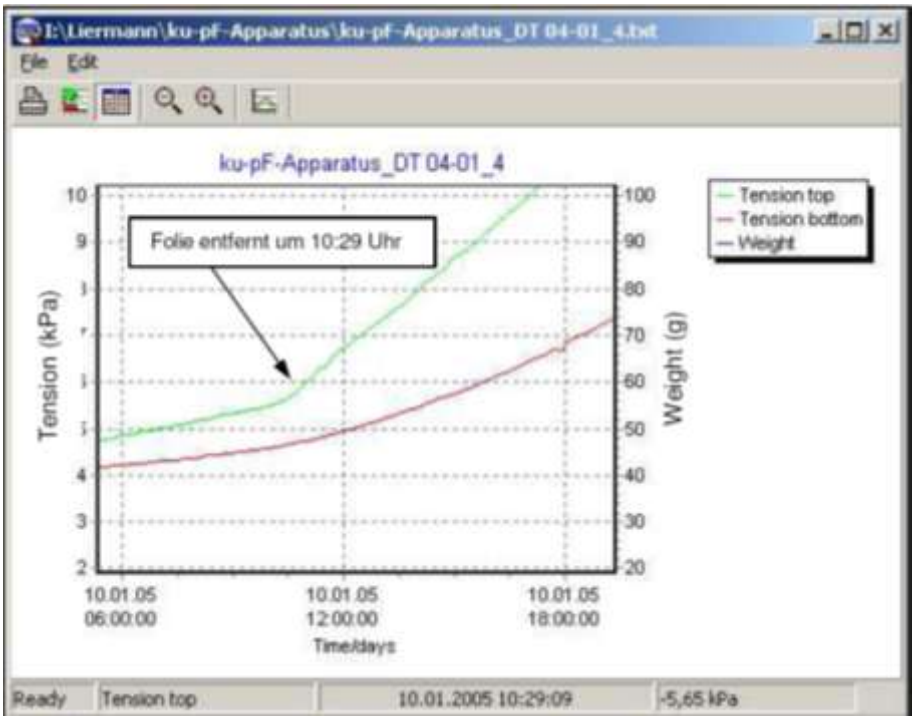
8. Optimisation of the test run

A test runs should always be started with covered soil samples. Under these conditions the flow velocity is zero and the pressure difference on the tensiometers is approx. 0.3 kPa (altitude Dh=3cm at v=0 according to equation 2).

After approx. 3 hours, these initial values have been recorded with sufficient statistical reliability. The covers can be removed from the samples. The mass loss is displayed in the graph menu. The flow of water through the samples begins with the start of evaporation.

The current test data are displayed during the test in the main menu. For optimal test control, the difference between the water tensions (gradient) in a sample should not exceed a magnitude of approx. 5kPa. This difference can be controlled by varying the current evaporation rate on the sample surface. The sample surface is partially covered by a perforated sheet for this purpose. When the perforated sheet is completely removed, it should be kept on the sample holder and its weight also included in the weight record.

The evaporation protection measures can be seen on the tension curve. Relevant comments should also be entered in the text box as supplementary information.



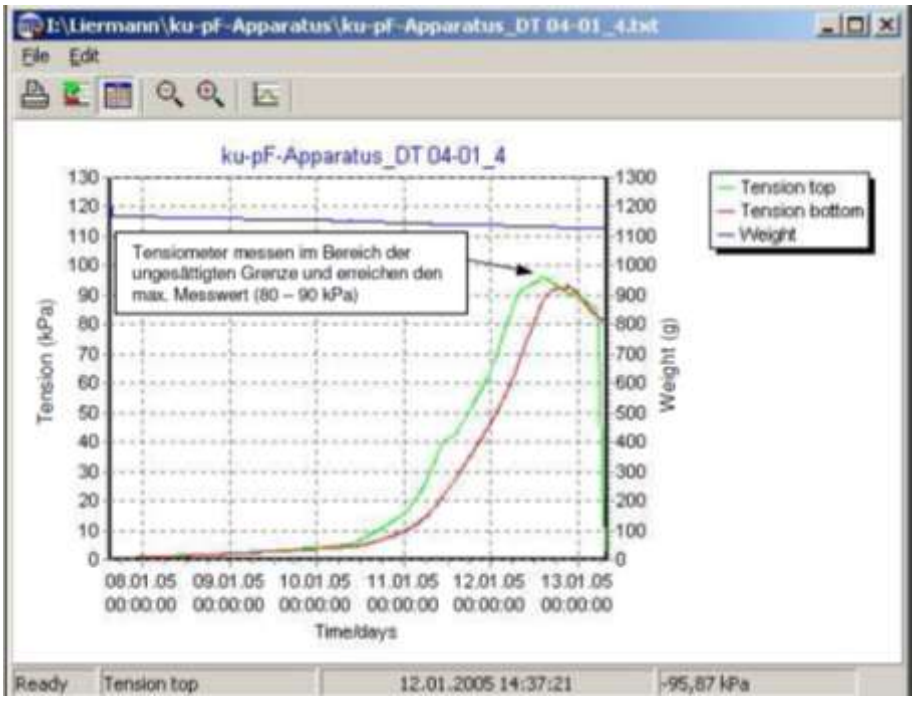
Clicking on a data point displays the tensiometer, the measurement time and the reading I the bottom menu bar.

9. Recording measurement data

The measurement data can be transferred to the connected PC during the ongoing test operation using “READ” and can be presented online. The graphic depiction always corresponds to the last read-out date.

Establish the connection to the ku-pF apparatus DT 04-01 by means of "Connect". the current project is loaded and the data can be read out.

The progress of the evaporation can be checked in the graph menu and a possible test end estimated.



The unsaturated limit is created on the top tensiometer (“top”) approaching its measurement limit (80 – 90 kPa). The curve here is concave, i.e. the ascent reduces and at maximum (tensiometer limit) is zero. In the area before maximum, the venting of the tensiometer starts (release of dissolved air, expansion of air bubbles). In the direct vicinity of the tensiometers, the increase in water tension is reduced by the release of water. This reduced increase in the tension curve can be explained by the measurement principle of the tensiometers and the low conductivity of the samples when discharging the water from the tensiometer.

10. Evaluation

The data set should be transferred to a spreadsheet system (e.g. Excel) for complete evaluation of the tests.

This complete evaluation includes the following:

- a plausibility test of the recorded readings, possible with a correction of the tensiometer values;
- the calculation of gradients of water movement, of ku values and the current water content.

The following are inserted in the table for this purpose:

- Column for test duration in minutes
- Column for the difference in tensions (corrected)
- Column for running average in tension difference
- Column for the water movement gradients
- Column for water content
- Column for the pF level
- Column for the flow velocity
- Column for the conductivity ku

Test run in minutes:

According to the sampling rate (cycle time) selected at the test start, the duration of time between the individual measurements of a sample is between 10 and 40 minutes. The time column is automatically filled with the appropriate range of times.

Tension difference:

At the start of the test the soil samples are closed with the cover, and the flow velocity is zero. According to equations 1 and 2, the difference in tensiometer values would have to be 3cmWS or 0.3kPa. Any deviations from this setpoint value (drift of the tensiometers) are described by a correction K:

$$TensN1 - TensN2 + K = 0.3\ (kPa)$$

The correction value K is calculated from the recorded tensiometer values of each sample before removal of the cover.

The tension difference column (corrected) contains the current values:

$$D\text{-}TensN = TensN1 - TensN2 + K$$

Running average for tension difference:

If the time selected at the start of the test is too small, the changes in readings will also be slight. Parameters showing differences in these values can indicate greater jumps. A running average smooths out these series of measurements n:

D-TensN(m) = average (Sz - 1; Sz + 1)

S = column of the range D-TensN ; z = current row

Water movement gradients:

According to equation 2, one obtains the gradients (cmWS/cm) from the respective column value of the tension difference:

GR = D-TensN(m)/0.3 – 1

Water content:

The current water content of the sample i is determined by the starting weight of the sample, its dry weight and the weight change in the test run. The weight of the saturated sample Msi was determined before installation of the tensiometers. To determine the dry weight, the tensiometers are removed at the end of the test of the test and the samples with filter insert lifted out of the holder.

The remains of sealant on the sample ring must be removed. The soil sample cylinders are lifted out of the filter plates placed horizontally on a dish with the entire soil material to dry at 105°C. The dry samples are weighed with the corresponding filter plate (to be numbered!) and the moistened filter paper:

Mtr i = sample (dry) + sample ring + filter plate + filter paper (wet)

The soil sample is then removed and the tare weight calculated:

Mtara i = sample ring + filter plate + filter paper (wet)

The weight of the dishes should be taken into consideration.

The water content Mwi on saturation at the start of the test is constituted by the difference:

Mwi = Ms i - Mtr i

The volume of the sample with the tensiometer holes is 245 cm³. The volumetric water content of the sample at the start of the test is calculated as follows:

$$W_i(Vol\%) = 100 * \frac{M_{wi\,(g)}}{245} \qquad \textbf{(5)}$$

This initial water content is reduced in each step of the test. The total water loss up to step n is as follows:

$M_0 - M_n$

M_0 recorded mass of the sample when removing the cover (g)

M_n recorded mass of the sample after time increment n in (g)

The water content of a considered sample I after step n is therefore:

$$W_n(Vol\%) = 100 * \frac{M_{w\,(g)} - (M_0 - M_n)}{245} \quad \textbf{(6)}$$

A column for the water content in % is created for each sample using this formula.

pF level:

The pF value (LOG10 of the water tension in cm) is created from the tensiometer values:

pF = LOG10 ((Tens1+Tens2) / 2)

Flow velocity:

The flow velocity in the centre of the sample is calculated using equation 3.

With a cross-section area of the sample of 41 cm², the flow velocity during a measurement can be calculated as follows:

$$v = \frac{1}{2} * \frac{\Delta M * 60}{41 * \Delta t} \quad \text{(cm/h)} \quad \textbf{(7)}$$

ΔM is the difference between consecutive readings from the sample mass column.

ku value:

The ku value in cm/h is formed by dividing the values from the flow velocity and gradient columns.

ku = flow velocity / gradient (cm/h)

Δt = cycle time

The

- pF curve : pF level above water content
- ku function: ku value above water content

can be depicted and adapted to analytical printouts **using the calculated columns.**

The **cry density** of the respective soil sample is:

$$p_i = \frac{m_{tri} - m_{tara\,i}}{245\ cm^3} \qquad \textbf{(8)}$$

The incorporation of the kf value (saturated hydraulic conductivity) is required for a complete representation of the ku function. The kf value may be calculated on the sample ring samples with the dome permeameter according to HARTGE or in a separate field test with the hood infiltrometer IL-2700 (see UGT product range).

An alternative evaluation of test data can be performed using inverse simulation.

In this case there is no assumption of a linear water tension curve by sample length.

Calculation tools can be found in the software package.

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12. Notes

The following should be noted when using the ku-pF apparatus:

- *It is essential to ensure freely rotating operation before putting into operation!*
- *It is essential to prevent any tensile load on the data cables!*
- *It is essential to prevent all lifting load on the rotating carrier and on the weighing platform!*
- The weighing platform should be brought to the measurement position by actuating the “Lift up” button twice in the “Tools” submenu.
- Position the apparatus so it is level. Align the scales.
- Before starting the test, the tensiometer transportation tubes should be replaced by appropriately open receptacles (supplied on delivery). Fill these to the top with (bi) distilled water.
- No water may get into the manual vacuum pump when filling the tensiometers.
- Check the hose connections before each online presentation of reference values. No water may be trapped in them.
- Saturation of the samples “without holes”:
    - soaked in water up to the top edge of the filter base for at least 12 hours
    - then fill up to the centre of the sample for a further 12 hours
- Do not forget to weigh the saturated samples.
- **Caution!** It is essential to remove the transportation tubes after installing the tensiometers.
- Note that osmotic processes between the soil water and the tensiometer filling cannot be ruled out after inserting the tensiometers.
- Test the tensiometers at “zero” and “reference” value immediately prior to starting the test using online presentation. Where applicable fill outside the water container using olive or manual vacuum pump. Calibrate in exceptional cases.
- Start the test with perforated sheet and cover. Runtime approx. 3 hours.
- Then remove both and position on the carrier or on the rotating carrier. Start of the evaporation!
- After the first 12 hours, decide whether evaporation protection is necessary.
- Place perforated sheet on if required.
- During measurement, avoid all strain on the measuring station.
- Avoid draughts or fluctuations in the room temperature.
- After the test has ended (air entry into the “top” tensiometer), immediately remove the tensiometers from the soil samples and rinse in (bi) distilled water. **The ceramics must not be wiped down.** An ultrasonic bath is recommended for cleaning. Extremely dirty ceramics can be rinsed in 10% hydrochloric acid (HCl) where necessary. To do this, carefully unscrew the cup stem, taking care not to touch the ceramics. After this it is essential to rinse the tensiometers with (bi) distilled water.