AQUAPROBE SOIL MOISTURE METER

T-S-30

AQUAPROBE SOIL MOISTURE METER
MEASUREMENT SYSTEM

1.   AQUAPROBE SOIL MOISTURE METER

1.1 GENERAL OVERVIEW

The James Instruments AquaProbe T-S-30 is a revolutionary digital moisture meter for soils. It allows the user to measure the complex dielectric constant of the mixture of water and material under investigation. As it has been shown in many studies that the complex dielectric constant is directly related to the amount of water present, the built in microprocessor can convert this value directly into the percentage of moisture. The AquaProbe consist of a 50 MHz probe and logging unit that can processes data from the unit and can store it for later retrieval.

The AquaProbe has 5 stainless steel prongs that penetrate into the soil to obtain a moisture content reading. Each prong is 8.9 cm (3.5 inches) in length with a diameter of 0.3 cm (0.125 inches). First, use the penetrator template and the rubber mullet to introduce it on the soil, then remove the penetrator and insert the Aquaprobe sensor on the holes previously preformed on the soil. For more accuracy, calibration is recommended.

In order to perform the calibration, the sensor is placed at the bottom of a container, which should be filled with the material to analyze. The material should be compacted around the prongs so that the entire prong is covered by the material under investigation. This procedure should be done at 4 or five different moistures levels that should be well measured by standard procedures (oven dry), calibration errors will dramatically affect field results. The volume tested is that enclosed by the four outer prongs of the sensor unit. The robust prongs have been designed to be inserted into various materials. Most commonly used materials are silty or clayey gravel and sand, silty soils and clayey soils. There is also a special calibration for a general type of soils 1 and 2.

Proper cleaning and maintenance of probes is required for accurate readings. Any contaminating material attached to the probes can influence subsequent readings. Stainless steel probes should be cleaned before and after testing has been completed. The AquaProbe prongs cover a surface depth of about 10 cm (4 inches). For accurate readings, it is recommended to remove the top layer of the material to be tested as this is generally the driest region. Keep in mind that moisture always flows to the bottom of these materials. The more moisture suspected in the material, the deeper the depth you want your testing to be. A note of caution, it has been found that the moisture content of sand and aggregates, etc. can vary by as much as 5 percent through a rather small volume.

The unit comes from the factory with a variety of modes to assist the user in determining moisture content. The unit comes pre-programmed to analyze sand (SP, Ottawa), lean clay, silt and general type of soil 1 and 2. There is also a mode to read the output of the sensor directly. The AquaProbe can also be programmed with up to ten different user programs. These are correlation factors that pertain to the direct material

the user is dealing with and should be used for the most accurate moisture results. There are also the capabilities to upload data stored in the unit to a P.C. for later analysis, as well as a clock to help synchronize and differentiate the results.

Finally, the unit comes with a P.C. software which simplifies uploading of data to a Windows compatible P.C. and analyzing the data for later programming of the unit. When required, the software will automatically monitor the serial communication port specified by the user. Once transmission of data from the AquaProbe unit has occurred, this information will appear in the edit window in the software. The data can then be analyzed by the built-in software of the program or with a regular spread sheet. The built-in software will take the user step by step through each record and allow the user to enter the moisture percentage associated with each reading. All the readings shall have an associated moisture percentage, with these results the data can be graphically displayed and the optimal correlation relationship can be determined. Coefficients representing this relationship are displayed for subsequent loading into the AquaProbe unit.

The AquaProbe is an easy and accurate way of testing moisture in a controlled or uncontrolled environment. Every effort has been made in providing a user friendly robust and accurate system for the measurement of moisture in soils and granular materials. A robust sensor which responds to water content has been created. This feeds into the main microprocessor unit of the AquaProbe allowing the user an instantaneous direct reading of the moisture content of the material under test.

1.2 GENERAL NOTES ON THE USER PROGRAM

For best results with the James Instruments' AquaProbe, user programs should be created for the different materials that the equipment will be used with. These are precise correlations that account for material differences inherent to local conditions. A simple least squares linear correlation between the output of the probe and the moisture content of the material is all that is required.

It is desirable when performed the calibration to emulate the field conditions. The material used for testing should pass the sieve ¼" or No. 4.

1.3 CALIBRATION PROCEDURE

Calibration can be performed via a simple procedure. Please follow the points below describing the calibration procedure.

1.3.1   Calibration for cohesive soils

1. First a two to three kilogram sample passing sieve ¼" or No. 4 should be collected.

2. The material under investigation should be baked at 105° C to 110° C for 24 hours or until the sample no longer loses any weight.

3. The material after being taken out from the oven should be weighted with a scale with precision of at least 1 gram.   The dried sample should be left to cool down at a relatively low temperature (10 to 30°C or room temperature).   The user should add water to obtain a sample with 5% moisture of dry weight of the sample. To obtain homogeneous moisture levels, the sample should be mixed carefully.

4. The sensor should be attached inside the container. Screws should be used to fix the sensor to the container. Turn on the instrument and select the "Direct Mode". The container has to be filled in three layers one on top of the other (as shown in Fig. 1). Use the compactor tool and applied ten or more blows per layer, the compactor tool should compact the soil until the AquaProbe direct reading reaches a stable maximum value (readings should be stable after 3 or 5 blows with the compactor tool resting on the soil), desire height 1.5" (3.8 cm) after compaction. The second layer should be approx. 3 inches (7.5 cm) thick (after compaction), leaving exposed just the tips of the prongs. The third layer should cover the sensor's prongs by approx. 1 inch (2.5 cm) after compaction.   After compaction, the sensor should be covered by approx. 1 inch (2.5 cm).
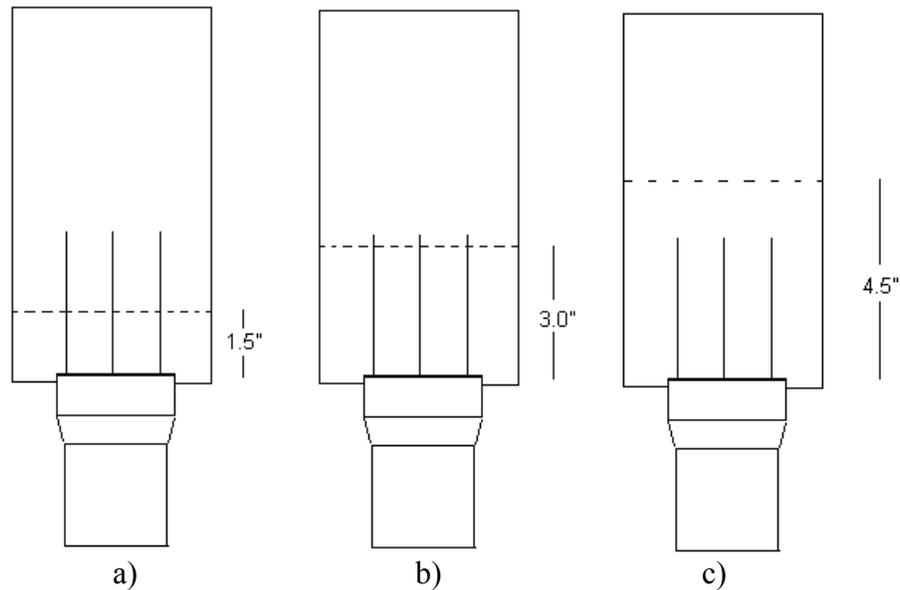
Fig. 1- Compact Soil inside the container, ideal height after compaction (distance are only as a recommendation, small variations would not affect results).
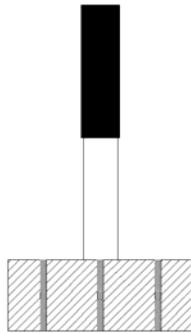

Fig. 2- Compactor tool

5. Then a reading from the sample should then be taken with the AquaProbe in the Direct Mode and the moisture content (percentage of dry weight) should be recorded, as well as the corresponding reading. The reading can be recorded either digitally or manually. The moisture content should be recorded manually. In order to obtain even more accuracy, a small sample (200grs) of the soil sample after being tested with the AquaProbe can be oven dry as presented in the point 2 of the calibration procedure.

6. Sieve the remaining soil using the sieve number 4 or ¼", apply pressure to force the soil through the sieve to reduce the size of the soil clusters. The sieved soil sample is going to be used to obtain higher moisture level readings. In order to do that, water should be added to the remaining soil and the sample mixed thoroughly. Enough water to increase the moisture content by 1 – 3% increments

(of dry weight) should be added. The increment depends upon the number of sets of data the end user wishes to use.

Note: Water (grs) = (Weight of remaining sample (grs))*2/ [100+Previous Moisture value (%)]
This example will give you the water needed to increase 2% the moisture level of the remaining soil.
Previous moisture value (%) could be zero after oven dry of the sample or the total moisture level of the previous test.

7. Continue the procedure as presented in points 5 and 6 until the sample reaches saturation; at this point the reading from the meter will become constant (Direct Mode Reading: 409.5) (for sand, this point will be between 20 – 30%, for other soils this point will be between 15 – 20%). Constant data points equal to 409.5 should not be used for correlation. From five to ten moisture values are normally adequate to produce accurate and reliable results (the minimum number of data sets is three) and the maximum moisture value recorded should be at least the optimum moisture value from Proctor test.

Note: Moisture (%) = (Weight of Wet Sample – Weight of Dry Sample) / (Weight of Dry Sample-Tare)

1.3.2   Calibration for granular soils

1. First a two to three kilogram sample passing sieve ¼" or No. 4 should be collected.

2. The material under investigation should be baked at 105° C to 110° C for 24 hours or until the sample no longer loses any weight.

3. The material after being taken out from the oven should be left to cool down at a relatively low temperature (10 to 30°C or room temperature). Weight the dry sample and add water to obtain a sample with 3 to 5% moisture of dry weight. The user should add water to obtain a sample with 5% moisture of dry weight of the sample. To obtain homogeneous moisture levels, the sample should be mixed carefully.

4. The sensor should be attached inside the container.   Turn on the instrument and select the Direct Mode. The container is going to be filled in three layers one on top of the other (as shown in Fig. 1). First, place the soil needed for the first layer, lift up the container 3 inches of a hard surface and drop the container one time carefully with the AquaProbe on the bottom. Then, use the compactor tool and applied ten blows per layer, the compactor tool should compact the soil until the AquaProbe direct reading reaches a stable maximum value (readings should be stable after 3 or 5 blows), desire height 1.5" (3.8 cm) after compaction. Then, place the soil needed for the second layer, lift up the container 3 inches of a hard

surface and drop the container one time carefully with the AquaProbe on the bottom. The second layer should be approx. 3 inches (7.5 cm) thick (after compaction), leaving exposed just the tips of the prongs. Finally, place the soil needed for the third layer, lift up the container 3 inches of a hard surface and drop the container one time carefully with the AquaProbe on the bottom. The third layer should cover the sensor's prongs by approx. 1 inch (2.5 cm) after compaction.   After compaction, the sensor should be covered by approx. 1 inch (2.5 cm).

5. Then a reading from the sample should be taken with the AquaProbe in the Direct Mode and the moisture content (percentage of dry weight) as well as the corresponding reading should then be recorded. The reading can be recorded either digitally or manually. The moisture content should be recorded manually. In order to obtain even more accurate results, a small sample (200grs) of the soil sample after being tested with the AquaProbe can be oven dry as presented in the point 2 of the calibration procedure (to double check moisture content).

6. The remaining soil sample is going to be used to obtain higher moisture level calibration results.   In order to do that, water should be added to the remaining soil and the sample mixed thoroughly. Enough water to increase the moisture content by 1 – 3% increments (of dry weight) should be added. The increment depends upon the number of data sets the end user wishes to use.

Note: Water (grs) = (Weight of remaining sample (grs))*0.02/ [1+Previous Moisture value (%)/100] This example will give you the water needed to increase 2% the moisture level of the remaining soil. Previous moisture value (%) could be zero after oven dry of the sample or the total moisture level of the previous test.

7. Continue the procedure as presented in points 5 and 6 until the sample reaches saturation; at this point the reading from the meter will become constant (Direct Mode Reading: 409.5) (for sand, this point will be between 20 – 30%, for other soils this point will be between 7 – 15%). Constant data points equal to 409.5 should not be used for correlation. Constant data points equal to 409.5 should not be used for correlation. From five to ten moisture values are normally adequate to produce accurate and reliable results (the minimum number is three). The maximum moisture value recorded should be at least the optimum moisture value from Proctor test.

Note: Moisture (%) = (Weight of Wet Sample – Weight of Dry Sample)/(Weight of Dry Sample-Tare)

1.3.3 AquaProbe Calibration

After the data has been collected, a correlation relationship needs to be established. This is a linear relationship of the form

% Moisture = Gain * Direct Reading + Offset

Where:
% Moisture – Final Value
Gain – Multiplier obtained from the Data
Direct Reading – Value obtained from the meter
Offset – additive factor from gathered data

From the data generated above a best fit line through data can be generated. This can be accomplished either with a spreadsheet or with the accompanying software. In inserting the percentage moisture with the software, the time, and date stamp field can be used to identify which tests were associated with which moisture percentages. The Gain and Offset parameters are the two values that need to be programmed into the AquaProbe in order to define the User program (see Ch. User Prog).

2.   AQUAPROBE LOGGING UNIT

CONTROL PANEL

Plus Key
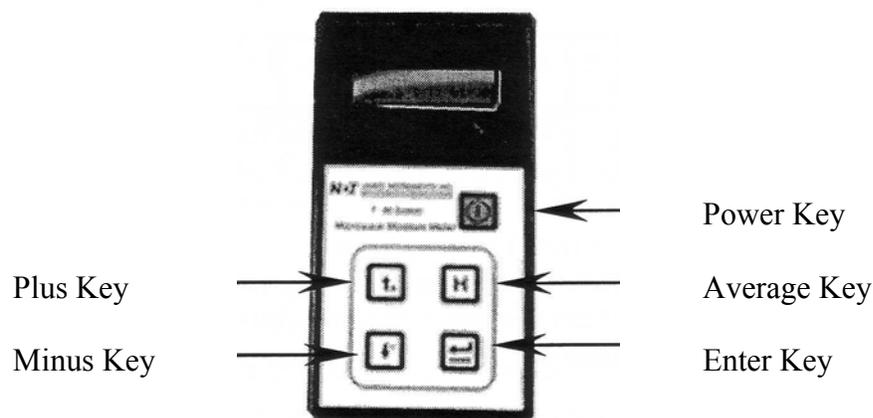
Minus Key

Power Key

Average Key

Enter Key

Fig. 3- Front Panel

- **Power Key** – Momentarily push this key to turn on the unit. Pressing it again turns off the unit. The unit will power up displaying the same menu selection as when it was powered down.

- **Average Key** – Depressing this key holds the current value and an "A" appears next to this value on the display. This then displays a running average of readings entered by pressing this key.

- **Enter Key** – This key can be used to store data points in the units. Depressing this will display an "S" next to the value being read for a few seconds. The reading will then be stored in the unit along with the type of material being used and the date and time. This can subsequently uploaded to the P.C. for later retrieval. It is also used in various ancillary functions such as changing the date and the time, uploading the data to a P.C. and programming the unit for user materials.

- **Plus Key** – This key is used to scroll through various settings.

- **Minus Key** – This key is used to scroll through various settings.

3.   UNIT OPERATION

The AquaProbe was designed for simple operation. Upon start up, the unit should show a brief (five second) display of our company name and software version. The unit will then proceed directly to the menu item it was last on before it was turned off. The menu structure is as follows:

    Sand
    Lean Clay
    Silt
    General Type of Soil 1
    General Type of Soil 2
    Direct
    User 1-10
    Ch. User Mat.
    Upload Data
    Change Date

You can scroll through the menu by pressing an arrow key. Either arrow key will allow you to scroll through the memory. The Sand, Lean Clay, Silt, General Type of Soil 1 and 2 , Direct, and User modes will simply show the instantaneous reading of the sensor, menu item selected, and the date/time. Pressing the Enter key while in any of these modes will record the reading, menu item selected, and date/time that the reading was taken in the main memory for later upload to a personal computer. The memory is non – volatile and will not be erased by turning off the power.

3.1 SAND

The AquaProbe's reading of moisture in sand is superior to other techniques. Moisture contents up to 15 to 20 percent by dry weight can be rapidly and accurately determined by the AquaProbe. The reading obtained in this mode is generally within 2 – 3% of the actual moisture level. More accurate readings can be obtained by pre-calibrating the unit to the specific sand being tested.

3.2 LEAN CLAY

This is the general category for lean clay. The AquaProbe will generally read moisture levels up to the 12 to 18 percent of moisture by dry weight. Accuracy for clay varies according to the type of clay and the moisture levels. Usually readings within 2-3% of the actual moisture levels are obtained. More accurate results can be obtained by pre-calibrating the unit to the specific material being tested.

3.3 GENERAL TYPE OF SOILS 1 & 2

General type of soil refers to a mix of silt, clay and sand obtained with different percentage of each one, the average correlation was obtained and programmed into the system. Different types of soils may show moisture results within 3% of the actual value. More accurate readings can be obtained by pre-calibrating the unit to the specific soil being tested. General type of soil 1 is a sandy and General type of soil 2 has less sand.

3.4 DIRECT

This mode is used when calibrating the unit directly to a user material. This shows the raw reading coming to the A-D converter of the unit from the sensor. By recording the direct reading for a range of different moisture values and correlating these values, the unit will then be calibrated for the specific material being monitored by the AquaProbe.

3.5 USER PROGRAM

The AquaProbe can be programmed with up to ten different user materials for subsequent testing. These are labeled on the unit 0 – 9 and are displayed in sequential order. AquaProbe programming is performed in the *Ch. User Mat.* section. The final value from the user generated calibration function will be displayed instantaneously with different outputs from the probe.

3.5.1   Change User Program

To change the user program please follow these steps:

- Use the plus and minus keys to select the menu item Ch. User Mat.?
  (Enter for Yes)

- Pressing enter will bring up the following message:
  User Prog.?   X
  (0-9) where X is the user program that you wish to change ranging from 0 to 9.

- Use the plus and minus keys to change the value of X until you have reached the user program you are interested in.

- Pressing enter brings the message.
  OFFSET
  sXX.XX

Where:

s is the sign either + or –

X is the value

- Pressing the plus or minus keys will increment this value. Pressing and holding the plus or minus key will rapidly increment this value.

- Once the proper value has been reached, press the enter key. The unit will display the following:
  GAIN
  x.xxx   where:
  x is the value to be entered.

- Again pressing the plus or minus keys will increment this value. Pressing and holding the plus or minus key will rapidly increment this value.

- Finally pressing the enter key enters these values into memory and sets up the user program for subsequent use.

For further information regarding the meaning of the OFFSET and GAIN parameters, please refer to the *General Notes on the User Program.*

3.6 CHANGE DATE

To change date and time please follow these steps:

- Press the + or – arrow key until you get to
  Change Date?
  (press Enter for Yes)

- Pressing enter will display the date and time in the following format:
  hh:mm
  MM/DD/YY
  Where:
  hh – hour range 0 – 24
  mm – minute range 1 – 60
  MM – month range 1 – 12
  DD – day range 1 – 31
  YY – Year range 00 – 99

The cursor should be blinking over the two hour digits

- Pressing the plus or minus keys will increment the digits at the cursor location. Holding the plus or minus key will increment the value rapidly.

- Pressing the enter Key will store the value selected and move the cursor to the next proper position.

- Pressing the enter key at the year position will bring the user to the "Change Date" menu screen describe above.

DISPLAY

x	x	x	x	x	x	x	x	x			h	h	:	m	m
n	n	n	.	n		%	A				M	M	/	D	D

- X – Menu item currently being used
- n – Current moisture reading
- A – auxiliary character used to show data being stored and held
- hh – Current hour
- mm – Current time
- MM – Current month
- DD – Current day

4.   FIELD TESTING

The AquaProbe Moisture Meter is very simply to use in the field.   First, select an area without coarse material (avoid areas having coarse aggregate greater than ½ " particle diameter) and use the penetrometer to make the perforations in the soil. After the perforations have been made the user can place the sensor into the holes made on the ground.

In order to make the perforations on the soil, the compactor having 5 holes should be used to guide the penetrometer prongs straight into the ground vertically. First place the compactor disc without the handle on the ground and use the pentrometer as well as the rubber mallet to make the holes. Once the penetrometer disc is in contact with the compactor disc, the compactor disc has to be removed and the penetrometer has to be used to finish the perforations.
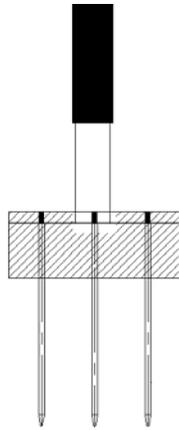

Fig. 4 Penetrometer for field testing

Then, place the AquaProbe sensor on the holes left on the ground and press it against the ground until the sensor is in close contact with the ground. The unit will indicate on the screen the moisture content of the soil enclosed by the four external prongs. It is recommended to use the user program for the material being tested. If the calibration has not been performed previously, one of the programs included with the system can be used, otherwise the direct reading will give the user an idea of the areas with higher or lower moisture content (but not quantification of the moisture content can be done in the direct mode) as a relative indication of moisture content (the higher the direct reading on the screen, the higher the moisture content of the soil).
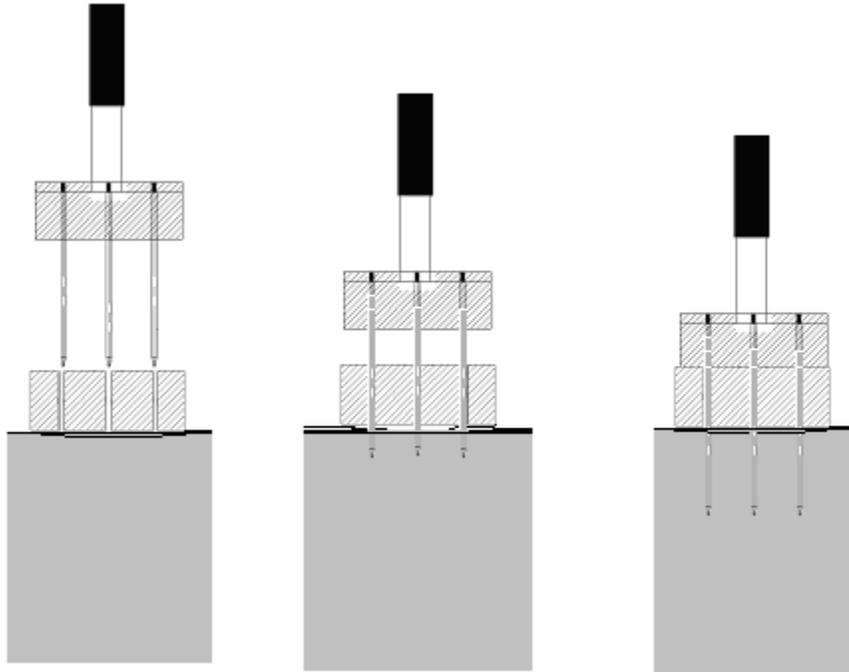
Fig. 3 a) - AquaProbe in-situ moisture measurements

The area measured by the AquaProbe is the cylinder surrounded by the outer prongs. As the moisture value may change significantly from one location to another, it is recommended to take at least three readings from an area of 1 sq. ft. of soil. This value will be a good estimation of the moisture content.
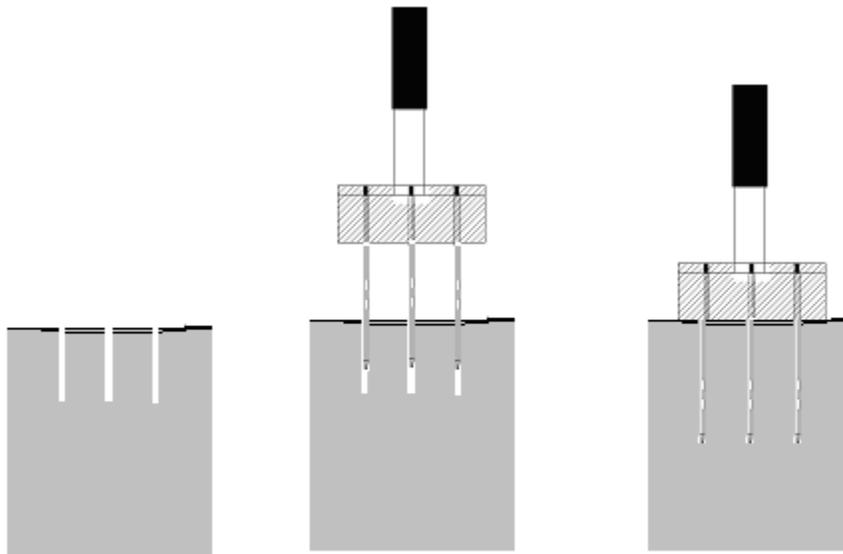

Fig. 3 b)- AquaProbe in-situ moisture measurement

5. UPLOAD DATA

P.C. SOFTWARE

File

- **Open** (Ctrl + O)
  Opens previously saved files containing data.

- **Close**
  Closes currently open files

- **Save**

- **Saves As**

Saves uploaded data. Files are saved as *.txt for later analysis via spreadsheet or insertion in your favorite word processor.

- **Exit**
  Terminates the program and returns to your operating system.

Tools

- **Upload** (Ctrl + U)
  This command is used to upload data from module to the CPU.

For proper upload of data to a P.C. please follow these steps:

- Open AquaProbe software (title of screen should read AquaProbe Regression Analysis) on the P.C.

- Connect P.C. and AquaProbe by the RS-232 serial port

- On the AquaProbe use the + or – arrow keys until the "Upload Data screen appears on the display.

- Press Enter.

- Go to the AquaProbe software (needs to be installed on P.C.) click on the upload icon ![upload icon] or press CTRL + U

- AquaProbe software will ask you to "Please start upload."

- At this moment press the + arrow to erase data or the – arrow to save data after upload (AquaProbe software waits 10 seconds for the upload information). If no data is received after 10 seconds, a "No data received" sub screen will appear on the computer screen.

- Data will appear on the screen after the + or – arrow key selection was made.

- Save data in desired folder.

Please follow the bottom steps in order to upload the data stored in the unit to a P.C.

- Connect the unit to the correct serial port of the P.C. using the supplied serial cable.

- Use the plus or minus keys until the following message is displayed:
  Upload Data (Enter for Yes)

- Pressing enter will display the following message:
  Erase Data?

  + for Yes or – for No

- Pressing either button will commence the upload process and display the message:

  Data Upload in Process

  Once the process is complete the following message will be displayed:

  Upload Complete!

  For a few seconds and then the Upload Data message from above will appear.

Data Analysis

Data Analysis option is used to obtained the calibration parameters for different materials. By pressing the Analyze key the software will start the analysis of the data currently on the software environment.

- **Analyze** (Ctrl + A)

This option allows the user to view individual record, graph data, and determine the correct coefficients for the user program. This key should only be used when data is uploaded from the unit that was saved in direct mode. It is then used to analyze the data and generate a user program. This feature is not enabled until a data file has been brought up on the screen.

This shows the record number, date the record was taken, time the record was taken, value of the direct readout, and corresponding percentage moisture that needs to be completed by the user in order to generate a correlation curve.

Pressing the OK button updates the data in the file and brings up the next record in the file. Pressing the cancel button cancels the entire operation.

Once the last data point has been entered the Finish button can be pressed in order to generate a correlation curve.

Microwave Moisture Regression Analysis

Gain = 0.1431   Offset = -005.53
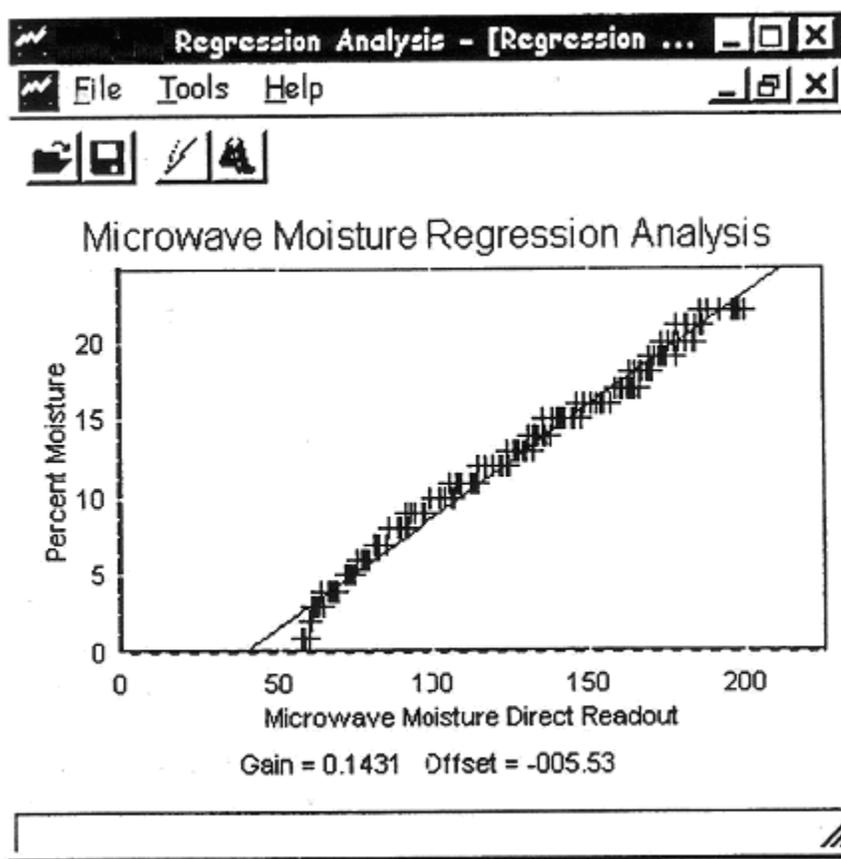
This will produce a display of the correlated data and the appropriate OFFSET and GAIN parameters to be entered in the AquaProbe.

Ports

This command allows setting the correct (RS – 232) Com port. It can be Com 1 through Com 4. The default setting is Com 1.

APPENDIX A
LEAST SQUARES ANALYSIS

For this method, we assume that there exists a linear relationship between the output of the probe and the amount of moisture in the material to be tested.

This relationship takes the form:

% Moisture = Gain * Direct Reading + Offset
 or
$$y = a*x + b$$

What need to be determined are the parameters *Gain* or *a and Offset* or *b* from a given set of points determined by testing.

We can then define:

$$S_{xx} = \Sigma x_i^2 - (\Sigma x_i)^2/n$$

$$S_{yy} = \Sigma y_i^2 - (\Sigma y_i)^2/n$$

$$S_{xy} = \Sigma x_i y_i^2 - (\Sigma x_i \Sigma y_i)/n$$

Where x_i and y_i are individual pairs of values for x and y defining each of the pairs of points to be plotted. The quantity n is the number of points.

The Gain of the line, a is now simply: $a = S_{xy}/S_{xx}$

The Offset, b can be calculated as: $b = y_i/n - ax_i/n$

This is performed automatically by the accompanying software and is also available in most spread sheet programs.

APPENDIX B CALIBRATION

- Dry sample using oven (105 to 110 C). It is suggested to weight sample prior to drying.

- When sample has lost all moisture, calibration can be started.

- Weight dried sample

- Add water by 2 percent increments.
  i.e. 4,000 grams – 2 percent water = 80 grams of water

- Turn the T-S-30 AquaProbe on

- Using up or down arrows, scroll through the menu selection until Direct Mode appears on the T-S-30 display (it is recommended to erase all prior data saved in the T-S-30).

- Take 10 readings for each percentage starting at 0%. Store each reading by pressing enter.

- After T-S-30 has hit full saturation (direct reading 409.5 percent), uploading data to P.C. Software is necessary.

- Uploading can be done by connecting the AquaProbe to the P.C. using the supplied RS-232 cable.

- Use instructions in the T-S-30 manual pages 5-9 to successfully accomplish calibration.

- Once analysis has been completed with the T-S-30 P.C. Software, the **Offset** and the **Gain** will be displayed.

- Write down these two values.

- Return to the T-S-30 and enter a user program. (T-S-30 manual page 12 "Change user program")

- Once the gain and offset have been entered in the T-S-30, calibration has been completed.

James Instruments Inc. warrants to the original user, that each product

of its manufacture is free from defects in material and factory workmanship.

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correction without charge, any part found to have material or workmanship

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