# APPLICATION OF THE NEW HYPROP DEVICE TO MEASURE THE SOIL WATER CHARACTERISTIC CURVE AND OTHER SOIL DRYING PROPERTIES

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ABSTRACT
The Tempe cell is commonly used to measure the entire soil water characteristic curve (SWCC) for sand and silt material with low air entry values (AEV) and suction up to 500 kPa. This technique, however, is time-consuming and requires several weeks or months to complete the test. The SWCC is used to describe the relationship between the amount of water in the soil and the matric suction. This study was undertaken to evaluate the ability of the HYPROP device to measure the SWCCs of sand and silt material and to compare the results to those obtained using a Tempe cell. The results show that the two apparatus yielded similar AEVs for beach sand and gold tailings within experimental error. The results also show that the HYPROP can generate the SWCCs of beach sand and gold tailings within ten days (compared to six weeks using a Tempe cell). The HYPROP device also yielded other useful unsaturated soil properties that describe the soil drying behavior. This technique shows promise in the rapid and accurate measurement of SWCC of sand and silt material and in obtaining unsaturated soil properties.

RÉSUMÉ
La cellule Tempe est couramment utilisée pour mesurer la courbe caractéristique de l'eau du sol (CCES) pour matériaux de sable et de limon avec de faibles valeurs d'entrée d'air (VEA) jusqu'à une succion de 500 kPa. Cette technique, cependant, prend du temps et nécessite plusieurs semaines ou mois pour terminer le test. Le CCES est utilisé pour décrire la relation entre la quantité d'eau dans le sol et la succion matricielle. Cette étude a été entreprise pour évaluer la capacité de l'appareil HYPROP à mesurer les CCES des matériaux de sable et de limon et de comparer les résultats à ceux obtenus à l'aide d'une cellule Tempe. Les résultats montrent que les deux appareils ont donné des VEAs similaires pour le sable de plage et les résidus d'extraction d'or dans les limites de l'erreur expérimentale. Les résultats montrent également que l'HYPROP peut générer les SWCCs du sable de plage et des résidus d'extraction d'or en dix jours contre six semaines avec une cellule Tempe. Le dispositif HYPROP fournit également d'autres données utiles sur les propriétés du sol non saturé qui décrivent le comportement de séchage du sol. Il s'agit de la technique la plus prometteuse pour la mesure du CCES du sable et du limon, y compris les propriétés du sol non saturé.

## 1 INTRODUCTION

The soil-water characteristic curve (SWCC) has become a valuable conceptual tool for the estimation of unsaturated soil property functions in geotechnical engineering practices (Fredlund and Rahardjo, 1993; Fredlund, 2002). The SWCC is used to describe the relationship between the amount of water in the soil and the matric suction. The SWCC is commonly measured using a Tempe pressure cell for soil material with low air entry values (AEV) up to 500 kPa. This method is time-consuming and takes several weeks or months to complete a test. The newly developed HYPROP is an automated device (METER Environment, 2018) that takes days (typically 4 to 10 days) to generate a SWCC in the wet range (up to 300 kPa). The HYPROP also measures the permeability function (i.e., unsaturated hydraulic conductivity versus soil suction). The objective of this study was to evaluate the ability of the new HYPROP device to measure the SWCCs of beach sand and gold tailings samples within days and to compare the results to those obtained using a Tempe cell. It was shown that, in addition to generating accurate SWCCs, the HYPROP device can yield other useful data for unsaturated soil properties, such as unsaturated hydraulic conductivity curves.

## 2 DEVICES AND TEST PROCEDURES

### 2.1 Apparatus

Two devices were used in this study: a Tempe pressure cell apparatus and a new HYPROP device (METER Environment, 2018). The Tempe cell components and setup are shown in Figures 1 and 2, and the HYPROP components and setup are shown in Figures 3 and 4. The Tempe cell device is made up of three main parts: i) the bottom part fitted with a 500 kPa ceramic high air entry disc and an outlet of water from the sample; ii) an acrylic cylinder (7 cm dia. x 9 cm high) to hold the sample; and iii) a lid fitted with an inlet for air pressure supply.

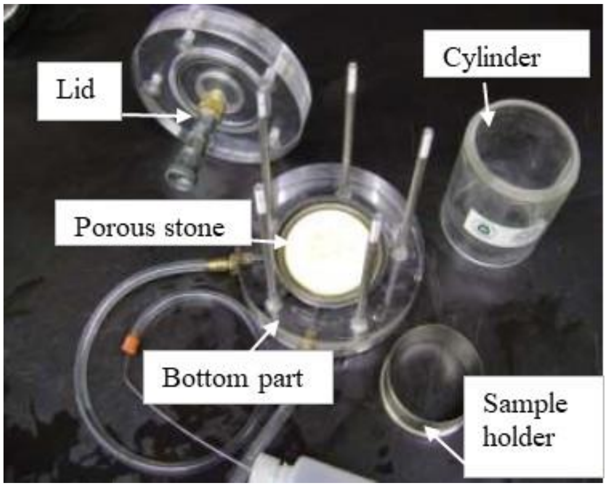


Figure 1. Components of the Tempe cell.

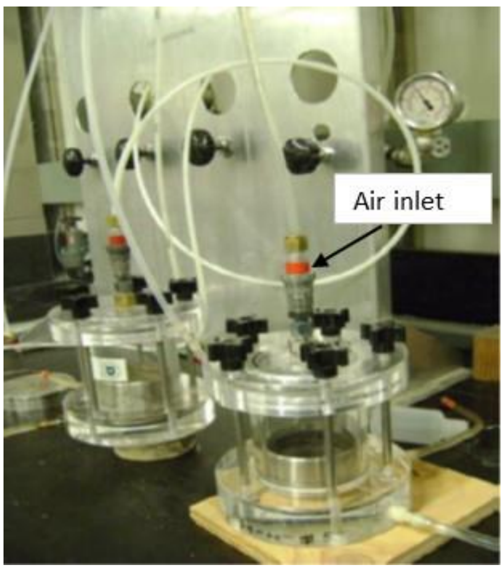


Figure 2. Tempe cell measurement setup.

The HYPROP device comprises a bottom part fitted with two mini-tensiometers to measure water potential, a cell (8 cm dia. x 5 cm high) to hold the sample and a balance for weighing the sample.

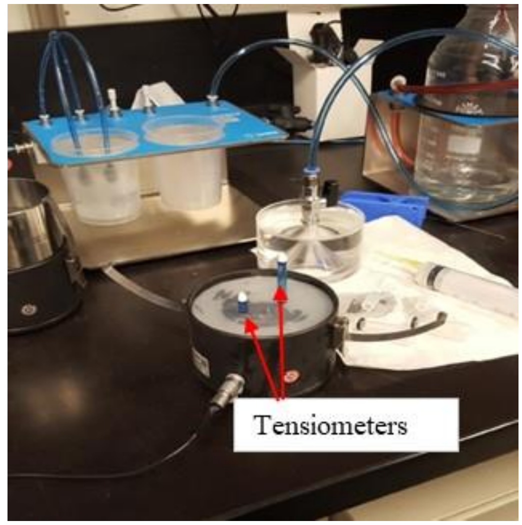


Figure 3. Components of the HYPROP device.

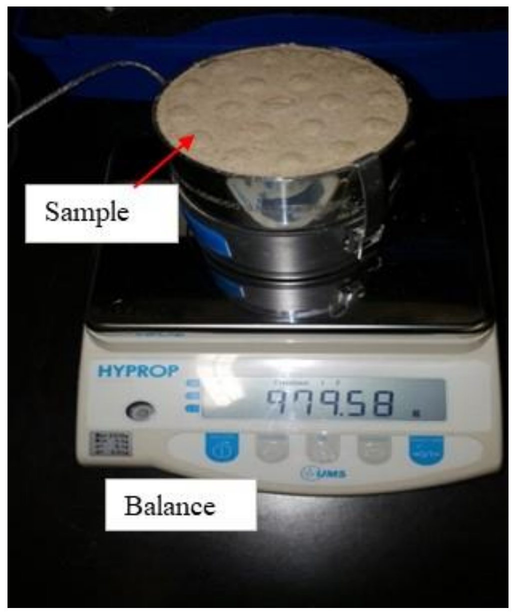


Figure 4. HYPROP measurement setup.

## 2.2 Tempe Cell Procedure

The SWCC was measured following the standard method recommended by Fredlund and Rahardjo (1993). Once a saturated sample is confined in a Tempe cell (Figure 1) the air pressure is applied over the sample through the inlet on top of the lid, and the water released from the sample is collected at the base of the cell. The change in the sample is monitored by weighing the overall mass of the soil specimen until the changes in mass become constant, and it is assumed that the steady-state is reached. At this stage the applied air pressure equates to the soil suction. It can take 2 to 4 days to reach this steady state. Higher air pressures are applied in steps until the maximum suction is reached. At the end of the test, the sample is removed from the cell, and the final water content is determined by oven-drying. This water content together with the previous changes in weight are used to back-calculate the water contents corresponding to the other suction values. The matric suction is then plotted against the corresponding water contents to give the SWCC.

### 2.3 HYPROP Test Procedure

Before measurement, a saturated sample is confined in a measuring cell (Figure 4) and two precision mini-tensiometers (Figure 3) are inserted in the sample to measure water potential at different levels within the sample; the sample then rests on a laboratory scale. The HYPROP is set up to run on an automated mode. The HYPROP-Fit software can detect the scale and the measuring heads and automatically assigns measuring values to the tensions. Over time as the sample dries, the instrument measures the changing water potential and the changing sample weight simultaneously. It calculates the moisture content from the weight measurements and plots changes in water potential correlated to the changes in moisture content. The HYPROP generates a SWCC for soil samples in as few as 4 to 10 days. The HYPROP also measures the permeability function (unsaturated hydraulic conductivity versus soil suction). In this study, a third scale with a cell of water was used to measure the potential evaporation (changes in mass of water over time).

### 2.4 Sample Characterization

A sieve test was performed on the beach sand and dispersed hydrometer-sieve tests were performed on gold tailings samples, following the procedure outlined in ASTM (2007) Standard D422-63 for analyzing the particle size of soils. The automated KSAT (METER) was used to measure saturated hydraulic conductivities ($K_s$) of beach sand and gold tailings samples using falling head technique. An Atterberg Limits test was not conducted on the gold tailings in this work; the results presented in this paper were obtained from the literature (Salfate et al., 2010).

## 3 RESULTS AND DISCUSSION

### 3.1 Particle Size Distribution and Saturated Hydraulic conductivity

Table 1 and Figure 5 show the particle size distribution (PSD) data for the two samples tested in this study. The amount of fines (< 44 μm) averaged 10% and about 1% for the gold tailings and beach sand, respectively. Hence, about 90% and 99% of the gold tailings and beach sand, respectively, are sands. The uniformity coefficient (Cu) (Cu = D60 / D10) for the gold tailings sample is 1.9 which is considered well sorted (i.e., Cu < 4). The uniformity coefficient of the beach sand sample is 1.4 and is also considered well sorted. Saturated hydraulic conductivities for gold tailings and beach sand are $6x10^{-7}$ and $2x10^{-6}$ m/s, respectively.

Plastic Limits and Liquid Limits for the gold tailings sample are 20 and 23, respectively (Salfate et al., 2010).

Table 1. Particle size distribution (PSD) and saturated hydraulic conductivity ($K_s$) data for the tested samples.

| | *Fine | Silt | Sand | $K_s$ |
|---|---|---|---|---|
| | (%) | (%) | (%) | (m/s) |
| Beach sand | ~ 1 | ~ 1 | 99 | $2x10^{-6}$ |
| Gold tailings | 10 | 10 | 90 | $6x10^{-7}$ |

* Fine < 44 µm

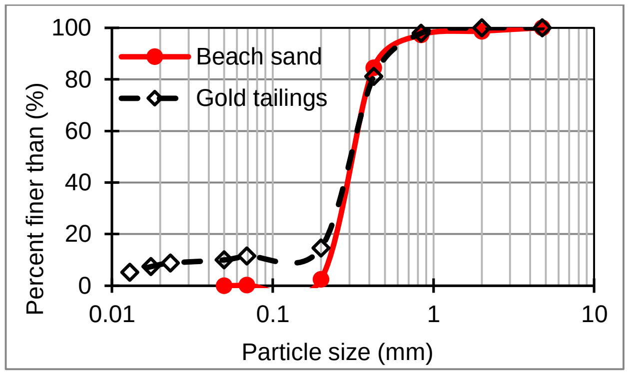


Figure 5. Particle size distribution (PSD) for tested samples.

### 3.2 Soil Water Characteristic Curve

Tables 2 and 3 and Figures 6 and 7 compare the SWCC data for the beach sand and gold tailings measured using the Tempe cell and HYPROP device. The SWCC shows the relationships between the volumetric water content and soil suction. The best-fit lines for the SWCCs were obtained using the Fredlund and Xing (1994) analysis that allows the SWCC to go to zero water content as the soil suction goes to 1,000,000 kPa. In Figure 6, the Tempe cell and HYPROP techniques exhibit similar SWCCs for the beach sand with AEVs of about 3 and 4 kPa, respectively. These AEVs are the same within experimental error. Figure 7 compares the SWCC data for the gold tailings measured using the Tempe cell and HYPROP device. Again, the two techniques exhibit similar SWCCs with AEVs of about 11 and 10 kPa for the Tempe cell and HYPROP, respectively. The major difference between the two techniques is in the duration of the test measurements. The HYPROP took about 9 days to complete the test compared to about 40 days with the Tempe cell. Hence, it can be concluded that the HYPROP generates a SWCC about four times faster than the Tempe cell.

Table 2. SWCC properties for the beach sand.

| | AEV (kPa) | Test duration (days) |
|---|---|---|
| Tempe cell | 3 | 40 |
| HYPROP | 4 | 9 |

Table 3. SWCC properties for the gold tailings.

| | AEV (kPa) | Test duration (days) |
|---|---|---|
| Tempe cell | 11 | 40 |
| HYPROP | 10 | 9 |

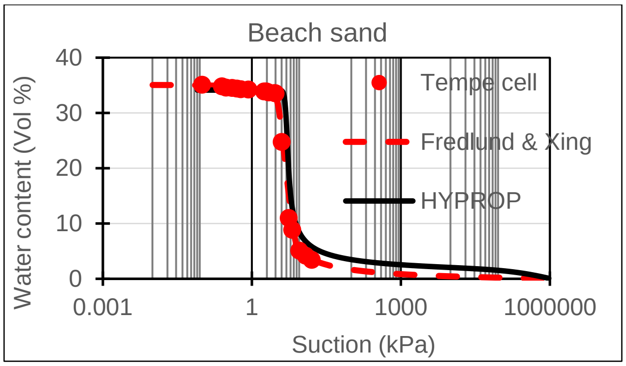


Figure 6. SWCCs for the beach sand measured using the Tempe cell and HYPROP.

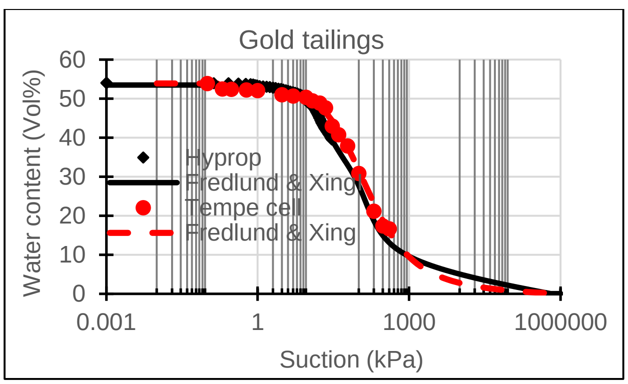


Figure 7. SWCCs for the gold tailings measured using the Tempe cell and HYPROP.

Some other pros and cons of the HYPROP technique over the Temp cell are summarized as follows:

- The HYPROP produces a series of higher resolution data (over 100), which provide more detailed information related to the SWCC.
- On the contrary, the Tempe cell is labor-intensive, and it requires daily monitoring and measurement of the weight of the cell. Additionally, the Tempe cell yields relatively little data that are subjected to human errors during measurement.
- The ranges for soil suction measurement for the HYPROP device and Tempe cell can be extended up to 100 and 500 kPa, respectively; the smaller soil suction range can be considered the major limitation of the HYPROP.

### 3.3 Unsaturated Hydraulic Conductivity

The HYPROP measures the unsaturated hydraulic conductivity (K) of the tested samples. Unsaturated hydraulic conductivity is the most common flow state in soils, but it is not the most frequently measured hydraulic property. This is where the HYPROP is advantageous. Figure 8 presents the measured K data using the HYPROP for beach sand and gold tailings samples. As suction increases, the K of the beach sand decreases more rapidly than that of the gold tailings. For example, as suction increases from 2 to 2.5 kPa, the K for beach sand decreases by approximately 3 and a half orders of magnitude, and the K of the gold tailings decreases by one order of magnitude. The rapid decrease in K is due to the porous texture of the sand material as shown in the slopes of the PSD and SWCC for the beach sand.

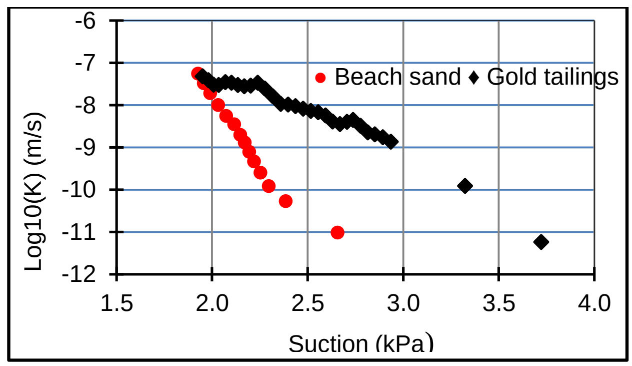


Figure 8. Unsaturated hydraulic conductivities.

### 3.4 Drying Properties

Figures 9 and 10 show the drying curves (AE/PE ratio of actual evaporation (AE) over potential evaporation (PE) versus time) and associated soil suction curves for the beach sand and gold tailings measured using the HYPROP device. Figure 11 compares the soil suction curves between the beach sand and gold tailings. Figures 9 and 10 show that the AE/PE ratios remain high ( i.e., ≥ 1) when the soils are saturated or near saturated up to Day 4 and Day 5 for the beach sand and gold tailings, respectively. The ratios start to decline thereafter as drying proceeds in the unsaturated zones. The deflections in the drying curves indicate the onset of the unsaturated zones of the samples (saturation boundaries). The beach sand displays a steeper desaturation slope than the gold tailings sample. The desaturation slopes are similar to those of the SWCCs for the beach sand and gold tailings, as shown in Figures 6 and 7.

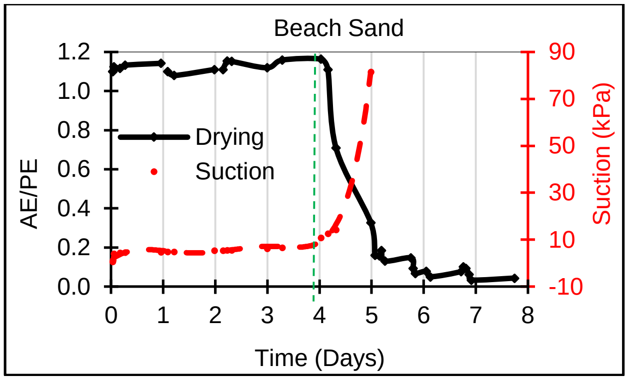


Figure 9. Drying and suction curves for the beach sand.

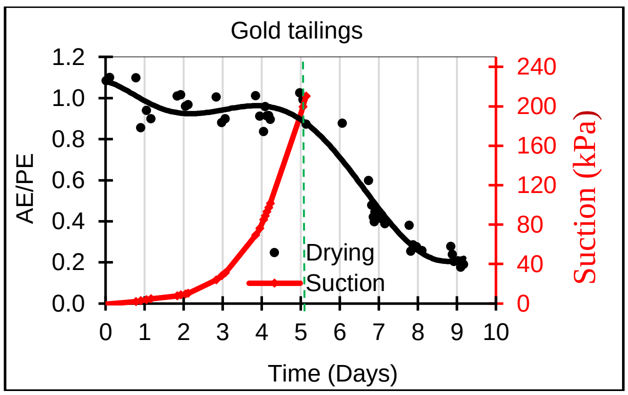


Figure 10. Drying and suction curves for the gold tailings.

The curves as shown in Figure 11 indicate that the soil suction values of both samples remain very low in the saturated zones (i.e., up to Day 2 and Day 4 for the gold tailings and beach sand, respectively). As drying proceeds in the unsaturated zones, soil suctions start to increase at a faster rate. The gold tailings gain suction even faster when compared to the beach sand. On Day 5, the gold tailings achieved a suction value of about 2.5 times higher (200 kPa) than the beach sand (80 kPa). The changes in the soil suction and AE/PE ratio are considered as a function of soil texture, water availability and evaporation rate (Wilson et al., 1997).

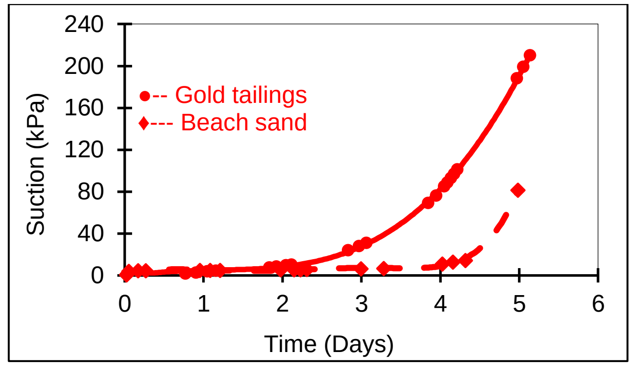


Figure 11. Suction curves for beach sand and gold tailings.

## 4 SUMMARY AND CONCLUSIONS

The SWCCs for both the beach sand and gold tailings were measured using the HYPROP device and Tempe cell. The results show that the two measurement techniques produce similar SWCCs and AEVs within experimental error. The major advantage of the HYPROP device over the Tempe cell is that the HYPROP measures SWCC four times faster than the Tempe cell. Other advantages of the HYPROP device included:

- The HYPROP is an automated device that generates a significantly larger number of data with higher resolution. Hence, more accurate data can be expected from this device.
- On the contrary, the Tempe cell is labor-intensive and is subjected to human errors during measurement.
- The HYPROP generates other useful hydraulic properties, such as the unsaturated hydraulic conductivities of the tested samples and so on.
- The HYPROP device will go a long way in reducing the SWCC measurement time and in enhancing its accuracy. Similar testing on clayey soils (including oil sand tailings) are currently underway at the laboratory to fully evaluate the performance of the HYPROP device.

## ACKNOWLEDGEMENTS


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