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U.S. Patent # 11,353,391 B2
U.S. Patent # 10,739,242 B2



Upstream Technologies

Automated MPD Infiltrometer

Testing Procedures & Results



This document includes:

- Accuracy - Gauge Range and Reproducibility (GR&R) Results
- Altitude Testing Results
- Near Freezing (34 Degrees F) Testing Results
- Dynamic Temperature Testing Results

MPD Infiltrometer Accuracy Testing

Background:

Upstream Technologies Automated MPD Infiltrometer calculates Field Hydraulic Conductivity of Soil (K_{sat}), following ASTM Standard D8152.

The ASTM Standard outlines the method and equation for calculating K_{sat} using falling head data (over time) from a graduated cylinder tapped into the soil.



The ASTM Standard D8152 details the equation for calculating K_{sat} that Upstream's Automated MPD follows. Because this is an equation, it will produce the same result, every time, on the same set of data. By default, any equation is 100% repeatable and accurate provided the inputs are the same each time.

It is therefore required to measure the accuracy and repeatability of a device's ability to measure falling head data in the ASTM defined graduated cylinder. This document details the procedures and results for accuracy, repeatability, altitude variations and temperature variations.

GR&R Test Procedure:

To baseline the Automated MPD, the following criteria was used:

- 20 MPD heads were selected at random
- 8 cylinders were filled with water at the following levels:
 - 35, 30, 25, 20, 15, 10, 6, 3.5 centimeters.
- An MPD head was placed on the 35cm cylinder and turned on.
- After a water level measurement was achieved, the head would be moved to the next cylinder (water level) and a measurement taken. This was repeated until all water levels were measured and the data recorded automatically.
- The above procedure was then repeated 2 more times with the same MPD Heads for a total of 3 tests per head per water level. 24 measurements per MPD Head.
- Total # of tests: 480 with all data recorded and stored and available on the MPD Server
- Ambient Temperature = 70 degrees Fahrenheit (21 Celsius)



Accuracy, Range and Reproducibility Results:

<p>Accuracy comparing 20 MPD heads. Each measuring 8 water levels 3 separate times each:</p>	<p>Accuracy: +/- 3 mm Range: 6 mm +/- 0.9% over the range of the cylinder</p>
<p>Accuracy comparing results from a single MPD head measuring 8 water levels, 3 times, total of 24 tests:</p>	<p>Accuracy: +/- 2 mm Range: 4 mm +/- 0.5% over the range of the cylinder</p>

(Raw data on following page)

Accuracy, Repeatability & Reproduceability Test													
20 MPD Heads					Each tested 3 different times at 8 water levels								
70 Degrees F					480 total measurements								
Static Water Level in Centimeters													
	35	30	25	20	15	10	6	3.5	Accuracy in millimeters				
Max:	35.3	30.3	25.3	20.1	15.2	10.2	6.3	3.7	3.0	Plus 0.86%			
Min:	34.8	29.9	24.9	19.8	14.7	9.7	5.9	3.4	-3.0	Minus 0.86%			
Range:	0.5	0.4	0.4	0.3	0.5	0.5	0.4	0.3	6.0	Range 1.71%			
Average	35.01	30.06	25.11	19.93	14.91	9.97	6.09	3.53	Percent shown is to the range of cylinder				
TEST A													
Date	Test ID	Head #	35	30	25	20	15	10	6	3.5	Accuracy in millimeters		
10/18/2018	9100	25579	35.2	30.0	25.0	19.9	14.9	10.0	6.0	3.6	Max	Min	Range
10/18/2018	9101	42286	35.2	30.1	25.2	19.9	15.0	10.2	6.2	3.7	2	-1	3
10/18/2018	9102	31726	34.9	30.1	25.3	19.9	15.0	10.1	6.2	3.5	3	-1	4
10/18/2018	9203	20848	35.0	30.1	25.2	19.9	15.0	9.9	6.0	3.6	2	-1	3
10/18/2018	9104	42110	34.9	30.0	25.1	19.8	15.0	10.0	6.0	3.5	1	-2	3
10/18/2018	9105	50569	35.0	30.0	25.3	19.9	15.1	10.1	6.2	3.5	3	-1	4
10/18/2018	9106	27205	34.9	29.9	25.1	19.8	15.0	9.9	6.0	3.6	1	-2	3
10/18/2018	9107	9276	35.1	30.1	25.3	20.1	15.2	10.1	6.2	3.6	3	1	2
10/18/2018	9108	3536	34.8	29.9	25.2	19.8	14.9	9.9	5.9	3.5	2	-2	4
10/18/2018	9109	64415	35.1	29.9	25.3	19.9	15.0	10.0	6.0	3.5	3	-1	4
10/19/2018	9136	51000	35.2	30.2	25.1	20.0	14.9	10.0	6.1	3.5	2	-1	3
10/19/2018	9137	60486	35.0	29.9	25.1	20.0	14.9	9.8	6.0	3.6	1	-2	3
10/19/2018	9138	62434	35.1	30.0	25.1	19.8	14.8	9.8	5.9	3.4	1	-2	3
10/19/2018	9139	61407	35.2	30.3	25.1	20.0	15.0	10.0	6.2	3.6	3	0	3
10/19/2018	9140	52789	34.9	29.9	25.0	19.8	14.8	9.7	6.0	3.5	0	-3	3
10/19/2018	9141	58199	34.9	29.9	24.9	19.9	14.9	9.8	6.0	3.5	0	-2	2
10/19/2018	9142	56718	34.9	30.0	24.9	19.9	14.8	9.8	6.1	3.5	1	-2	3
10/19/2018	9143	56109	35.0	30.0	25.1	20.0	14.9	9.9	6.1	3.5	1	-1	2
10/19/2018	9144	63128	35.1	30.2	25.1	20.0	14.8	9.9	6.0	3.5	2	-2	4
10/19/2018	9145	5969	35.0	30.1	25.1	19.9	14.8	9.8	6.0	3.5	1	-2	3
TEST B													
Date	Test ID	Head #	35	30	25	20	15	10	6	3.5	Accuracy in millimeters		
10/22/2018	9157	25579	35.0	29.9	25.0	19.9	14.9	10.0	6.1	3.5	Max	Min	Range
10/22/2018	9158	42286	34.9	30.1	25.1	19.9	14.9	10.0	6.1	3.6	1	-1	2
10/22/2018	9159	31726	34.9	30.1	25.2	20.0	15.0	10.0	6.1	3.5	2	-1	3
10/22/2018	9160	20848	34.9	29.9	25.2	20.0	14.9	10.0	6.1	3.5	2	-1	3
10/22/2018	9161	42110	35.0	30.0	25.0	19.9	14.8	10.0	6.1	3.5	1	-2	3
10/22/2018	9162	50569	35.0	30.0	25.1	20.0	14.9	10.1	6.2	3.5	2	-1	3
10/22/2018	9163	27205	35.0	30.0	25.1	19.9	14.9	10.0	6.2	3.6	2	-1	3
10/22/2018	9164	9276	35.0	30.0	25.0	20.0	14.9	10.0	6.1	3.5	1	-1	2
10/22/2018	9165	3536	34.9	30.1	25.1	19.9	14.9	10.0	6.1	3.6	1	-1	2
10/22/2018	9166	64415	34.9	29.9	25.0	19.8	14.8	10.0	6.1	3.6	1	-2	3
10/22/2018	9146	51000	35.3	30.2	25.3	20.1	14.9	10.0	6.1	3.4	3	-1	4
10/22/2018	9147	60486	34.9	29.9	25.0	19.9	14.8	10.0	6.1	3.7	2	-2	4
10/22/2018	9148	62434	35.1	30.1	25.1	19.9	14.9	9.9	6.0	3.5	1	-1	2
10/22/2018	9149	61407	35.1	30.1	25.2	20.0	14.9	10.1	6.2	3.6	2	-1	3
10/22/2018	9150	52789	35.1	30.0	25.2	20.0	14.9	10.0	6.1	3.5	2	-1	3
10/22/2018	9151	58199	34.9	30.0	25.1	19.9	14.9	10.0	6.1	3.5	1	-1	2
10/22/2018	9152	56718	35.0	30.0	25.1	19.9	14.9	10.0	6.1	3.5	1	-1	2
10/22/2018	9153	56109	34.9	29.9	25.1	19.9	14.9	10.0	6.1	3.5	1	-1	2
10/22/2018	9154	63128	34.9	29.9	25.1	19.9	14.9	10.0	6.1	3.5	1	-1	2
10/22/2018	9155	5969	34.9	29.9	25.1	19.9	14.9	9.9	6.1	3.6	1	-1	2
TEST C													
Date	Test ID	Head #	35	30	25	20	15	10	6	3.5	Accuracy in millimeters		
10/22/2018	9167	25579	35.1	30.1	25.2	20.1	15.1	10.1	6.2	3.5	Max	Min	Range
10/22/2018	9168	42286	35.0	30.2	25.0	19.9	15.0	10.1	6.2	3.5	2	-1	3
10/22/2018	9169	31726	35.1	30.3	25.2	19.9	14.8	10.1	6.2	3.5	3	-2	5
10/22/2018	9170	20848	35.1	30.2	25.0	19.9	14.9	10.0	6.1	3.6	2	-1	3
10/22/2018	9171	42110	35.0	30.2	25.1	19.9	14.9	9.9	6.0	3.5	2	-1	3
10/22/2018	9172	50569	35.1	30.2	25.1	20.0	15.0	10.0	6.1	3.5	2	0	2
10/22/2018	9173	27205	34.9	30.3	25.2	20.0	14.9	10.1	6.3	3.6	3	-1	4
10/22/2018	9174	9276	35.0	30.1	25.0	19.9	14.9	9.9	6.0	3.5	1	-1	2
10/22/2018	9175	3536	35.1	30.2	25.2	20.0	14.9	10.0	6.1	3.5	2	-1	3
10/22/2018	9176	64415	35.1	30.2	25.1	19.9	14.9	10.2	6.3	3.7	3	-1	4
10/22/2018	9182	51000	35.0	30.1	25.0	19.9	14.9	10.0	6.1	3.5	1	-1	2
10/22/2018	9813	60486	34.9	30.0	24.9	19.8	14.7	9.7	5.9	3.5	0	-3	3
10/22/2018	9184	62434	34.8	30.0	25.1	19.9	14.8	9.9	6.0	3.4	1	-2	3
10/22/2018	9185	61407	35.2	30.3	25.2	20.0	15.0	10.2	6.3	3.6	3	0	3
10/22/2018	9186	52789	35.0	30.0	25.2	20.0	15.0	10.0	6.2	3.5	2	0	2
10/22/2018	9177	58199	35.1	30.2	25.1	20.0	14.9	10.0	6.1	3.5	2	-1	3
10/22/2018	9178	56718	35.0	30.1	25.1	20.0	14.9	10.0	6.1	3.6	1	-1	2
10/22/2018	9179	56109	35.0	30.1	25.2	19.9	14.9	9.9	6.0	3.4	2	-1	3
10/22/2018	9180	63128	34.9	30.2	25.1	20.0	14.8	9.8	5.9	3.4	2	-2	4
10/22/2018	9181	5969	34.9	30.2	25.1	19.8	14.7	9.8	5.9	3.4	2	-3	5

MPD Infiltrometer Altitude Testing

Background:

The MPD heads use a pressure sensor to detect the water level in the MPD cylinder. Each MPD head is calibrated in Minneapolis, Minnesota and then shipped world-wide. Minneapolis is approximately 950 feet above sea level. The MPD electronics, compensates for barometric pressure to achieve accuracy at any elevation in the world.

Procedure:

6 MPD Heads were chosen randomly and placed in an atmospheric chamber:



Each of the 6 MPD heads was calibrated at the following elevations above sea level:

Units: Feet / Meters

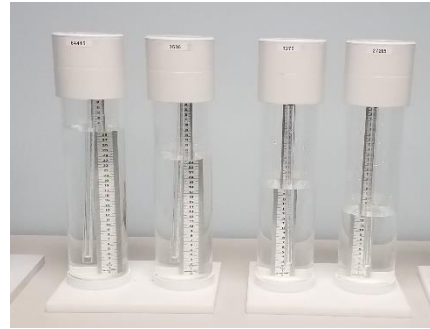
<ul style="list-style-type: none">• 2,000 / 610• 3,000 / 915	<ul style="list-style-type: none">• 4,000 / 1,220• 5,000 / 1,524	<ul style="list-style-type: none">• 10,000 / 3048• 15,000 / 4,572
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After calibration of each head was complete, the MPD heads were tested in Minneapolis for accuracy. (Approximately 950 feet above sea level)

Each head was tested at 4 different water levels:

- 30 cm
- 20 cm
- 10 cm
- 3.5 cm

4 measurements were recorded per water level. The raw results are shown in the table below.



The results show an **accuracy within 3 millimeters** for all elevations.

2,000 feet	
Actual Water Level in Cylinder (Centimeters)	MPD Water Level Measurement (Centimeters)
30.0	30.1
30.0	30.2
30.0	30.2
30.0	30.2
20.0	20.1
20.0	20.1
20.0	20.1
20.0	20.1
10.0	10.1
10.0	10.1
10.0	10.1
10.0	10.1
3.5	3.6
3.5	3.6
3.5	3.6
3.5	3.6

3,000 feet	
Actual Water Level in Cylinder (Centimeters)	MPD Water Level Measurement (Centimeters)
30.0	30.2
30.0	30.2
30.0	30.2
30.0	30.3
20.0	20.1
20.0	20.1
20.0	20.1
20.0	20.1
10.0	9.9
10.0	9.9
10.0	10.0
10.0	10.0
3.5	3.5
3.5	3.5
3.5	3.5
3.5	3.5

4,000 feet	
Actual Water Level in Cylinder (Centimeters)	MPD Water Level Measurement (Centimeters)
30.0	30.1
30.0	30.1
30.0	30.1
30.0	30.1
20.0	20.0
20.0	20.0
20.0	20.0
20.0	20.0
10.0	9.9
10.0	9.9
10.0	9.9
10.0	9.9
3.5	3.5
3.5	3.5
3.5	3.5
3.5	3.5

5,000 feet	
Actual Water Level in Cylinder (Centimeters)	MPD Water Level Measurement (Centimeters)
30.0	30.0
30.0	30.0
30.0	30.0
30.0	30.0
20.0	19.8
20.0	19.8
20.0	19.8
20.0	19.8
10.0	9.7
10.0	9.7
10.0	9.7
10.0	9.7
3.5	3.5
3.5	3.5
3.5	3.5
3.5	3.5

10,000 feet	
Actual Water Level in Cylinder (Centimeters)	MPD Water Level Measurement (Centimeters)
30.0	30.1
30.0	30.1
30.0	30.1
30.0	30.1
20.0	20.1
20.0	20.1
20.0	20.1
20.0	20.1
10.0	9.9
10.0	10.0
10.0	10.0
10.0	10.0
3.5	3.5
3.5	3.5
3.5	3.5
3.5	3.5

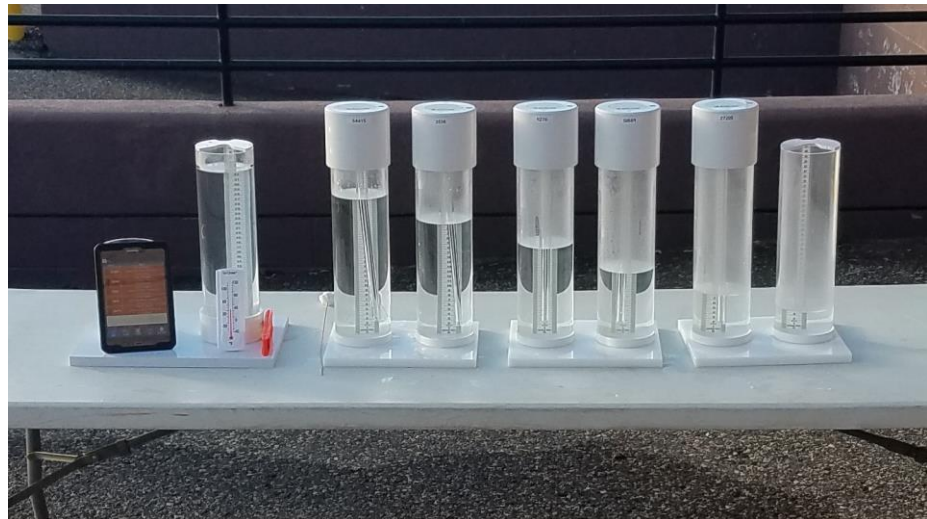
15,000 feet	
Actual Water Level in Cylinder (Centimeters)	MPD Water Level Measurement (Centimeters)
30.0	30.0
30.0	30.0
30.0	30.0
30.0	30.0
20.0	19.8
20.0	19.9
20.0	19.9
20.0	19.9
10.0	9.9
10.0	9.9
10.0	9.9
10.0	9.9
3.5	3.5
3.5	3.5
3.5	3.5
3.5	3.5

MPD Infiltrometer Cold Weather Testing

34° F 1° C

Background:

- The MPD will not work below 33° F (1° C)
- MPD Heads are calibrated at 70° F. (21° C) at Upstream Technologies Inc.
- Cold Temperature testing was conducted with 5 MPD heads at 34° F. (1° C)
- 7 Water levels were tested for each head: 30cm, 25, 20, 15, 10, 6 & 3.5cm



Results:

		Static Water Level in Centimeters							Accuracy in millimeters		
		30	25	20	15	10	6	3.5	3.0	Plus	
Max:		30.2	25.3	20.1	15.1	9.9	6.0	3.5	3.0	Plus	
Min:		30.1	25.1	19.8	14.8	9.7	5.7	3.5	-3.0	Minus	
Range:		0.1	0.2	0.3	0.3	0.2	0.3	0.0	6.0	Range	
Average:		30.12	25.20	19.94	14.88	9.82	5.88	3.50	Note: % of range cylinder		
34 Degrees F:											
TEST 1		Static Water Level in Centimeters							Accuracy in millimeters		
Date	Head #	30	25	20	15	10	6	3.5	Max	Min	Range
10/23/2018	27205	30.1	25.2	20.0	14.9	9.9	6.0	3.5	2.0	-1.0	1
10/23/2018	50569	30.2	25.3	20.1	15.1	9.9	6.0	3.5	3.0	-1.0	2
10/23/2018	9276	30.1	25.2	19.9	14.8	9.8	5.9	3.5	2.0	-2.0	0
10/23/2018	9536	30.1	25.1	19.8	14.8	9.8	5.8	3.5	1.0	-2.0	-1
10/23/2018	64415	30.1	25.2	19.9	14.8	9.7	5.7	3.5	2.0	-3.0	-1

When comparing the 5 different heads, over the 7 water levels, the worst case accuracy was less than: +/- 1% (+/- 3 mm) with a total range of 2% (6mm)

When comparing a single head unto itself over the 7 different water levels, accuracy was slightly higher.

Accuracy was similar to tests performed at 70 degrees F.

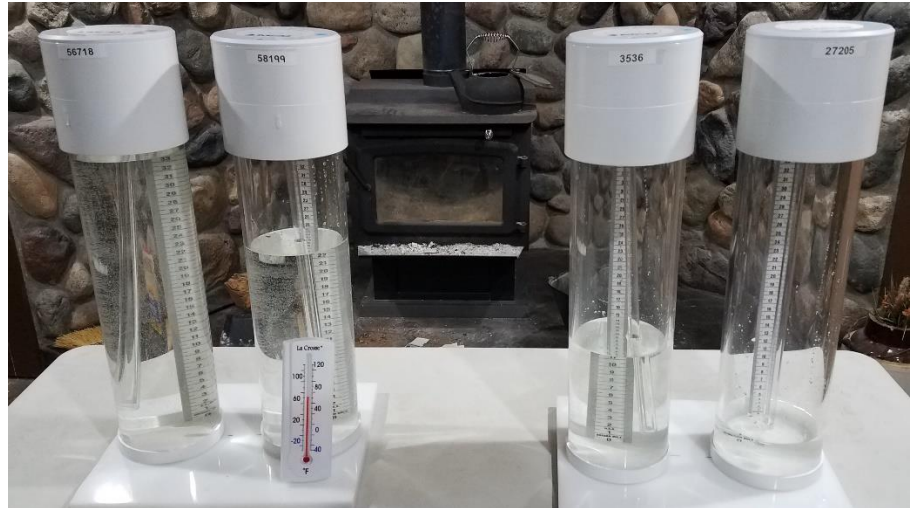
Dynamic Temperature Testing

The purpose of this test is to emulate testing in the field, where an MPD test is started early in the morning and the temperature rises while a test is running.

Procedure:

4 MPD heads were placed on cylinders with 4 different static water levels

- 30 cm
- 20 cm
- 10 cm
- 3.5 cm



- The test began with an ambient temperature of 15.5° C (60° F) .
- The MPD heads were turned on and began collecting static water height data at 60 second intervals
- Room temperature was then slowly raised to 43° C (110° F) and then allowed to cool naturally
- Entire test lasted 9 hours
- (wood stove in background was the heat source).



Each of the different water levels produced the same basic result. The static water level reading rose as the temperature rose by the following amounts:

5.8 mm (1.6%) change in static water height reading per 10-degree Celsius change

3.2 mm (0.9%) change in static water height reading per 10-degree Fahrenheit change

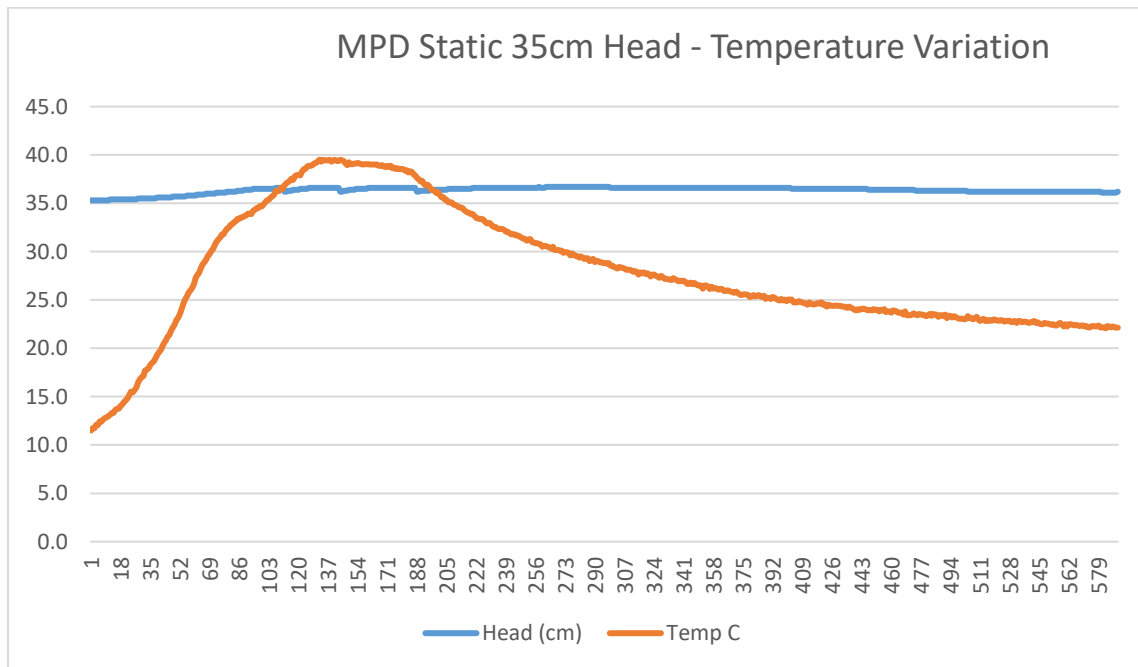
NOTES:

The laws of thermal dynamics demand the water level will physically rise in the cylinder as the temperature rises. Therefore, what we are seeing here, is not a flaw in the measurement method, but an accurate measurement of the rising water as the temperature rises, and a lowering of the water as the temperature cooled.

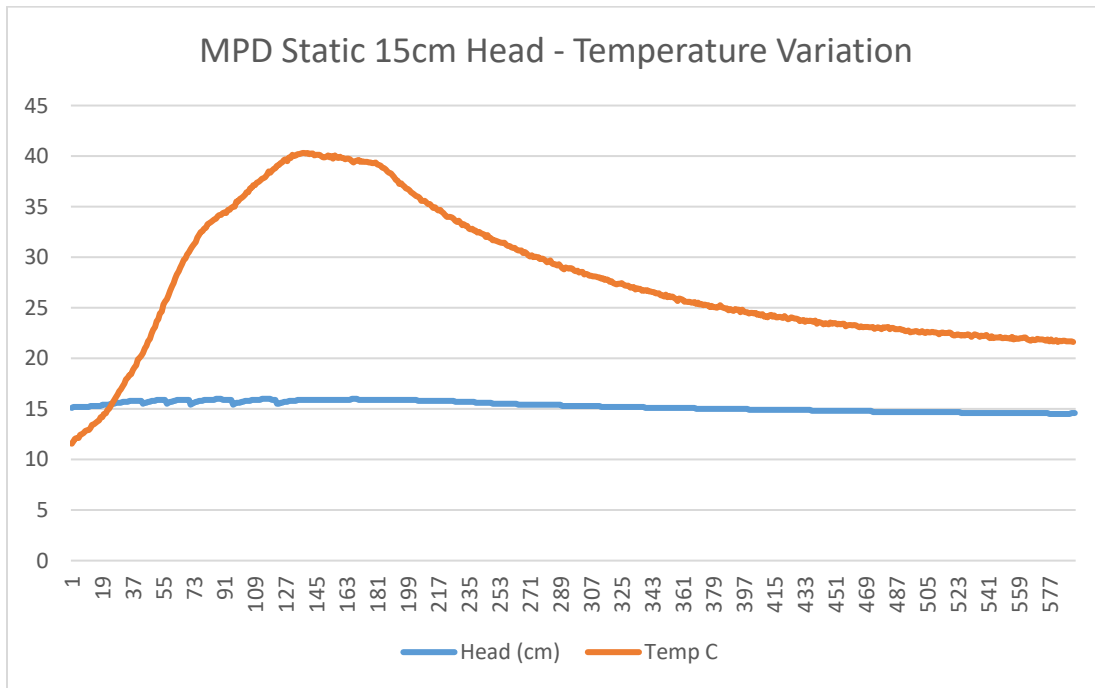
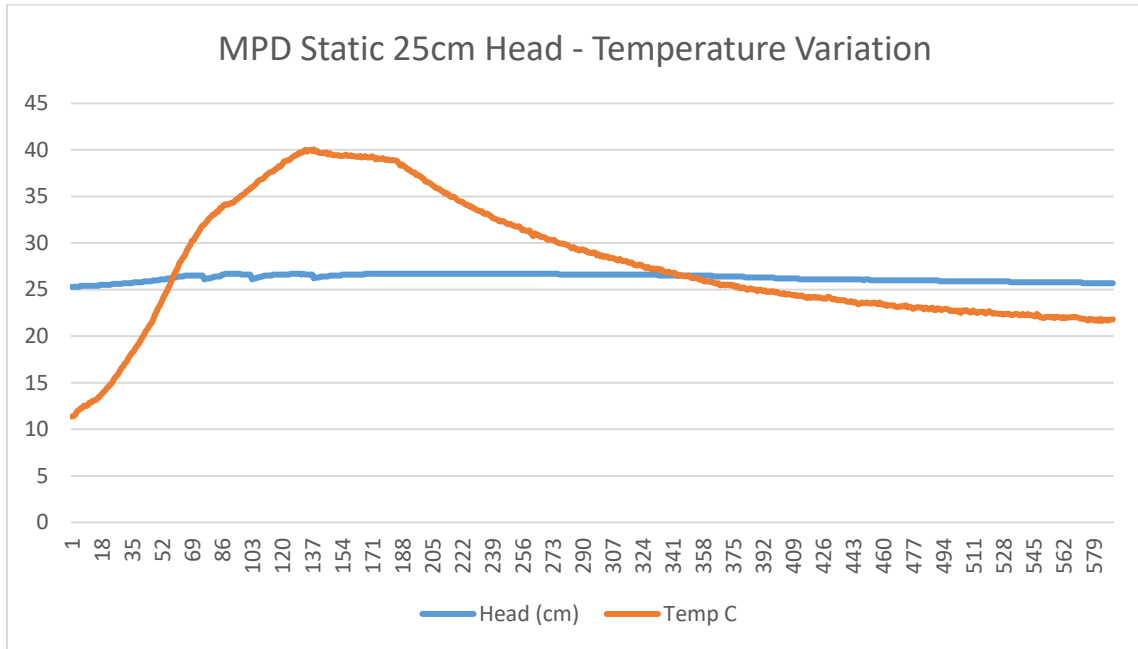
The purpose of this measurement is for user awareness of this phenomenon. While this is not a significant % change in height readings, the user should be cautioned about long tests during wild temperature swings. Also, note that as the temperature changes, the water level is dropping during a real infiltration test, which lessens the effects of this anomaly.

A 30° C change in temperature (50° F) during a test, should not significantly affect the Ksat result.

----- Degrees in Celsius
 ----- Water Head Level in Centimeters



Left Scale = Degrees Celsius
Bottom Scale = Number of Readings or Minutes
Reading was taken once every minute.



MPD Static 5cm Head - Temperature Variation

