India Mark II and India Mark III Borehole Hand Pump Variation Study in Uganda

Revision 3.7 | July 30, 2018 (Revised on May 11, 2021)

Field Study Data:
20 July 2018 – 03 August 2018
Kampala Uganda (July 20, 21, 22)
Jinja Uganda (July 23, 24, 25)
Masindi Uganda (July 26)
Murchison Park Uganda (July 27, 28)
Gulu Uganda (July 29, 30, 31)
Kampala Uganda (August 1, 2, 3)

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DOCUMENT REVISION HISTORY

Revision, Date	Comment
R1.0, 30 Jul 2018	Initial Document Creation
R3.0, 4 Aug 2018	Importing all Data for Artifacts 1-10
R3.1, 7 Aug 2018	Importing data for Artifacts 11 -25, sending out to team for review
R3.2, 7 Aug 2018	Added gender study, and internal measurement error, general document clean-up
R3.3, 8 Aug 2018	Updated Artifacts 7 – 15, and 17 – 24. Added Artifact A27
R3.4, 8 Aug 2018	Updated liter estimates, added Artifact 28
R3.4, 13 Aug 2018	Transitioned document to Microsoft word online for document sharing. Added contact information for Evelynn
R3.5, 15 Aug 2018	Added DOE surface plots, wave form images, water estimates, pump sensor information, and coefficient of variation
R3.6, 20 Aug 2018	Added Discharge test by Immy Irot (Artifact 29)
R3.7, 11 May 2021	Added images of pump sites and stores. Removed the "Water Particulate Count" placeholder artifact. Added Figure and table captions. Added the cost for servicing the cup seals.

Brief Overview of this Study

The purpose of this study is to characterize the variation in parameters associated with Ugandan borehole pump parts, usage, performance, and operating environment. Ultimately, we hope to use this and other information to design improved borehole pump parts that are robust to variation. Academically, this information will be used to explore the extent to which uncertainty quantification is possible and useful in an engineering for global development setting.

Purpose of this Report

The purpose of this report is to clearly convey the data collected during a BYU Design Exploration Research Group trip to Uganda in July-August 2018. This report provides our observations regarding the data, and also provides other observations regarding the Ugandan context, which while included here for completeness, we consider them valuable yet anecdotal.

The report exists in two main parts: The body, and the artifacts. The body is a few pages. Artifacts are small self-contained test reports. Together the artifacts take the vast majority of the space in this report.

Key Findings

For us that are used to having clean water readily available in our homes, it is important to realize that without these water hand pumps, many of the people we came in contact with would not have clean water. The local communities are dependent on functional pumps to get access to clean water daily.

Before the water officials installs a new water hand pump, the local village must set up a committee to ensure that the pump would be managed. The committee is in charge of taxing the local families so that when the pump needs service, they can readily call for repairs. Due to the lack of resources of the committee, a pump that fails would often go un-repaired for weeks or months before the committee could pay a private pump mechanic to start the repairs.

The local users and water officials were supportive of our work and would often ask us to share any findings with them.

We were able to find pump parts and supplies in each of the communities we visited. This study investigated the qualities of pump cup seals found in local retail shops in the study area.

By interviewing pump technicians, we found that pump performance could be improved with adherence to the preventive maintenance schedule outlined in the "Installation & Maintenance Manual for the India Mark II Handpump" Edition 2008 page 28-34 and Annexes 1-4.

We believe that the research we performed and the results we found in Uganda could and should be extended to areas around the world where the local population depends on hand pumps for their clean water supply. Additional research can and needs to be completed around improving the performance and longevity of borehole pumps around the world. Specifically, the systematic collection of data to determine failure conditions that have been reported during this research project. These failures include the pump subassemblies of; the handle, pump head, head flange, riser pipe, pump rod, cylinder, pump rod grommets, and Dynamic Water Table monitoring.

Methods used to Assess Variation

Multiple methods were used to assess the variation related to the India Mark II and India Mark II[1] borehole pump parts, usage, performance, and operating environment. The Table below summarizes the methods used and the results. Note the reference to specific artifacts for more detail. Also assessed is Internal Measurement Error, which characterizes the variation that exists when measuring the same sample many times.

Table 1. Summary of artifacts, methods, and results for the study.

Key Parameter	Method used to Test	Result	See Artifact
Cup Seal Weight (g)	Purchased 112 seals from 6 Ugandan stores. Measured each seal using precision scale. Calculated statistics.	Mean = 17.5891 Stdev = 1.33278 Spec value = none Spec tol. = none	A1
Cup Seal Volume (cm^3)	Purchased 112 seals from 6 Ugandan stores. Measured each seal using water displacement method with precision instruments. Calculated statistics.	Mean = 12.7056 Stdev = 0.245873 Spec value = none Spec tol. = none	A2
Cup Seal Density (g/cm^3)	Calculated density based on the measurement of seal weight and seal volume.	Mean = 1.41672 Stdev = 0.0841749 Spec value = none Spec tol. = none	A3
Cup Seal Durometer (Shore A)	Purchased 112 seals from 6 stores. Measured each using durometer. Four measurements were made per seal. Calculated statistics.	Mean = 86.0536 Stdev = 3.4368 Spec value = 80 Spec tol. = +/-5	A4
Cup Seal Geometry: Outer Diameter (DIM 1), (mm)	Purchased 112 seals from 6 stores, took precision photo of each. Measured each optically with MATLAB image processing. Calculated statistics.	Mean = 64.2653 Stdev = 0.530363 Spec value = 63.5 Spec tol. = +0.5	A5
Cup Seal Geometry: Inner Diameter (DIM 2), (mm)	Purchased 112 seals from 6 stores, took precision photo of each. Measured each optically with MATLAB image processing. Calculated statistics.	Mean = 41.8651 Stdev = 0.227975 Spec value = 42.5 Spec tol. = +0.8	A6
Cup Seal Geometry: Height (DIM 3), (mm)	Purchased 112 seals from 6 stores, used digimatic indicator to measure seal height at four places on the seal.	Mean = 12.4019 Stdev = 0.429384 Spec value = 14 Spec tol. = +/-0.5	A7

[1] Uganda-Modified pumps U2 and U3 are derivatives of India Mark II and India Mark III pumps.

Cup Seal Geometry: Base Thickness (DIM 4), (mm)	Purchased 112 seals from 6 stores, used digimatic indicator to measure seal thickness at four places on the seal base.	Mean = 4.22616 Stdev = 0.175371 Spec value = 4.0 Spec tol. = +0.5	A8
Cup Seal Geometry: Wall Thickness (DIM 5), (mm)	Purchased 112 seals from 6 stores, used digimatic indicator to measure wall thickness at eight places on the seal wall.	Mean = 4.1533 Stdev = 0.180924 Spec value = (4.0) ref Spec tol. = +.05	A9
Cup Seal Geometry: Wall Angle (DIM 6), deg)	Purchased 112 seals from 6 stores took precision photo of each. Measured each optically with MATLAB image processing. Calculated statistics.	Mean = 7.52808 Stdev = 2.22381 Spec value = 5 Spec tol. = none	A10
Locations of Stores and Boreholes	This artifact simply lists the names, contacts, and locations (GPS) of the stores and boreholes.	See artifact	A11
Operating Environment: Water pH Test	Water samples were taken at each borehole at various times throughout the day. pH test strips were used an matched to color scale.	See artifact	A12
Operating Environment: Water Hardness Test	Water samples were taken at each borehole at various times throughout the day. Water hardness test strips were used an matched to color scale.	See artifact	A13
Operating Environment: Water Salinity Test	Water samples were taken at each borehole at various times throughout the day. A salinity meter was used to measure salinity in PPT.	See artifact	A14
Operating Environment: Water Temperature Test	Water samples were taken at each borehole at various times throughout the day. A salinity tester also provided water temperature.	See artifact	A15
Pump Performance: Borehole 1	A design of experiments (DOE) was carried out varying stroke length and stroke frequency. The measured parameter was amount of water discharged.	See artifact	A16
Pump Performance: Borehole 2	A design of experiments (DOE) was carried out varying stroke length and stroke frequency. The measured parameter was amount of water discharged.	See artifact	A17
Pump Performance: Borehole 3	A design of experiments (DOE) was carried out varying stroke length and stroke frequency. The measured parameter was amount of water discharged.	See artifact	A18
Pump Performance: Borehole 4	A design of experiments (DOE) was carried out varying stroke length and stroke frequency. The measured parameter was amount of water discharged.	See artifact	A19
Pump Usage: Borehole 1	A custom sensor system was deployed and used to understand usage. A camera was also used to characterize gender balance.	See artifact	A20
Pump Usage: Borehole 2	A custom sensor system was deployed and used to understand usage. A camera was also used to characterize gender balance.	See artifact	A21
Pump Usage: Borehole 3	A custom sensor system was deployed and used to understand usage. A camera was also used to characterize gender balance.	See artifact	A22
Pump Usage: Borehole 4	A custom sensor system was deployed and used to understand usage. A camera was also used to characterize gender balance.	See artifact	A23
Field Trip Anecdotal Observations	n/a	See artifact	A24

Internal Measurement Error assessment	The same measurement methods described above were carried out on the same seal at least 33 times. The % error was calculated.	See artifact	A25
Water Coverage Reports	These were provided to us by the district. They are repeated here for completeness.	See artifact	A26
Uganda Contact List	n/a	See artifact	A27
Discharge test by Immy Irot	Discharge test done after we left Uganda	See artifact	A28

Discussion

There is evidence that entire communities depend on and benefit in many ways from functioning borehole pumps. This includes daily access to dependable, affordable clean water and social-behavioral traditions that may add to the stability of the community. The factors contributing to the breakdown and often slow repair of pumps is deeply rooted in the local culture and traditions of the community and should be studied.

Conclusions

See each individual Artifact (especially A24).

References

ERPF, K. (2007) ***India Mark Handpump Specifications***. (Revision 2-2007), v.2, RWSN/Skat, St Gallen, Switzerland

SKAT (2008) ***Installation & Maintenance Manual for the India Mark II Handpump***. (Edition 2008), Skat, Rural Water Supply Network, St Gallen, Switzerland

Artifacts

Table 2: Artifacts included in this report.

Artifact Number	Revision	Title
Artifact A1	1.1	Cup Seal Weight measurements
Artifact A2	1.1	Cup Seal Volume measurements
Artifact A3	1.0	Cup Seal Density calculations
Artifact A4	1.0	Cup Seal Durometer measurements
Artifact A5	1.0	Cup Seal DIM1 Outer Diameter measurements
Artifact A6	1.0	Cup Seal DIM2 Inner Diameter measurements
Artifact A7	1.0	Cup Seal DIM3 Height measurements
Artifact A8	1.0	Cup Seal DIM4 Base Thickness measurements
Artifact A9	1.0	Cup Seal DIM5 Wall Thickness measurements
Artifact A10	1.0	Cup Seal DIM6 Wall Angle measurements
Artifact A11	1.1	Locations of Stores and Boreholes
Artifact A12	1.0	Operating Environment: Water pH Test
Artifact A13	1.0	Operating Environment: Water Hardness Test
Artifact A14	1.0	Operating Environment: Water Salinity Test
Artifact A15	1.0	Operating Environment: Water Temperature Test
Artifact A16	1.1	Pump Performance: Borehole 1 (Jinja)
Artifact A17	1.1	Pump Performance: Borehole 2 (Jinja)
Artifact A18	1.1	Pump Performance: Borehole 3 (Gulu)
Artifact A19	1.1	Pump Performance: Borehole 4 (Gulu)
Artifact A20	1.1	Pump Usage: Borehole 1 (Jinja)
Artifact A21	1.1	Pump Usage: Borehole 2 (Jinja)
Artifact A22	1.1	Pump Usage: Borehole 3 (Gulu)
Artifact A23	1.1	Pump Usage: Borehole 4 (Gulu)
Artifact A24	1.1	Anecdotal Findings
Artifact A25	1.0	Internal Measurement Error Analysis
Artifact A26	1.0	Water Coverage Report (Gulu and Jinja)
Artifact A27	1.1	Uganda Contact List
Artifact A28	1.0	Discharge test by Immy Irot

Cup Seal Weight — Artifact A1

Artifact Prepared by: Tom Naylor and Christopher Mattson | Revision 1.1
Tests Performed by: Tom Naylor
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
Measure the weight in grams (g) of individual cup seals.

Summary of Test Results:

Summary of test results can be seen in Table A1.1.

Table A1.1. Summary of weight test results.

Spec (g)	Spec Min (g)	Spec Max (g)	Samples (count)	Mean (g)	Stdev (g)	Min (g)	Max (g)	Range (g)	Median (g)
None	None	None	112	17.5891	1.33278	14.685	23.142	8.457	17.5405

Test Equipment and Set up:
The Sartorius AY303 scale (see Figure A1.1) was used to measure seal weight with readability 0.001 g, repeatability 0.005 g, and linearity 0.005 g. The AY303 was powered using eight 1.5 V batteries to make the device portable. Before use, the scale was leveled using the adjustable legs and the built-in bubble level. Measures were taken to ensure that there was no airflow in the test environment, as the scale is sensitive enough to be affected by it. Also before use, the scale was able to sit for a short period of time while connected to the battery power supply (step 3 below). This resulted in a consistent readout.

Figure A1.1. Sartorius AY303 scale.

Test Procedure:

1. Balance scale using the built-in bubble level
2. Turn on scale and open lid
3. Wait for measured value to steady
4. Zero scale
5. Place seal on the center of the scale
6. Wait for measured value to steady
7. Record value
8. Remove seal
9. Repeat steps 3 – 8 (zeroing only when scale does not return to zero) until all measurements are taken

Test Results:
Figures A1.3 and A1.4 show the data, and Table A1.2 shows the raw data collected.

Observations and Conclusions:
Note that there were no Nitrile cup seals purchased from stores 2 or 3; therefore, there are no measurements recorded or reported for those stores in this document.

As can be seen in Figures A1.3 and A1.4, the weight of the seals from store 1 is noticeably more consistent than those of stores 6. Store 1 had a large box of seals from which they took these samples. No other store had as many seals for sale. This could be an indication that Store 1 is one of the larger suppliers in the area.

The seals from store 6 were noticeably dirtier at the time of purchase. Each seal was cleaned before it was measured. Figure A1.2 shows the state of the seals from store 6 at the time of purchase.

Figure A1.2. Dirty cup seals from store 6

Only 4 samples were purchased from store 7. With only 4 pieces of data, little can be said about any general trend for store 7.

There is no specification for the seal weight, so it cannot be stated if the variation in weight is acceptable or not.

Figure A1.4 shows 6 significant things for each store. The horizontal line below the box shows the small number in the data set (excluding outliers). The horizontal line above the box shows the large number in the data set (excluding outliers). The lower edge of the box is the 1st quartile line, and the upper edge is the 3rd quartile line. The line in the center of the box is the mean. Outliers in the data are represented by the "+" sign. The dashed horizontal line is the mean for all stores combined.

From the boxplots we can easily see that stores did not share the same mean nor the same variation, though stores 1 and 4 are the most similar. Store 1 was in Kampala, and store 4 in Jinja. The seals from store 4 where kept tied in a plastic bag in a bucket with other parts.

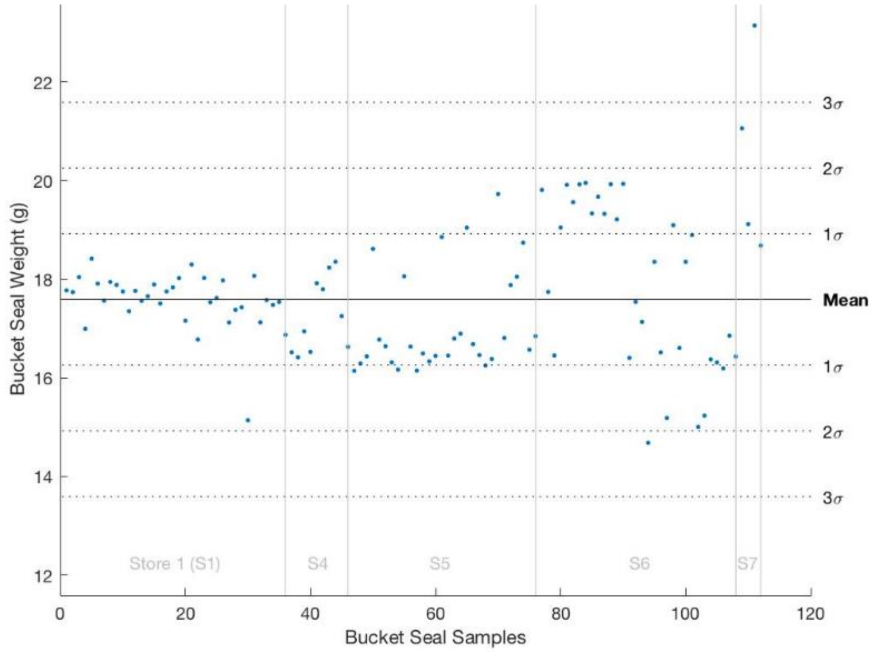

Figure A1.3. Cup seal weight. Ordered as tested.

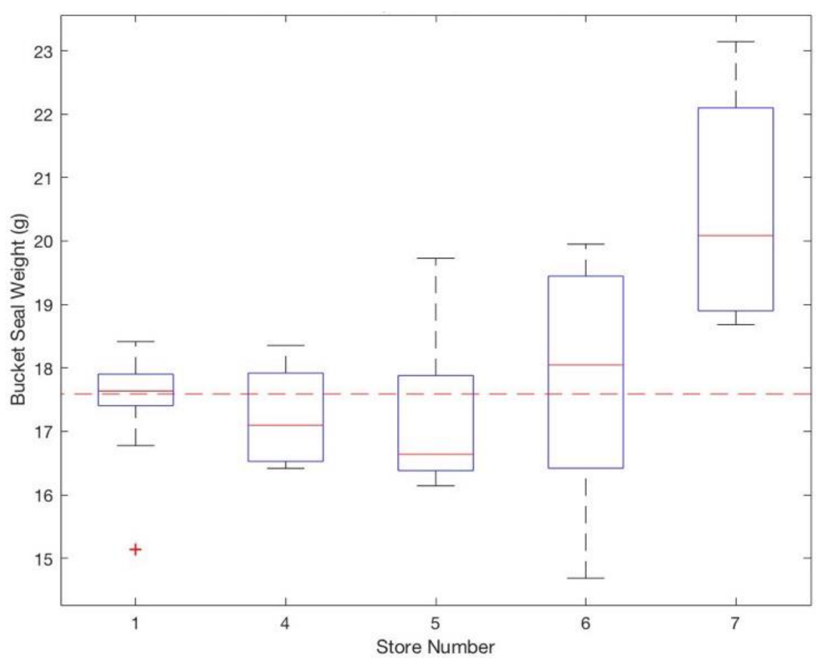

Figure A1.4. Cup seal weight. Boxplots for each store.

Table A1.2. Raw data for weight measurements. Units = grams.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	17.774	n/a	n/a	16.517	16.141	19.811	21.058
XX-002	17.738	n/a	n/a	16.418	16.292	17.743	19.116
XX-003	18.042	n/a	n/a	16.943	16.434	16.451	23.142
XX-004	16.993	n/a	n/a	16.526	18.616	19.047	18.683
XX-005	18.416	n/a	n/a	17.919	16.774	19.913	n/a
XX-006	17.912	n/a	n/a	17.795	16.642	19.562	n/a
XX-007	17.564	n/a	n/a	18.238	16.312	19.922	n/a
XX-008	17.944	n/a	n/a	18.353	16.166	19.953	n/a
XX-009	17.883	n/a	n/a	17.251	18.059	19.335	n/a
XX-010	17.751	n/a	n/a	16.628	16.634	19.672	n/a
XX-011	17.35	n/a	n/a	n/a	16.146	19.326	n/a
XX-012	17.765	n/a	n/a	n/a	16.496	19.925	n/a
XX-013	17.56	n/a	n/a	n/a	16.334	19.212	n/a
XX-014	17.655	n/a	n/a	n/a	16.445	19.932	n/a
XX-015	17.893	n/a	n/a	n/a	18.856	16.405	n/a
XX-016	17.508	n/a	n/a	n/a	16.45	17.541	n/a
XX-017	17.752	n/a	n/a	n/a	16.798	17.135	n/a
XX-018	17.836	n/a	n/a	n/a	16.897	14.685	n/a
XX-019	18.023	n/a	n/a	n/a	19.044	18.352	n/a
XX-020	17.157	n/a	n/a	n/a	16.682	16.516	n/a
XX-021	18.298	n/a	n/a	n/a	16.46	15.185	n/a
XX-022	16.777	n/a	n/a	n/a	16.252	19.096	n/a
XX-023	18.025	n/a	n/a	n/a	16.381	16.605	n/a
XX-024	17.533	n/a	n/a	n/a	19.728	18.352	n/a
XX-025	17.619	n/a	n/a	n/a	16.81	18.894	n/a
XX-026	17.976	n/a	n/a	n/a	17.88	15.007	n/a
XX-027	17.123	n/a	n/a	n/a	18.05	15.235	n/a
XX-028	17.38	n/a	n/a	n/a	18.738	16.373	n/a
XX-029	17.43	n/a	n/a	n/a	16.571	16.312	n/a
XX-030	15.141	n/a	n/a	n/a	16.845	16.193	n/a
XX-031	18.068	n/a	n/a	n/a	n/a	16.853	n/a
XX-032	17.127	n/a	n/a	n/a	n/a	16.433	n/a
XX-033	17.576	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	17.478	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	17.54	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	16.871	n/a	n/a	n/a	n/a	n/a	n/a
Mean	17.5688	n/a	n/a	17.2588	17.0644	17.843	20.4997
Stdev	0.561698	n/a	n/a	0.758023	1.02184	1.73068	2.04193
Min	15.141	n/a	n/a	16.418	16.141	14.685	18.683
Max	18.416	n/a	n/a	18.353	19.728	19.953	23.142
Range	3.275	n/a	n/a	1.935	3.587	5.268	4.459
Median	17.637	n/a	n/a	17.097	16.638	18.0475	20.087
CV[2]	0.0319713	n/a	n/a	0.0439210	0.0598814	0.0969949	0.996078

[2] CV stands for coefficient of variation, $C_v = \frac{\sigma}{\mu}$

Cup Seal Volume — Artifact A2

Artifact Prepared by: Tom Naylor and Christopher Mattson | Revision 1.1
Tests Performed by: Tom Naylor
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
Measure the volume (cm^3) of individual cup seals.

Summary of Test Results:

Summary of test results can be seen in Table A2.1.

Table A2.1. Summary of weight test results.

Spec (cm^3)	Spec Min (cm^3)	Spec Max (cm^3)	Samples (count)	Mean (cm^3)	Stdev (cm^3)	Min (cm^3)	Max (cm^3)	Range (cm^3)	Median (cm^3)
None	None	None	112	12.4099	0.449553	11.718	13.812	2.094	12.3865

Test Equipment and Set up:
The water displacement method was used to measure seal volume. The Sartorius AY303 scale (Figure A2.1) was used in the set up. See Artifact A1 (Cup Seal Weight) for scale specifications and setup. To measure volume, the seal was held by a steadying rod and a seal basket to keep the seal from touching the side and bottom of the vessel (see Figure A2.1).

Figure A2.1. Setup of seal volume test.

Test Procedure:

1. Balance scale using the built-in bubble level
2. Turn on scale and open lid
3. Fill container to the blue line with water (ensures the scale capacity is not exceeded)
4. Place container on scale and wait for the value to steady
5. Zero scale
6. Place seal in measuring basket
7. Hang basket on metal rod
8. Immerse seal into the water
9. Steady the rod and seal so it does not touch side or bottom of vessel
10. Wait for measured value to steady
11. Record number
12. Remove scale and zero scale as some water is removed along with the seal
13. Repeat steps 6 – 12 until all measurements are recorded

Test Results:
Figures A2.3 and A2.4 show the data, and Table A2.2 shows the raw data collected.

Observations and Conclusions:
Note that there were no Nitrile cup seals purchased from stores 2 or 3; therefore, there are no measurements recorded or reported for those stores in this document.

As can be seen in the box plots[3] (Figure A2.4), the seals from store 1 are the most consistent. Whether or not variations in seal volume affects seal performance is not known or speculated on in this report, other than to indicate how seal density varies (see Artifact A3).

Of the 4 samples that were purchased from store 7. It was found that two had a significantly different inner radius (see Figure A2.2). These seals were sold as replacement cup seals for the India Mark II. The figure below shows the two seal types purchased from the Store 7. With such an inner diameter difference, it is expected that two data points would be noticeably larger than the others, however this is not the case. The data shows only 1 seal with a noticeably larger volume than the others.

There is no specification for the seal volume, so it cannot be stated if the variation in volume is acceptable or not.

[3] Artifact 1 Cup Seal Weight provides a brief description about box plot interpretation.

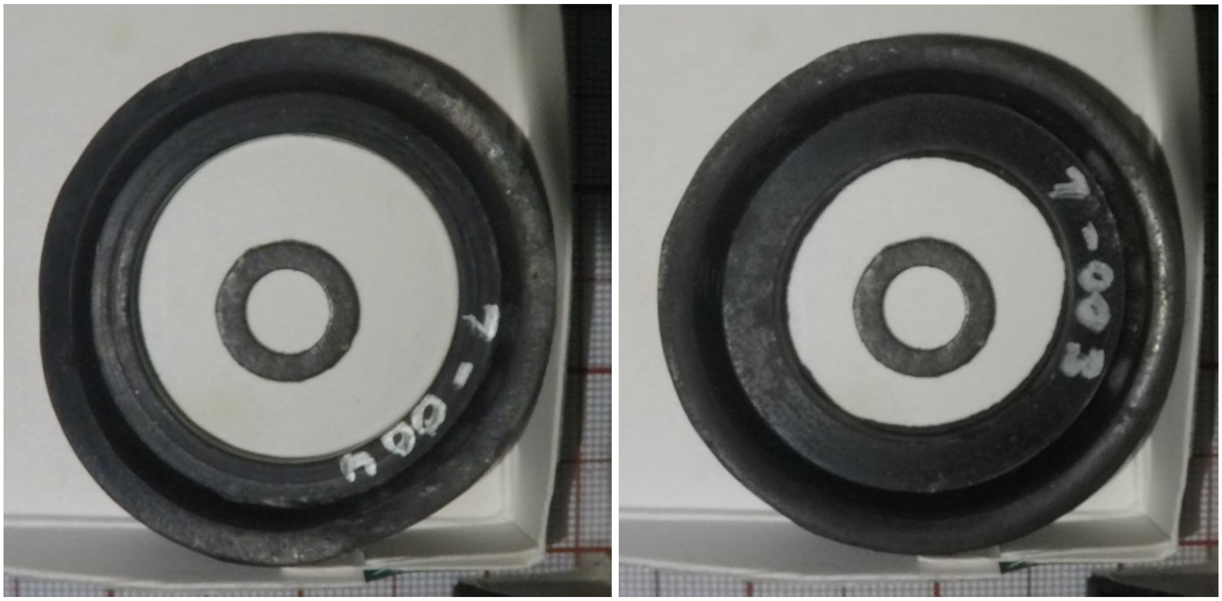

Figure A2.2. Differences for the inner diameter – seals purchased at store 7.

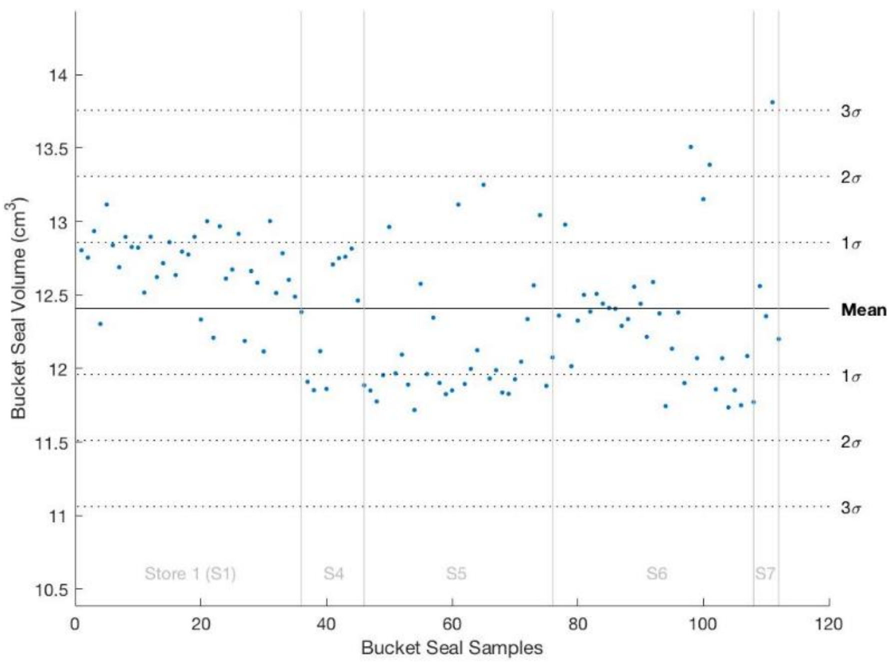

Figure A2.3. Cup seal volume. Ordered as tested.

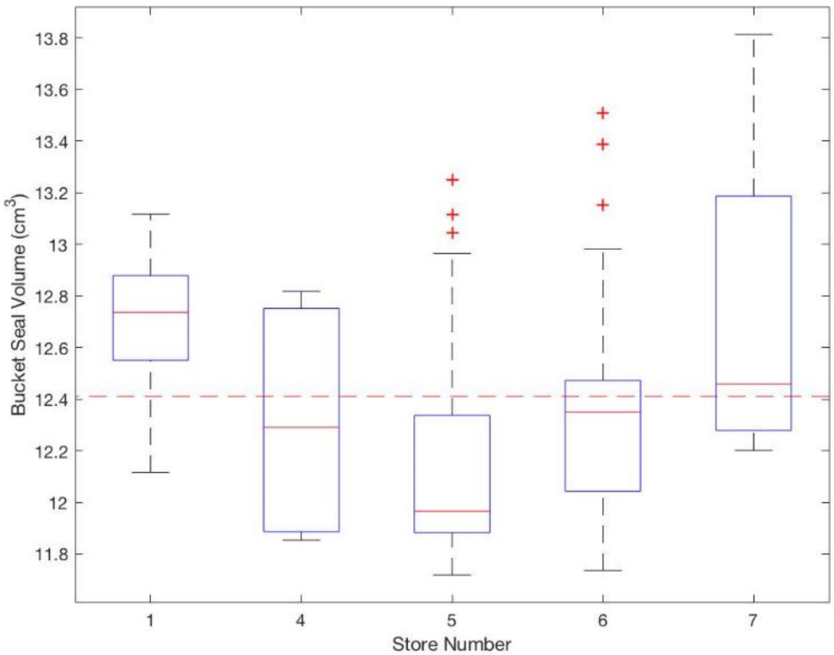

Figure A2.4. Cup seal volume. Boxplots for each store.

Table A2.2. Raw data for volume measurements. Units = cm^3.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	12.805	n/a	n/a	11.91	11.85	12.361	12.561
XX-002	12.755	n/a	n/a	11.853	11.776	12.98	12.356
XX-003	12.935	n/a	n/a	12.118	11.955	12.016	13.812
XX-004	12.304	n/a	n/a	11.862	12.964	12.326	12.201
XX-005	13.116	n/a	n/a	12.709	11.968	12.502	n/a
XX-006	12.84	n/a	n/a	12.751	12.095	12.388	n/a
XX-007	12.69	n/a	n/a	12.761	11.891	12.508	n/a
XX-008	12.896	n/a	n/a	12.817	11.718	12.442	n/a
XX-009	12.827	n/a	n/a	12.463	12.577	12.412	n/a
XX-010	12.823	n/a	n/a	11.886	11.963	12.407	n/a
XX-011	12.517	n/a	n/a	n/a	12.346	12.291	n/a
XX-012	12.897	n/a	n/a	n/a	11.902	12.337	n/a
XX-013	12.623	n/a	n/a	n/a	11.826	12.557	n/a
XX-014	12.717	n/a	n/a	n/a	11.851	12.441	n/a
XX-015	12.86	n/a	n/a	n/a	13.116	12.215	n/a
XX-016	12.636	n/a	n/a	n/a	11.895	12.588	n/a
XX-017	12.796	n/a	n/a	n/a	11.998	12.375	n/a
XX-018	12.776	n/a	n/a	n/a	12.125	11.744	n/a
XX-019	12.897	n/a	n/a	n/a	13.25	12.135	n/a
XX-020	12.334	n/a	n/a	n/a	11.932	12.381	n/a
XX-021	13.003	n/a	n/a	n/a	11.989	11.901	n/a
XX-022	12.21	n/a	n/a	n/a	11.837	13.509	n/a
XX-023	12.968	n/a	n/a	n/a	11.828	12.071	n/a
XX-024	12.612	n/a	n/a	n/a	11.927	13.153	n/a
XX-025	12.674	n/a	n/a	n/a	12.047	13.387	n/a
XX-026	12.917	n/a	n/a	n/a	12.337	11.859	n/a
XX-027	12.188	n/a	n/a	n/a	12.566	12.07	n/a
XX-028	12.664	n/a	n/a	n/a	13.044	11.736	n/a
XX-029	12.584	n/a	n/a	n/a	11.882	11.853	n/a
XX-030	12.116	n/a	n/a	n/a	12.076	11.75	n/a
XX-031	13.004	n/a	n/a	n/a	n/a	12.085	n/a
XX-032	12.514	n/a	n/a	n/a	n/a	11.772	n/a
XX-033	12.785	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	12.604	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	12.489	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	12.385	n/a	n/a	n/a	n/a	n/a	n/a
Mean	12.6878	n/a	n/a	12.313	12.151	12.3297	12.7325
Stdev	0.247475	n/a	n/a	0.424741	0.43087	0.445642	0.734615
Min	12.116	n/a	n/a	11.853	11.718	11.736	12.201
Max	13.116	n/a	n/a	12.817	13.25	13.509	13.812
Range	1	n/a	n/a	0.964	1.532	1.773	1.611
Median	12.736	n/a	n/a	12.2905	11.9655	12.349	12.4585
CV	0.0195050	n/a	n/a	0.0344953	0.0354596	0.0361438	0.0576961

Cup Seal Density	Artifact A3

Artifact Prepared by: Tom Naylor and Christopher Mattson | Revision 1.0
Tests Performed by: Tom Naylor
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Calculation:
To calculate the seal density from the measured seal weight and seal volume.

Summary of Test Results:

Summary of test results can be seen in Table A3.1.

Table A3.1. Summary of density test results.

Spec (g/cm^3)	Spec Min (g/cm^3)	Spec Max (g/cm^3)	Samples (count)	Mean (g/cm^3)	Stdev (g/cm^3)	Min (g/cm^3)	Max (g/cm^3)	Range (g/cm^3)	Median (g/cm^3)
none	none	none	112	1.41672	0.0841749	1.24967	1.67646	0.426789	1.39155

Test Equipment and Set up:
None needed for the density calculation.

Calculation Procedure:
Density is simply calculated as the measured weight (see Artifact A1) divided by the measured volume (see Artifact A2).

Test Results:
Figures A3.1 and A3.2 show the data, and Table A3.2 shows the calculated density.

Observations and Conclusions:
Note that there were no Nitrile cup seals purchased from stores 2 or 3; therefore, there are no measurements recorded or reported for those stores in this document.

As can be seen in the plots[4] (Figure A3.2), the seals from store 1 are remarkably consistent in their density. Those from stores 4 and 5, are less but similarly consistent. Interestingly stores 4 and 5 are both in the city of Jinja (a few hours east of Kampala). Both stores 1 and 5 have outliers. Store 6 is very inconsistent. Although there are only 4 samples from store 7, its mean is noticeably different than the other stores as shown in the box plots (see Figure A3.2). Both stores 6 and 7 were in the city of Gulu (which is many hours north of Kampala). The similarities in stores 4 and 5 and in stores 6 and 7 could be an indication of a particular supplier, or of different handling or environmental conditions in those cities.

[4] Artifact 1 Cup Seal Weight provides a brief description about box plot interpretation.

It is not yet known how seal density affects seal performance, though it is possible that it does.

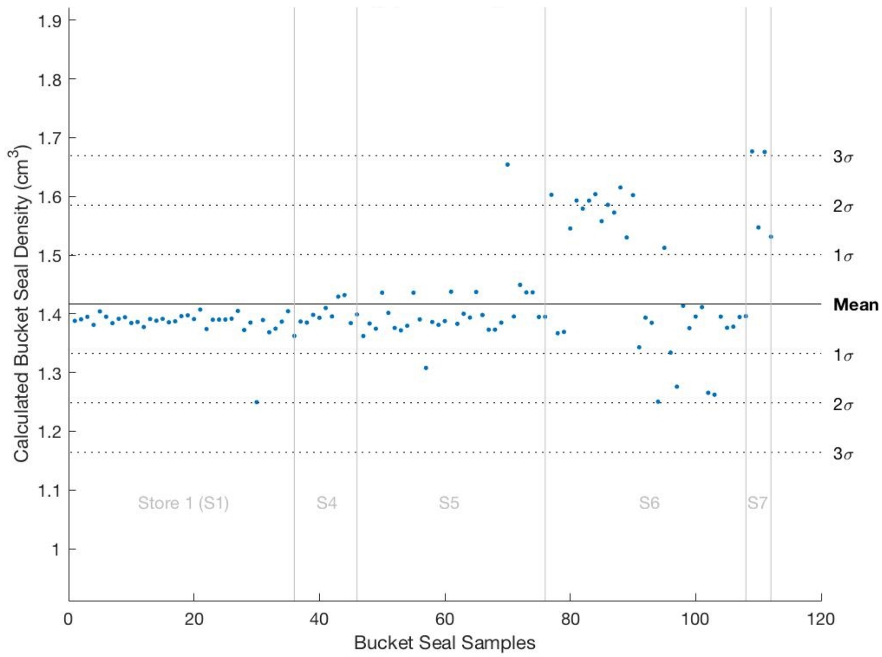

Figure A3.1. Cup seal density (calculated). Ordered as tested.

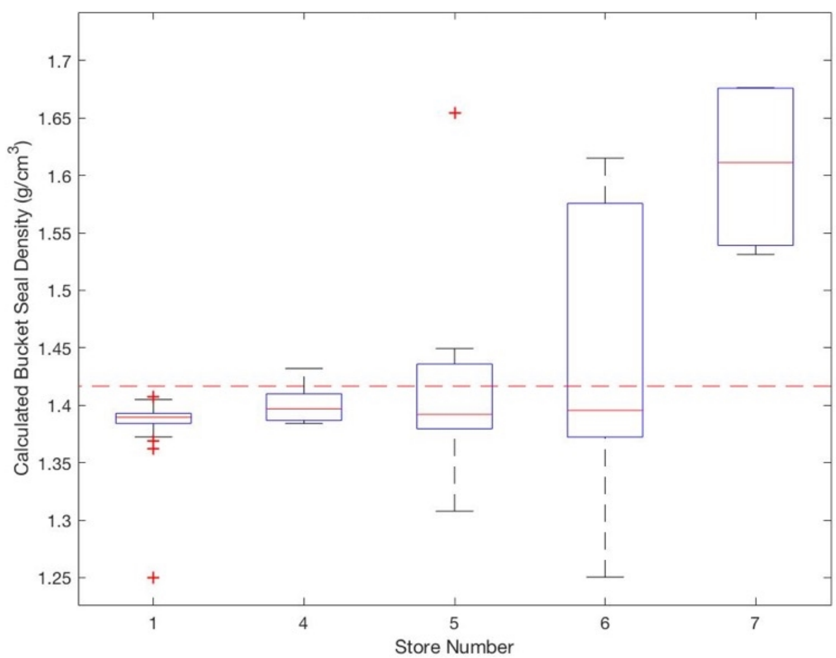

Figure A3.2. Cup seal density (calculated). Boxplots for each store.

Table A3.2. Raw data for density calculations. Units = g/cm^3.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	1.38805	n/a	n/a	1.38682	1.36211	1.6027	1.67646
XX-002	1.39067	n/a	n/a	1.38513	1.38349	1.36695	1.5471
XX-003	1.39482	n/a	n/a	1.39817	1.37465	1.36909	1.6755
XX-004	1.3811	n/a	n/a	1.39319	1.43598	1.54527	1.53127
XX-005	1.40409	n/a	n/a	1.40995	1.40157	1.59279	n/a
XX-006	1.39502	n/a	n/a	1.39558	1.37594	1.57911	n/a
XX-007	1.38408	n/a	n/a	1.4292	1.37179	1.59274	n/a
XX-008	1.39144	n/a	n/a	1.43193	1.37959	1.60368	n/a
XX-009	1.39417	n/a	n/a	1.38418	1.43588	1.55777	n/a
XX-010	1.38431	n/a	n/a	1.39896	1.39045	1.58556	n/a
XX-011	1.38611	n/a	n/a	n/a	1.30779	1.57237	n/a
XX-012	1.37745	n/a	n/a	n/a	1.38599	1.61506	n/a
XX-013	1.39111	n/a	n/a	n/a	1.38119	1.52998	n/a
XX-014	1.3883	n/a	n/a	n/a	1.38765	1.60212	n/a
XX-015	1.39137	n/a	n/a	n/a	1.43763	1.34302	n/a
XX-016	1.38557	n/a	n/a	n/a	1.38293	1.39347	n/a
XX-017	1.38731	n/a	n/a	n/a	1.40007	1.38465	n/a
XX-018	1.39606	n/a	n/a	n/a	1.39357	1.25043	n/a
XX-019	1.39746	n/a	n/a	n/a	1.43728	1.51232	n/a
XX-020	1.39103	n/a	n/a	n/a	1.39809	1.33398	n/a
XX-021	1.40721	n/a	n/a	n/a	1.37293	1.27594	n/a
XX-022	1.37404	n/a	n/a	n/a	1.37298	1.41358	n/a
XX-023	1.38996	n/a	n/a	n/a	1.38493	1.37561	n/a
XX-024	1.39018	n/a	n/a	n/a	1.65406	1.39527	n/a
XX-025	1.39017	n/a	n/a	n/a	1.39537	1.41137	n/a
XX-026	1.39165	n/a	n/a	n/a	1.4493	1.26545	n/a
XX-027	1.40491	n/a	n/a	n/a	1.43642	1.26222	n/a
XX-028	1.37239	n/a	n/a	n/a	1.43652	1.39511	n/a
XX-029	1.38509	n/a	n/a	n/a	1.39463	1.37619	n/a
XX-030	1.24967	n/a	n/a	n/a	1.39492	1.37813	n/a
XX-031	1.38942	n/a	n/a	n/a	n/a	1.39454	n/a
XX-032	1.36863	n/a	n/a	n/a	n/a	1.39594	n/a
XX-033	1.37474	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	1.3867	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	1.40444	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	1.36221	n/a	n/a	n/a	n/a	n/a	n/a
Mean	1.38447	n/a	n/a	1.40131	1.40386	1.44601	1.60758
Stdev	0.0251279	n/a	n/a	0.0172212	0.0557464	0.11843	0.0792431
Min	1.24967	n/a	n/a	1.38418	1.30779	1.25043	1.53127
Max	1.40721	n/a	n/a	1.43193	1.65406	1.61506	1.67646
Range	0.157544	n/a	n/a	0.0477492	0.34627	0.364635	0.145191
Median	1.38969	n/a	n/a	1.39687	1.39201	1.39561	1.6113
CV	0.0181498	n/a	n/a	0.0122894	0.0397094	0.0819012	0.0492934

Cup Seal Durometer	Artifact A4

Artifact Prepared by: Tom Naylor and Christopher Mattson | Revision 1.0
Tests Performed by: Tom Naylor
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To measure the durometer (rubber hardness) of the seals. To do this in four distinct places along the circumference of the seal.

Summary of Test Results:

Summary of test results can be seen in Table A4.1.

Table A4.1. Summary of durometer test results.

Spec (H)	Spec Min (H)	Spec Max (H)	Samples (count)	Mean (H)	Stdev (H)	Min (H)	Max (H)	Range (H)	Median (H)
75-85	75	85	112	86.0536	3.4368	75.75	96.75	21	85.625

Test Equipment and Set up:
The Starrett Handheld Digital Durometer (H, Shore A Scale) was used to measure the durometer as shown in the photos below. The durometer is capable of a resolution of 0.5 H, deviation <1% in the 20-90 HSA range.

Figure A4.1. Measurement of seal edge.

Test Procedure:
1. Set seal open face down on a hard flat surface
2. Turn on the durometer measurement device
3. If the device does not read zero, zero it
4. Place the pin on the outside round of the seal (pictured)
5. Press down and hold until the measurement is steady

6. Record value
7. Rotate seal 45 degrees and repeat steps 3 – 6 to measure hardness in different places
8. Take four measurements per seal following steps 3 – 7
9. Repeat steps 1-8 for each seal

Test Results:
Figures A4.2, A4.3, and A4.4 show the data, and Table A4.2 shows the raw data collected. Note that each point in the first scatter plot provided is the average of four durometer measurements for one seal. The variation of those four measurements is illustrated in Figure A4.4, showing lines representing the range with the mean value shown as a point.

Observations and Conclusions:
Note that there were no Nitrile cup seals purchased from stores 2 or 3; therefore, there are no measurements recorded or reported for those stores in this document.

As seen in the box plots[5] (Figure A4.3), the mean durometer is similar for every store. Given the outliers in measurements for store 1, it is difficult to conclude that anyone store is more consistent than another. Generally, from this data we can conclude that the durometer is relatively consistent at approximately 86 H (Shore A, or HSA). Nitrile is typically between 40-90 HSA, and the spec for this part is 85 HSA. Given the relatively large standard deviation, the measured values are at the high end of the expected Nitrile range. Roughly 15% of the sample tested had an average HSA above 90 HSA. To what extent this affects pump performance, it is not yet known. Also, it is worth noting that the internal measurement error (see Artifact A25) shows the durometer tests to have the largest amount of internal measurement error, at approximately 3.5%.

For the most part, the Cup Seal Durometer Variation plot shows wide variation within each sample (see Figure A4.4).

[5] Artifact 1 Cup Seal Weight provides a brief description about box plot interpretation.

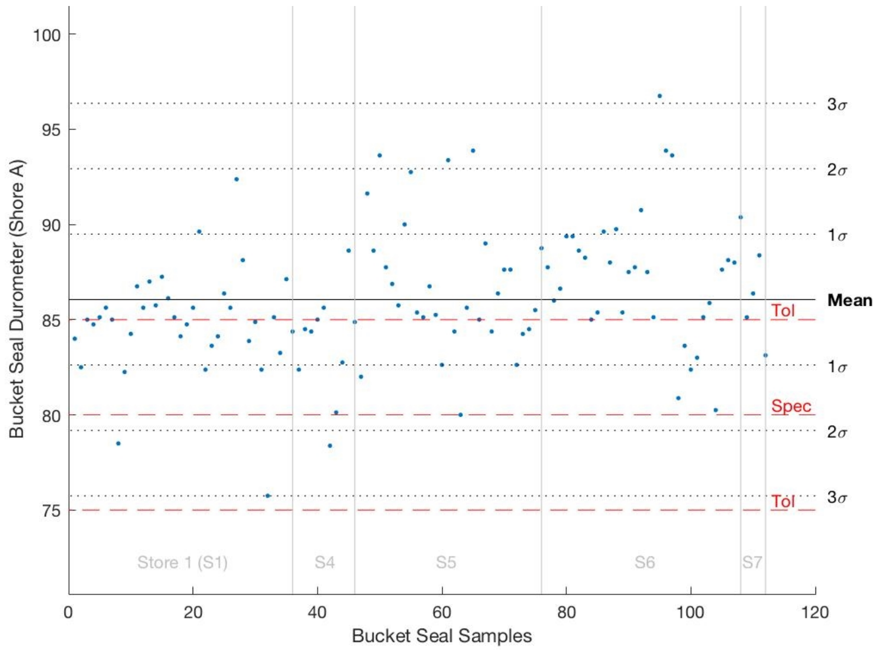

Figure A4.2. Cup seal durometer. Ordered as tested.

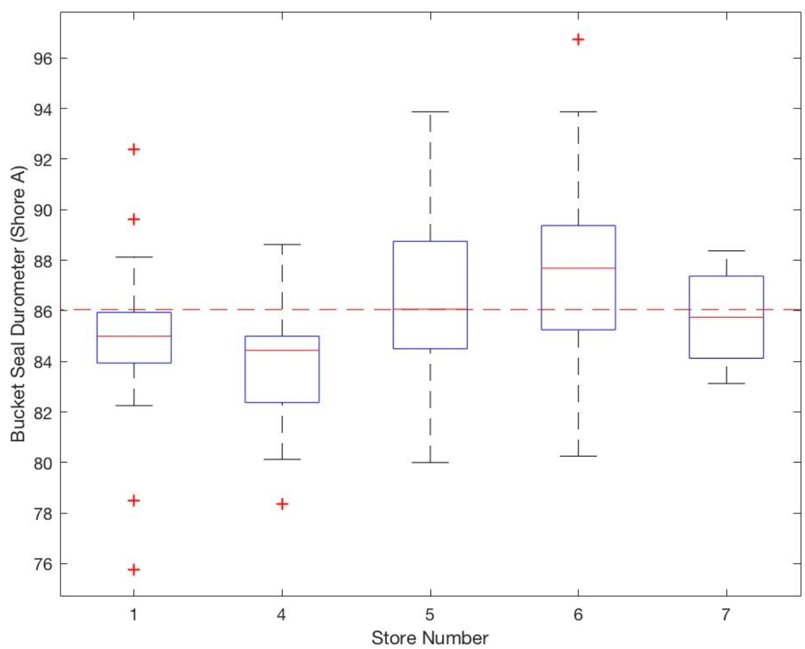

Figure A4.3. Cup seal durometer: Boxplot for each store.

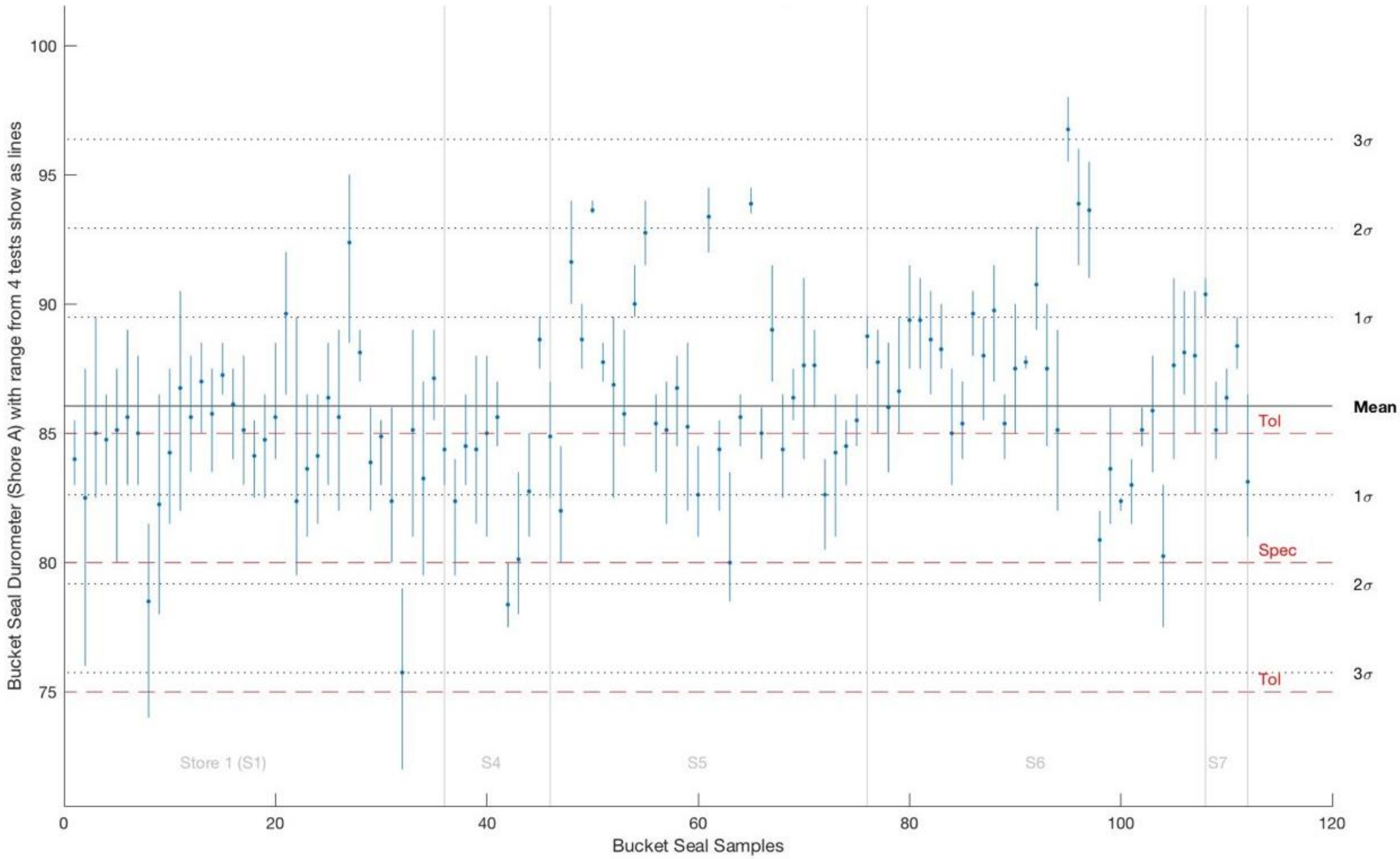

Figure A4.4. Cup seal durometer variation within sample. Four tests per sample.

Table A4.2. Raw data for durometer measurements. Units = Shore A.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	84	n/a	n/a	82.375	82	87.75	85.125
XX-002	82.5	n/a	n/a	84.5	91.625	86	86.375
XX-003	85	n/a	n/a	84.375	88.625	86.625	88.375
XX-004	84.75	n/a	n/a	85	93.625	89.375	83.125
XX-005	85.125	n/a	n/a	85.625	87.75	89.375	n/a
XX-006	85.625	n/a	n/a	78.375	86.875	88.625	n/a
XX-007	85	n/a	n/a	80.125	85.75	88.25	n/a
XX-008	78.5	n/a	n/a	82.75	90	85	n/a
XX-009	82.25	n/a	n/a	88.625	92.75	85.375	n/a
XX-010	84.25	n/a	n/a	84.875	85.375	89.625	n/a
XX-011	86.75	n/a	n/a	0	85.125	88	n/a
XX-012	85.625	n/a	n/a	0	86.75	89.75	n/a
XX-013	87	n/a	n/a	0	85.25	85.375	n/a
XX-014	85.75	n/a	n/a	0	82.625	87.5	n/a
XX-015	87.25	n/a	n/a	0	93.375	87.75	n/a
XX-016	86.125	n/a	n/a	0	84.375	90.75	n/a
XX-017	85.125	n/a	n/a	0	80	87.5	n/a
XX-018	84.125	n/a	n/a	0	85.625	85.125	n/a
XX-019	84.75	n/a	n/a	0	93.875	96.75	n/a
XX-020	85.625	n/a	n/a	0	85	93.875	n/a
XX-021	89.625	n/a	n/a	0	89	93.625	n/a
XX-022	82.375	n/a	n/a	0	84.375	80.875	n/a
XX-023	83.625	n/a	n/a	0	86.375	83.625	n/a
XX-024	84.125	n/a	n/a	0	87.625	82.375	n/a
XX-025	86.375	n/a	n/a	0	87.625	83	n/a
XX-026	85.625	n/a	n/a	0	82.625	85.125	n/a
XX-027	92.375	n/a	n/a	0	84.25	85.875	n/a
XX-028	88.125	n/a	n/a	0	84.5	80.25	n/a
XX-029	83.875	n/a	n/a	0	85.5	87.625	n/a
XX-030	84.875	n/a	n/a	0	88.75	88.125	n/a
XX-031	82.375	n/a	n/a	n/a	n/a	88	n/a
XX-032	75.75	n/a	n/a	n/a	n/a	90.375	n/a
XX-033	85.125	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	83.25	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	87.125	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	84.375	n/a	n/a	n/a	n/a	n/a	n/a
Mean	84.8368	n/a	n/a	83.6625	86.9	87.4141	85.75
Stdev	2.78674	n/a	n/a	2.90417	3.54898	3.55592	2.20322
Min	75.75	n/a	n/a	78.375	80	80.25	83.125
Max	92.375	n/a	n/a	88.625	93.875	96.75	88.375
Range	16.625	n/a	n/a	10.25	13.875	16.5	5.25
Median	85	n/a	n/a	84.4375	86.0625	87.6875	85.75
CV	0.0328482	n/a	n/a	0.0347129	0.0408398	0.0406790	0.0256935

Cup Seal Geometry: Outer Diameter (DIM 1)	Artifact A5

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.0
Tests Performed by: Christopher Mattson, and Hans Ottosson
Test Date: 31 July 2018 (photos taken on various days leading to analysis)
Test Location: Gulu, Uganda

Purpose:
The purpose of this artifact is to clearly describe how dimension 1 (DIM 1) was measured and the variation there of characterized. This artifact also, presents the resulting data and give reference to the necessary files to reproduce the results.

Purpose of the Test:
DIM 1 is the outer diameter of the cup seal for the India Mark II and India Mark III hand pumps for boreholes. To eventually be able to characterize pump performance as a function of geometric variation of the seals, key dimensions were measured on 112 cup seals purchased in Uganda. The cup seal is made of Nitrile, which is soft and prevents a hard measurement using a traditional measurement device (such as a pair of calipers). Therefore, an optical approach was taken. Key dimensions are shown in Figure A5.1.

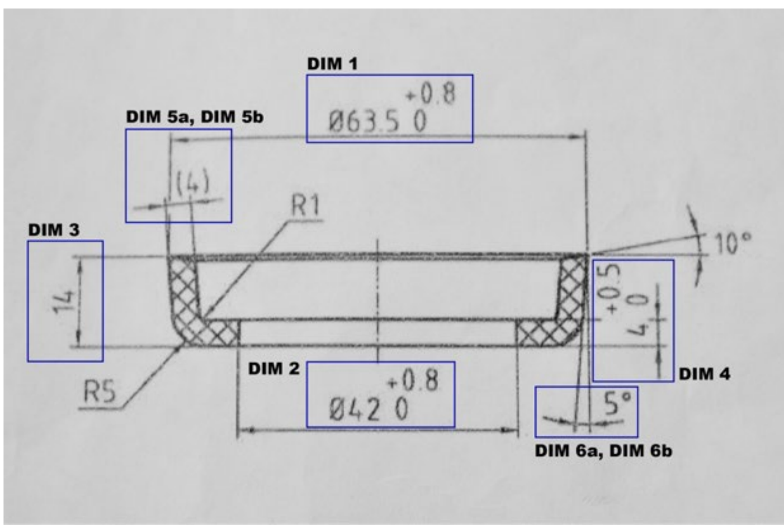

Figure A5.1. Cup seal dimensions.

Summary of Test Results:
Table A5.1 shows the summary statistics for all stores and all parts combined.

Table A5.1. Summary of test results.

Spec (mm)	Spec Min (mm)	Spec Max (mm)	Samples (count)	Mean (mm)	Stdev (mm)	Min (mm)	Max (mm)	Range (mm)	Median (mm)
63.5	63.5	64.3	112	64.2653	0.530363	62.8561	65.6768	2.82072	64.2558

Test Equipment and Set up:
A test fixture was used to simultaneously take a top, right and left size photo of each seal. This was done for every seal as it was placed in the "bucket up position" (cup seal with the opening of the bucket upward), as shown in Figure A6.2. The seal was placed on a white centering fixture, which helped place the seal in the camera frame.

MATLAB's (R2017b) image processing software was used to best fit a circle to dimension of interest (DIM 1).

Camera Settings:

Camera = GoPro Hero 5
Trigger = GoPro Smart Remote (activates the shutter of all cameras simultaneously)
Macro Lens = 2x macro
Wide Angle Setting: Narrow
Resolution: 12 MP

MATLAB Settings:

Function =
```
[center2, radius2] = imfindcircles(RGBs,[Rmin …
    Rmax],'ObjectPolarity','dark','Sensitivity',.993);
```
Sensitivity = 0.993 (1.0 is max sensitivity)
File Resolution Adjustment = 50% reduction via `RGBs = imresize(RGBc, .5);`

Reference:

A black washer was used as a known (black circle) reference. Its diameter was measured at 18.7825 mm. This was used to scale MATLAB's pixel measurements to mm.

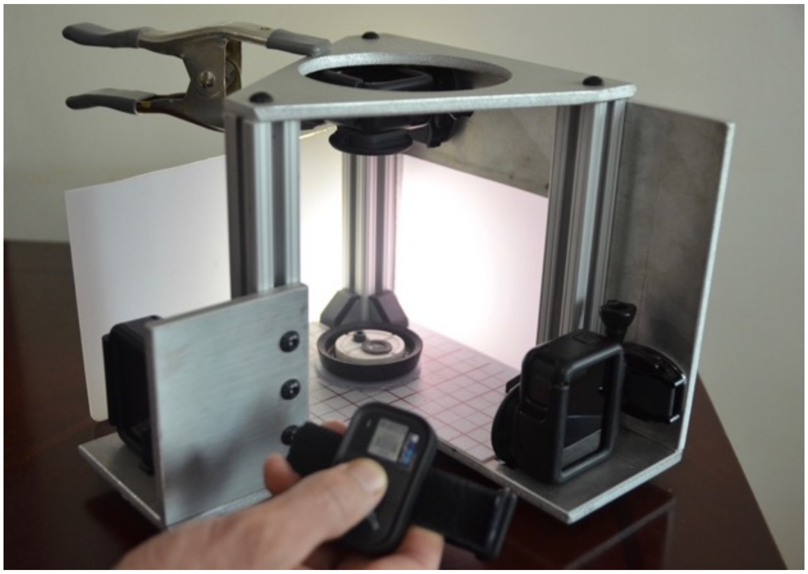

Figure A5.2. Photo test fixture.

Test Procedure:

1. Set test fixture on stable surface in a well-lit area.
2. Ensure that the cameras are turned on and connected to the GoPro Smart remote.
3. Place washer on the white centering fixture.
4. Place cup seal in the upward position (as seen in picture).
5. Take picture of the upper side with the remote.
6. Turn seal over.
7. Take picture with remote.
8. Replace seal with new seal and repeat until done, keeping track of the order of seals.
9. Once done, upload pictures to computer and rename files ('store number'-'seal number'-t-u for upper side and 'store number'-'seal number'-t-d for bottom side).
10. Run MATLAB script and save the results.

Test Results:

Figure A5.3 shows the visual output from the analysis of a seal. Figures of this type for each seal can be found in the DIM1_Results folder.

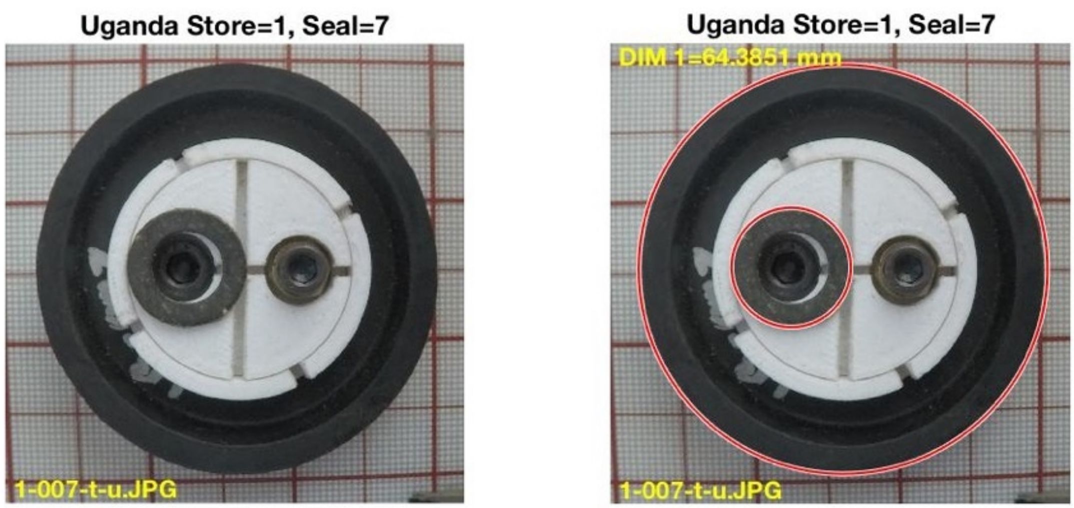

Figure A5.3. Visual output from cup seal analysis.

Table A5.2 is the complete set of collected data, with summary statistics.

Accounting for Internal Measurement Error:

A study of internal measurement error was carried out for this measurement set up. The result of this study is provided in Artifact A25. In that artifact it is shown that the error associated with this measurement device is less than one half percent. Nevertheless, this means that the measurements displayed in this artifact could be larger by 0.95 mm or smaller by 0.95 mm simply because of measurement error. This number is based on a 6 sigma analysis.

Observations and Conclusions:

Note that there were no Nitrile cup seals purchased from stores 2 or 3; therefore, there are no measurements recorded or reported for those stores in this document.

Perhaps the most significant thing to observe from the data is that many of the seals are out of specification, with many being larger than the upper tolerance limit. Even more interesting is that nearly all the seals from the town of Jinja (stores 4 and 5) are measured at above the upper tolerance limit. Worth noting is that very few <3% of the seals are below the lower specification limit (63.5 mm).

Also, worth noting is that the MATLAB image processing software places a circle as well as it can to the image. As shown in Figure A6.4, the image processing may actually be a better measure of how misshapen the seal is. As a note, this is one of just a few extreme misshapen seals.

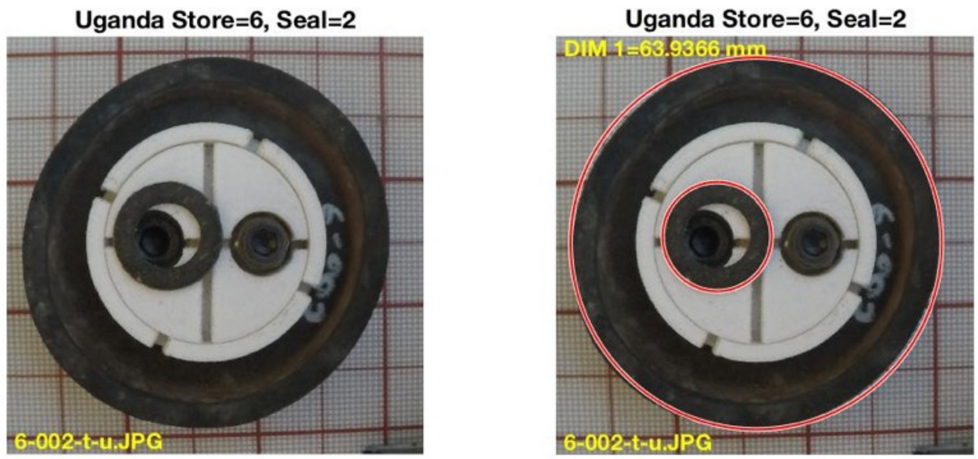

Figure A5.4. Example of output when seal shape is oval.

It is quite possible that a more sophisticated image processing method would yield different, possibly more accurate results.

Files Associated with this Artifact:
Within the archive the analysis associated with DIM can be found in the folder called "Bucket_Seal_Dimensional_Analysis/DIM1". The photos analyzed and the MATLAB code are included in the folder.

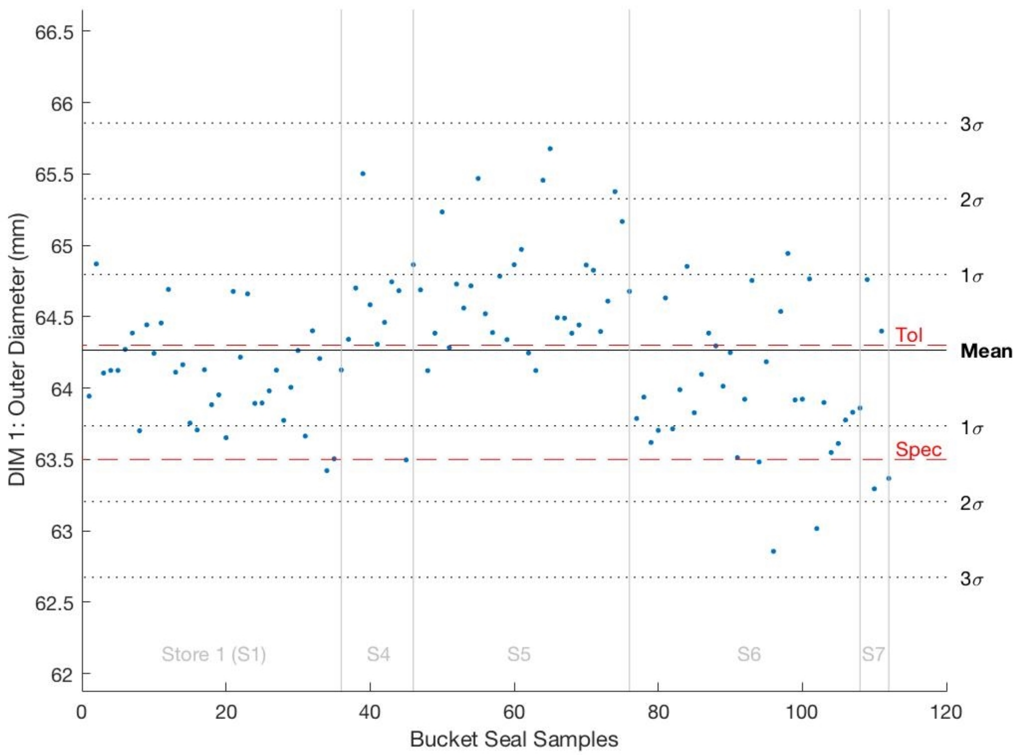

Figure A5.5. DIM 1: Outer diameter. Ordered as tested.

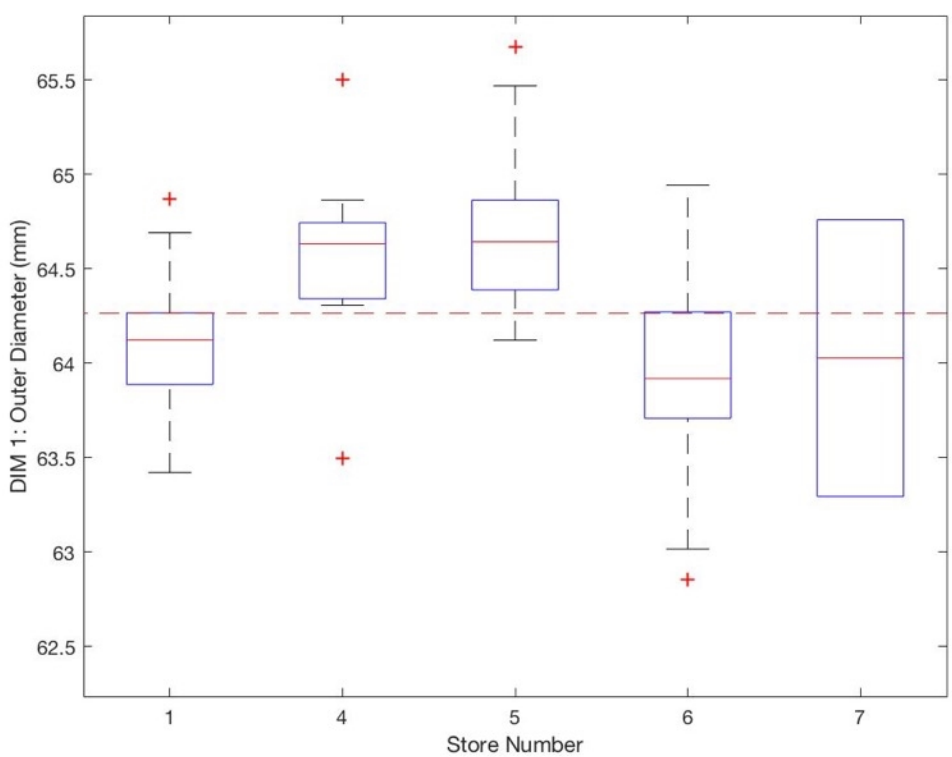

Figure A5.6. DIM 1: Outer Diameter. Boxplots for each store.

Table A5.2. Raw data for DIM1 (outer diameter) measurements. Units = mm.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	63.9433	n/a	n/a	64.3414	64.6879	63.7869	64.7598
XX-002	64.8693	n/a	n/a	64.7003	64.1217	63.9366	63.294
XX-003	64.1052	n/a	n/a	65.5016	64.3841	63.6188	64.3991
XX-004	64.1235	n/a	n/a	64.583	65.2337	63.7035	63.3669
XX-005	64.1231	n/a	n/a	64.3065	64.2839	64.6311	n/a
XX-006	64.2706	n/a	n/a	64.4599	64.7283	63.7138	n/a
XX-007	64.3851	n/a	n/a	64.744	64.5606	63.9886	n/a
XX-008	63.7007	n/a	n/a	64.6825	64.716	64.852	n/a
XX-009	64.4427	n/a	n/a	63.4963	65.4683	63.8271	n/a
XX-010	64.2433	n/a	n/a	64.8641	64.5204	64.0961	n/a
XX-011	64.4555	n/a	n/a	0	64.3885	64.3844	n/a
XX-012	64.691	n/a	n/a	0	64.7836	64.2951	n/a
XX-013	64.1105	n/a	n/a	0	64.3391	64.0128	n/a
XX-014	64.1632	n/a	n/a	0	64.8637	64.2487	n/a
XX-015	63.7542	n/a	n/a	0	64.971	63.5126	n/a
XX-016	63.7064	n/a	n/a	0	64.2452	63.9214	n/a
XX-017	64.128	n/a	n/a	0	64.1227	64.7535	n/a
XX-018	63.8829	n/a	n/a	0	65.4553	63.4824	n/a
XX-019	63.9519	n/a	n/a	0	65.6768	64.184	n/a
XX-020	63.6522	n/a	n/a	0	64.4927	62.8561	n/a
XX-021	64.6768	n/a	n/a	0	64.4899	64.5365	n/a
XX-022	64.2163	n/a	n/a	0	64.3834	64.943	n/a
XX-023	64.6597	n/a	n/a	0	64.4413	63.9168	n/a
XX-024	63.8923	n/a	n/a	0	64.8616	63.9222	n/a
XX-025	63.8951	n/a	n/a	0	64.8251	64.7644	n/a
XX-026	63.9802	n/a	n/a	0	64.396	63.0159	n/a
XX-027	64.1254	n/a	n/a	0	64.6087	63.8986	n/a
XX-028	63.7735	n/a	n/a	0	65.3758	63.5482	n/a
XX-029	64.0049	n/a	n/a	0	65.1667	63.6113	n/a
XX-030	64.2628	n/a	n/a	0	64.6769	63.776	n/a
XX-031	63.6633	n/a	n/a	n/a	n/a	63.8302	n/a
XX-032	64.401	n/a	n/a	n/a	n/a	63.8596	n/a
XX-033	64.2066	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	63.421	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	63.5043	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	64.1263	n/a	n/a	n/a	n/a	n/a	n/a
Mean	64.0976	n/a	n/a	64.568	64.709	63.9821	63.955
Stdev	0.340623	n/a	n/a	0.505645	0.4154	0.490018	0.736585
Min	63.421	n/a	n/a	63.4963	64.1217	62.8561	63.294
Max	64.8693	n/a	n/a	65.5016	65.6768	64.943	64.7598
Range	1.44834	n/a	n/a	2.00532	1.55508	2.08693	1.46573
Median	64.1233	n/a	n/a	64.6328	64.6428	63.9191	63.883
CV	0.00531413	n/a	n/a	0.00783120	0.00641951	0.00765867	0.0115172

Cup Seal Geometry: Inner Diameter (DIM 2)	Artifact A6

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.0
Tests Performed by: Christopher Mattson, and Hans Ottosson
Test Date: 31 July 2018 (photos taken on various days leading to analysis)
Test Location: Gulu, Uganda

Purpose of the Test:
DIM 2 is the inner diameter of the cup seal for the India Mark II and India Mark III hand pumps for boreholes. The purpose if this test is to measure the purchased seals using an optical method in order to characterize the variation in the seal's inner diameter (DIM2).

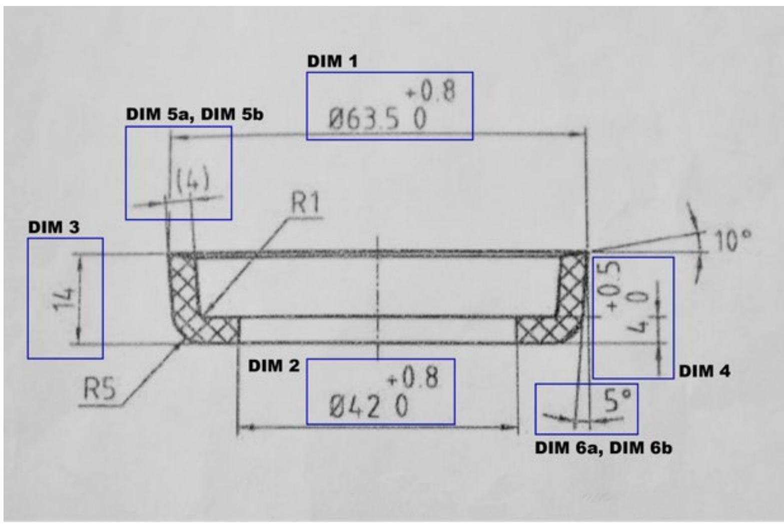

Figure A6.1. Cup seal dimensions.

Summary of Test Results:
Table A6.1 shows the summary statistics for all stores and all parts combined.

Table A6.1. Summary of test results.

Spec (mm)	Spec Min (mm)	Spec Max (mm)	Samples (count)	Mean (mm)	Stdev (mm)	Min (mm)	Max (mm)	Range (mm)	Median (mm)
42.0	42.0	42.8	110	41.8651	0.227975	41.4178	42.7086	1.29075	41.8484

Test Equipment and Set up:
A test fixture was used to simultaneously take a top, right and left side photo of each seal. This was done for every seal as it was placed in the "bucket down position" (cup seal with the opening of the cup downward), opposite of that shown in Figure A6.2. The seal was placed in an edge fixture, which helped place the seal in the camera frame.

Camera Settings:

Camera = GoPro Hero 5
Trigger = GoPro Smart Remote (activates the shutter of all cameras simultaneously).
Macro Lens = 2x macro
Wide Angle Setting: Narrow
Resolution: 12 MP

MATLAB Settings:

Function = `[center2, radius2] = imfindcircles(RGBs,[Rmin … Rmax],'ObjectPolarity','bright','Sensitivity',.993);`

Sensitivity = 0.993 (1.0 is max sensitivity)
File Resolution Adjustment = 50% reduction via `RGBs = imresize(RGBc, .5);`

Reference:

A black washer was used as a known reference that was a black circle. Its diameter was measured at 18.7825 mm. This was used to scale MATLAB's pixel measurements to mm.

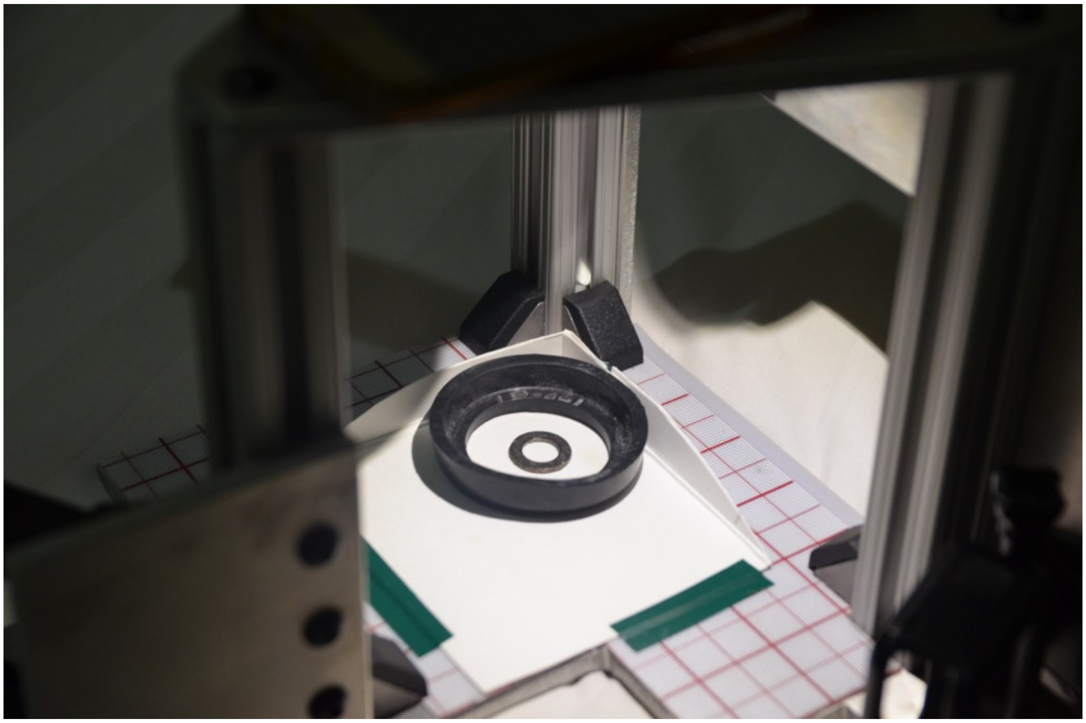

Figure A6.2. Placement of the cup seal in the photo test fixture.

Test Procedure:

1. Set test fixture on stable surface in a well-lit area.
2. Ensure that top camera is turned on and connected to the GoPro Smart remote.
3. Place washer on the white surface so that it will be inside of the seal.
4. Place cup seal in the upward position next to the white walls (as seen in picture).
5. Take picture with the remote.
6. Replace seal with new seal and repeat until done, keeping track of the order of seals.

7. Once done, upload pictures to computer and rename files ('store number'-'seal number'-cb).
8. Run MATLAB script and save the results.

Test Results:
Figure A6.3 is produced by MATLAB as the result of the DIM2 analysis for one seal. Images of this nature were kept for all DIM2 measurements made. Table A6.2 has the complete set of collected data, with summary statistics.

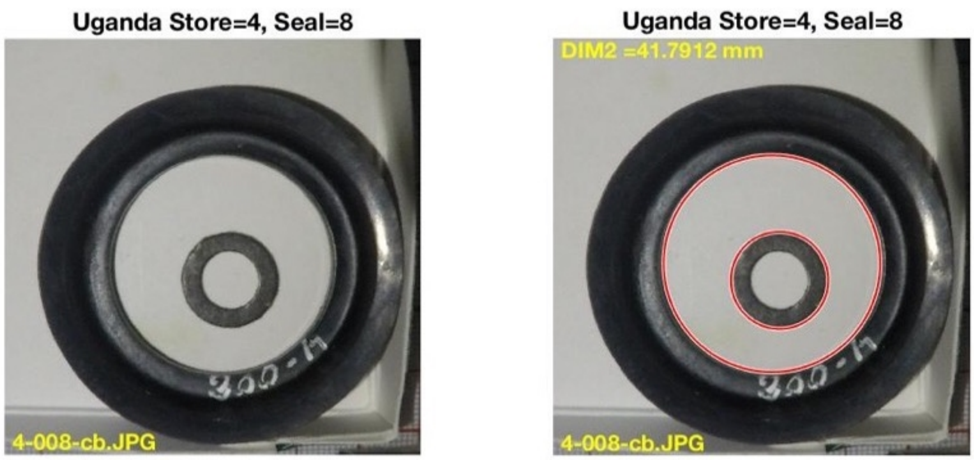

Figure A6.3. Automatic measurement of the inner diameter.

Accounting for Internal Measurement Error:
A study of internal measurement error was carried out for this measurement set up. The results of this study is provided in Artifact A25. In that artifact it is shown that the error associated with this measurement device is approximately ¼ percent. This means that the measurements displayed in this artifact could be larger by 0.31 mm or smaller by 0.31 mm simply because of measurement error.

Observations and Conclusions:
Note that there were no Nitrile cup seals purchased from stores 2 or 3; therefore, there are no measurements recorded or reported for those stores in this document.

An important observation is that 75% of the seals are lower than the lower limit of the specification. It is quite possible that being below the specification limit is better than being above the specification limit in this case.

All stores are showing as similar, as shown in the box plot. It is also worth noting that the standard deviation of this measurement is significantly lower than the standard deviation of DIM1. DIM2 is a feature in a more structurally sound area of the seal as compared to DIM1.

Because it was determined that two of the seals from store 7, were not for the India Mark II or III, even though they were sold as such. They were not measured as part of this test. Therefore, the number of samples for this test is 110 (not 112, as for most other tests performed).

Files Associated with this Artifact:
Within the archive the analysis associated with DIM can be found in the folder called "Bucket_Seal_Dimensional_Analysis/DIM2". The photos analyzed and the MATLAB code are included in the folder.

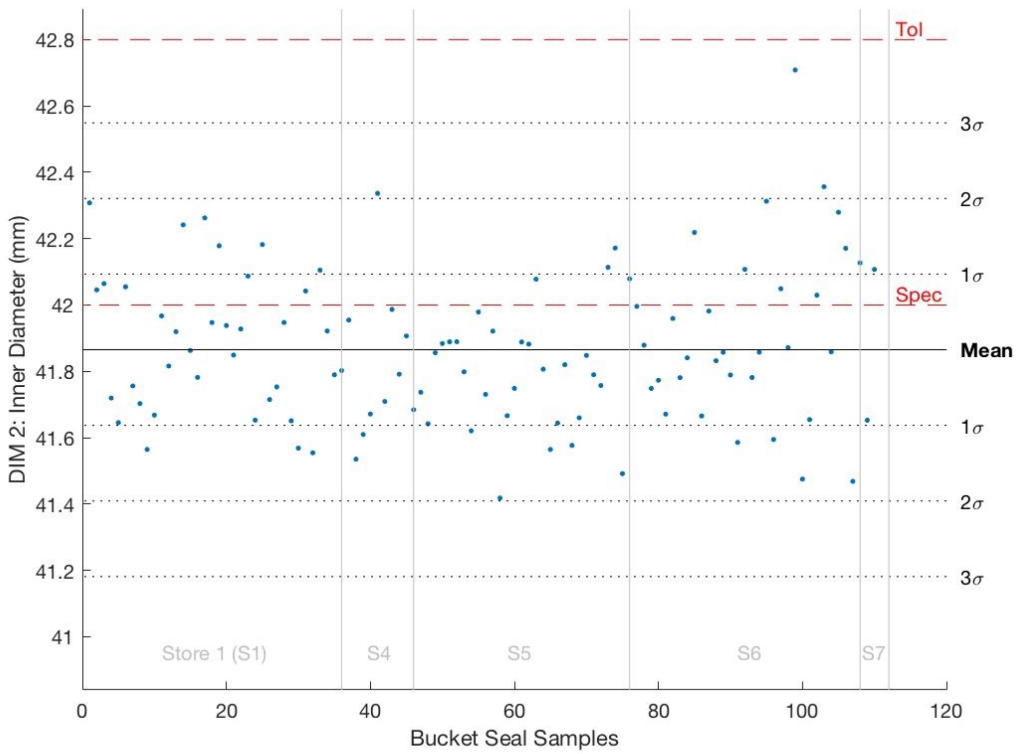

Figure A6.4. DIM 2: Inner diameter. Ordered as tested.

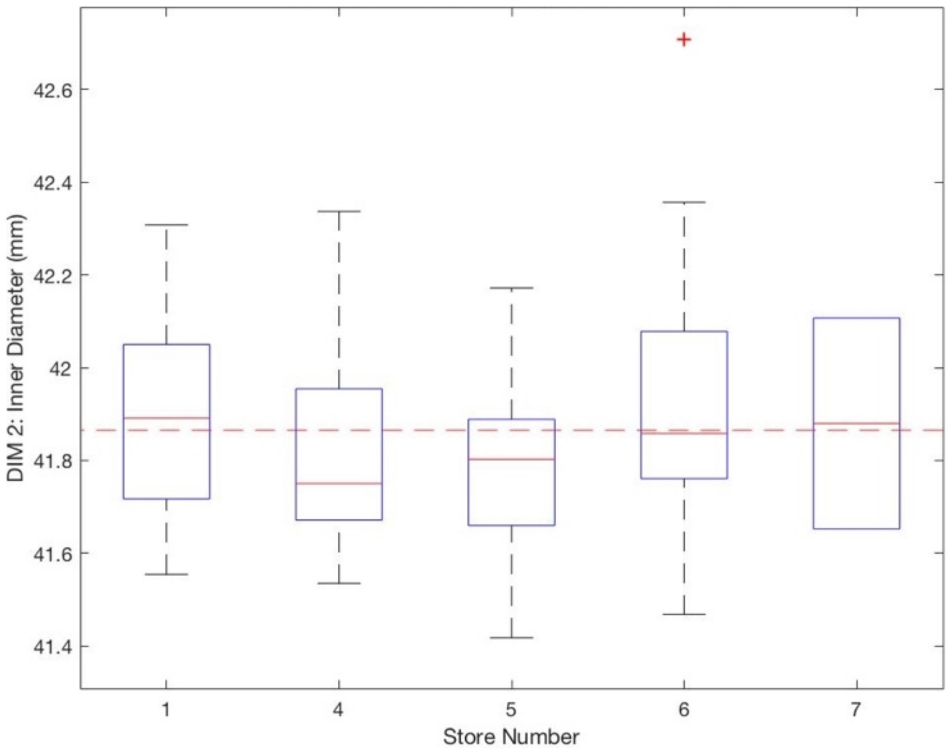

Figure A6.5. DIM 2: Inner diameter. Boxplot for each store.

Table A6.2. Raw data for DIM2 (inner diameter) measurements. Units = mm.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	42.308	n/a	n/a	41.9546	41.7368	41.9958	n/a
XX-002	42.0454	n/a	n/a	41.5351	41.6418	41.8789	41.6525
XX-003	42.0645	n/a	n/a	41.6097	41.856	41.7483	n/a
XX-004	41.7193	n/a	n/a	41.6713	41.8838	41.773	42.1071
XX-005	41.6454	n/a	n/a	42.3367	41.8888	41.6709	n/a
XX-006	42.0548	n/a	n/a	41.709	41.8893	41.9594	n/a
XX-007	41.756	n/a	n/a	41.9867	41.7985	41.781	n/a
XX-008	41.7028	n/a	n/a	41.7912	41.6207	41.8408	n/a
XX-009	41.5644	n/a	n/a	41.9065	41.9787	42.2185	n/a
XX-010	41.6678	n/a	n/a	41.6843	41.7305	41.6654	n/a
XX-011	41.9671	n/a	n/a	0	41.9212	41.9818	n/a
XX-012	41.8159	n/a	n/a	0	41.4178	41.8319	n/a
XX-013	41.9194	n/a	n/a	0	41.6663	41.8572	n/a
XX-014	42.2416	n/a	n/a	0	41.7487	41.7888	n/a
XX-015	41.8627	n/a	n/a	0	41.8884	41.5855	n/a
XX-016	41.7817	n/a	n/a	0	41.8818	42.1074	n/a
XX-017	42.2626	n/a	n/a	0	42.0778	41.7813	n/a
XX-018	41.9471	n/a	n/a	0	41.8064	41.8577	n/a
XX-019	42.1784	n/a	n/a	0	41.5643	42.3128	n/a
XX-020	41.938	n/a	n/a	0	41.6438	41.5944	n/a
XX-021	41.849	n/a	n/a	0	41.8199	42.049	n/a
XX-022	41.9276	n/a	n/a	0	41.5768	41.8716	n/a
XX-023	42.0869	n/a	n/a	0	41.6598	42.7086	n/a
XX-024	41.6527	n/a	n/a	0	41.8479	41.4751	n/a
XX-025	42.1822	n/a	n/a	0	41.7897	41.6545	n/a
XX-026	41.7148	n/a	n/a	0	41.7571	42.0295	n/a
XX-027	41.7528	n/a	n/a	0	42.1134	42.3566	n/a
XX-028	41.9472	n/a	n/a	0	42.1716	41.8588	n/a
XX-029	41.6509	n/a	n/a	0	41.4916	42.2796	n/a
XX-030	41.5682	n/a	n/a	0	42.0789	42.1709	n/a
XX-031	42.0421	n/a	n/a	n/a	n/a	41.4682	n/a
XX-032	41.5544	n/a	n/a	n/a	n/a	42.127	n/a
XX-033	42.105	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	41.9215	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	41.7895	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	41.8021	n/a	n/a	n/a	n/a	n/a	n/a
Mean	41.8886	n/a	n/a	41.8185	41.7983	41.915	41.8798
Stdev	0.20892	n/a	n/a	0.235574	0.181953	0.273491	0.321507
Min	41.5544	n/a	n/a	41.5351	41.4178	41.4682	41.6525
Max	42.308	n/a	n/a	42.3367	42.1716	42.7086	42.1071
Range	0.753612	n/a	n/a	0.801659	0.753796	1.24039	0.454679
Median	41.8911	n/a	n/a	41.7501	41.8024	41.8583	41.8798
CV	0.00498751	n/a	n/a	0.00563325	0.00435312	0.00652490	0.00767690

Cup Seal Geometry: Height (DIM 3)	Artifact A7

Artifact Prepared by: Hans Ottosson and Christopher Mattson | Revision 1.0
Tests Performed by: Hans Ottosson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
The purpose of this test is to measure the overall height of the cup seal, and to do this is 4 places along the circumference of the seal.

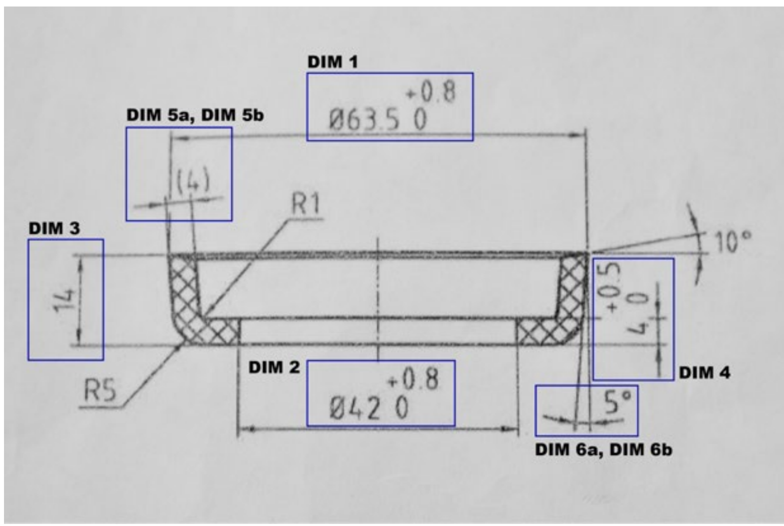

Figure A7.1. Cup seal dimensions.

Summary of Test Results:
The results shown in Table A7.1 represent the statistics for the average heights for each seal.

Table A7.1. Summary of test results.

Spec (mm)	Spec Min (mm)	Spec Max (mm)	Samples (count)	Mean (mm)	Stdev (mm)	Min (mm)	Max (mm)	Range (mm)	Median (mm)
14	13.5	14.5	112	12.4019	0.429384	11.355	13.1475	1.7925	12.4625

Test Equipment and Set up:
A Mitotoyo Digimatic Indicator (manufacturers part number 575-123) was used to measure the height of each seal in four places (at 0, PI/2, PI, 3/2PI, and 2PI). The indicator accuracy is 0.02 mm, and a measurement force of 1.8 N. A custom stand was built to hold the indicator and provide a flat surface for the sample to rest on (see Figure A7.2). Each seal was measured with the indicator head near the center of the wall thickness.

Figure A7.2. Measurement of the seal height.

Test Procedure:

1. Make sure that the instrument is at zero before taking measurement.
2. Place the needle of the indicator at the center of the top edge of the seal as seen in image.
3. Read and record measurement.
4. Rotate the seal 90° and record measurement (do this 3 times for a total of 4 measurements).
5. Replace seal with new seal and repeat until done, keeping track of the order of seals.

Test Results:
The following plots and tables provide the data and results.

Observations and Conclusions:
No data was collected from store 2 or 3.

It is worth noticing that all (100%) of the seals are below specification for the height. A lower dimension here, would make the seal stiffer in the bucket region. At this point in the research, it is unclear if this would be desirable or not.

Also note that seals from store 1 measure noticeably more consistent than the others. While the scatter plot with variation in height across samples, suggests the variation in height across individual seals appears to be the smallest with story 5.

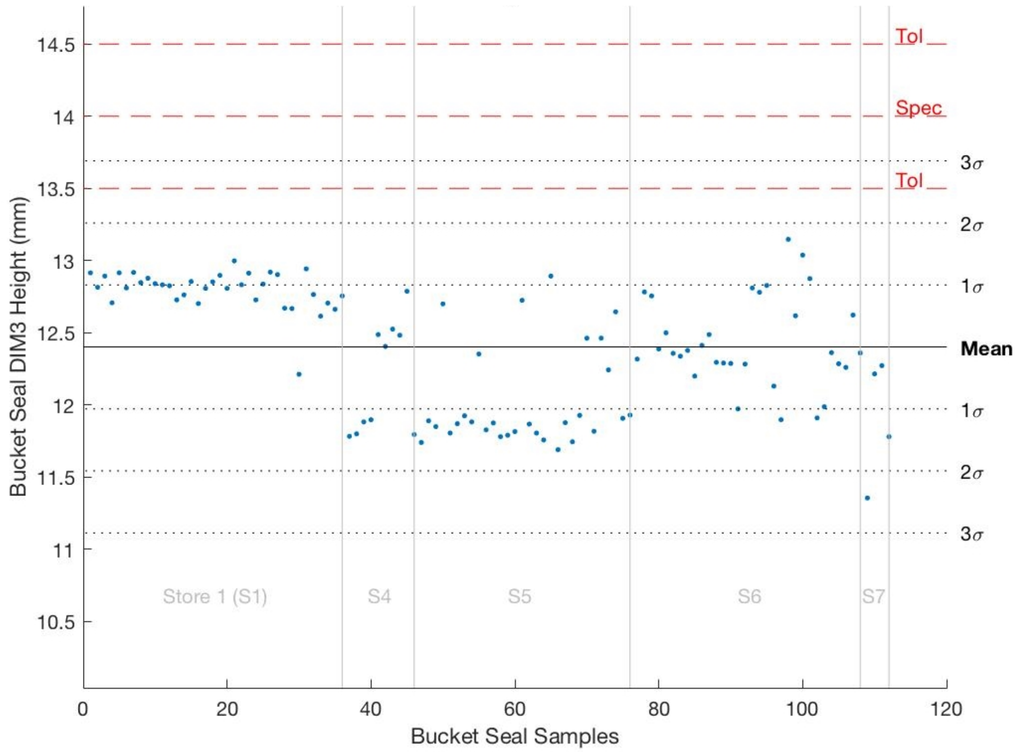

Figure A7.3. DIM 3: Cup seal height. Ordered as tested.

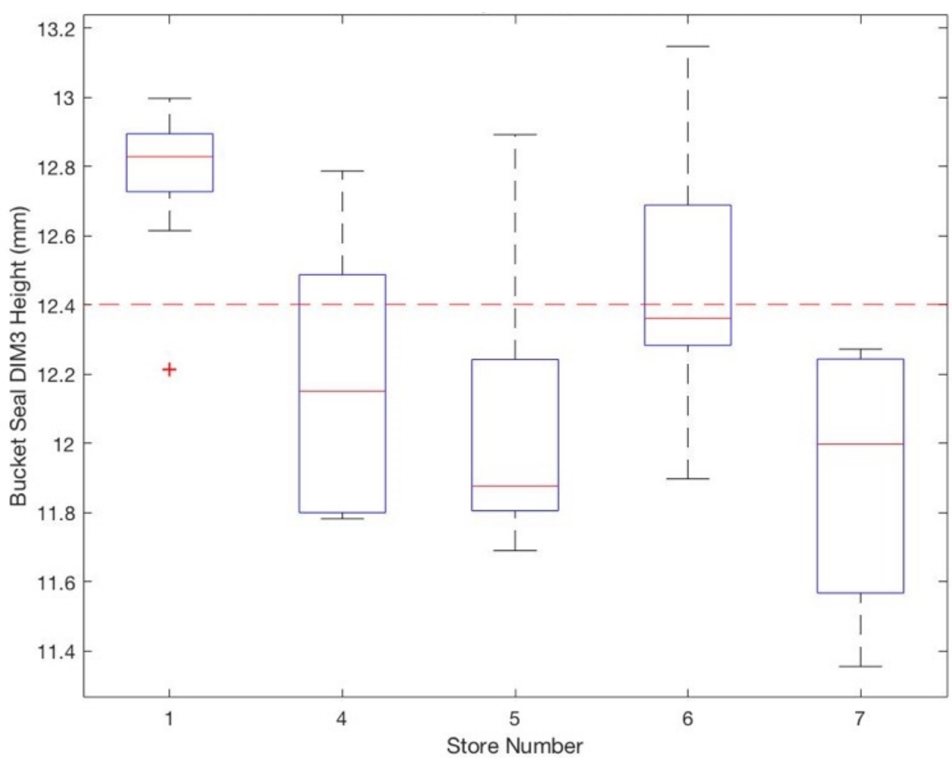

Figure A7.4. DIM 3: Cup seal height. Boxplots for each store.

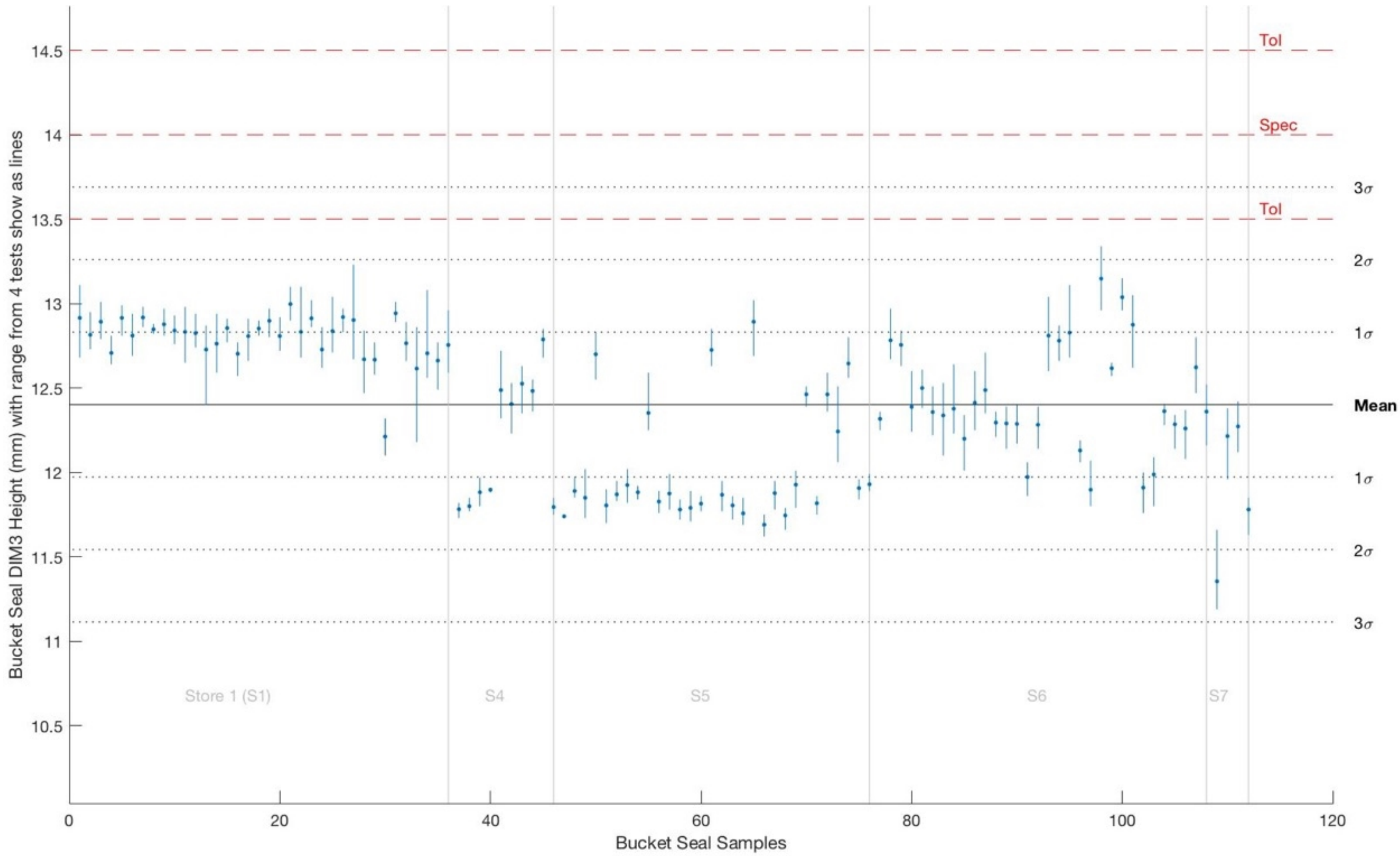

Figure A7.4. DIM 3: Cup seal height variation within sample. Four tests per sample.

Table A7.2. Raw data for DIM3 (height) measurements. Units = mm.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	12.915	n/a	n/a	11.7825	11.74	12.3175	11.355
XX-002	12.815	n/a	n/a	11.8	11.89	12.7825	12.215
XX-003	12.8925	n/a	n/a	11.8825	11.85	12.755	12.2725
XX-004	12.7075	n/a	n/a	11.8975	12.7	12.3875	11.78
XX-005	12.915	n/a	n/a	12.4875	11.805	12.5	n/a
XX-006	12.81	n/a	n/a	12.405	11.87	12.3575	n/a
XX-007	12.9175	n/a	n/a	12.525	11.925	12.3375	n/a
XX-008	12.8475	n/a	n/a	12.4825	11.8825	12.3775	n/a
XX-009	12.8775	n/a	n/a	12.7875	12.3525	12.2	n/a
XX-010	12.84	n/a	n/a	11.795	11.8275	12.4125	n/a
XX-011	12.8325	n/a	n/a	n/a	11.875	12.4875	n/a
XX-012	12.825	n/a	n/a	n/a	11.78	12.295	n/a
XX-013	12.7275	n/a	n/a	n/a	11.79	12.29	n/a
XX-014	12.7625	n/a	n/a	n/a	11.815	12.2875	n/a
XX-015	12.855	n/a	n/a	n/a	12.725	11.9725	n/a
XX-016	12.7025	n/a	n/a	n/a	11.8675	12.2825	n/a
XX-017	12.8075	n/a	n/a	n/a	11.805	12.81	n/a
XX-018	12.8525	n/a	n/a	n/a	11.7575	12.78	n/a
XX-019	12.8975	n/a	n/a	n/a	12.8925	12.8275	n/a
XX-020	12.8075	n/a	n/a	n/a	11.69	12.13	n/a
XX-021	12.9975	n/a	n/a	n/a	11.8775	11.8975	n/a
XX-022	12.8325	n/a	n/a	n/a	11.745	13.1475	n/a
XX-023	12.9125	n/a	n/a	n/a	11.9275	12.6175	n/a
XX-024	12.7275	n/a	n/a	n/a	12.4625	13.0375	n/a
XX-025	12.8375	n/a	n/a	n/a	11.8175	12.875	n/a
XX-026	12.92	n/a	n/a	n/a	12.4625	11.91	n/a
XX-027	12.9025	n/a	n/a	n/a	12.2425	11.9875	n/a
XX-028	12.67	n/a	n/a	n/a	12.645	12.3625	n/a
XX-029	12.6675	n/a	n/a	n/a	11.9075	12.285	n/a
XX-030	12.2125	n/a	n/a	n/a	11.93	12.26	n/a
XX-031	12.9425	n/a	n/a	n/a	n/a	12.6225	n/a
XX-032	12.765	n/a	n/a	n/a	n/a	12.36	n/a
XX-033	12.615	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	12.705	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	12.6625	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	12.755	n/a	n/a	n/a	n/a	n/a	n/a
Mean	12.7981	n/a	n/a	12.1845	12.0286	12.436	11.9056
Stdev	0.136308	n/a	n/a	0.386366	0.34769	0.315641	0.427894
Min	12.2125	n/a	n/a	11.7825	11.69	11.8975	11.355
Max	12.9975	n/a	n/a	12.7875	12.8925	13.1475	12.2725
Range	0.785	n/a	n/a	1.005	1.2025	1.25	0.9175
Median	12.8287	n/a	n/a	12.1513	11.8762	12.3613	11.9975
CV	0.0106506	n/a	n/a	0.0317096	0.0289053	0.0253812	0.0359406

Cup Seal Geometry: Base Thickness (DIM 4)	Artifact A8

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.0
Tests Performed by: Hans Ottosson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
This test is to characterize the base thickness, which is DIM 4 in the image below.

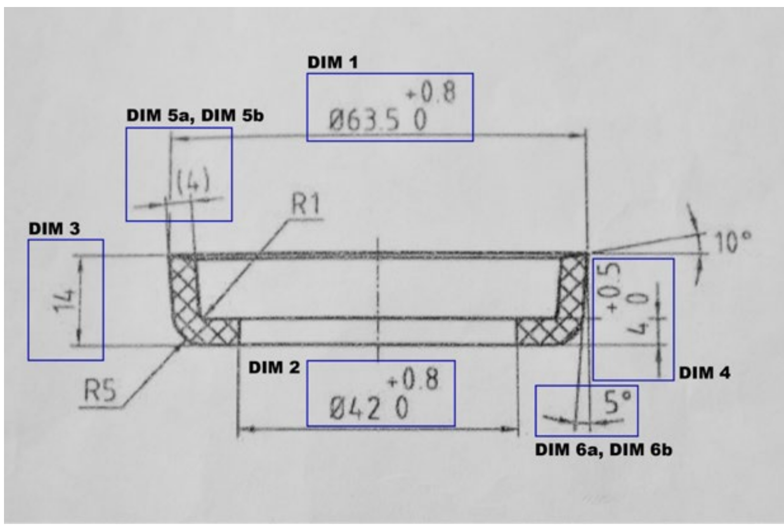

Figure A8.1. Cup seal dimensions.

Summary of Test Results:

Summary of test results can be seen in Table A8.1.

Table A8.1. Summary of test results.

Spec (mm)	Spec Min (mm)	Spec Max (mm)	Samples (count)	Mean (mm)	Stdev (mm)	Min (mm)	Max (mm)	Range (mm)	Median (mm)
4.0	4.0	4.5	112	4.22616	0.175371	3.7525	4.77	1.0175	4.2425

Test Equipment and Set up:
A Mitotoyo Digimatic Indicator (manufacturers part number 575-123) was used to measure the height of each seal in four places (at 0, PI/2, PI, 3/2PI, and 2PI). The indicator accuracy is 0.02 mm, and a measurement force of 1.8 N. A custom stand was built to hold the indicator and provide a flat surface for the sample to rest on. Each seal was measured without the indicator tip touching the walls of the seal.

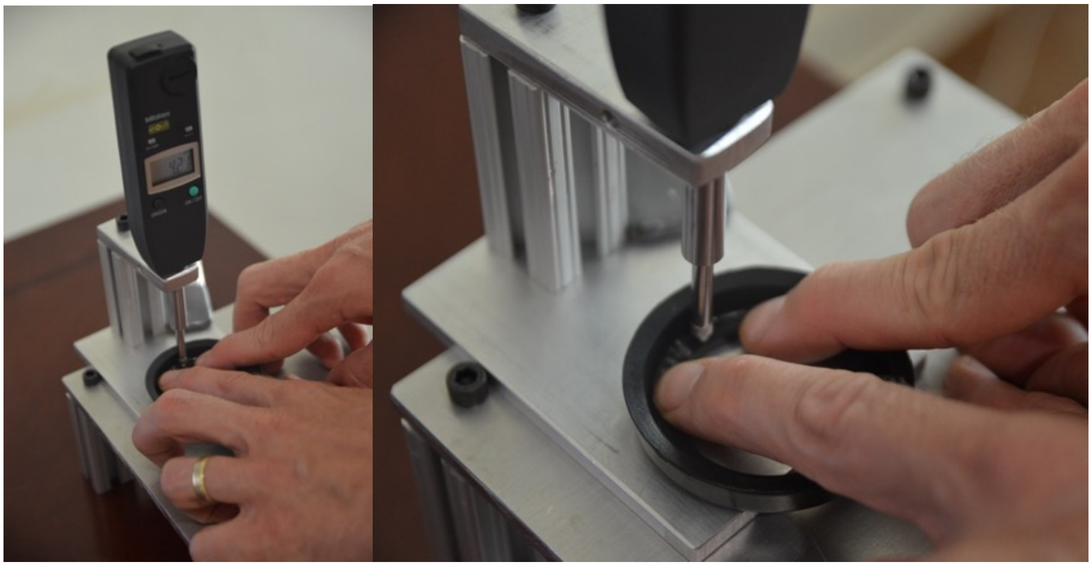

Figure A8.2. Measurement of the cup seal base.

Test Procedure:

1. Make sure that the instrument is at zero before taking measurement.
2. Place the needle of the indicator close to the edge of the seal as seen in image.
3. Read and record measurement.
4. Rotate the seal 90° and record measurement (do this 3 times for a total of 4 measurements).
5. Replace seal with new seal and repeat until done, keeping track of the order of seals.

Test Results:

The following plots and tables provide the data and results.

Observations and Conclusions:

No data was collected from store 2 or 3.

Nearly all of the measurements are within the specification limits. From a molding perspective, this is one of the easiest dimensions to control. The box plots show that stores 4 and 5 pull the mean down, while stores 1 and 6 pull it up. This is possibly meaningful as stores 4 and 5 have the characteristic of being the only seals from Jinja.

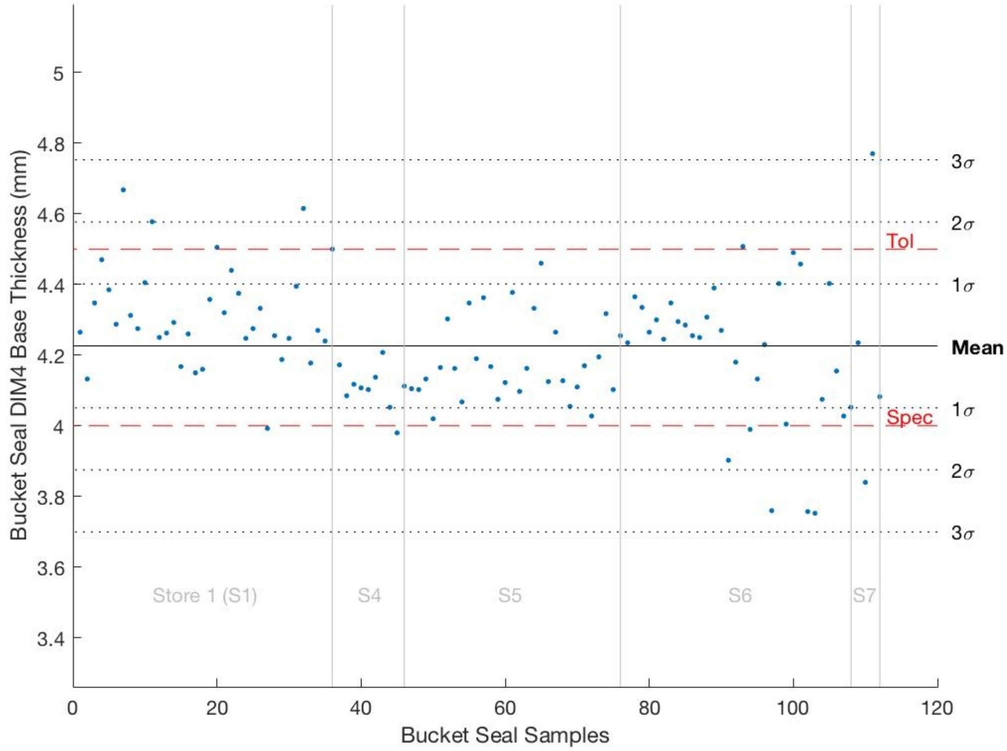

Figure A8.3. DIM 4: Cup seal base thickness. Ordered as tested.

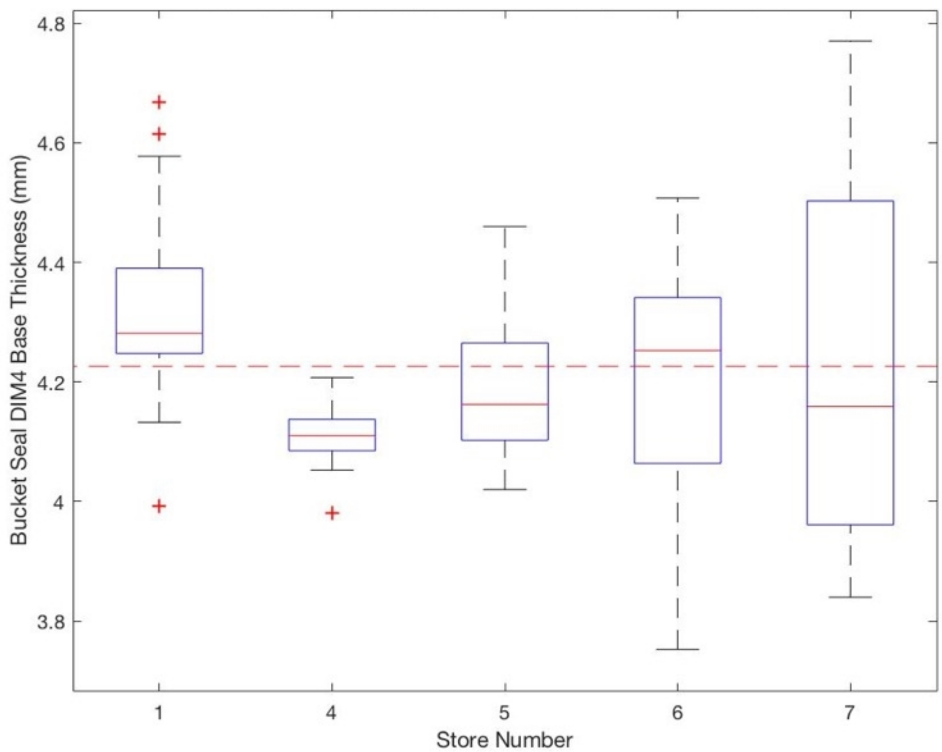

Figure A8.4. DIM 4: Cup seal base thickness. Boxplots for each store.

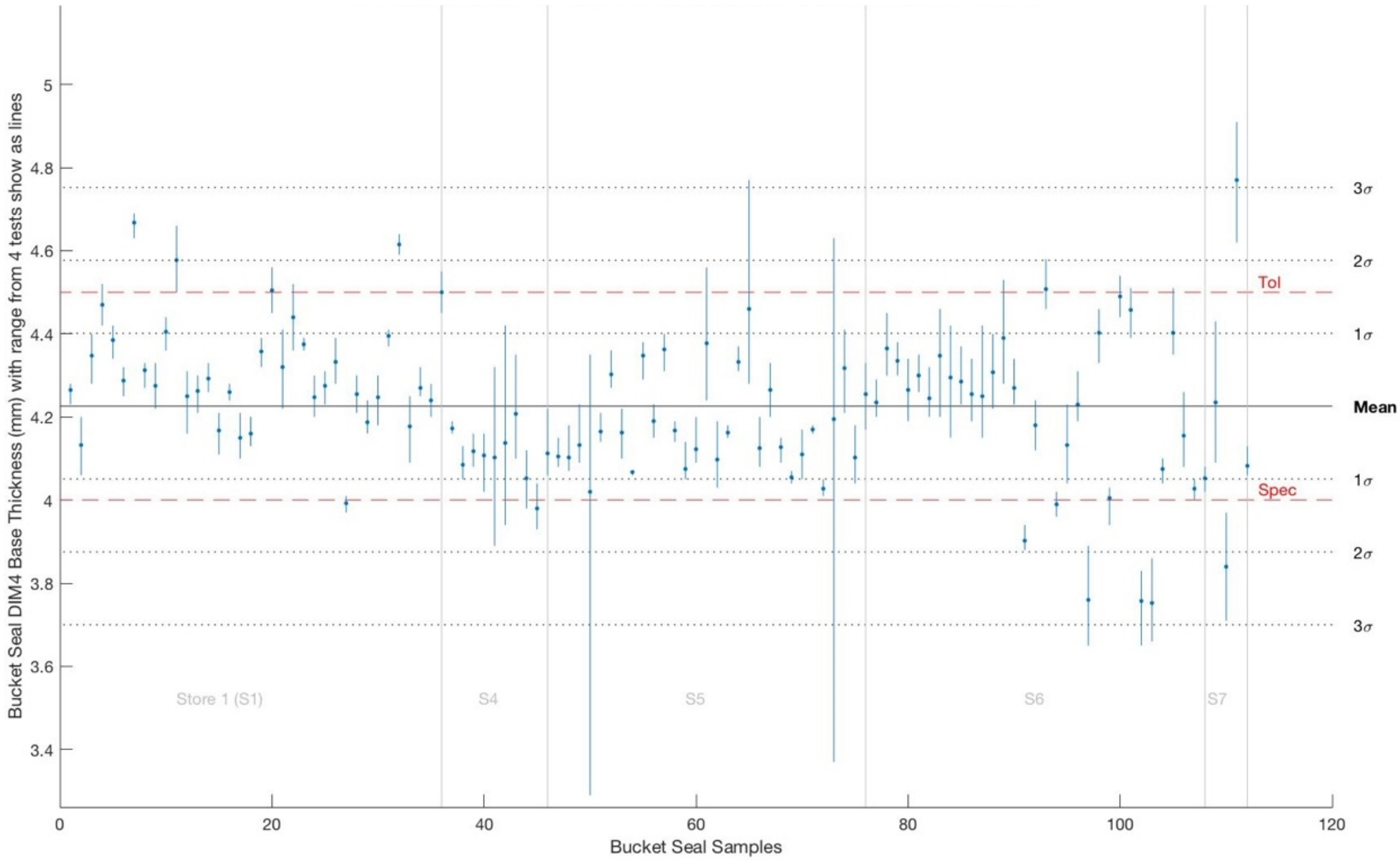

Figure A8.5. DIM 4: Cup seal base thickness variation within sample. Four tests per sample.

Table A8.2. Raw data for DIM4 (base thickness) measurements. Units = mm.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	4.265	n/a	n/a	4.1725	4.105	4.235	4.235
XX-002	4.1325	n/a	n/a	4.085	4.1025	4.365	3.84
XX-003	4.3475	n/a	n/a	4.1175	4.1325	4.335	4.77
XX-004	4.47	n/a	n/a	4.1075	4.02	4.265	4.0825
XX-005	4.385	n/a	n/a	4.1025	4.165	4.3	n/a
XX-006	4.2875	n/a	n/a	4.1375	4.3025	4.245	n/a
XX-007	4.6675	n/a	n/a	4.2075	4.1625	4.3475	n/a
XX-008	4.3125	n/a	n/a	4.0525	4.0675	4.295	n/a
XX-009	4.275	n/a	n/a	3.98	4.3475	4.285	n/a
XX-010	4.405	n/a	n/a	4.1125	4.19	4.255	n/a
XX-011	4.5775	n/a	n/a	n/a	4.3625	4.25	n/a
XX-012	4.25	n/a	n/a	n/a	4.1675	4.3075	n/a
XX-013	4.2625	n/a	n/a	n/a	4.075	4.39	n/a
XX-014	4.2925	n/a	n/a	n/a	4.1225	4.27	n/a
XX-015	4.1675	n/a	n/a	n/a	4.3775	3.9025	n/a
XX-016	4.26	n/a	n/a	n/a	4.0975	4.18	n/a
XX-017	4.15	n/a	n/a	n/a	4.1625	4.5075	n/a
XX-018	4.16	n/a	n/a	n/a	4.3325	3.99	n/a
XX-019	4.3575	n/a	n/a	n/a	4.46	4.1325	n/a
XX-020	4.505	n/a	n/a	n/a	4.125	4.23	n/a
XX-021	4.32	n/a	n/a	n/a	4.265	3.76	n/a
XX-022	4.44	n/a	n/a	n/a	4.1275	4.4025	n/a
XX-023	4.375	n/a	n/a	n/a	4.055	4.005	n/a
XX-024	4.2475	n/a	n/a	n/a	4.11	4.49	n/a
XX-025	4.275	n/a	n/a	n/a	4.17	4.4575	n/a
XX-026	4.3325	n/a	n/a	n/a	4.0275	3.7575	n/a
XX-027	3.9925	n/a	n/a	n/a	4.195	3.7525	n/a
XX-028	4.255	n/a	n/a	n/a	4.3175	4.075	n/a
XX-029	4.1875	n/a	n/a	n/a	4.1025	4.4025	n/a
XX-030	4.2475	n/a	n/a	n/a	4.255	4.155	n/a
XX-031	4.395	n/a	n/a	n/a	n/a	4.0275	n/a
XX-032	4.615	n/a	n/a	n/a	n/a	4.0525	n/a
XX-033	4.1775	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	4.27	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	4.24	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	4.5	n/a	n/a	n/a	n/a	n/a	n/a
Mean	4.31667	n/a	n/a	4.1075	4.18342	4.20078	4.23187
Stdev	0.141628	n/a	n/a	0.0624166	0.114275	0.206451	0.393898
Min	3.9925	n/a	n/a	3.98	4.02	3.7525	3.84
Max	4.6675	n/a	n/a	4.2075	4.46	4.5075	4.77
Range	0.675	n/a	n/a	0.2275	0.44	0.755	0.93
Median	4.28125	n/a	n/a	4.11	4.1625	4.2525	4.15875
CV	0.0328096	n/a	n/a	0.0151958	0.0273162	0.0491459	0.0930789

Cup Seal Geometry: Wall Thickness (DIM 5)	Artifact A9

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.0
Tests Performed by: Hans Ottosson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand and describe the wall thickness as it varies seal to seal, and across a given seal. We do this by measuring the wall thickness at both the base (near R1) and at the edge (near the 10 deg dimension).

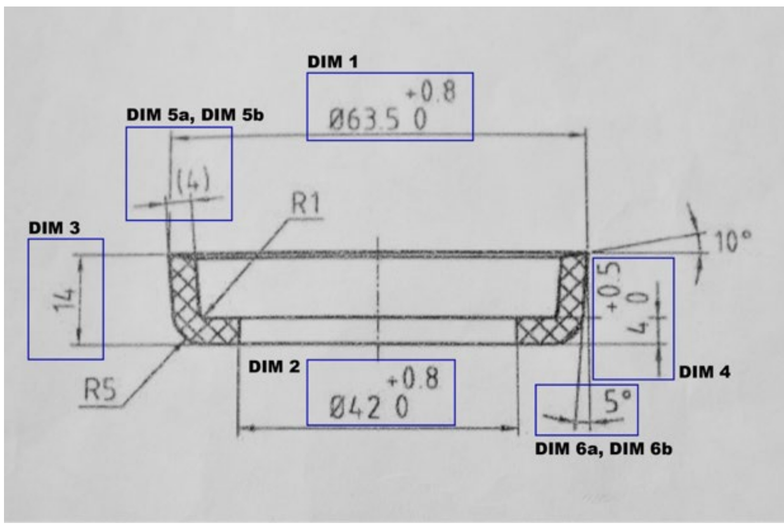

Figure A9.1. Cup seal dimensions.

Summary of Test Results:
Summary of test results can be seen in Tables A9.1 and A9.2.

Table A9.1. Summary of test results at base.

Spec (mm)	Spec Min (mm)	Spec Max (mm)	Samples (count)	Mean (mm)	Stdev (mm)	Min (mm)	Max (mm)	Range (mm)	Median (mm)
4.0	3.5	4.5	112	4.182	0.188661	3.8175	4.6375	0.82	4.16125

Table A9.2. Summary of test results at edge.

Spec (mm)	Spec Min (mm)	Spec Max (mm)	Samples (count)	Mean (mm)	Stdev (mm)	Min (mm)	Max (mm)	Range (mm)	Median (mm)
4.0	3.5	4.5	112	4.1533	0.180924	3.7	4.6025	0.9025	4.16

Test Equipment and Set up:
A Mitotoyo Digimatic Indicator (manufacturers part number 575-123) was used to measure the wall thickness of each seal in four places (at 0, PI/2, PI, 3/2PI, and 2PI). The indicator accuracy is 0.02 mm, and a measurement force of 1.8 N. A custom stand was built to hold the indicator and provide a flat surface for the sample to rest on. Each seal was measured with the indicator head near the base of the seal (as seen in the left photo) and near the edge of the seal (as seen in the right photo). The center photo indicated that the finger was used to line up the indicator with the edge for the wall thickness measurement at the edge.

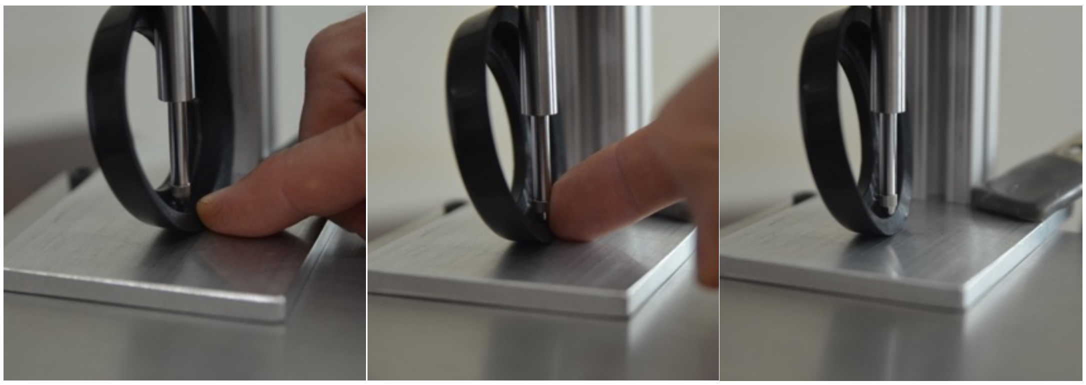

Figure A9.2. Measurement of the seal wall thickness.

Test Procedure:

1. Make sure that the instrument is at zero before taking measurement.
2. Place the needle of the indicator close to the base as seen in above image on the left.
3. Read and record measurement. Place the needle of the indicator close to the edge of the seal as seen in middle and left images, using finger as a guide.
4. Read and record measurement.
5. Rotate the seal 90° and repeat steps 2-4 (do this 3 times for a total of 8 measurements).
6. Replace seal with new seal and repeat until done, keeping track of the order of seals.

Test Results:
The following plots and tables provide the data and results.

Observations and Conclusions:
No data was collected from store 2 or 3.

The first scatter plot shows the average of 4 measurements per seal, plotted as just one point (the mean). The second scatter plot shows the range as well as the mean.

Nearly all measurements (all but 5) are within the specification limit, and none are below the specifications. A thicker seal in this dimension is most likely more desirable than one that is thinner.

It is interesting to note that there does not appear to be a correlation between the base thickness and the wall thickness. A deeper analysis may reveal a correlation not obviously seen now. At both the base and the edge the seals from store 1 appear most consistent.

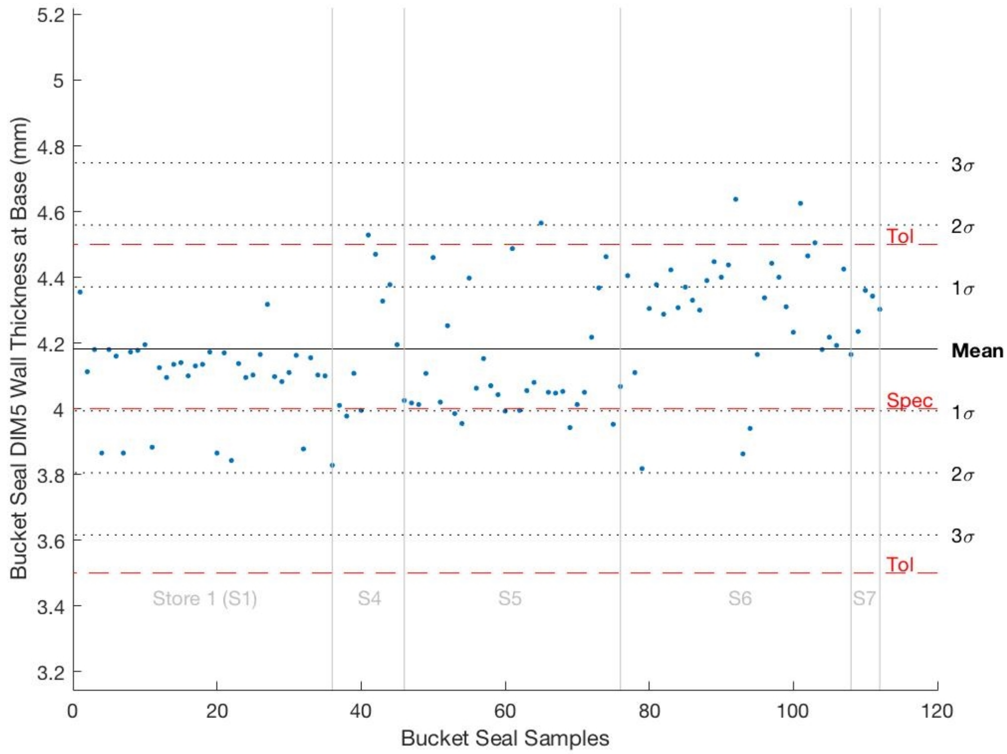

Figure A9.3. DIM 5: Cup seal wall thickness at base. Ordered as tested.

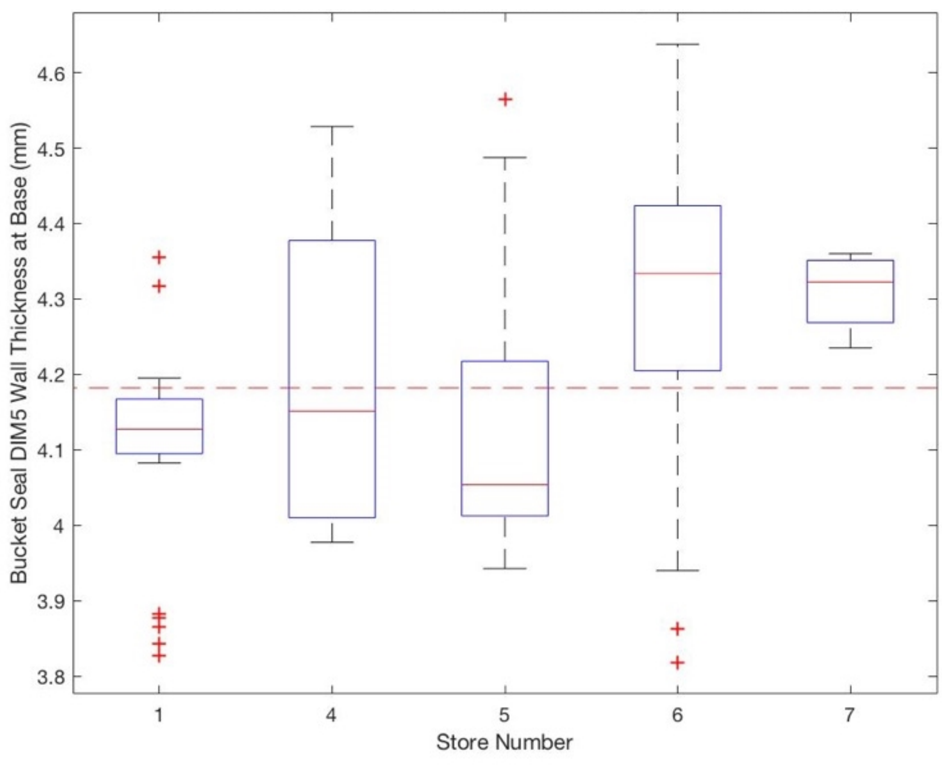

Figure A9.4. DIM 5: Cup seal wall thickness at base. Boxplots for each store.

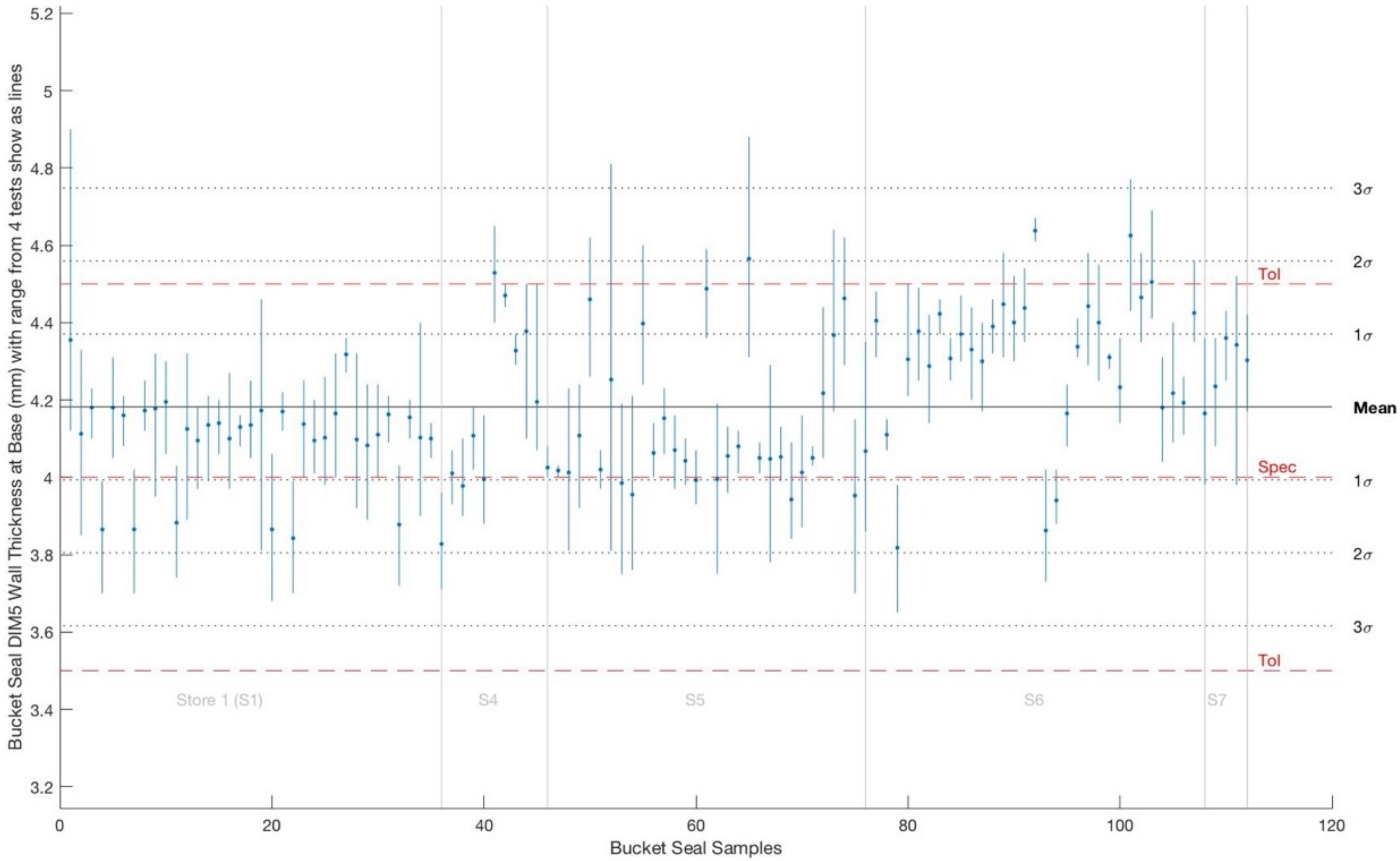

Figure A9.5. DIM 5: Cup seal wall thickness at base variation within sample. Four tests per sample.

Table A9.3. Raw data for DIM5 (wall thickness at base) measurements. Units = mm.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	4.355	n/a	n/a	4.01	4.0175	4.405	4.235
XX-002	4.1125	n/a	n/a	3.9775	4.0125	4.11	4.36
XX-003	4.18	n/a	n/a	4.1075	4.1075	3.8175	4.3425
XX-004	3.865	n/a	n/a	3.995	4.46	4.305	4.3025
XX-005	4.18	n/a	n/a	4.5285	4.02	4.3775	n/a
XX-006	4.16	n/a	n/a	4.47	4.2525	4.2875	n/a
XX-007	3.865	n/a	n/a	4.3275	3.985	4.4225	n/a
XX-008	4.1725	n/a	n/a	4.3775	3.955	4.3075	n/a
XX-009	4.1775	n/a	n/a	4.195	4.3975	4.37	n/a
XX-010	4.195	n/a	n/a	4.025	4.0625	4.33	n/a
XX-011	3.8825	n/a	n/a	n/a	4.1525	4.3	n/a
XX-012	4.125	n/a	n/a	n/a	4.07	4.39	n/a
XX-013	4.095	n/a	n/a	n/a	4.0425	4.4475	n/a
XX-014	4.135	n/a	n/a	n/a	3.9925	4.4	n/a
XX-015	4.14	n/a	n/a	n/a	4.4875	4.4375	n/a
XX-016	4.1	n/a	n/a	n/a	3.995	4.6375	n/a
XX-017	4.13	n/a	n/a	n/a	4.055	3.8625	n/a
XX-018	4.135	n/a	n/a	n/a	4.08	3.94	n/a
XX-019	4.1725	n/a	n/a	n/a	4.565	4.165	n/a
XX-020	3.865	n/a	n/a	n/a	4.05	4.3375	n/a
XX-021	4.17	n/a	n/a	n/a	4.0475	4.4425	n/a
XX-022	3.8425	n/a	n/a	n/a	4.0525	4.4	n/a
XX-023	4.1375	n/a	n/a	n/a	3.9425	4.31	n/a
XX-024	4.095	n/a	n/a	n/a	4.0125	4.2325	n/a
XX-025	4.1025	n/a	n/a	n/a	4.05	4.625	n/a
XX-026	4.165	n/a	n/a	n/a	4.2175	4.465	n/a
XX-027	4.3175	n/a	n/a	n/a	4.3675	4.505	n/a
XX-028	4.0975	n/a	n/a	n/a	4.4625	4.18	n/a
XX-029	4.0825	n/a	n/a	n/a	3.9525	4.2175	n/a
XX-030	4.11	n/a	n/a	n/a	4.0675	4.1925	n/a
XX-031	4.1625	n/a	n/a	n/a	n/a	4.425	n/a
XX-032	3.8775	n/a	n/a	n/a	n/a	4.165	n/a
XX-033	4.155	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	4.1025	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	4.1	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	3.8275	n/a	n/a	n/a	n/a	n/a	n/a
Mean	4.0941	n/a	n/a	4.20135	4.13108	4.30656	4.31
Stdev	0.128701	n/a	n/a	0.209601	0.180932	0.187974	0.0554902
Min	3.8275	n/a	n/a	3.9775	3.9425	3.8175	4.235
Max	4.355	n/a	n/a	4.5285	4.565	4.6375	4.36
Range	0.5275	n/a	n/a	0.551	0.6225	0.82	0.125
Median	4.1275	n/a	n/a	4.15125	4.05375	4.33375	4.3225
CV	0.0314357	n/a	n/a	0.0498890	0.0437977	0.0436483	0.0128748

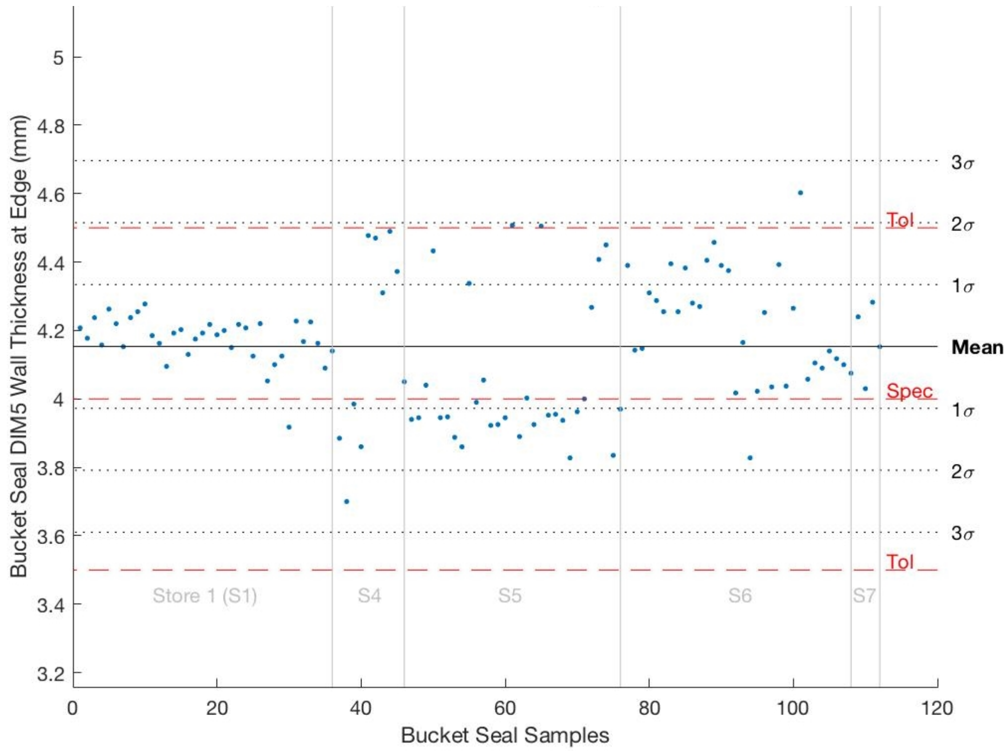

Figure A9.6. DIM 5: Cup seal wall thickness at edge. Ordered as tested.

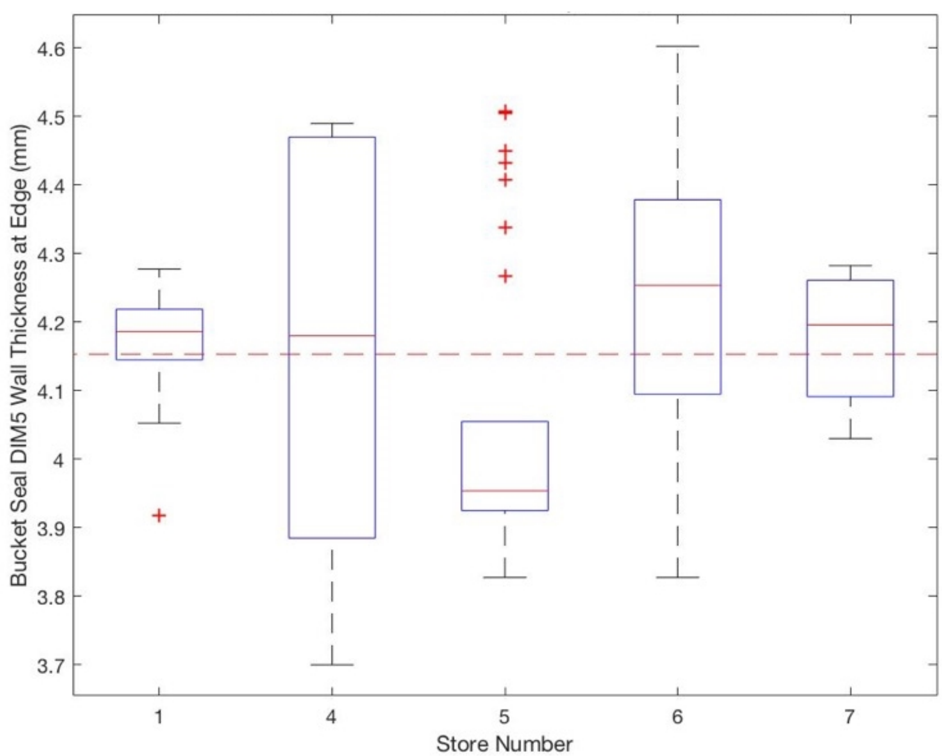

Figure A9.7. DIM 5: Cup seal wall thickness at Edge. Boxplots for each store.

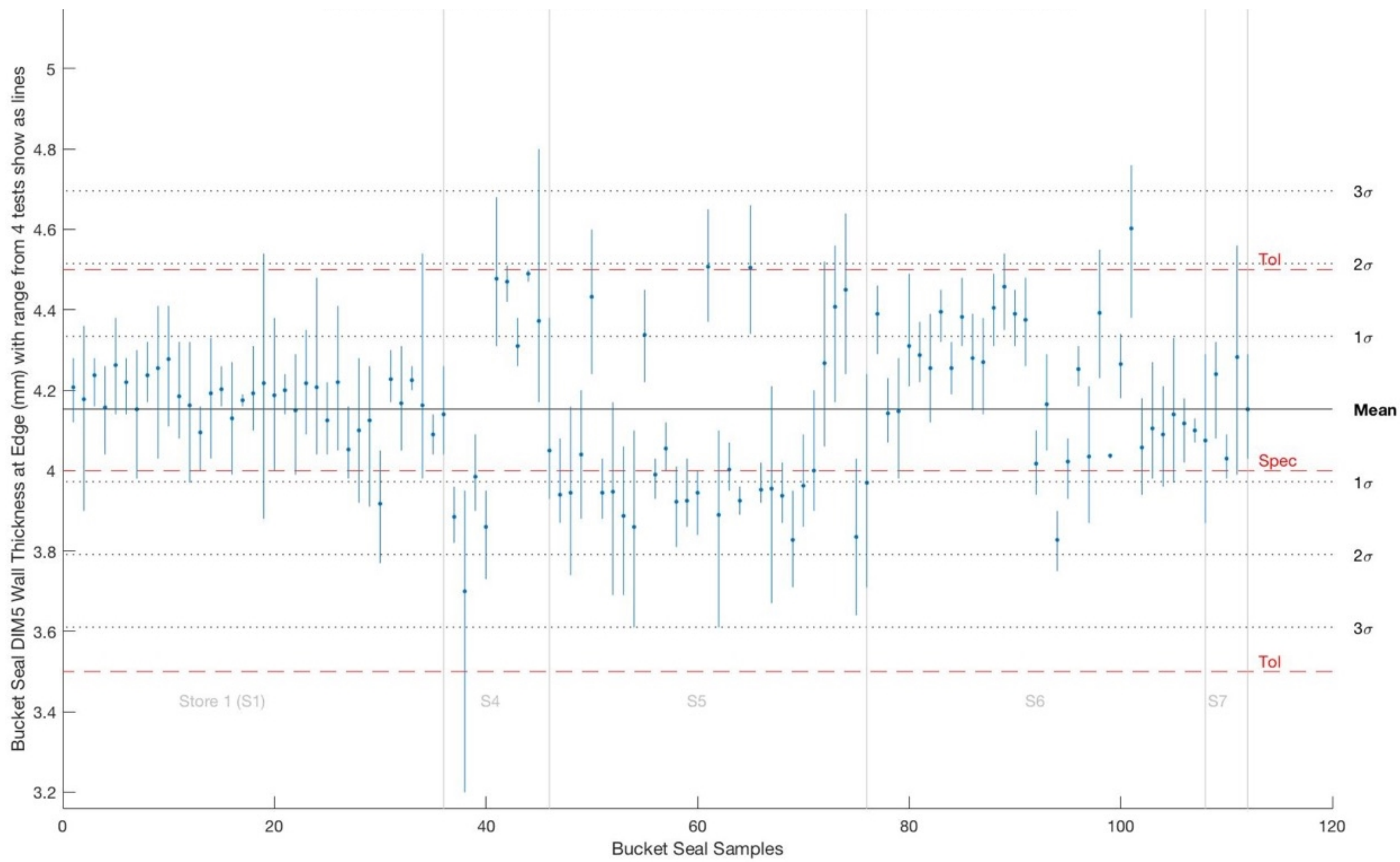

Figure A9.8. DIM 5: Cup seal wall thickness at edge variation within sample. Four tests per sample.

Table A9.4. Raw data for DIM5 (wall thickness at edge) measurements. Units = mm.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	4.2075	n/a	n/a	3.885	3.94	4.39	4.24
XX-002	4.1775	n/a	n/a	3.7	3.945	4.1425	4.03
XX-003	4.2375	n/a	n/a	3.985	4.04	4.1475	4.2825
XX-004	4.1575	n/a	n/a	3.86	4.4325	4.31	4.1525
XX-005	4.2625	n/a	n/a	4.4775	3.945	4.2875	n/a
XX-006	4.22	n/a	n/a	4.47	3.9475	4.255	n/a
XX-007	4.1525	n/a	n/a	4.31	3.8875	4.395	n/a
XX-008	4.2375	n/a	n/a	4.49	3.86	4.255	n/a
XX-009	4.255	n/a	n/a	4.3725	4.3375	4.3825	n/a
XX-010	4.2775	n/a	n/a	4.05	3.99	4.28	n/a
XX-011	4.185	n/a	n/a	n/a	4.055	4.27	n/a
XX-012	4.1625	n/a	n/a	n/a	3.9225	4.405	n/a
XX-013	4.095	n/a	n/a	n/a	3.925	4.4575	n/a
XX-014	4.1925	n/a	n/a	n/a	3.945	4.39	n/a
XX-015	4.2025	n/a	n/a	n/a	4.5075	4.375	n/a
XX-016	4.13	n/a	n/a	n/a	3.89	4.0175	n/a
XX-017	4.175	n/a	n/a	n/a	4.0025	4.165	n/a
XX-018	4.1925	n/a	n/a	n/a	3.925	3.8275	n/a
XX-019	4.2175	n/a	n/a	n/a	4.505	4.0225	n/a
XX-020	4.1875	n/a	n/a	n/a	3.9525	4.2525	n/a
XX-021	4.2	n/a	n/a	n/a	3.955	4.035	n/a
XX-022	4.15	n/a	n/a	n/a	3.9375	4.3925	n/a
XX-023	4.2175	n/a	n/a	n/a	3.8275	4.0375	n/a
XX-024	4.2075	n/a	n/a	n/a	3.9625	4.265	n/a
XX-025	4.125	n/a	n/a	n/a	4	4.6025	n/a
XX-026	4.22	n/a	n/a	n/a	4.2675	4.0575	n/a
XX-027	4.0525	n/a	n/a	n/a	4.4075	4.105	n/a
XX-028	4.1	n/a	n/a	n/a	4.45	4.09	n/a
XX-029	4.125	n/a	n/a	n/a	3.835	4.14	n/a
XX-030	3.9175	n/a	n/a	n/a	3.97	4.1175	n/a
XX-031	4.2275	n/a	n/a	n/a	n/a	4.1	n/a
XX-032	4.1675	n/a	n/a	n/a	n/a	4.075	n/a
XX-033	4.225	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	4.1625	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	4.09	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	4.14	n/a	n/a	n/a	n/a	n/a	n/a
Mean	4.17368	n/a	n/a	4.16	4.05225	4.22016	4.17625
Stdev	0.0676585	n/a	n/a	0.296912	0.213429	0.166034	0.111514
Min	3.9175	n/a	n/a	3.7	3.8275	3.8275	4.03
Max	4.2775	n/a	n/a	4.49	4.5075	4.6025	4.2825
Range	0.36	n/a	n/a	0.79	0.68	0.775	0.2525
Median	4.18625	n/a	n/a	4.18	3.95375	4.25375	4.19625
CV	0.0162108	n/a	n/a	0.0713731	0.0526693	0.0393431	0.0267019

Cup Seal Geometry: Wall Angle (DIM 6)	Artifact A10

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.0
Tests Performed by: Christopher Mattson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
This test measures the angle of the side walls, shown as being 5 degrees in the image below. No tolerance is specified, but +/- 2 degrees is assumed.

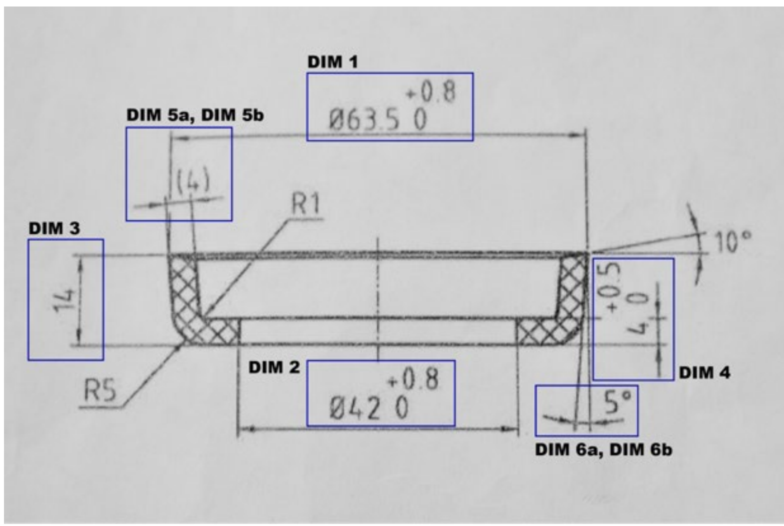

Figure A10.1. Cup seal dimensions.

Summary of Test Results:

Summary of test results can be seen in Table A10.1.

Table A10.1. Summary of test results.

Spec (°)	Spec Min (°)	Spec Max (°)	Samples (count)	Mean (°)	Stdev (°)	Min (°)	Max (°)	Range (°)	Median (°)
5°	4. 5°	5. 5°	112	7.52808°	2.22381°	1.56507°	12.496°	10.9309°	7.48053°

Test Equipment and Set up:
The same test fixture used to take photos for DIM 1 (see Artifact A1) was used to take photos for the DIM 6 analysis. This was done for every seal as it was placed in the "bucket up position".

Test Procedure:
1. Ensure that the pictures are located in the right folder, accessible to MATLAB.
2. Run MATLAB script.

3. For each image, mark a line for the slope.
4. Repeat until done.
5. Check the MATLAB results to ensure that the script completed.

Test Results:
A representative visual result can be seen in Figure A10.2. Notice the blue line in the image that represents the edge of the seal. The angle of this line is assumed to be the wall angle.

Figure A10.2. Images used for finding cup seal angle.

Observations and Conclusions:
No data was collected from store 2 or 3.

The first observation is that the mean is outside of the spec limits. Recall that the spec limits are artificial (i.e., not actually specified), but are generously large for angle measurements.

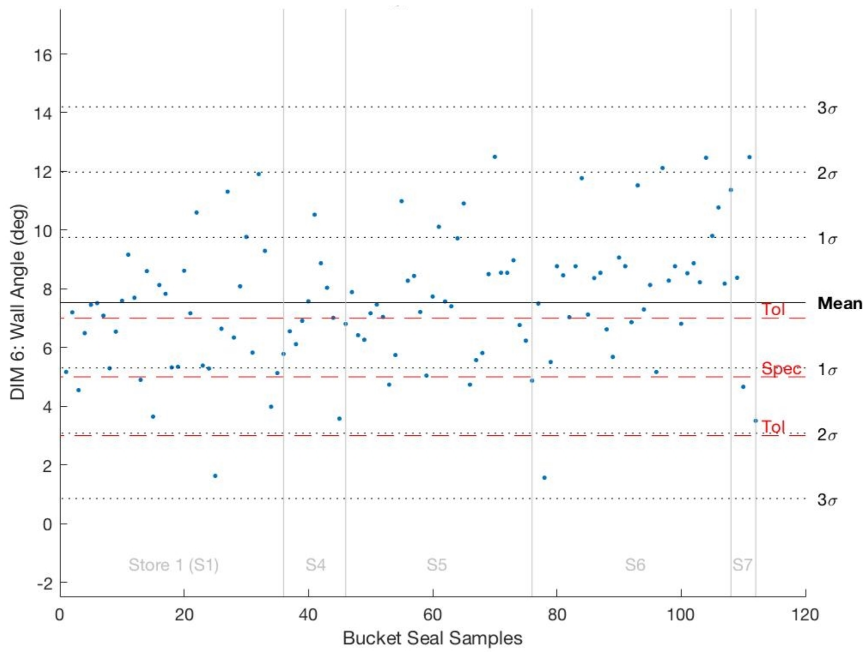

Figure A10.3. DIM 6: Cup seal wall angle. Ordered as tested.

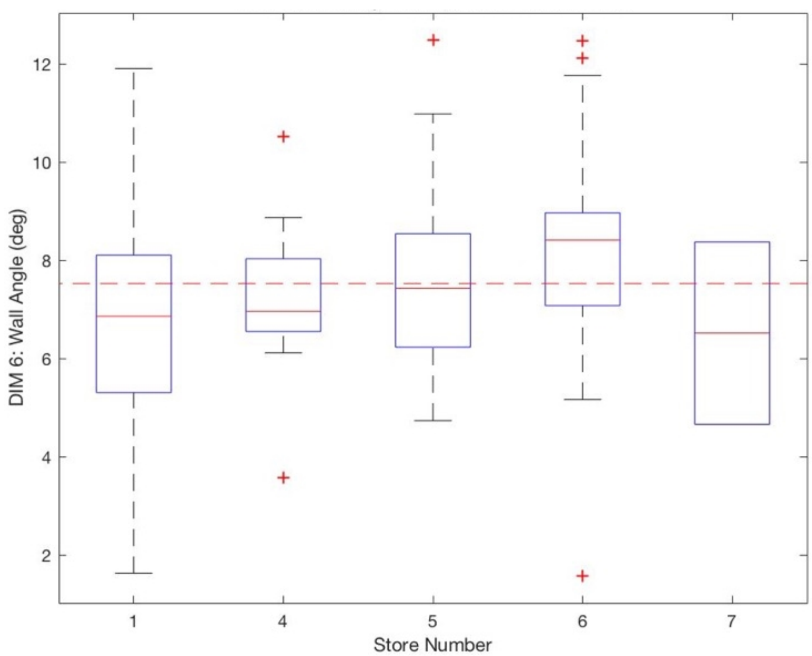

Figure A10.4. DIM 6: Cup seal wall angle. Boxplots for each store.

Table A10.2. Raw data for DIM6 (wall angle) measurements. Units = deg.

Seal	Store 1	Store 2	Store 3	Store 4	Store 5	Store 6	Store 7
XX-001	5.16847	n/a	n/a	6.55255	7.88835	7.49586	8.37601
XX-002	7.19923	n/a	n/a	6.1155	6.41879	1.56507	4.66055
XX-003	4.54804	n/a	n/a	6.91123	6.26349	5.50548	12.4881
XX-004	6.49077	n/a	n/a	7.57295	7.16724	8.76906	3.50353
XX-005	7.45706	n/a	n/a	10.5251	7.46519	8.45891	n/a
XX-006	7.51214	n/a	n/a	8.87056	7.04204	7.03342	n/a
XX-007	7.08517	n/a	n/a	8.03571	4.73558	8.76906	n/a
XX-008	5.29008	n/a	n/a	7.01186	5.74416	11.7683	n/a
XX-009	6.54039	n/a	n/a	3.57633	10.9855	7.12502	n/a
XX-010	7.59464	n/a	n/a	6.80426	8.27589	8.36589	n/a
XX-011	9.16235	n/a	n/a	0	8.43838	8.54528	n/a
XX-012	7.69605	n/a	n/a	0	7.20996	6.61799	n/a
XX-013	4.89909	n/a	n/a	0	5.04245	5.67925	n/a
XX-014	8.60448	n/a	n/a	0	7.73737	9.0665	n/a
XX-015	3.64449	n/a	n/a	0	10.114	8.77076	n/a
XX-016	8.1301	n/a	n/a	0	7.57089	6.86369	n/a
XX-017	7.82908	n/a	n/a	0	7.40373	11.5237	n/a
XX-018	5.32275	n/a	n/a	0	9.71879	7.29864	n/a
XX-019	5.34545	n/a	n/a	0	10.9077	8.1301	n/a
XX-020	8.61565	n/a	n/a	0	4.73558	5.16524	n/a
XX-021	7.16724	n/a	n/a	0	5.5722	12.1169	n/a
XX-022	10.5994	n/a	n/a	0	5.81248	8.28068	n/a
XX-023	5.3837	n/a	n/a	0	8.49856	8.76906	n/a
XX-024	5.284	n/a	n/a	0	12.496	6.80905	n/a
XX-025	1.62728	n/a	n/a	0	8.54696	8.53077	n/a
XX-026	6.63947	n/a	n/a	0	8.54528	8.87056	n/a
XX-027	11.3099	n/a	n/a	0	8.97263	8.22281	n/a
XX-028	6.34019	n/a	n/a	0	6.76617	12.4649	n/a
XX-029	8.08626	n/a	n/a	0	6.23175	9.8025	n/a
XX-030	9.7697	n/a	n/a	0	4.87139	10.77	n/a
XX-031	5.82634	n/a	n/a	n/a	n/a	8.1762	n/a
XX-032	11.9083	n/a	n/a	n/a	n/a	11.3682	n/a
XX-033	9.29331	n/a	n/a	n/a	n/a	n/a	n/a
XX-034	3.98252	n/a	n/a	n/a	n/a	n/a	n/a
XX-035	5.12819	n/a	n/a	n/a	n/a	n/a	n/a
XX-036	5.78239	n/a	n/a	n/a	n/a	n/a	n/a
Mean	6.89621	n/a	n/a	7.19761	7.57262	8.33434	7.25705
Stdev	2.18434	n/a	n/a	1.81617	1.95209	2.24091	4.05983
Min	1.62728	n/a	n/a	3.57633	4.73558	1.56507	3.50353
Max	11.9083	n/a	n/a	10.5251	12.496	12.4649	12.4881
Range	10.281	n/a	n/a	6.94877	7.76042	10.8998	8.98457
Median	6.86232	n/a	n/a	6.96155	7.43446	8.4124	6.51828
CV	0.316745	n/a	n/a	0.252330	0.257783	0.268877	0.559433

Locations of Stores and Boreholes	Artifact A11

Artifact Prepared by: Tom Naylor and Christopher Mattson | Revision 1.1
Information compiled by: Tom Naylor and Christopher Mattson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of this Artifact:
The purpose of this artifact is to clearly describe where the tests performed for this study took place.

Information Regarding Stores:

Table A11.1 contains name, contact information, location, and number of seals purchased.

Table A11.1. Store information, Uganda.

Store (city in Uganda)	Name	Phone Number[6]	GPS Location	Samples Purchased (count)
Store 1 (Kampala)	Buyaya Technical Services LTD	0774613444	0.3120200, 32.5804750	36
Store 2 (Kampala)	Bukasa Traders	0784745827	0.3119129, 32.5802447	0
Store 3 (Kampala)	Buyaya Technical Services LTD	0701251130	0.3007919, 32.5764662	0
Store 4 (Jinja)	Jogobalin Mudima Electrical & Plumbing Engineers	0772451170	0.4299121, 33.216026	10
Store 5 (Jinja)	Plumber Sanchois Tecn & Cons	0753595981	0.431205, 33.213630	30
Store 6 (Gulu)	Vintoy Enterprises - SMC LTD	0759426263	2.770391, 32.298859	32
Store 7 (Gulu)	Dam & J Agro Machinery	0772634607, 0752634607, 0701634607	2.770682, 32.298802	4

[6] Uganda Country Code is 256, when dialing Uganda from the USA, omit the 0 (first digit) in the telephone number.

Description of each store:

Store 1 (Kampala)
Store temp = 81.2°F
Store humidity = 54 %
The shop is in the old town market area. The shop is a garage-style store front with inventory going deep into the shop. The cashier sits near the opening of the garage door and patrons can enter and look, though crowded. Many other people affiliated with the store are also in the store, possibly ready to help. Pump cup seals are in a large box directly behind the cashier at shoulder height when sitting. The box is approximately 30 cm by 30 cm by 50 cm. There are hundreds of Nitrile cup seals within. Seals are sold in pairs. Leather seals are kept strung up with approximately 30 on the string (like a necklace). These are kept hanging 3 m into the shop at approximately elbow height.

Figure A11.1. Store 1: Buyaya Technical Services LTD.

This shop is a branch outlet to the company's larger shop (Store 3). We purchased many seals of varying types in this shop. This shop was identified as Godfrey asked people in advance, where we might buy borehole pump parts. There was one pump technician in the store. He was relatively quiet. He led us to Store 3.

Upon arrival, it was apparent that the presence of 4 Americans made them nervous. We quickly split in two and left only 2 Americans in the store.

Store 2 (Kampala)
Store temp = Not recorded
Store humidity = Not recorded
This shop was very near Store 1. It was found as two of the researchers left store 1 to ease the American presence. Store two was a small storefront with many people and much material. The store was approximately as deep as it was wide. When asked about the cup seals, the owners responded that they had leather cup seals only. We purchased 6. No Nitrile seals were purchased from this store.

Store 3 (Kampala)
Store temp = 79.9°F
Store humidity = 59.7 %
This shop was the main store for which store one was a branch outlet. This store was a more developed, customer centric place compared to store 1. Seals were kept on strings. A portion of seals were measured but not purchased at this store. These measurements are not included in this report.

Figure A11.2. Store 3: Buyaya Technical Services LTD (main branch).

Store 4 (Jinja)
Store temp = 84.3°F
Store humidity = 41.3 %
Finding cup seals in Jinja was initially much more difficult than in Kampala. Eventually after visiting multiple shops and displaying the cup seal as an example of what we wanted, we found store 4. Store 4 is a very small shop, roughly half the size of store 2 (which is smaller than store 1). To access the store front, three or four steps are climbed. The shop is not one you can enter, but largely one where the shop owner finds what is wanted and brings it out. The cup seals were available and kept in a plastic bag within a bucket with other parts. This store had only 14 seals. Initially the price was much higher than expected, so we did not buy any. After discovering very few places to purchase cup seals, we returned and purchased 10 seals.

Figure A11.3. Store 4: Jogobalin Mudima Electrical & Plumbing Engineers.

Store 5 (Jinja)
Store temp = 77.3°F
Store humidity = 63.2 %
Store 5 was within Jinja's main market, it was about equal in size to store 4. We were led to store 5 when Godfrey asked another vendor (he knew in the central market) if he knew of a place that sold borehole pump parts.

The person at the store was the son of the store's owner, he was extremely open and interested in what research we were performing.

They had only a few cup seals on hand, but after learning we wanted to buy more they left for 5 minutes and came back with more (presumably from another store in the central market). We are unsure of how the seals brought back were kept (on a string, in a box, etc.). The seals cost more than twice that of the seals purchased in store 1.

Figure A11.4. Store 5: Plumber Sanchois Tecn & Cons.

Store 6 (Gulu)
Store temp = 89.4°F
Store humidity = 35.6 %
Store 6 was considered by many who we talked to be the only location in Gulu to purchase cup seals. It was located directly next to a high-end pump store that sold electric pumps and hand irrigation pumps. That store did not sell cup seals but did direct us to the neighboring store were we initial bought a few sets (4 seals), as the store owner had indicated he did not have more. After returning from Store 7, across the street, the worker at Store 6 indicated that he had found more seals for us in his shop, and we bought an additional 28 seals.

Store six was constructed as a wider less deep shop, not of garage style as the other stores were. Cup seals were kept on a string, necklace style.

Figure A11.5. Store 6: Vintoy Enterprises - SMC LTD.

Store 7 (Gulu)
Store temp = 88°F
Store humidity = 45.1 %
Store 7 was a very small shop across the street from Store 6. This shop sold primarily belt driven equipment and replacement belts. They did sell borehole pump systems and when asked about the cup seal, the shop worker quickly found a small box of pump seals. Each seal was in a bagged seal set containing roughly 10 seals. The shop worker described these seals as certified seals for our application. He opened a seal set, and when asked if we could purchase only the cup seal he quickly agreed. We purchased 4 seals. We later learned that two of the seals were of a noticeably different inner diameter (DIM2).

Figure A11.6. Store 7: Dam & J Agro Machinery.

Information Regarding Boreholes:

Table A11.2 contains information regarding the boreholes that were visited for this study.

Table A11.2. Borehole information, Uganda.

Borehole Pump (city in Uganda)	Caretaker	Phone Number	GPS Location	Observation Date
Borehole 1 (Near Jinja)	Mr. Sandee (Caretaker)	Immy (lives to the west of the borehole by two houses) 0705832096 0784324432	0˚ 29.499' N, 33˚ 10.993' E	24 July 2018
Borehole 2 (Near Jinja)	Mr. Stephen (Caretaker)	Alfred (lives directly to the east of the borehole) 0784355555 0753661555	0˚ 28.638' N, 33˚ 12.223' E	25 July 2018
Borehole 3 (Gulu)	Mr. Kilama (Caretaker) Mrs. Evelynn[7] (Technician)	Evelynn (lives across the street, down a cross street) 0782827904	2.7878157, 32.2997101	30 July 2018
Borehole 4 (Gulu)	Mr. Christopher (Caretaker)	Evelynn (lives further down across the street, down a cross street) 0782827904	2.7876261, 32.2967024	31 July 2018

Description of each borehole:

<u>Borehole 1 (Near Jinja)</u>

Borehole 1 is located 20 minutes outside of Jinja by motorcycle. The borehole is in a rural setting, where the population density is less than the other boreholes studied. Figure A11.7 shows the setting and the sensor setup directly below. The wooden fence surrounding the borehole pump is in line with India Mark II and III installation specs indicating that a fence should be constructed around the borehole to keep animals out of the water supply area.

[7] Evelynn is also a trained pump technician.

Figure A11.7. Borehole 1 near Jinja.

The borehole pump is an India Mark III and was recently repaired for a cracked coupler pipe (failed coupler shown in Figure A11.8). There is noticeable side to side pump handle movement, which has caused the top plate guiding the pump rod into the pipe to become worn. This causes significant lateral movement in the pump rod. It is believed by many that the lateral movement of pump rods eventually causes riser pipe failure as the PVC failure shown in Figure A11.9.

Figure A11.8. Borehole 1 near Jinja.

Figure A11.9. PVC pipe failure due to the pump rod being out of alignment.

From the early morning pump start up test (counting full strokes until water is dispensed), it is believed that the foot value for this pump needs cleaning or replacement.

Figure A11.10. Failed riser pipe coupler.

Borehole 2 (Near Jinja)

Borehole 2 is located 2 km closer to town than borehole 1. It is in an area with slightly greater population density and is near municipal water tap. The borehole was repaired July 7th 0f this year, though it was later discovered that only the head and chain parts where repaired, not the cylinder parts. A technician that came by while we observed the pump described to us that borehole pump 2 needs new cup seals.

Figure A11.11. Borehole 2 near Jinja.

Borehole 3 (Gulu)

Borehole 3 is located in a more populated village within Gulu. It is within a 15 minutes' walk from our hotel (Churchill Courts). The pump on borehole 3 is an India Mark II, with a 1 ¼ inch PVC riser pipe (see Figure A11.9).

Figure A11.12. Borehole 3 in Gulu.

It was originally anticipated that the next closest borehole pump would be closed and under repair on the day we observed borehole 3. We expected a larger than normal showing at the pump. We in the day we verified that the other borehole had not closed at all that day.

Borehole 3's pump had recently been repaired by Evelynn, the pump technician. The failure was in the PVC riser pipe. The pump rod had rubbed against the side of the PVC until it failed. We purchased the failed sample from Evelynn.

<u>Borehole 4 (Gulu)</u>

Borehole 4 is approximately 300 meters from borehole 3 and was scheduled to be under repair for drainage on the day we observed borehole 3. It was not repaired on the day we observed borehole 3 or 4.

Figure A11.13. Borehole 4 in Gulu.

Operating Environment: Water pH Test	Artifact A12

Artifact Prepared by: Christopher Mattson | Revision 1.0
Tests Performed by: Tom Naylor, Hans Ottosson, Christopher Mattson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand the acidity of the borehole pump water and the variation thereof. This information will used to establish the working environment of the pump parts and seals.

Results:
Table A12.1 shows the collected data. All numbers are on the 0.0-14.0 pH Scale.

Table A12.1. Water pH test results.

Test	Borehole 1	Borehole 2	Borehole 3	Borehole 4	LaPonya (hotel)	Churchill (hotel)
1	4.5	6.8	4.5	4.5	4.5	4.5
2	5	6.8	5	4.5	--	--
3	5	6.8	4.5	4.5	--	--
4	--	6.5	5.5	4.5	--	--
5	--	--	4.5	--	--	--
Mean	4.833	6.725	4.8	4.5	4.5	4.5
Stdev	0.2887	0.15	0.4472	0	n/a	n/a
Min	4.5	6.5	4.5	4.5	4.5	4.5
Max	5	6.8	5.5	4.5	4.5	4.5
Range	0.5	0.3	1	0	0	0
Median	5	6.8	4.5	4.5	4.5	4.5
CV	0.05974	0.02230	0.09317	0	n/a	n/a

Test Equipment and Set up:
Plastic pH indicator strips were used to measure the pH level in the water. One set of strips was used to measure in the range of 0.0 – 14.0 and another set was used to measure in the range 6.5 – 10.0. The first set was the Hydrion strips from Micro Essential Lab and the second set was the MColorpHast strips from EMD Millipore Corporation.

Figure A12.1. Measuring pH values.

Test Procedure:

1. Take water sample from pump.
2. Immerse pH strip (range 0.0 – 14.0) in water and hold still.
3. Remove strip and immediately match strip to correct pH level.
4. If the pH level is in the 6 – 10 range, also test with the strip with range 6.5 – 10.0.
5. Record pH level.

Conclusions:

Typical drinking water has a pH value between 6 and 10 on the pH scale.

Operating Environment: Water Hardness Test	Artifact A13

Artifact Prepared by: Christopher Mattson | Revision 1.0
Tests Performed by: Tom Naylor, Hans Ottosson, Christopher Mattson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand the hardness of the borehole pump water and the variation thereof. This information will used to establish the working environment of the pump parts and seals.

Results:
The table below shows the collected data. All numbers ppm (mg/l) on the 0 to 1000 scale (0 = soft, 150 = hard, and 1000 = very hard)

Table A13.1. Water hardness test results.

Test	Borehole 1	Borehole 2	Borehole 3	Borehole 4	LaPonya (hotel)	Churchhill (hotel)
1	100	180	80	20	60	100
2	120	180	100	20	--	--
3	100	180	60	20	--	--
4	--	180	40	20	--	--
5	--	--	60	--	--	--
Mean	106.6667	180	68	20	60	100
Stdev	11.5470	0	22.8035	0	n/a	n/a
Min	100	180	40	20	60	100
Max	120	180	100	20	60	100
Range	20	0	60	0	0	0
Median	100	180	80	20	60	100
CV	0.108253	0	0.335346	0	n/a	n/a

Test Equipment and Set up:
WaterWorks Total Hardness test strips were used to test hardness of the water. A color chart on the container shows 8 different hardness levels from soft to very hard.

Test Procedure:
1. Take water sample from pump.
2. Immerse hardness strip in water and hold still for 3 seconds.
3. Remove and immediately match strip to correct hardness level (use black scale – ppm).
4. Complete color matching within 1 minute.
5. Record hardness level.

Conclusions:
There is wide variation in the water hardness tests performed in Uganda by the team. Generally, the data shows harder water is found in the Jinja area compared to Gulu, and the single test performed in Kampala. Hard water is known to create scaling in pipes and appliances.

Operating Environment: Water Salinity Test	Artifact A14

Artifact Prepared by: Christopher Mattson | Revision 1.0
Tests Performed by: Tom Naylor, Hans Ottosson, Christopher Mattson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand the salinity of the borehole pump water and the variation thereof. This information will used to establish the working environment of the pump parts and seals.

Results:
Table A14.1 shows the collected data. All numbers ppt (parts per trillion).

Table A14.1. Water salinity test results.

Test	Borehole 1	Borehole 2	Borehole 3	Borehole 4	LaPonya (hotel)	Churchill (hotel)
1	0.0933	0.29	0.058	0.09	0.05	0.1
2	0.0643	--	0.0110	0.0082	--	--
3	0.02	0.29	0.05	0.08	--	--
4	0.14	0.29	0.07	0.1	--	--
5	0.12	--	0.02	0.02	--	--
Mean	0.12	0.29	0.05	0.09	0.05	0.1
Stdev	0.0933	0	0.058	0.09	n/a	n/a
Min	0.0643	0.29	0.0110	0.0082	0.05	0.1
Max	0.02	0.29	0.05	0.08	0.05	0.1
Range	0.14	0	0.07	0.1	0	0
Median	0.12	0.29	0.02	0.02	0.05	0.1
CV	0.778	0	1.16	1	n/a	n/a

Test Equipment and Set up:
Salinity tester EC170, manufactured by Extech Instruments was used to measure salinity. The EC170 has a resolution of 0.01ppt and a basic accuracy of ±2% FS.

Test Procedure:
1. Take water sample from pump.
2. Immerse salinity tester in water and hold still.
3. Record the salinity level shown on the display.

Conclusions:
The salinity is noticeably higher in the Jinja area when compared to Gulu and the single test carried out in Kampala.

Operating Environment: Water Temperature Test	Artifact A15

Artifact Prepared by: Christopher Mattson | Revision 1.0
Tests Performed by: Tom Naylor, Hans Ottosson, Christopher Mattson
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand the temperature of the borehole pump water and the variation thereof. This information will used to establish the working environment of the pump parts and seals.

Results:
Table A15.1 shows the collected data. All numbers in degrees F.

Table A15.1. Water temperature test results.

Test	Borehole 1	Borehole 2	Borehole 3	Borehole 4	LaPonya (hotel)	Churchill (hotel)
1	Not recorded	71.8	74.3	72.9	Not recorded	Not recorded
2	74.3	74.8	80	79	--	--
3	81.7	77.0	81	79.5	--	--
4	--	74.9	78.8	79	--	--
5	--	--	78.6	--	--	--
Mean	78.0000	74.625	78.54	77.6	n/a	n/a
Stdev	5.2326	2.1391	2.5609	3.1422	n/a	n/a
Min	74.3	71.8	74.3	72.9	n/a	n/a
Max	81.7	77	81	79.5	n/a	n/a
Range	7.4	5.2	6.7	6.6	n/a	n/a
Median	78	74.8	80	79	n/a	n/a
CV	0.0670846	0.0286647	0.0326063	0.0404923	n/a	n/a

Test Equipment and Set up:
Salinity tester EC170, manufactured by Extech Instruments was used to measure the water temperature. The EC170 has a resolution of 0.1°F and a basic accuracy of ±0.9°F.

Test Procedure:
1. Take water sample from pump.
2. Immerse salinity tester in water and hold still.
3. Record the temperature shown on the display.

Conclusions:
The overall temperature conditions are described by this test, showing an overall average of 77.19 degrees F, with a max range of 7.4. Any variation from hole to hole is not obviously meaningful.

Pump Performance: Borehole 1 (Jinja)	Artifact A16

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson and Tom Naylor
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how much water each borehole pump discharges based on varying stroke length and stroke frequency. This information will used to characterize the pump performance as a function of stroke frequency and stroke length.

Results:
The data collected is shown in Table A16.1.

Table A16.1. Pump performance test results for borehole 1.

Test	Stroke length (deg estimated)	Stroke length (deg measured)	Stroke frequency (Hz estimated)	Stroke frequency (Hz measured)	User (for coding)	Water Volume (liters)
1	30	29.9	0.67	0.68	4	1.86
2	20	23.1	1.33	1.29	6	2.18
3	30	30.4	1.33	1.25	9	3.40
4	40	37.9	1.00	1.02	11	5.26
5	30	23.0	1.00	1.04	13	2.95
6	20	21.3	1.00	1.03	15	1.22
7	40	38.2	0.67	0.68	17	3.13
8	20	20.2	0.67	0.70	19	0.13
9	40	36.4	1.33	1.32	21	4.35
10	30	28.7	0.67	0.71	23	1.50
11	20	20.7	1.33	1.345	25	2.04
12	30	27.8	1.33	1.38	27	3.13
13	40	37.5	1.00	1.00	29	3.99
14	30	28.8	1.00	1.01	31	2.72
15	20	20.3	1.00	0.99	33	1.27
16	40	35.4	0.67	1.04	35	3.99
17	20	20.0	0.67	1.01	37	1.27
18	40	36.4	1.33	1.33	39	4.45

Test Equipment and Set up:
A full factorial Design-of-Experience (DOE) was planned where stroke length of 20, 30, and 40 degrees were paired with the frequencies 0.67, 1.00, and 1.33 Hz. A metronome app was used

on an Android phone to set the pace. The experience was randomized using MATLAB, and a scale was used to measure the weight of the water after each experience.

Test Procedure:

1. Set correct frequency on the metronome.
2. Pump until water flows.
3. Forward user on sensor remote.
4. Put bucket under spout.
5. Pump 20 strokes.
6. Weigh water.
7. Record user number and weight.
8. Forward user on sensor remote.
9. Repeat steps 2 – 8 until each experiment is done.

Observations and Conclusions:

A response surface was created to visualize the results from the DOE (see Figure A16.1). It can be said that in general, a longer stroke and a higher frequency will yield a larger volume of water for borehole 1. Each borehole DOE vary due to the efficiency of the pump, making it hard to compare their individual outputs.

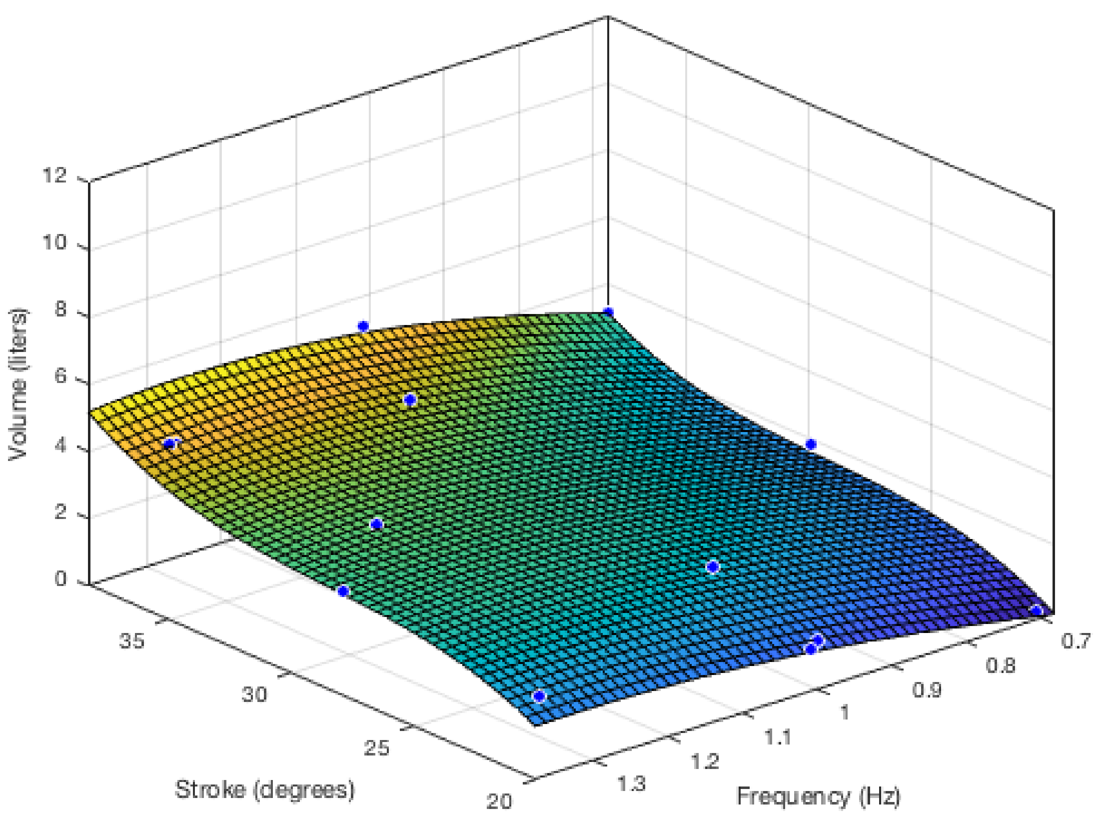

Figure A16.1. DOE borehole 1.

Equation for the response surface:
Linear model Poly33:

```
f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y
             + p12*x*y^2 + p03*y^3
```

Coefficients (with 95% confidence bounds):

```
p00 = -45.16  (-139.2, 48.87)
p10 = 4.441  (-3.144, 12.03)
p01 = 3.288  (-185.9, 192.5)
p20 = -0.1529  (-0.4109, 0.105)
p11 = 0.03618  (-2.472, 2.544)
p02 = 3.135  (-177.6, 183.9)
p30 = 0.0017  (-0.001156, 0.004556)
p21 = 0.005708  (-0.02763, 0.03904)
p12 = -0.164  (-0.8996, 0.5717)
p03 = -1.104  (-58.39, 56.18)
```

Goodness of fit:
SSE: 1.64
R-square: 0.9493
Adjusted R-square: 0.8922
RMSE: 0.4527

Files Associated with this Artifact:
Within the archive the MATLAB code associated with this artifact can be found in the folder called “DOE_Analysis”.

Pump Performance: Borehole 2 (Jinja)	Artifact A17

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson and Tom Naylor
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how much water each borehole pump discharges based on varying stroke length and stroke frequency. This information will used to characterize the pump performance as a function of stroke frequency and stroke length.

Results:
The data collected is shown in Table A17.1.

Table A17.1. Pump performance test results for borehole 2.

Test	Stroke length (deg estimated)	Stroke length (deg measured)	Stroke frequency (Hz estimated)	Stroke frequency (Hz measured)	User (for coding)	Water Volume (liters)
1	20	17.6	0.67	0.68	30	5.99
2	20	17.6	1.00	0.98	21	8.62
3	20	21.3	1.33	1.19	22	5.31
4	30	28.4	1.33	1.22	28	6.08
5	40	40.7	1.33	1.07	24	5.90
6	30	32.1	1.00	0.97	20	8.30
7	20	21.2	1.00	0.97	29	7.35
8	40	32.8	1.00	0.92	19	6.89
9	40	32.9	0.67	0.53	23	7.94
10	30	32.8	0.67	0.65	35	6.30
11	20	20.4	0.67	0.66	40	10.70
12	30	33.7	0.67	0.66	39	6.40
13	40	41.1	0.67	0.67	37	7.30
14	30	35.3	1.00	0.89	35	6.30
15	40	43.7	1.00	0.95	25	9.30
16	40	41.1	1.33	1.05	34	7.80
17	30	31.6	1.33	1.16	31	7.71
18	20	22.7	1.33	1.29	38	9.39

Test Equipment and Set up:
A full factorial DOE was planned where stroke length of 20, 30, and 40 degrees were paired with the frequencies 0.67, 1.00, and 1.33 Hz. A metronome app was used on an Android phone

to set the pace. The experience was randomized using MATLAB, and a scale was used to measure the weight of the water after each experience.

Test Procedure:

1. Set correct frequency on the metronome.
2. Pump until water flows.
3. Forward user on sensor remote.
4. Put bucket under spout.
5. Pump 20 strokes.
6. Weigh water.
7. Record user number and weight.
8. Forward user on sensor remote.
9. Repeat steps 2 – 8 until each experiment is done.

Observations and Conclusions:

A response surface was created to visualize the results from the DOE (see Figure A17.1). The irregularities in the DOE results for borehole 2 could be due to cup seals needing to be replaced (as stated by technician). Each borehole DOE vary due to the efficiency of the pump, making it hard to compare their individual outputs.

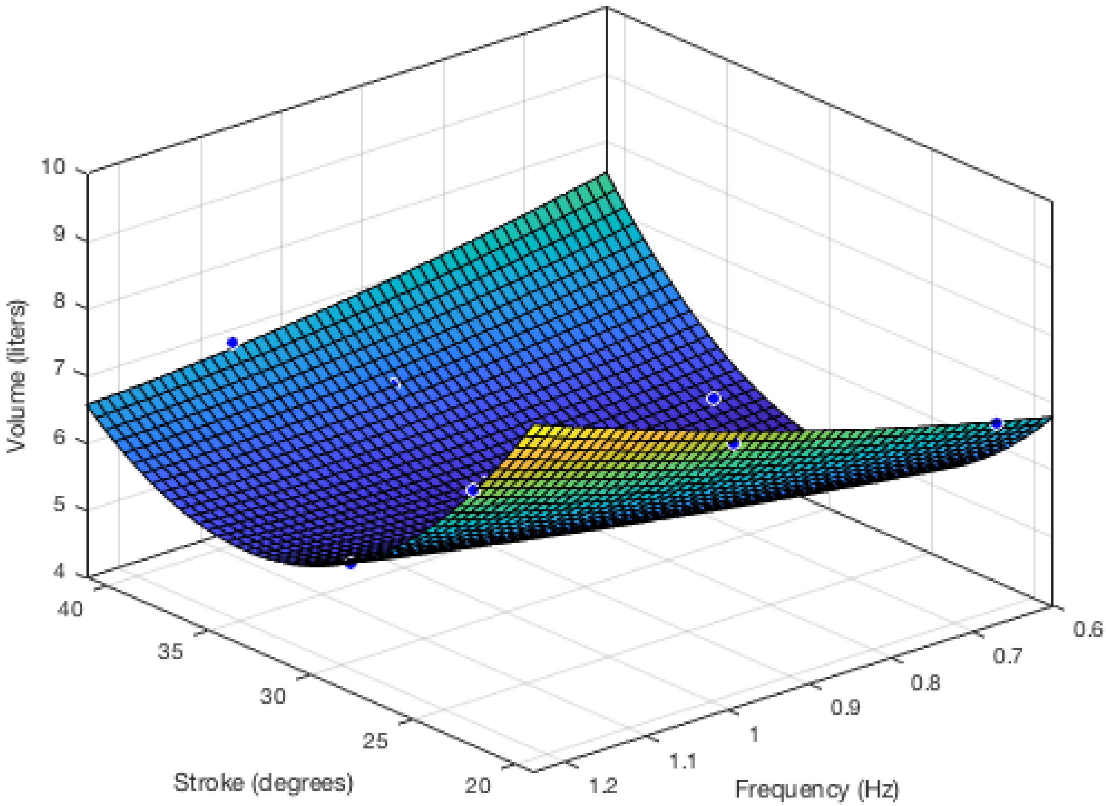

Figure A17.1. DOE borehole 2.

Equation for the response surface:

Linear model Poly22:

f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2

Coefficients (with 95% confidence bounds):

p00 = 17.02 (8.998, 25.05)
p10 = -0.9515 (-1.243, -0.6604)
p01 = 5.384 (-8.056, 18.82)
p20 = 0.01883 (0.01352, 0.02415)
p11 = -0.2388 (-0.3969, -0.08079)
p02 = 1.561 (-4.418, 7.54)

Goodness of fit:

SSE: 0.1053
R-square: 0.9872
Adjusted R-square: 0.966
RMSE: 0.1873

Files Associated with this Artifact:

Within the archive the MATLAB code associated with this artifact can be found in the folder called “DOE_Analysis”.

Pump Performance: Borehole 3 (Gulu)	Artifact A18

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson and Tom Naylor
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how much water each borehole pump discharges based on varying stroke length and stroke frequency. This information will used to characterize the pump performance as a function of stroke frequency and stroke length.

Results:
The data collected is shown in Table A18.1.

Table A18.1. Pump performance test results for borehole 3.

Test	Stroke length (deg estimated)	Stroke length (deg measured)	Stroke frequency (Hz estimated)	Stroke frequency (Hz measured)	User (for coding)	Water Volume (liters)
1	20	24.5	0.67	0.68	7	2.90
2	20	32.6	1.33	1.35	9	5.99
3	30	33.9	1.33	1.29	11	6.03
4	40	42.7	1.00	1.02	13	7.03
5	30	34.0	1.00	1.03	16	5.31
6	20	24.0	1.00	1.02	19	3.67
7	40	42.0	0.67	0.68	22	6.94
8	30	34.2	0.67	0.67	26	5.35
9	40	41.7	1.33	1.35	29	7.67
10	30	34.1	0.67	0.68	32	5.44
11	20	24.8	1.33	1.36	35	4.35
12	30	33.2	1.33	1.35	37	5.76
13	40	42.3	1.00	0.97	39	6.94
14	30	34.2	1.00	1.05	41	5.76
15	20	23.8	1.00	1.03	43	3.86
16	40	43.0	0.67	0.71	45	7.17
17	20	24.5	0.67	0.67	47	3.67
18	40	42.3	1.33	1.3	49	7.44

Test Equipment and Set up:
A full factorial DOE was planned where stroke length of 20, 30, and 40 degrees were paired with the frequencies 0.67, 1.00, and 1.33 Hz. A metronome app was used on an Android phone to set the pace. The experience was randomized using MATLAB, and a scale was used to

measure the weight of the water after each experience.

Test Procedure:

1. Set correct frequency on the metronome.
2. Pump until water flows.
3. Forward user on sensor remote.
4. Put bucket under spout.
5. Pump 20 strokes.
6. Weigh water.
7. Record user number and weight.
8. Forward user on sensor remote.
9. Repeat steps 2 – 8 until each experiment is done.

Observations and Conclusions:

A response surface was created to visualize the results from the DOE (see Figure 18.1). It can be said that in general, a longer stroke will yield a larger volume of water for borehole 3. Each borehole DOE vary due to the efficiency of the pump, making it hard to compare their individual outputs.

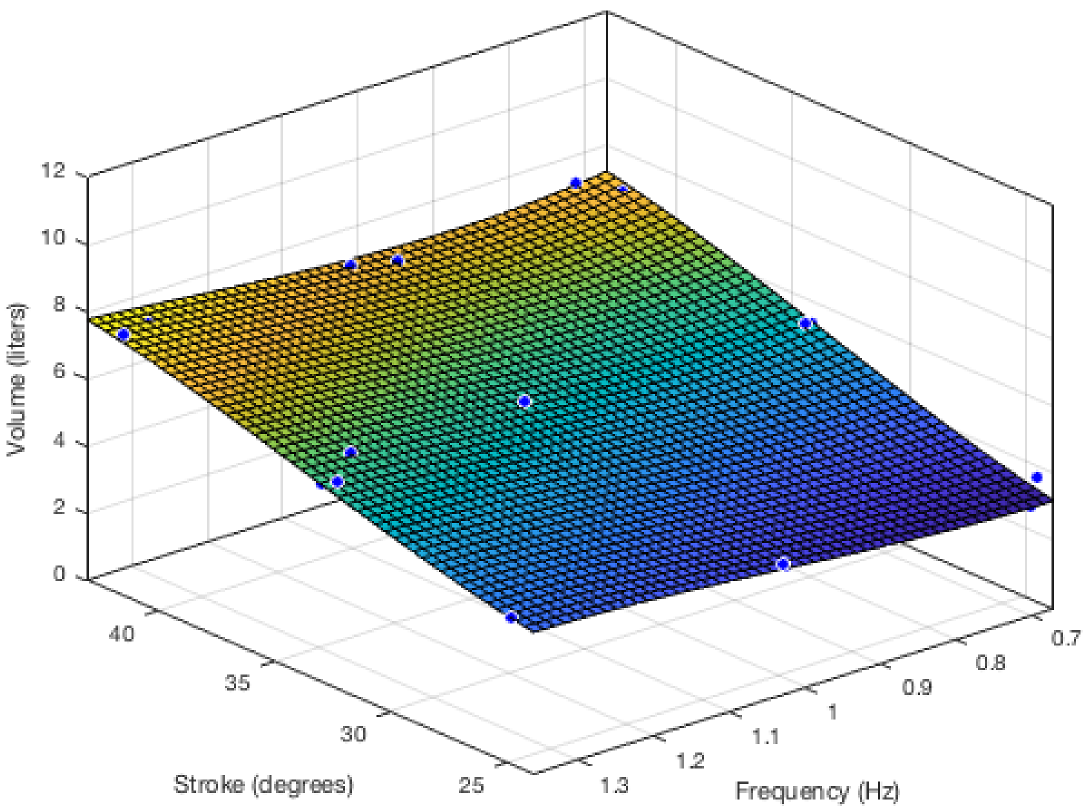

Figure A18.1. DOE borehole 3.

Equation for the response surface:
Linear model Poly33:
    f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y
                + p12*x*y^2 + p03*y^3
Coefficients (with 95% confidence bounds):
      p00 = 8.941 (-159.2, 177.1)
      p10 = -0.6836 (-15.3, 13.93)
      p01 = -4.342 (-154.2, 145.5)
      p20 = 0.03366 (-0.3937, 0.4611)
      p11 = -0.434 (-2.147, 1.279)
      p02 = 11.91 (-135.2, 159)
      p30 = -0.000336 (-0.004497, 0.003825)
      p21 = 9.905e-05 (-0.01604, 0.01624)
      p12 = 0.1921 (-0.3363, 0.7205)
      p03 = -5.393 (-52.76, 41.97)

Goodness of fit:
  SSE: 0.4971
  R-square: 0.9861
  Adjusted R-square: 0.9704
  RMSE: 0.2493

Files Associated with this Artifact:
Within the archive the MATLAB code associated with this artifact can be found in the folder called "DOE_Analysis".

Pump Performance: Borehole 4 (Gulu)	Artifact A19

Artifact Prepared by: Christopher Mattson and Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson and Tom Naylor
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how much water each borehole pump discharges based on varying stroke length and stroke frequency. This information will used to characterize the pump performance as a function of stroke frequency and stroke length.

Results:
The data collected is shown in Table A16.1.

Table A19.1. Pump performance test results for borehole 4.

Test	Stroke length (deg estimated)	Stroke length (deg measured)	Stroke frequency (Hz estimated)	Stroke frequency (Hz measured)	User (for coding)	Water Volume (liters)
1	30	33.0	0.67	0.71	3	5.90
2	20	23.6	1.33	1.37	5	6.17
3	30	35.4	1.33	1.29	7	9.34
4	40	46.0	1.00	1.01	9	9.80
5	30	35.7	1.00	1.00	11	7.67
6	20	23.9	1.00	0.98	13	4.54
7	40	42.0	0.67	0.68	15	7.53
8	20	22.1	0.67	0.66	18	3.31
9	40	43.1	1.33	1.21	20	9.62
10	30	32.6	0.67	0.69	22	5.31
11	20	24.0	1.33	1.32	24	5.17
12	30	32.5	1.33	1.34	26	8.12
13	40	43.9	1.00	0.98	28	9.07
14	30	31.1	1.00	0.94	30	6.67
15	20	21.7	1.00	0.99	34	3.86
16	40	40.4	0.67	0.68	36	7.17
17	20	22.3	0.67	0.68	39	3.99
18	40	42.6	1.33	1.34	42	10.98

Test Equipment and Set up:
A full factorial DOE was planned where stroke length of 20, 30, and 40 degrees were paired with the frequencies 0.67, 1.00, and 1.33 Hz. A metronome app was used on an Android phone

to set the pace. The experience was randomized using MATLAB, and a scale was used to measure the weight of the water after each experience.

Test Procedure:

1. Set correct frequency on the metronome.
2. Pump until water flows.
3. Forward user on sensor remote.
4. Put bucket under spout.
5. Pump 20 strokes.
6. Weigh water.
7. Record user number and weight.
8. Forward user on sensor remote.
9. Repeat steps 2 – 8 until each experiment is done.

Observations and Conclusions:

A response surface was created to visualize the results from the DOE (see Figure 19.1). It can be said that in general, a longer stroke and a higher frequency will yield a larger volume of water for borehole 4. Each borehole DOE vary due to the efficiency of the pump, making it hard to compare their individual outputs.

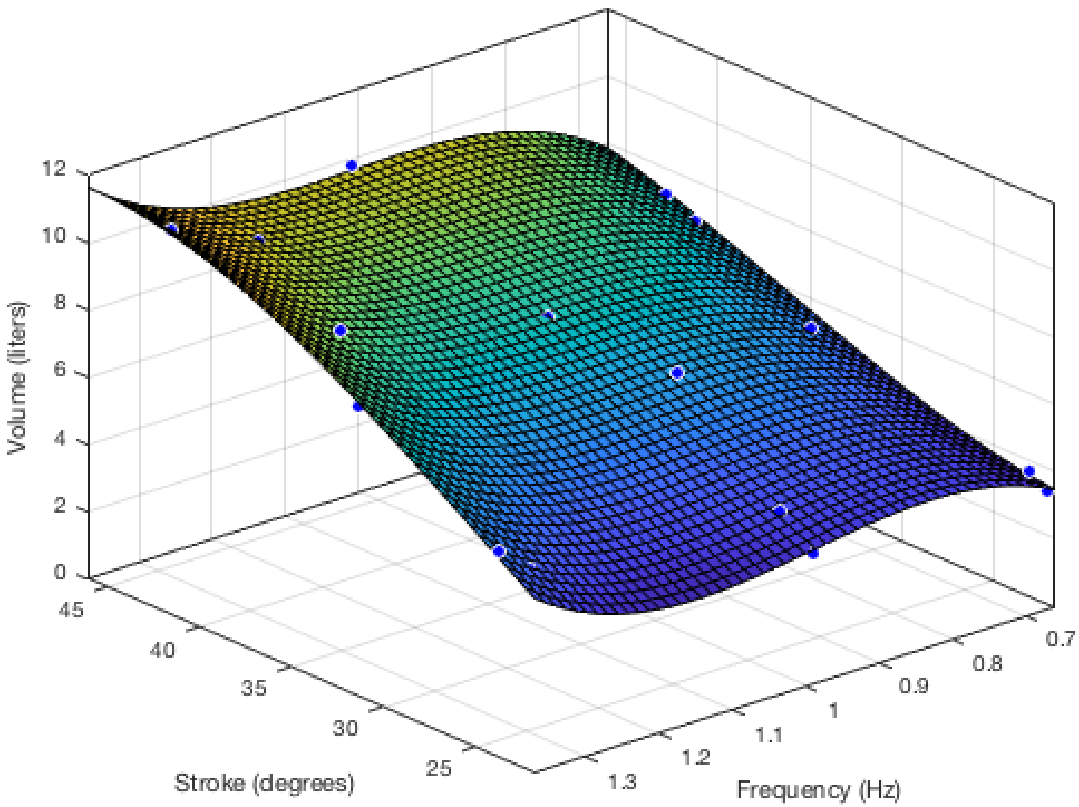

Figure A19.1. DOE borehole 4.

Equation for the response surface:
Linear model Poly33:

```
f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y
               + p12*x*y^2 + p03*y^3
```

Coefficients (with 95% confidence bounds):

```
p00 = -16.98  (-66.22, 32.26)
p10 = -1.622  (-5.343, 2.099)
p01 = 109.8  (-28.69, 248.3)
p20 = 0.0384  (-0.06692, 0.1437)
p11 = 1.255  (-0.2545, 2.764)
p02 = -133.1  (-279.6, 13.35)
p30 = -0.0002693  (-0.001345, 0.000806)
p21 = -0.01382  (-0.0329, 0.005268)
p12 = -0.09833  (-0.6615, 0.4648)
p03 = 45.54  (-3.459, 94.53)
```

Goodness of fit:

```
SSE: 1.002
R-square: 0.9887
Adjusted R-square: 0.9761
RMSE: 0.3538
```

Files Associated with this Artifact:
Within the archive the MATLAB code associated with this artifact can be found in the folder called “DOE_Analysis”.

Pump Usage: Borehole 1 (Jinja)	Artifact A20

Artifact Prepared by: Christopher Mattson and Jake Hunter | Revision 1.1
Gender Balance Tests Performed by: Jake Hunter
Gender Balance Test Date: Test Date: 07 August 2018
Gender Balance Test Location: Video footage from Uganda, Video analysis in Provo, Utah USA

Purpose of the Test:
To understand how borehole pumps are used. The extent to which they are used, the frequency of stroke, the stroke length, the down time, the gender balance and more.

Borehole Statistics
The data gathered from borehole 1 showed that there were 526 users with 5 or more strokes. The average stroke length was 34 degrees, and the average frequency was 0.89 Hz. The effective time the pump was used was 9.51 hours. With the results from the DOE for this borehole, it is estimated that 7200 liters of water was pumped. The wave form for all users can be seen in Figure A20.1.

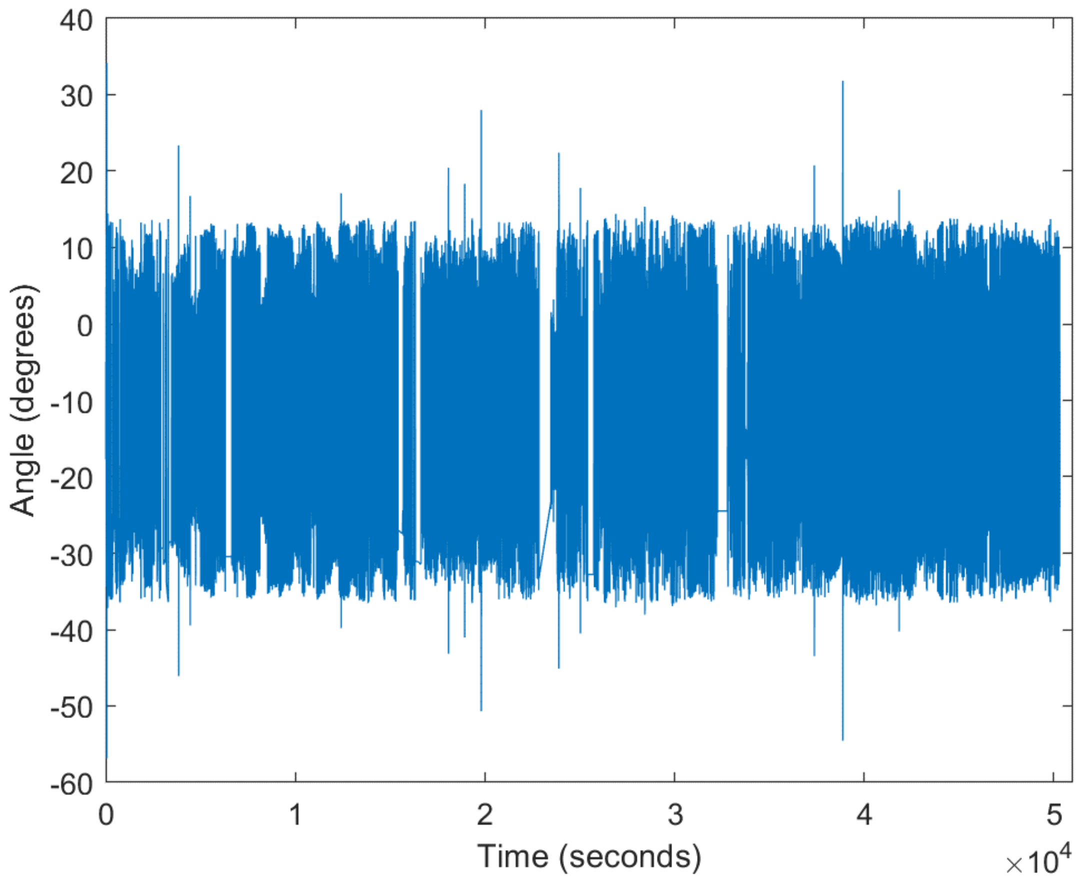

Figure A20.1. Time series for borehole 1.

Test Equipment and Set up for collecting usage data:
A sensor and an accompanying remote were used to gather user stroke and frequency data. The sensor and the remote communicate over Bluetooth. Data is collected and stored on the sensor that is attached to the pump handle. Inside the sensor is an accelerometer to measure handle movement. The remote has a user interface, notifying the operator about pump handle movement and has a button to tell the sensor when a new user starts. Both the sensor and remote were powered by battery packs.

Gender Balance Test Results:
The data collected is shown in Table A20.1.

Table A20.1. Gender balance test results for borehole 1.

Test	People deemed to be of Child Stature	People deemed to be female	People deemed to be male	Combined female and male
Number of users (fraction of total)	497 (0.82)	62 (0.10)	47 (0.08)	109 (0.18)
Minutes of pumping (fraction of total)	316 (0.478)	170 (0.257)	175 (0.265)	345 (0.522)

Gender Balance Test Procedure
Video footage was taken at each borehole site. The footage was analyzed, and each user was deemed to be either of child stature, or to be female or male. Females were identified by their clothing, which are noticeably different than those of the males. The start time and stop time of each user was recorded (see Figure A20.2).

If a user was filling a bucket, then paused to change buckets, then continued pumping, this was considered one user. If while changing the buckets someone else started pumping, however briefly, this was considered another user. People who returned to the pump site multiple times were considered new users each time.

Video footage was only analyzed during the visible light period of the day.

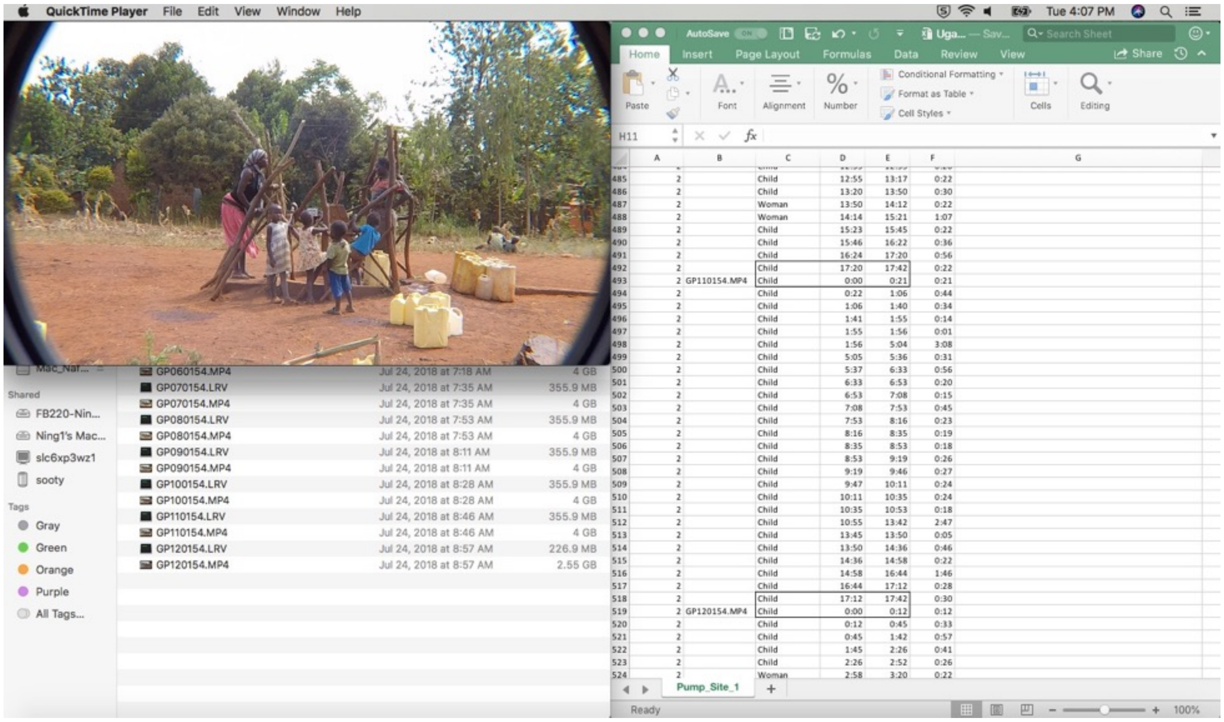

Figure A20.2. Gender analysis for borehole 1.

Pump Usage: Borehole 2 (Jinja)	Artifact A21

Artifact Prepared by: Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how borehole pumps are used. The extent to which they are used, the frequency of stroke, the stroke length, the down time, the gender balance and more.

Borehole Statistics
The data gathered from borehole 2 showed that there were 204 users with 5 or more strokes. The average stroke length was 30 degrees, and the average frequency was 1.14 Hz. The effective time the pump was used was 3.43 hours. With the results from the DOE for this borehole, it is estimated that 4470 liters of water was pumped. The wave form for all users can be seen in Figure A21.1.

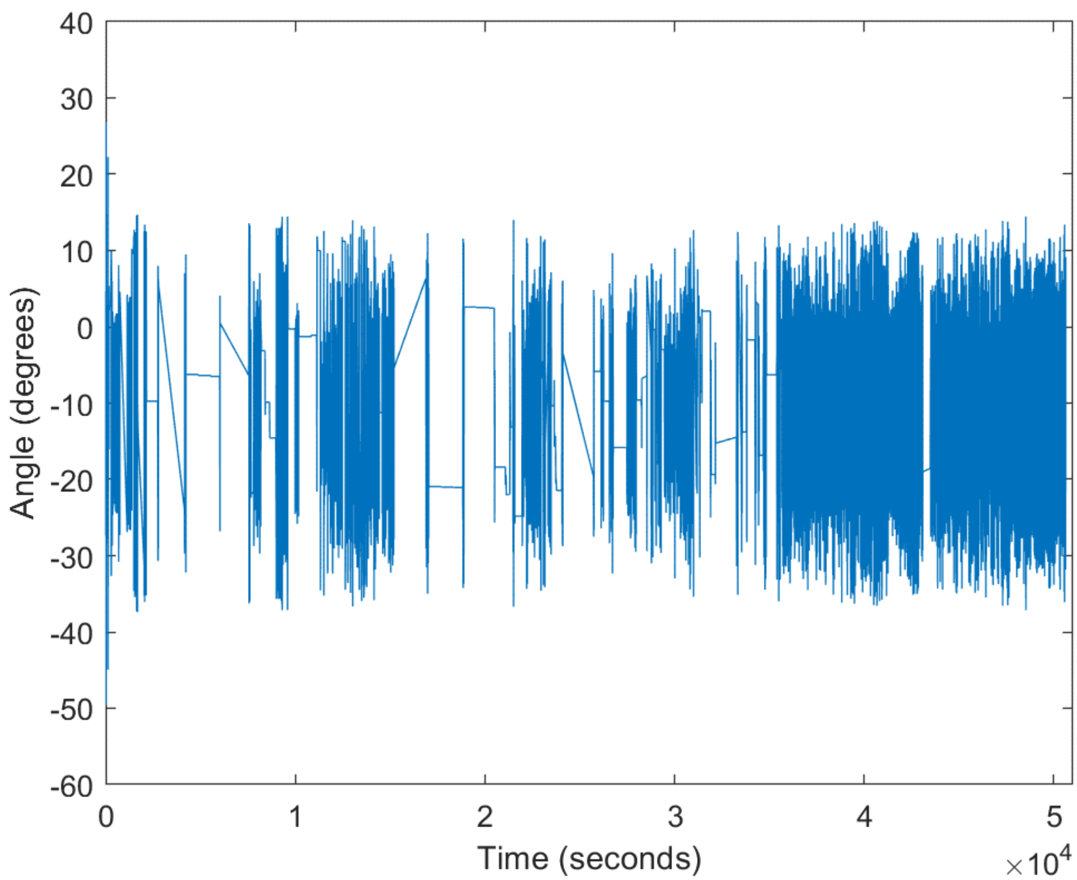

Figure A21.1. Time series for borehole 2.

Test Equipment and Set up for collecting usage data:
A sensor and an accompanying remote were used to gather user stroke and frequency data. The sensor and the remote communicate over Bluetooth. Data is collected and stored on the sensor that is attached to the pump handle. Inside the sensor is an accelerometer to measure handle movement. The remote has a user interface, notifying the operator about pump handle movement and has a button to tell the sensor when a new user starts. Both the sensor and remote were powered by battery packs.

Gender Balance Test Results:
The data collected is shown in Table A21.1.

Table A21.1. Gender balance test results for borehole 2.

Test	People deemed to be of Child Stature	People deemed to be female	People deemed to be male	Combined female and male
Number of users (fraction of total)	177 (0.80)	25 (0.11)	20 (0.09)	45 (0.20)
Minutes of pumping (fraction of total)	201 (0.640)	49 (0.156)	64 (0.204)	113 (0.360)

Gender Balance Test Procedure
Video footage was taken at each borehole site. The footage was analyzed, and each user was deemed to be either of child stature, or to be female or male. Females were identified by their clothing, which are noticeably different than those of the males. The start time and stop time of each user was recorded.

If a user was filling a bucket, then paused to change buckets, then continued pumping, this was considered one user. If while changing the buckets someone else started pumping, however briefly, this was considered another user. People who returned to the pump site multiple times were considered new users each time.

Video footage was only analyzed during the visible light period of the day.

Pump Usage: Borehole 3 (Gulu)	Artifact A22

Artifact Prepared by: Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how borehole pumps are used. The extent to which they are used, the frequency of stroke, the stroke length, the down time, the gender balance and more.

Borehole Statistics
The data gathered from borehole 3 showed that there were 214 users with 5 or more strokes. The average stroke length was 36 degrees, and the average frequency was 0.94 Hz. The effective time the pump was used was 6.24 hours. With the results from the DOE for this borehole, it is estimated that 6220 liters of water was pumped. The wave form for all users can be seen in Figure A22.1.

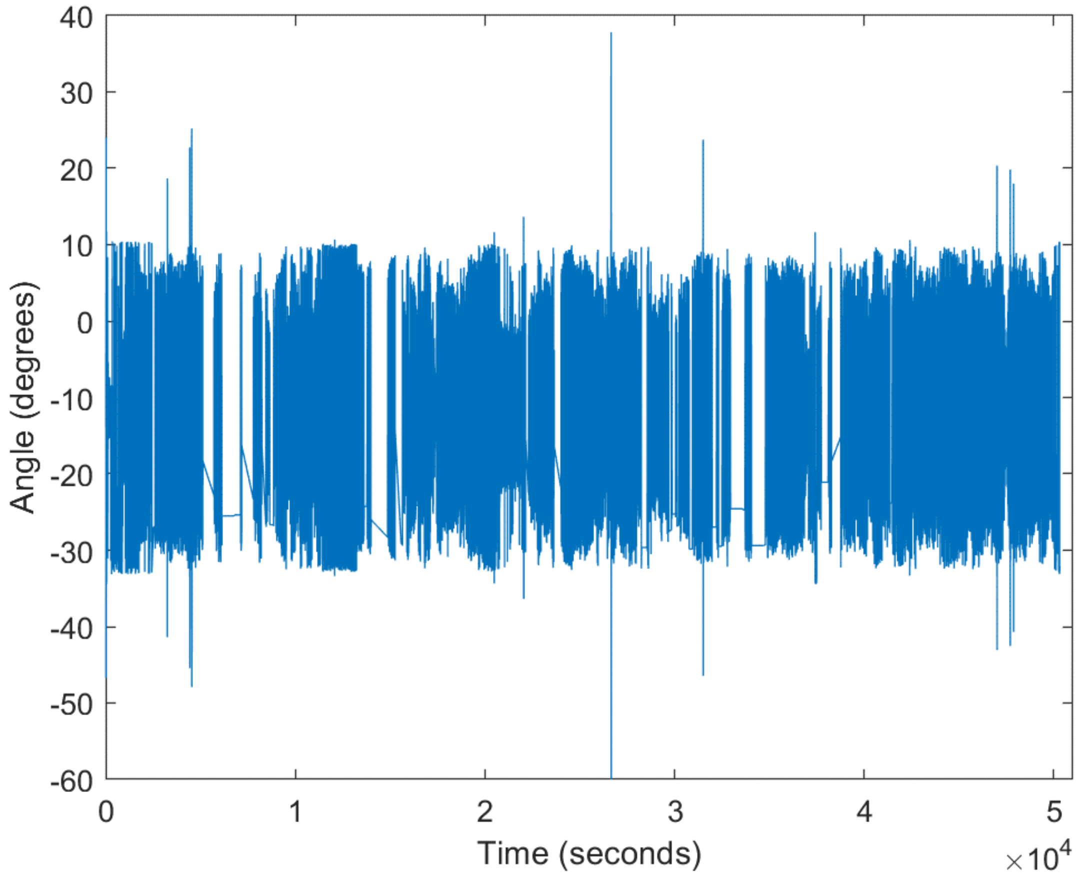

Figure A22.1. Time series for borehole 3.

Test Equipment and Set up for collecting usage data:
A sensor and an accompanying remote were used to gather user stroke and frequency data. The sensor and the remote communicate over Bluetooth. Data is collected and stored on the sensor that is attached to the pump handle. Inside the sensor is an accelerometer to measure handle movement. The remote has a user interface, notifying the operator about pump handle movement and has a button to tell the sensor when a new user starts. Both the sensor and remote were powered by battery packs.

Gender Balance Test Results:
The data collected is shown in Table A22.1.

Table A22.1. Gender balance test results for borehole 3.

Test	People deemed to be of Child Stature	People deemed to be female	People deemed to be male	Combined female and male
Number of users (fraction of total)	73 (0.38)	98 (0.52)	19 (0.1)	117 (0.62)
Minutes of pumping (fraction of total)	172 (0.301)	362 (0.634)	37 (0.065)	399 (0.699)

Gender Balance Test Procedure
Video footage was taken at each borehole site. The footage was analyzed, and each user was deemed to be either of child stature, or to be female or male. Females were identified by their clothing, which are noticeably different than those of the males. The start time and stop time of each user was recorded.

If a user was filling a bucket, then paused to change buckets, then continued pumping, this was considered one user. If while changing the buckets someone else started pumping, however briefly, this was considered another user. People who returned to the pump site multiple times were considered new users each time.

Video footage was only analyzed during the visible light period of the day.

Pump Usage: Borehole 4 (Gulu)	Artifact A23

Artifact Prepared by: Hans Ottosson | Revision 1.1
Tests Performed by: Hans Ottosson
Test Date: Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of the Test:
To understand how borehole pumps are used. The extent to which they are used, the frequency of stroke, the stroke length, the down time, the gender balance and more.

Borehole Statistics
The data gathered from borehole 4 showed that there were 392 users with 5 or more strokes. The average stroke length was 31 degrees, and the average frequency was 0.94 Hz. The effective time the pump was used was 8.62 hours. With the results from the DOE for this borehole, it is estimated that 10350 liters of water was pumped. The wave form for all users can be seen in Figure A22.1.

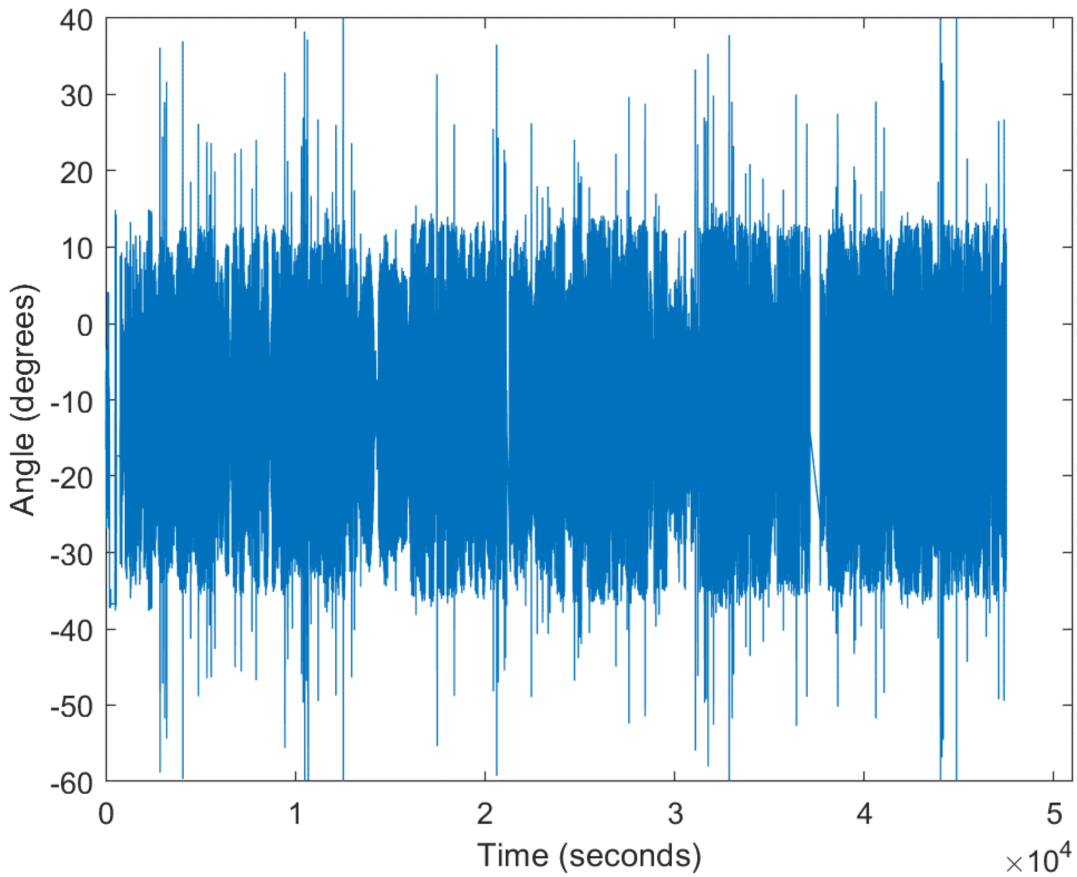

Figure A23.1. Time series for borehole 4.

Test Equipment and Set up for collecting usage data:
A sensor and an accompanying remote were used to gather user stroke and frequency data. The sensor and the remote communicate over Bluetooth. Data is collected and stored on the sensor that is attached to the pump handle. Inside the sensor is an accelerometer to measure handle movement. The remote has a user interface, notifying the operator about pump handle movement and has a button to tell the sensor when a new user starts. Both the sensor and remote were powered by battery packs.

Gender Balance Test Results:
The data collected is shown in Table A23.1.

Table A23.1. Gender balance test results for borehole 4.

Test	People deemed to be of Child Stature	People deemed to be female	People deemed to be male	Combined female and male
Number of users (fraction of total)	88 (0.34)	144 (0.56)	26 (0.10)	170 (0.66)
Minutes of pumping (fraction of total)	80 (0.161)	354 (0.714)	62 (0.125)	416 (0.839)

Gender Balance Test Procedure
Video footage was taken at each borehole site. The footage was analyzed, and each user was deemed to be either of child stature, or to be female or male. Females were identified by their clothing, which are noticeably different than those of the males. The start time and stop time of each user was recorded.

If a user was filling a bucket, then paused to change buckets, then continued pumping, this was considered one user. If while changing the buckets someone else started pumping, however briefly, this was considered another user. People who returned to the pump site multiple times were considered new users each time.

Video footage was only analyzed during the visible light period of the day.

Anecdotal Findings	Artifact A24

Artifact Prepared by: James Mattson and Hans Ottosson | Revision 1.1
Observations by: James Mattson, Christopher Mattson, Hans Ottosson, Tom Naylor
Test Date: 20 July 2018 – 03 August 2018
Test Location: Uganda

Purpose of this Artifact:
To capture some of the anecdotal findings that we believe to be true. To the extent possible, these findings were validated through non-leading discussion with Ugandans.

Findings:
Additional research can and needs to be completed around improving the performance and longevity of borehole pumps in Uganda. This includes but is not limited to collecting data to determine failure conditions that have been reported during the field study. These include:

<u>Handle Assemble</u>
Handle assembly including bearing, bearing house (seat), axle alignment and movement causing possible effect on chain and pump rod function and movement resulting in possible wear on the riser pipe. See photos of failed PVC, Pump rod bushing and handle.

<u>Chain Malfunction</u>
Chain breakage due to lack of preventative maintenance (monthly greasing) and improper pump handle use.

<u>Pump Head Assembly failures</u>
This includes the handle stabilizers, chain and flange-pump rod bushing and its effect on pump rod function.

<u>Riser Pipe failure</u>

PVC pipe fails at a high rate with vertical cracks, wear from side-to-side pump rod movement and wear from warn or missing pump rod gaskets.

Galvanized pipe fails at a moderate rate with failure due to horizontal breaking where threads meet the socket, general rust and pitting and wear do to side to side movement in the pump rod and warn or missing pump rod gaskets.

Stainless steel pipe failures were reported at a very low rate. Only one failure was noted, and it was at the thread socket joint.

<u>Pump Rod failures</u>
A moderate rate of failure was reported for galvanized pump rod and at a very low rate with stainless steel pump rods.

Cylinder Assembly failures

Cup seal with excessive wear due to the method of pump handle use, particulates in the water, and other factors to be determined.

Foot valve failure due to warn seals and debris at valve seat.

Upper check valve failure due to warn seals and debris that valve seat.

Figure A24.1. Failed pump cylinder copper lining.

Nitrile Cup Seal

Pump caretakers and mechanics reported that the nitrile cup seal wears out and needs to be changed frequently. Some mechanics keep old cup seals with them as backups. Some reported that they still install leather cup seals.

Pump rod Grommets

Including wear and absence. These grommets are designed to stabilize the pump rod and prevent side-to-side movement of the pump rod.

Dynamic Water Table

The depth of the cylinder in the borehole needs to be adjusted according to the specifications in the Operator’s manual.

Observations and anecdotal reports from Users, Pump Caretakers, Pump Mechanics, and Government Officials indicate following:

Boreholes and pumps are developed by both government and no-government efforts. In this studies area there were 1300 government sponsored pumps and 700 non-government sponsored pumps.

Government sponsored pumps may be developed based on the following: 1. That a water source is found. 2. That the new site is not close to an existing functioning pump. 3. That monies for the cost of the new borehole and pump be paid to the government in advance of the work beginning. 4. That each site/community form a pump committee comprising of nine members who oversee the pump use, maintenance, and repair. 5. It was reported that cost for a new borehole and pump were.

A sizable portion of many Village/Communities depend on pumps to deliver clean water.

When pumps fail it affects the user by requiring them to spend more time getting a day's supply water.

Users spend between 45 minutes to 90 minutes a day in the water collecting process.

Users may be required to pay a monthly fee to use the pump. Often this fee is not collected. This fee is approximately 1,000 shillings per household per month. These fees are often the only source of funds to repair borehole pumps.

Collected money may be used to pay the Caretaker and is saved for use when repairs are needed.

The price to service the cup seals in an India Mark II hand pump in Jinja, Uganda as of May 8th, 2021 is 40,000 Ugandan Shillings for the seals and 160,000 Ugandan Shillings for labor.

Government sponsored pumps are maintained and repaired by Government Pump Mechanics for a fee. If the Pump Committee cannot afford to repair the pump it is not fixed and government options are not offered. The community must find water at another source.

The caretaker may receive a stipend fee for managing the use of the pump. A caretaker in Gulu received 30,000 shillings per month to care for the borehole.

Governance model of Water District is organized as follows
1. User. 2. Local pump committee. 2. Sub-country Water Official. 3. County Water Official
4. State Water Minister 5. Ugandan Minister of Water. This hierarchy of governance also shows the flow of a repair request.

Maintenance and availability of pump mechanics:

Government sponsored pumps are repaired by qualified Government Pump Mechanics for a fee.

Private pumps are not repaired or maintain by government pump mechanics. Private pumps are maintained and repaired by the owner or community. The availability of private pump mechanics is unknown but is reported that they do exist.

Repairs to both private and government pumps require payment in full prior to service. It is commonly reported by users that pumps will stand unrepaired for weeks or months until funds for the repair can be gathered by the local committees or community.

It was reported that many pump mechanics feel overwhelmed due to the workload.

The cost to service an India Mark II hand pump to replace the two cup seals costs USD 58-85.

<u>Availability of repair parts:</u>

Repair parts for the Mark II were available in this research area through local retail shops and large suppliers of the new and used parts.

<u>Locating and access to pump sites:</u>

Locating and gaining access to pumps was not a barrier for this research team.

Permission to do this research was sought and granted by local water officials and support was given by local committees. It was noted that the research process did not seem to affect the users.

Summary

There is a large, yet unmeasured number, of people who depend on Borehole Pumps for clean potable water and when existing pumps fail it places these communities at risk of the health complications from using poor quality water and places an extra burden time and energy on users to secure water from another borehole.

Gaining access to the location of and permission to study borehole pumps was not a barrier in this study. There was general understanding and support for this and future study efforts.

Additional research can and needs to be completed around improving the performance and longevity of borehole pumps in Uganda. This should include collecting data to determine failure conditions that have been observed and reported during this research project. Specifically, the subassemblies of; the handle, pump head, flange-pump rod bushing, pump rod grommets, cylinder design, plunger assembly and pipe/socket.

There is general support from Government Officials and Local Committees for this work.

Internal Measurement Error Analysis	Artifact A25

Artifact Prepared by: Christopher Mattson | Revision 1.0
Tests by: Christopher Mattson
Data for tests collected by: Christopher Mattson, Hans Ottosson, Tom Naylor
Test Date: 07 August 2018
Test Data collected: 20 July 2018 – 03 August 2018
Test Location: Data collected in Uganda, Analysis done in Provo, Utah, USA

Purpose of this Test:
The purpose of this test is to characterize the uncertainty associated with the measurements methods themselves. We are interested in this uncertainty because it cannot be attributed to part variation, and therefore must be discovered to more fully characterize a part's actual variation. There is potential error in the measurements of Weight, Volume, Durometer, DIM1-DIM6. For each, a single seal was measured repeatedly 33 times or more, each time the researchers tried to reduce bias by ignoring previously measured values.

Summary of Results:
Table A25.2 shows the coefficient of variation (CV), the % error, and 3*Standard Deviation.

Table A25.1. Summary of results.

Test	Weight	Volume	Durometer	DIM1 Outer Diam	DIM2 Inner Diam	DIM3 Height	DIM4 Thickness	DIM6 Angle
CV	0.0002	0.0011	0.0337	0.0049	0.0025	0.0025	0.0030	0.0165
% Error	0.02%	0.11%	3.37%	0.49%	0.25%	0.25%	0.30%	1.65%
Stdev	0.0028	0.0130	2.9058	0.3146	0.1029	0.0296	0.0124	0.1770
3*Stdev	0.0084	0.039	8.7174	0.9438	0.3087	0.0888	0.0372	0.531

In all cases except the durometer tests and the wall angle test (DIM6), the percent error is less than half a percent. For the wall angle test, it is reasonable to expect a larger number as the test for the angle was not automated, but instead required a human to subjectively draw a line representing the wall angle on top of an image. The durometer percent error is comparatively high, but the reason for this is not known.

The number representing 3*Stdev is important as it represents the idea that we are 99.73% confident that the actual error is less than the amount shown. Note that the units for the amount shown for 3*Stdev is the native units for the item being evaluated. I.e., for weight it is grams, for volume it is g/cm^3, etc.

Test Procedure:
A single sample (IME-1) was tested many times (33 times or more). The procedure called for the complete measuring method to be carried out 33 times or more. This meant that the same part was put into and removed from the test fixture each time. Measurements were collected and the statistics were calculated on the whole set of measurements for that sample.

Table A25.2. Data for the internal measurement error analysis (weight and volume)

Test	Seal	Weight (g)	Volume (cm^3)
1	IME-1	16.76	12.014
2	IME-1	16.758	12.004
3	IME-1	16.759	12.035
4	IME-1	16.762	12.026
5	IME-1	16.754	12.036
6	IME-1	16.759	12.036
7	IME-1	16.757	12.024
8	IME-1	16.756	12.025
9	IME-1	16.762	12.018
10	IME-1	16.756	12.055
11	IME-1	16.76	12.041
12	IME-1	16.758	12.023
13	IME-1	16.759	12.05
14	IME-1	16.76	12.044
15	IME-1	16.756	12.016
16	IME-1	16.761	12.022
17	IME-1	16.764	12.02
18	IME-1	16.758	12.049
19	IME-1	16.755	12.023
20	IME-1	16.757	12.027
21	IME-1	16.757	12.024
22	IME-1	16.75	12.014
23	IME-1	16.76	12.028
24	IME-1	16.756	12.024
25	IME-1	16.759	12.02
26	IME-1	16.758	12.033
27	IME-1	16.759	12.036
28	IME-1	16.76	12.006
29	IME-1	16.754	12.035
30	IME-1	16.756	12.024
31	IME-1	16.758	12.031
32	IME-1	16.753	12.045
33	IME-1	16.76	12.056
mean		16.7579	12.0292
standard deviation		0.0028	0.0130
min		16.7500	12.0040
max		16.7640	12.0560
range		0.0140	0.0520
median		16.7580	12.0260
coefficient of variation		**0.0002**	**0.0011**

Table A25.3. Data for the internal measurement error analysis (hardness)

Test	Seal	Durometer L1 (HSA)	Durometer L2 (HSA)	Durometer L3 (HSA)	Durometer L4 (HSA)
1	IME-1	85	87.5	78	85.5
2	IME-1	82.5	81.5	80	79.5
3	IME-1	82.5	84.5	83.5	84.5
4	IME-1	81.5	82.5	83	86
5	IME-1	81.5	85	85.5	84.5
6	IME-1	82	84	85	84.5
7	IME-1	82.5	83.5	81.5	84.5
8	IME-1	84.5	82	87.5	86.5
9	IME-1	83	82.5	85	85.5
10	IME-1	85.5	85	86	83
11	IME-1	82	88.5	84.5	87
12	IME-1	84	83.5	89	86.5
13	IME-1	85.5	85.5	87	87.5
14	IME-1	86	86.5	87	87
15	IME-1	81	84	86.5	89.5
16	IME-1	79.5	86.5	89.5	88.5
17	IME-1	80.5	86.5	86	85
18	IME-1	80	89.5	89.5	89.5
19	IME-1	88	89.5	91.5	89.5
20	IME-1	87	90	91	89
21	IME-1	86	86	88	91
22	IME-1	87	89	90.5	90.5
23	IME-1	89.5	86	86	85.5
24	IME-1	82	90.5	91	89.5
25	IME-1	89	85	90	91
26	IME-1	81.5	89	85.5	87.5
27	IME-1	87.5	89	87	85.5
28	IME-1	83	87.5	88	90.5
29	IME-1	88.5	87	90.5	89
30	IME-1	86	88.5	85.5	87.5
31	IME-1	80	91	89.5	84.5
32	IME-1	89	87.5	89.5	89
33	IME-1	90.5	87.5	91	87.5
mean		84.3485	86.4091	86.9242	87.0152
standard deviation		3.1412	2.6054	3.2861	2.5905
min		79.5000	81.5000	78.0000	79.5000
max		90.5000	91.0000	91.5000	91.0000
range		11.0000	9.5000	13.5000	11.5000
median		84.0000	86.5000	87.0000	87.0000
coefficient of variation		**0.0372**	**0.0302**	**0.0378**	**0.0298**

Table A25.4. Data for the internal measurement error analysis (height)

Test	Seal	Height L1 (mm)	Height L2 (mm)	Height L3 (mm)	Height L4 (mm)
1	IME-1	11.87	11.9	11.87	11.79
2	IME-1	11.87	11.76	11.91	11.79
3	IME-1	11.99	11.76	11.92	11.8
4	IME-1	11.96	11.85	11.84	11.79
5	IME-1	11.93	11.83	11.87	11.81
6	IME-1	11.94	11.75	11.88	11.78
7	IME-1	11.88	11.82	11.91	11.82
8	IME-1	11.94	11.83	11.91	11.81
9	IME-1	11.92	11.87	11.9	11.79
10	IME-1	11.87	11.85	11.85	11.8
11	IME-1	11.94	11.84	11.89	11.81
12	IME-1	11.95	11.82	11.89	11.82
13	IME-1	11.88	11.83	11.89	11.82
14	IME-1	11.95	11.84	11.9	11.84
15	IME-1	11.95	11.83	11.86	11.82
16	IME-1	11.94	11.87	11.84	11.83
17	IME-1	11.95	11.81	11.85	11.77
18	IME-1	11.97	11.75	11.88	11.85
19	IME-1	11.97	11.89	11.89	11.81
20	IME-1	11.92	11.81	11.88	11.81
21	IME-1	11.97	11.84	11.87	11.78
22	IME-1	11.93	11.86	11.83	11.78
23	IME-1	11.92	11.79	11.86	11.84
24	IME-1	11.94	11.83	11.86	11.81
25	IME-1	11.95	11.87	11.9	11.83
26	IME-1	11.91	11.85	11.87	11.79
27	IME-1	11.91	11.84	11.86	11.81
28	IME-1	11.97	11.81	11.86	11.82
29	IME-1	11.81	11.81	11.89	11.78
30	IME-1	11.99	11.81	11.88	11.82
31	IME-1	11.91	11.87	11.86	11.8
32	IME-1	11.91	11.83	11.87	11.81
33	IME-1	11.96	11.84	11.88	11.82
mean		11.9294	11.8291	11.8764	11.8076
standard deviation		0.0395	0.0370	0.0223	0.0195
min		11.8100	11.7500	11.8300	11.7700
max		11.9900	11.9000	11.9200	11.8500
range		0.1800	0.1500	0.0900	0.0800
median		11.9400	11.8300	11.8800	11.8100
coefficient of variation		**0.0033**	**0.0031**	**0.0019**	**0.0017**

Table A25.5. Data for the internal measurement error analysis (thickness)

Test	Seal	Thickness L1 (mm)	Thickness L2 (mm)	Thickness L3 (mm)	Thickness L4 (mm)
1	IME-1	4.25	4.13	4.16	4.17
2	IME-1	4.23	4.13	4.16	4.19
3	IME-1	4.24	4.14	4.16	4.17
4	IME-1	4.23	4.15	4.17	4.18
5	IME-1	4.24	4.13	4.17	4.17
6	IME-1	4.21	4.15	4.16	4.21
7	IME-1	4.23	4.14	4.16	4.19
8	IME-1	4.22	4.12	4.16	4.17
9	IME-1	4.25	4.13	4.17	4.17
10	IME-1	4.22	4.13	4.17	4.21
11	IME-1	4.26	4.14	4.17	4.18
12	IME-1	4.25	4.13	4.17	4.17
13	IME-1	4.2	4.14	4.17	4.19
14	IME-1	4.24	4.13	4.16	4.18
15	IME-1	4.27	4.13	4.17	4.2
16	IME-1	4.26	4.14	4.17	4.21
17	IME-1	4.27	4.13	4.17	4.17
18	IME-1	4.26	4.15	4.17	4.19
19	IME-1	4.2	4.14	4.17	4.18
20	IME-1	4.27	4.14	4.17	4.22
21	IME-1	4.26	4.12	4.16	4.18
22	IME-1	4.24	4.13	4.17	4.2
23	IME-1	4.2	4.13	4.17	4.17
24	IME-1	4.25	4.12	4.17	4.2
25	IME-1	4.22	4.15	4.17	4.17
26	IME-1	4.24	4.13	4.17	4.18
27	IME-1	4.24	4.13	4.17	4.17
28	IME-1	4.26	4.13	4.16	4.19
29	IME-1	4.23	4.14	4.16	4.18
30	IME-1	4.25	4.13	4.18	4.17
31	IME-1	4.2	4.12	4.17	4.18
32	IME-1	4.24	4.13	4.17	4.19
33	IME-1	4.23	4.15	4.17	4.17
mean		4.2382	4.1342	4.1673	4.1839
standard deviation		0.0210	0.0090	0.0052	0.0146
min		4.2000	4.1200	4.1600	4.1700
max		4.2700	4.1500	4.1800	4.2200
range		0.0700	0.0300	0.0200	0.0500
median		4.2400	4.1300	4.1700	4.1800
coefficient of variation		**0.0050**	**0.0022**	**0.0012**	**0.0035**

Table A25.6. Data for the internal measurement error analysis (outside diameter, inside diameter, and wall angle)

Test	Seal	Outside Diam. (mm)	Inside Diam. (mm)	Wall Angle (deg)
1	IME-1	64.2799	41.8398	10.751
2	IME-1	64.0315	41.8965	10.7131
3	IME-1	64.25	41.6876	10.722
4	IME-1	63.8495	41.8731	10.8987
5	IME-1	63.489	41.7982	10.7681
6	IME-1	64.1377	41.4879	10.751
7	IME-1	64.0707	41.7241	10.8855
8	IME-1	64.2004	41.6485	10.3048
9	IME-1	64.3824	41.806	10.5948
10	IME-1	64.4536	41.9639	10.5948
11	IME-1	63.8006	41.7627	10.416
12	IME-1	63.8949	41.8429	10.9391
13	IME-1	64.2696	41.8275	10.6197
14	IME-1	63.7639	41.7342	10.8685
15	IME-1	64.4486	41.7452	10.9422
16	IME-1	63.7146	41.7476	10.5948
17	IME-1	64.6399	41.95	10.9013
18	IME-1	64.5341	41.7902	10.416
19	IME-1	63.8608	41.6497	10.3048
20	IME-1	63.7267	41.7239	10.6922
21	IME-1	64.4775	41.8836	10.823
22	IME-1	63.7861	41.7142	10.4915
23	IME-1	64.3154	41.7083	10.823
24	IME-1	64.0061	41.7168	10.8403
25	IME-1	64.3203	41.6725	10.6457
26	IME-1	64.1205	41.9869	11.0035
27	IME-1	64.4979	41.8385	10.7014
28	IME-1	63.9603	41.8102	10.8685
29	IME-1	63.9515	41.6168	10.6457
30	IME-1	64.7374	41.843	10.7014
31	IME-1	64.6342	41.6115	10.5915
32	IME-1	63.9456	41.7667	10.6698
33	IME-1	63.9474	41.6193	10.5948
34	IME-1	63.8391	41.7552	10.7244
35	IME-1	63.8988	41.8083	10.5915
36	IME-1	64.1076	41.7729	10.9422
37	IME-1	63.6103	41.8232	--
38	IME-1	--	41.8474	--
39	IME-1	--	41.8464	--
40	IME-1	--	41.7833	--
mean		64.1069	41.7731	10.7038
standard deviation		0.3146	0.1029	0.1770
min		63.4890	41.4879	10.3048
max		64.7374	41.9869	11.0035
range		1.2484	0.4990	0.6987
median		64.0707	41.7781	10.7073
coefficient of variation		**0.0049**	**0.0025**	**0.0165**

Water Coverage Report (Gulu and Jinja)	Artifact A26

Artifact Prepared by: Christopher Mattson | Revision 1.0
Tests Performed by: Bosco Kilama (Gulu Water District Manager)
Test Date: Test Date: 2014—2018
Test Location: Gulu, Uganda

Purpose of this Test and Artifact:
In Gulu and Jinja we met with the district water supervisor. The goal in meeting the supervisors was to disclose our research objectives, ask for their support, and ask for access to any records regarding the number of boreholes, pumps, defects, etc.

Our visit to the supervisor in Jinja resulted in general numbers, described below. Our visit in Gulu results in multiple blank forms for water/borehole assessment, and yearly data on boreholes numbers and water coverage. The reports were given to us as is, without modification.

The purpose of this artifact is to convey the data shared with us by the district water manager.

Results from Gulu:
Water District Manager: Mr. Bosco Kilama, Civil Engineer
Telephone Number: 0775594463
Email: kilamabiky@gmail.com

The following tables come directly from Mr. Kilama. They are reformatted to match the table style of this document, but the numbers are identical, the words are identical, the bolded items and highlighted items are exactly as he had them.

Note that there is no data from 2017. Note as well that it does not appear that the population information is regularly updated. The assumptions about how many people are served by a borehole vs a tap vs a protected spring is valuable. It is also interesting in the sense that we did not observe the numbers to be as stated here. With limited observations we saw the same number of people or less using a tap vs a borehole, and the same number of people using protected springs as boreholes.

Table A26.1. Water coverage report 2014.

THE DISTRIBUTION OF SAFE WATER SOURCES BY TYPE PER SUBCOUNTY AS OF JUNE 2014										
RURAL AND URBAN WATER COVERAGE										
County	Sub-County	Population	BH[8]	SP	SW	Piped Water	HDW	Total water point	Population Served	% Coverage
ASWA	1. Awach	15,229	30	10	7	1	7	55	12,100	79.5
	2. Patiko	11,319	28	7	5	0	0	40	8,800	77.7
	3. Bungatira	31,385	37	29	14	0	6	86	16,600	52.9
	4. Unyama	16,216	30	22	6	0	1	59	11,850	73.1
	5. Paicho	17,741	25	20	2	0	4	51	10,150	57.2
	6. Palaro	9,056	28	2	1	0	5	36	8,200	90.5
	Sub Total	100,946	178	90	35	1	23	327	67,700	67.1
	Total for RWS	**100,946**	**178**	**90**	**35**	**1**	**23**	**327**	**67,700**	67.1
URBAN WATER COVERAGE										
Gulu Municipal	1. Laroo	29,018	26	13	13	1	6	59	21,300	73.4
	2. Layibi	34,677	18	14	9	1	8	50	19,150	55.2
	3. Pece	49,495	16	18	7	1	7	49	18,800	38.0
	4. Bar-dege	50,112	21	11	18	1	4	55	20,200	40.3
	Sub Total	163,302	81	56	47	4	25	213	79,450	48.7
	Grand Total	264,248	259	146	82	5	48	540	147,150	55.7
Note:										
Deep borehole serves 250 people										
Shallow well serves 150 people										
Piped water network serves 1000 people										
Protected spring serves 150 people										

[8] BH = borehole, SP = protected spring, SW = shallow well, HDW = hand dug well, and all BH are assumed to be deep water wells.

Table A26.2. Water coverage report 2015.

THE DISTRIBUTION OF SAFE WATER SOURCES BY TYPE PER SUBCOUNTY AS OF JUNE 2015										
RURAL AND URBAN WATER COVERAGE										
County	Sub-County	Population	BH	SP	SW	Piped Water	HDW	Total water point	Population Served	% Coverage
ASWA	1. Awach	19,502	36	10	7	1	7	61	13,600	69.7
	2. Patiko	18,540	31	7	5	0	0	43	9,550	51.5
	3. Bungatira	32,948	39	29	14	0	6	88	17,100	51.9
	4. Unyama	17,009	32	22	6	0	1	61	12,350	72.6
	5. Paicho	24,306	29	20	3	0	4	56	11,300	46.5
	6. Palaro	13,510	31	2	1	1	5	40	9,950	73.6
	Sub Total	**125,815**	**198**	**90**	**36**	**2**	**23**	**349**	73,850	58.7
	Total for RWS	**125,815**	**198**	**90**	**36**	**2**	**23**	**349**	**73,850**	58.7
URBAN WATER COVERAGE										
Gulu Municipal	1. Laroo	32,410	26	13	13	1	6	59	21,300	65.7
	2. Layibi	36,445	18	14	9	1	8	50	19,150	52.5
	3. Pece	48,405	16	18	7	1	7	49	18,800	38.8
	4. Bar-dege	35,016	21	11	18	1	4	55	28,501	81.4
	Sub Total	**152,276**	**81**	**56**	**47**	**4**	**25**	**213**	**87,751**	57.6
	Grand Total	**278,091**	**279**	**146**	**83**	**6**	**48**	**562**	**161,601**	58.1
Note:										
Deep borehole serves 250 people										
Shallow well serves 150 people										
Piped water network serves 1000 people										
Protected spring serves 150 people										

Table A26.3. Water coverage report 2016.

THE DISTRIBUTION OF SAFE WATER SOURCES BY TYPE PER SUBCOUNTY AS OF JUNE 2016										
RURAL AND URBAN WATER COVERAGE										
County	Sub-County	Population	BH	SP	SW	Piped Water	HDW	Total water point	Population Served	% Coverage
ASWA	1. Awach	19,502	38	10	7	1	7	63	14,100	72.3
	2. Patiko	18,540	33	7	5	0	0	45	11,700	63.1
	3. Bungatira	32,948	42	30	14	0	6	92	20,100	61.0
	4. Unyama	17,009	33	22	7	1	1	64	15,400	90.5
	5. Paicho	24,306	33	20	3	0	4	60	13,950	57.4
	6. Palaro	13,510	31	2	1	0	5	39	10,500	77.7
	Sub Total	**125,815**	**210**	**91**	**37**	**2**	**23**	**363**	85,750	68.2
	Total for RWS	**125,815**	**210**	**91**	**37**	**2**	**23**	**363**	**85,750**	68.2
URBAN WATER COVERAGE										
Gulu Municipal	1. Laroo	29,018	26	13	13	1	6	59	21,300	73.4
	2. Layibi	34,677	18	14	9	1	8	50	19,150	55.2
	3. Pece	49,495	16	18	7	1	7	49	18,800	38.0
	4. Bar-dege	50,112	21	11	18	1	4	55	20,200	40.3
	Sub Total	163,302	81	56	47	4	25	213	79,450	48.7
	Grand Total	264,248	259	146	82	5	48	540	147,150	55.7
Note:										
Deep borehole serves 250 people										
Shallow well serves 150 people										
Piped water network serves 1000 people										
Protected spring serves 150 people										

Table A26.4. Water coverage report 2018.

THE DISTRIBUTION OF SAFE WATER SOURCES BY TYPE PER SUBCOUNTY AS OF JUNE 2018										
RURAL AND URBAN WATER COVERAGE										
County	Sub-County	Population	BH	SP	SW	Piped Water	HDW	Total water point	Population Served	% Coverage
ASWA	1. Awach	19,502	40	10	7	1	7	65	14,600	74.9
	2. Patiko	18,540	34	7	5	0	0	46	12,000	64.7
	3. Bungatira	32,948	45	30	14	0	6	95	21,000	63.7
	4. Unyama	17,009	34	22	7	1	1	65	15,700	92.3
	5. Paicho	24,306	36	20	3	0	4	63	14,850	61.1
	6. Palaro	13,510	31	2	1	0	5	39	10,500	77.7
	Sub Total	**125,815**	**220**	**91**	**37**	**2**	**23**	**373**	88,650	70.5
	Total for RWS	**125,815**	**220**	**91**	**37**	**2**	**23**	**373**	**88,650**	70.5
URBAN WATER COVERAGE										
Gulu Municipal	1. Laroo	32,410	26	13	13	1	6	59	21,300	65.7
	2. Layibi	36,445	26	14	9	1	8	58	21,150	58.0
	3. Pece	48,405	20	18	7	1	7	53	19,800	40.9
	4. Bar-dege	35,015	25	11	18	1	4	59	21,200	60.5
	Sub Total	**152,275**	**97**	**56**	**47**	**4**	**25**	**229**	**83,450**	54.8
	Grand Total	**278,090**	**317**	**147**	**84**	**6**	**48**	**602**	**172,100**	61.9
Note:										
Deep borehole serves 250 people										
Shallow well serves 150 people										
Piped water network serves 1000 people										
Protected spring serves 150 people										

Additional information from Gulu:
The district supervisor indicated without reference to documents that 377 boreholes are scheduled for decommission or have been decommissioned since 2014. And that currently there are 70+ boreholes awaiting repair.

Information from Jinja:
Water District Manager: Mr. David Ereemye
Telephone Number: 0772699778, 0759968334
Email: dereemye@yahoo.co.uk

We asked for a map of borehole locations. Mr. Ereemye's assistant (Alex) indicated that we could have such a document, but it did not materialize, even after reminders.

The district supervisor indicated, however, without reference to documents that the district had 1400 borehole pumps and that roughly 5% or 70 were dysfunctional. He also indicated that 40 boreholes were scheduled for decommission, but that none had yet been decommissioned because of the difficulty with paperwork and approval higher up, as decommissioning a borehole requires a place for an alternative water source.

Uganda Contact List	Artifact A27

Artifact Prepared by: Christopher Mattson | Revision 1.1

Purpose of this Artifact:
The purpose of this list is to facilitate future work within Uganda.

Table A27.1. Uganda contact list.

Name	City	Phone[9]	Email
Godfrey Lufafa (facilitator)	Kampala	0782 358 673	busogabird@gmail.com
Steven (Driver, 4-5 people + gear)	Kampala	0781 295 925 0793 617 861 0703 509 416	steveteb@gmail.com
Helen (shop worker, Shop 3)	Kampala	0777 158 999	
Paul M'Panga (US educated owner of Shop 3, and manufacturer of PVC extrusions in Mukono)	Kampala	0771 874 334 US 651 500 6573	paulmpanga@buyaya.co.ug
Edwin (Housing Jaaj's Home of Angles)	Jinja	0779 488 922	
Immy Irot (Okware) (Finance graduate living near borehole 1)	Jinja	0705 832 096 0784 324 432	emmieimma@gmail.com
Fred (steel vendor)	Kampala	0700 322 175	
Simon-Peter (Secretary of Butik Mataala, where there was during our visit a broken-down borehole pump)	Jinja	0775 567 947	
Henry Mugimba (Chairman near borehole 1)	Jinja	0752 548 801 0782 548 880	
Muhammad Mgobi (hand pump mechanic)	Jinja	0775 828 201	
David Mawerere (head of the association of hand pump mechanics)	Jinja	0772 631 368	

[9] Uganda country code is 256. Omit the 0 (first digit of the phone number when using the country code).

David Ereemye **(District Water Officer, Jinja)**	Jinja	0772 699 778 0759 968 334	dereemye@yahoo.co.uk
Abubaker Sekimuli Runs a drill team	Jinja	0752 082 970	
Alred (man living next to borehole 2)	Jinja	0784 355 555 0753 661 555	
Wahab (Driver, large safari van)	Entebee	0774 672 202 0704 910 776	
John (Worker Safari Guide, Son at YEBO lodge)	Murchison Falls Park		Muhumuzabonny2@gmail.com
Polycarp (Village Drill operator in Gulu)	Gulu	0777 762 311	
Bosco Kilama (Assistant District Water Officer, Gulu)	Gulu	0775 594 463	kilamabiky@gmail.com
Martin Luquere (Hand Pump Mechanic)	Gulu	0777 327 374	
Evelynn Aber (Hand Pump Mechanic, lives near borehole 3)	Gulu	0782 827 904	aberevelyne@gmail.com
Ravi (Indian salesman of pumps, high tech and low)	Kampala	0757 290 403	accounts@sevenhills.co.ug
Roy Labeja (RM, guide/helper in Gulu, lives near borehole 3)	Gulu	0772 795 251	
Dennis Okello (Assistant of in charge Water at the Sub-county level)	Gulu	0773 228 215	
Robinson Akena **(**Chairman of Sub-county)	Gulu	0788 381 925	
Charles Boton (Sub-county office worker)	Gulu	0775 848 930	
Orombi Patrick (Has a borehole needs a pump but not sure there is water)	Jinja	0782 758 639	Pat_orombi@yahoo.com

Alex Kyombo Fredrick (Assistant at Jijna Water Department)	Jinja	0772 304 796	
Magunda (Pump Mechanic)		0772 348 464	
Ojok (Pump mechanic who repaired borehole pump # 1)	Jinja		
Jacol (Street contact. Says he knows pump/parts supply retailers)	Gulu	0772 863 131	
Brian Gitta (Innovator – Bloodless Malaria test)	Kampala	0704 319 257	gittabrian@gmail.com, matibabu@thinkitlimited.com
Namansa Brayan (Plumber...Son of the owner of store #5)	Jinja	0753 595 981	Namansabrayan8@yahoo.com
Christopher (Keeper of Borehole #4)	Gulu	0770 549 777	
Innocent Kilama (Keeper of Borehole #3)	Gulu	0706 191 122	
Phillip Odiambo **(**Capable, articulate college student at church)	Gulu		fideliophill19899@gmail.com

Discharge Test: Borehole 1, (Jinja) Done by Immy Irot	Artifact A28

Artifact Prepared by: Hans Ottosson | Revision 1.0
Tests Performed by: Immy Irot
Test Date: Test Date: 2:30 pm, 15 August 2018
Test Location: Jinja, Uganda

Purpose of the Test:
To see variations over time and difference of pump performance after service. A discharge test is performed to measure the functionality of the borehole pump.

Test Equipment and Set up:
The same sensor that was used for testing pump performance and usage was left with Immy Irot at Borehole 1 to be used for testing borehole performance over time. The sensor data is to be sent to BYU after performed tests.

Test Procedure:

1. Charge sensor battery.
2. Attach sensor to pump handle.
3. Pump until water flows.
4. Put water container under spout.
5. Pump 40 strokes in about one minute.
6. Weigh water.
7. Record weight.
8. Send data file to BYU.
9. Charge sensor battery.
10. Delete sensor data from sensor.

Results:
It took 7 strokes to prime the pump (pumped at 1.1517Hz at an average stroke length of 45.4712°). After that, Immy pumped 40 continuous full strokes at a frequency of 1.0706Hz with an average stroke length of 49.0163° and got a volume of 11.2 liters.

Figure A28.1 displays the time series for the discharge test and Figure A28.2 shows the jerry can used for collecting water and the sensor placement.

Observations and Conclusions:
For an India Mark II and III hand pump to function well, at least 16 liters of water should be pumped during the 40 strokes. Something is not working well with the pump at borehole 1 to only produce 11.2 liters. When we were there, the pump needed 214 strokes to get primed in the morning, so we suspect the foot valve to be malfunctioning, but we also think that the cup seals need to be replaced. We hope to get discharge data after they have serviced the hand pump again to see if we get better results.

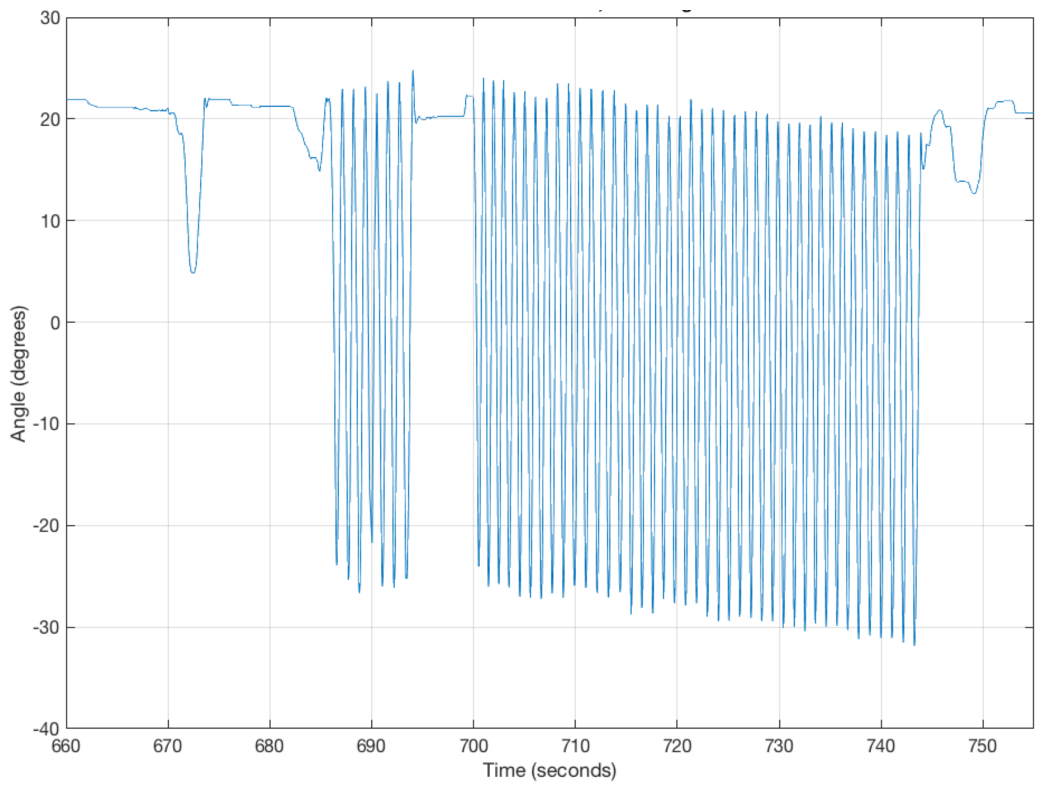

Figure A28.1. Time series for discharge test.

Figure A28.2. Jerry can used for test and placement of pump sensor.