DOE-FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

June 21, 2010 to August 26, 2010

105-P Reactor Disassembly Basin D & E Canal Cellular Grout Laboratory Testing

Principal Investigators:

Nadia Lima (DOE Fellow)
Florida International University

Michael G. Serrato, Mentor
Savannah River National Laboratory

Florida International University Collaborator and Program Director:

Leonel Lagos, Ph.D., PMP®

Prepared for:

U.S. Department of Energy
Office of Environmental Management
Under Grant No. DE-FG01-05EW07033

ABSTRACT

The 105-P Reactor located at Savannah River National Laboratory (SRNL) at the Savannah River Site (SRS) in South Carolina is obsolete and no longer needed for production. The Department of Energy has set a goal to reduce its footprint at SRS, therefore identifying the 105-P Reactor for decommissioning. Part of the decommissioning process involves filling all below grade areas with cementitious materials; this is referred to as in-situ decommissioning. The 105-P Reactor Disassembly Basin D & E Canal is one of these below grade areas that are being filled with cementitious materials. The section that is to be filled is on top of an underlying chase; therefore, it is imperative to use a proper filling material to avoid collapsing the cavity. Cellular grout is the lead candidate for filling this space because of its light weight. Before filling in any sub-grade area, it is important to validate the material by conducting a series of tests. This technical report contains the results and conclusions of a series of cured tests including compressive strength, hydraulic conductivity, dry density, and moisture content.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The 105-P Reactor went critical in 1954, shortly after the construction of the Savannah River Site. The Disassembly Basin D & E Canal was used to cool spent fuel rods and provided a radiological shield for workers (Ref 8). The reactor produced both tritium and plutonium to aid in the nation's defense during the Cold War era. Shortly after the Cold War ended in 1989, the 105-P Reactor went into cold standby and was therefore de-fueled in 1991. Since the reactor is no longer needed for production of nuclear materials, it is undergoing in-situ decommissioning under the American Recovery and Reinvestment Act (ARRA).

Part of the in-situ decommissioning process involves filling all sub-grade levels of the reactor with specially formulated grout mixtures. A cross-sectional view of the D & E Canal to undergo decommissioning can be seen in Figure 1. The cavity itself cannot be filled due to the workers' safety issue of drilling through irradiated materials located above the concrete slab layer. Therefore, the area to be filled is the remaining space on top of the PR-UZB-FF grouted layer. Modified cellular grout is the desired material to be placed into this section. Since the section that is to be filled is on top of the underlying D & E Canal chase, it is imperative to use a proper filling material to avoid collapsing the cavity. Cellular grout is the lead candidate for filling this space since it is known as a lightweight fill (Ref 2, Ref 9).

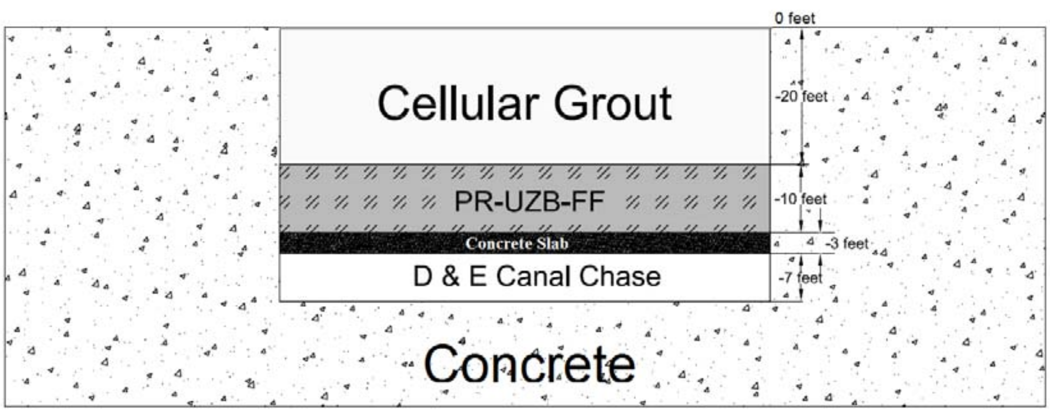


Figure 1: Cross-sectional view of the 105-P Reactor Disassembly Basin D & E Canal's cellular grout placement location.

Cellular grout, otherwise known as foam grout, is a lightweight material containing gas cells. These gas cells are created by adding a foaming agent to the neat cement, which in turn decreases its density (Ref 1). The end product is a lightweight material with a density range of 15-120 lbs/ft^3. The cost of cellular grout is about 40% less than that of regular concrete due to the increase in volume and exclusion of coarse and fine aggregates (Ref 1). The selection of cellular grout was based upon its low density, thermal conductivity, and excellent flow properties. These characteristics were ideal for filling the area. The compressive strength at 28 days is expected to yield values between 330-640 lbs/in^2 based on the specimen's water/cement ratio of 0.50 (Ref 1).

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2010, a DOE Fellow intern (Ms. Nadia Lima) spent 10 weeks doing a summer internship at the Savannah River National Laboratory under the supervision and guidance of Michael G. Serrato. The intern's project was initiated in June 21, 2010, and continued through August 26, 2010.

The cured properties of the cellular grout were tested in order to validate the material for its use in in-situ decommissioning of the 105-P Reactor Disassembly Basin D & E Canal. Validation was confirmed by comparing attained values to known book values in ACI 523.1 and National Bureau of Standards Data from "Insulating Concretes" (Ref 2, Ref 11). Since the area to be filled lies on top of an underlying cavity in the D & E Canal, a lightweight fill material is desired. Cellular grout was the lead candidate material due to its low density.

The specimen tested was a 6" x 12" cellular grout cylinder obtained from Gibson Pressure Grouting Service, Inc. in Atlanta, Georgia. The mix design of this grout consisted of neat cement (Portland Cement Type I and water) and a foaming agent. The individual specimens for each cured test were all prepared from the one 6" x 12" cellular grout cylinder. The cured property tests completed were compressive strength, saturated hydraulic conductivity, dry density and moisture content.

The attained values from each cured property test were within or close to the known book values. Many factors could influence these differences in values, including but not limited to the curing process of the cylinder, water to cement ratio of the mix, and specimen size and shape.

3. RESEARCH DESCRIPTIONS

3.1 Cellular Grout Mix Design

Before using this material to fill the 105-P Reactor Disassembly Basin D & E Canal, it is essential to be able to test a specimen of cellular grout to be assured that it has appropriate cured properties. This will validate the grout before placement.

The mix design to be utilized contains only neat cement and preformed foam. Neat cement is simply a mixture of cement and water. This mix design, as listed in the Pressure Grouting service visit trip report (Ref 1), is presented in Table 1.

Table 1: Cellular Grout per Yard Mix Design

Material	Quantity
Portland Cement Type I	695 lbs
Water	348 lbs (41 gallons)
VariMax Liquid Foam	17.9 cf

3.2 Methods and Experimental Procedures

3.2.1 Materials

The materials for the testing of the cellular grout specimen consist of:

- 6x12 inch cellular grout cylinder
- Hacksaw
- Level
- File
- Trautwein Soil Testing Equipment TW PERM-1, Calibration: 4/22/10-4/22/11
- Applied Test Systems (ATS) TM-4, Calibration: 12/15/09-12/15/10
- Tare #169 & #6
- Despatch Oven LO-I, Calibration: 8/6/10-8/6/11
- Caliper CDS-TC-5, Calibration: 9/9/2009-9/9/2010
- Scale S-65, Calibration: 6/8/2010-6/8/2011

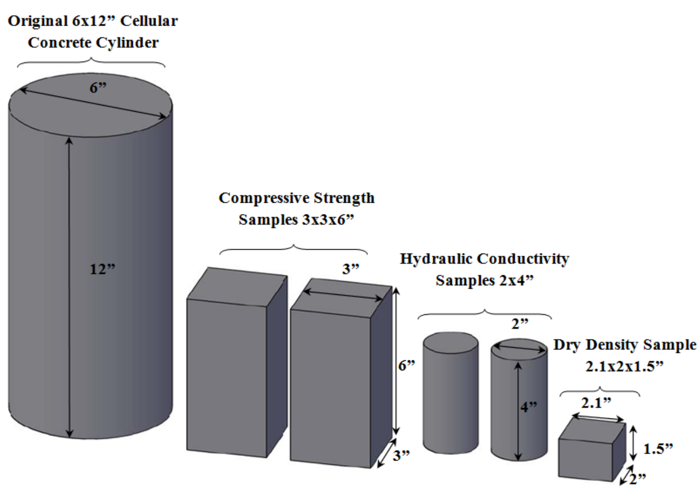
3.2.2 Cellular Grout: Cured Properties for Evaluation

The following cured properties of the cellular grout were evaluated in agreement with ASTM testing standards:

1. Compressive strength
2. Saturated hydraulic conductivity
3. Dry density
4. Moisture content

3.2.3 Sample Preparation Description

A sample preparation plan was created in order to produce 1-2 samples per test from the 6x12 inch cellular grout cylinder. The individual test samples were prepared to the nearest inch as seen in Figure 2:



:

Figure 2: Sample preparation.

<u>Compressive Strength</u>

From the 6x12 inch cylinder, two 3x6 inch blocks were cut out with a hack saw and filed smooth. The top and bottom of the blocks were cut to be as flat as possible by using a level.

<u>Saturated Hydraulic Conductivity</u>

From the 6x12 inch cylinder, two 2x4 inch cylinders were cut out with a hacksaw and filed smooth. The top and bottom of the cylinder were cut to be as flat as possible by using a level.

<u>Dry Density</u>

A 2.1x2.0x1.5 inch prism was cut from the 6x12 inch cylinder using a hacksaw and filed smooth.

<u>Moisture Content</u>

The same 2.1x2x1.5 prism used in the dry density test was used for moisture content testing.

The final sample dimensions are identified in Table 2.

Table 2: Sample Name, Dimension and Test

Sample	Dimension (inches)	Test
A	1.9x3.2	Saturated Hydraulic Conductivity/Dry Density
B	1.9x3.5	Saturated Hydraulic Conductivity
C	3x3x6	Compressive Strength
D	3x3x6	Compressive Strength
E	2.1x2x1.5	Dry Density/Moisture Content

3.2.4 Testing Procedures

All testing procedures were performed at room temperature of approximately 25ºC. The order of testing was compressive strength test, saturated hydraulic conductivity test, dry density test and moisture content test. Individual testing procedures were carried out as follows (Ref 3-7):

Compressive Strength Test

For the compressive strength test, samples C and D were used. This test was carried out in accordance with ASTM C 495 and ASTM C 109. The specimens were loaded onto the ATS (Applied Test Systems) TM-4 at two different rates. Specimen C was loaded at 0.040 in/min and specimen D was loaded at 0.020 in/min.

Saturated Hydraulic Conductivity Test

For the saturated hydraulic conductivity test, samples A and B were used. This test was carried out in accordance with ASTM D 5084 Method C (falling head) using Trautwein Soil Testing Equipment TW PERM-1. The permeant liquid used was water which remained at a room temperature of 25º C. The areas of the headwater and tailwater tubes were both 0.785 cm^2 with a 1-cm diameter. Both cells were pressurized to 10 psi. Head loss was recorded for a total of 5.5 hours for sample A.

Dry Density Test

Sample E was used to find dry density. The sample was placed in the oven at 121º C for 72 hours from 8/9/10-8/12/10. These specimens were then measured with caliper CDS-TC-5 and weighed using scale S-65 to calculate dry density.

Moisture Content Test

Sample E was also used to measure the moisture content of the sample. This prism was weighed before and after drying in the oven at 121º C for 72 hours from 8/9/10-8/12/10. Moisture content was calculated by subtracting one weight from another and dividing by the dry sample weight.

All tests were conducted on a 47+ day air cured 6x12 inch cellular grout cylinder. Cured property tests were utilized ASTM testing standards as listed in Table 3 (Ref 3-7).

Table 3: Cellular Grout Cured Properties Test Methods

Property	ASTM Test Method
Density	ASTM C 567 – Standard Test Method for Determining Density of Structural Lightweight Concrete
Saturated Hydraulic Conductivity	ASTM D 5084 – Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
Compressive Strength	ASTM C 495 – Standard Test Method for Compressive Strength of Lightweight Insulating Concrete ASTM C 109 - Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

4. RESULTS AND ANALYSIS

4.1 Compressive Strength Test

Sample C failed after adding a 2105 lb load and was found to have a compressive strength of approximately 278.4 psi. Sample D failed after adding a 2837 lb load and was found to have a compressive strength of approximately 315.2 psi. The specimens failed as seen in Figures 3 and 4. The types of fractures were found to be shear and columnar fractures. Shear fractures may occur due to the load being concentrated on one side more than another upon loading. Columnar fractures are common in specimens made from mortar or neat cement, as these specimens were. These results are tabulated in Table 4

Table 4: Compressive Strength of Samples C and D

Sample	Load (lbs)	Rate (in/min)	Compressive Strength (psi)	Type of Fracture
C	2105	0.04	278.4	Shear
D	2837	0.02	315.2	Columnar

Figure 3: Compressive strength, smaller sample after fracture.

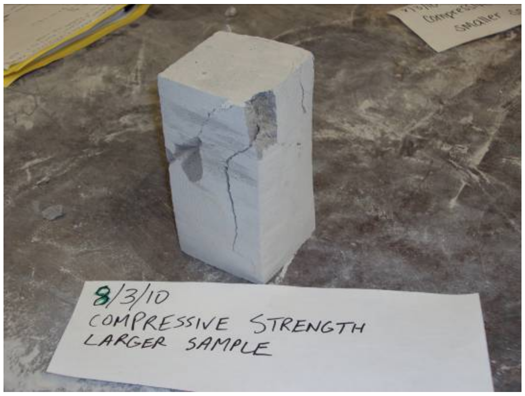


Figure 4: Compressive strength, larger sample after fracture.

4.2 Dry Density Test

The dry density was found after placing sample E into the oven at 121º C for 72 hours from 8/9/10-8/12/10. The dry density of the sample was found to be 35.77 lb/ft^3. Dry density was also evaluated using sample A. This sample was found to have a dry density of 29.76 lb/ft^3. These results are tabulated in Table 5.

Table 5: Dry Density

Sample	Dry Weight (grams)	Dry Density (lb/ft^3)
E	59.2	35.8
A	78.5	29.8

4.3 Saturated Hydraulic Conductivity Test

Sample A performed well while sample B did not permeate. The average inflow rate was 0.125 cm/hour and the average outflow rate was 0.135 cm/hour for sample A. The average corrected saturated hydraulic conductivity was found to be 5.001x10^{-5} cm/s for sample A. The specific gravity of this material is approximately 0.57 with respect to water. Since cellular grout is less dense than water, it is not easy to permeate (Figures 5 and 6).

Figure 5: Cellular grout remains floating in water.

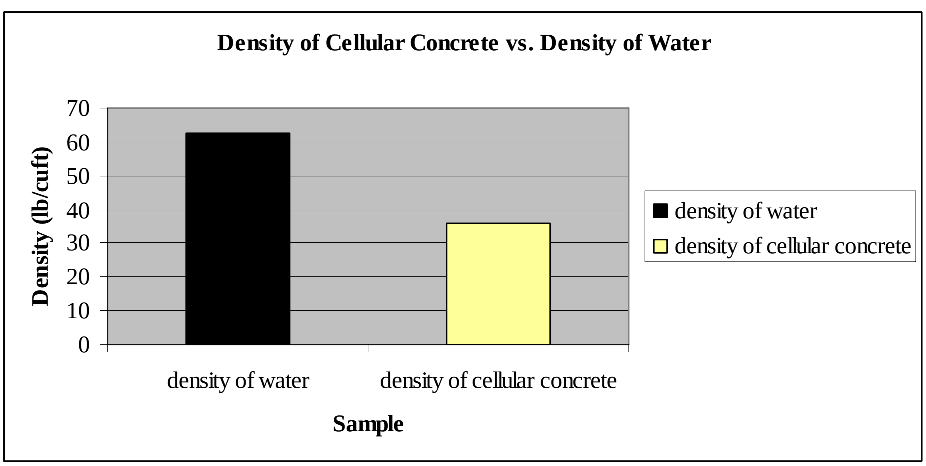


Figure 6: Density of cellular concrete vs. density of water.

The low permeation can also be explained by the fact that the saturated hydraulic conductivity coefficient k is proportional to unit weight. Therefore, low unit weights of cellular concrete produce low hydraulic conductivity coefficients. This is because of its high content of gas cells due to the addition of preformed foam. High cement content, as seen in this mix, may also cause a decrease in permeability (Ref 9). It took a few trials consisting of multiple hours at a time to achieve permeability in sample A. On the third day of leaving the valves open for 4-5 hours per day, permeability was achieved. After various trials, sample A was able to attain acceptable hydraulic conductivity values. As seen in Table 10 in Appendix A, sample A was able to absorb quite a bit of water. A graph of saturated hydraulic conductivity vs. time is shown in Figure 7 in Appendix A. Values obtained for sample B were not within an acceptable range. Valves were left open for sample B but it did not permeate. The sample was also vacuumed 2-3 times a day to aid in saturation but it was not successful.

The results for the saturated hydraulic conductivity test for sample A can be found in Table 6. The weight before and after permeation can be found in Table 10 in Appendix A.

Table 6: Saturated Hydraulic Conductivity Values of Sample A

Cell	Head	Tail	Time	Head-loss (cm)	Saturated hydraulic conductivity (cm/s)	Corrected Saturated hydraulic conductivity (cm/s)
10.2 psi	0 psi	0 psi	-	-		-
0.6	0	24	6:59am	24	$1.5x10^{-5}$	$4.1x10^{-5}$
0.6	0.7	23.4	7:29am	22.7		
0.6	0.7	23.4	7:29am	22.7	$1.8x10^{-5}$	$4.7x10^{-5}$
0.5	1.4	22.7	7:59am	21.3		
0.5	1.4	22.7	7:59am	21.3	$1.7x10^{-5}$	$4.7x10^{-5}$
0.5	2.1	22.1	8:29am	20		
0.5	2.1	22.1	8:29am	20	$1.7x10^{-5}$	$4.6x10^{-5}$
0.5	2.7	21.5	8:59am	18.8		
0.5	2.7	21.5	8:59am	18.8	$1.8x10^{-5}$	$4.9x10^{-5}$
0.5	3.3	20.9	9:29am	17.6		
0.5	3.3	20.9	9:29am	17.6	$1.9x10^{-5}$	$5.2x10^{-5}$
0.5	3.9	20.3	9:59am	16.4		
0.5	3.9	20.3	9:59am	16.4	$1.9x10^{-5}$	$5.1x10^{-5}$
0.5	4.5	19.8	10:29am	15.3		
0.5	4.5	19.8	10:29am	15.3	$2.1x10^{-5}$	$5.5x10^{-5}$
0.5	5	19.2	10:59am	14.2		
0.5	5	19.2	10:59am	14.2	$2.0x10^{-5}$	$5.4x10^{-5}$
0.5	5.5	18.7	11:29am	13.2		
0.5	5.5	18.7	11:29am	13.2	$1.9x10^{-5}$	$5.2x10^{-5}$
0.5	6	18.3	11:59am	12.3		
0.5	6	18.3	11:59am	12.3	$2.1x10^{-5}$	$5.6x10^{-5}$
0.5	6.4	17.8	12:29pm	11.4		

4.4 Moisture Content Test

Sample E was found to have a moisture content of 23.6% after placing in the oven at 121º C for 72 hours. Since the grout mixture had a water/cement ratio of 0.50, moisture content as high as 23.6% after leaving the sample in the oven for 72 hours is not surprising. These results are tabulated in Table 7.

Table 7: Moisture Content

Sample	Tare + Original Sample (grams)	Tare (grams)	Tare + Dried Sample (grams)	Dried Sample (grams)	Moisture (grams)	Moisture Content (%)	Time in Oven
E	244.1	170.9	230.1	59.2	14	23.6	72 hours

4.5 Result Averages and Data Comparison

The result averages for each cured test can be seen in Table 8 and Table 9 shows a comparison of the laboratory results versus the literature values.

Table 8: Cellular Grout Cured Property Test Results

Test	Result Average
Dry Density	32.8 lb/ft^3
Saturated Hydraulic Conductivity	5.0x10^{-5} cm/s
Compressive Strength	296.8 psi
Moisture Content	23.7%

Table 9: Data Comparison

Test	Lab Value	ACI 523.1	Trip Report Value
Dry Density	35.8 lb/ft^3, 29.8 lb/ft^3	up to 50 lb/ft^3	34-43 lb/ft^3
Saturated Hydraulic Conductivity	5x10^{-5} cm/s	1x10^{-6} - 1x10^{-5} cm/s	N/A
Compressive Strength	278.4 psi, 315.2 psi	N/A	330-640 psi
Moisture Content	23.7%	N/A	N/A

5. CONCLUSION

The dry density lab value of 35.77 lbs/ft^3 attained fit both literature values. The 29.76 lb/ft^3 density value obtained was outside of the National Bureau of Standards Data (Ref 11). This is due to the fact that it was not in the oven as long as the other sample. Hydraulic conductivity levels achieved were within the ACI 523.1 range of $1x10^{-6}$-$1x10^{-5}$ cm/s as seen in Table 9 (Ref 2).

The laboratory compressive strength results showed lower than average compressive strength values referenced in the National Bureau of Standards Data. Many factors can affect the compressive strength of material, including water-cement ratios, method of curing, specimen size and shape, and water content. In this case, the biggest factor is the method of curing the cellular concrete cylinder.

ASTM C 495 instructs to cure specimens at 70 ± 10 ºF for the first 24 hours. After 24 hours, the specimens are to be stored in a moist condition at 73.4 ± 3 ºF. After 7 days, the cylinders are to be stored at 70 ± 10 ºF, and after 25 days, the specimens are to be dried in an oven at 140 ± 5 ºF for 3 days. The cylinder attained from Gibson Pressure Grouting Service, Inc. was only stored in the lab at 70 ± 10 ºF for approximately 50 days before testing. However, the compressive strength results received in the lab were within the ACI 523.1 values of 225-350 psi for dry densities ranging from 30-35, if rounding down the lab dry density value.

Further testing must be done to assess the flow and workability of cellular grout to verify that this is the best material to use for filling the 105-P Reactor Disassembly Basin D & E Canal.

6. REFERENCES

1. Trip Report: Gibson Pressure Grouting Service, Inc. Visit- 6/10/2010, SRNL-L6010-2010-00012
2. ACI Committee 523. (2006). Guide for Cast-in-Place Low-Density Cellular grout. (2006). ACI. American Concrete Institute.
3. “Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter,” ASTM D 5084, American Society for Testing and Materials, 2004.
4. “Standard Test Method for Compressive Strength of Lightweight Insulating Concrete,” ASTM C 495, American Society for Testing and Materials, 2007.
5. “Standard Test Method for Determining Unsaturated and Saturated Hydraulic Conductivity in Porous Media by Steady-State Centrifugation,” ASTM D 6527, American Society for Testing and Materials, 2008.
6. “Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete,” ASTM C 42, American Society for Testing and Materials, 2004.
7. “Standard Test Method for Determining Density of Structural Lightweight Concrete,” ASTM C 567, American Society for Testing and Materials, 2006.
8. "With ARRA Funds, P-Reactor Disassembly Basin Project." U.S. Department of Energy 21 04 2010: 1-2. Web. <http://sro.srs.gov/nr_2010/2010sr15.pdf>.
9. *Guide Specification for Controlled Low Strength Materials (CLSM)*. National Ready Mix Concrete Association, n.d. Web. <http://flowablefill.org/CLSM%20Specifications%201.pdf>.
10. Ramamurthy, K., Kunhanandan Nambiar, E.K., Indu Siva Ranjani, G. (2009). A classification of studies on properties of foam concrete. *Cement & Concrete Composites*, 31, 388-396
11. National Bureau of Standards Data from “Insulating Concretes”, ACI Journal (Nov. 1956).

APPENDIX A.

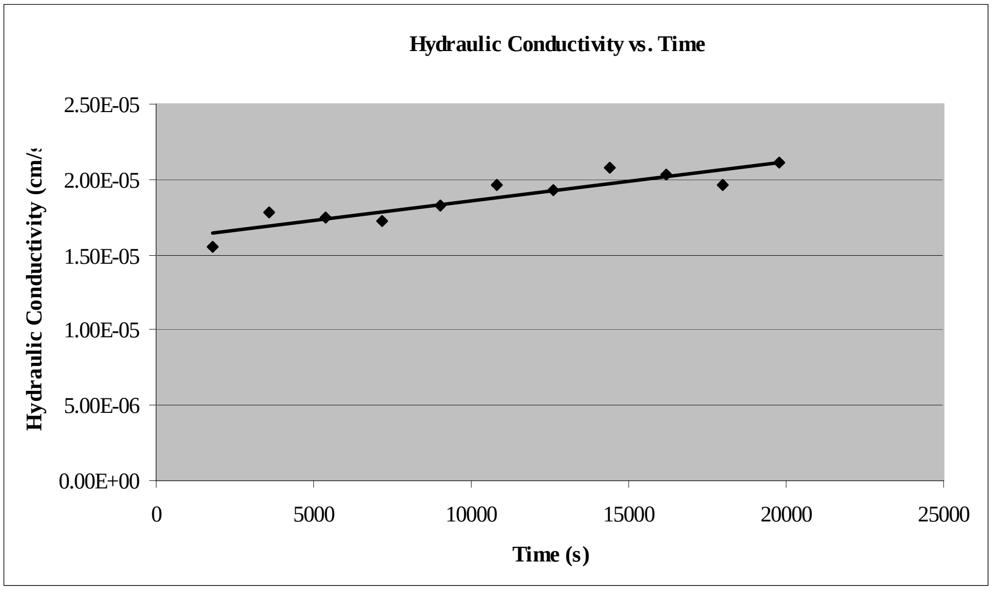


Figure 7: Saturated hydraulic conductivity vs time sample A.

Table 10: Dimensions and Weights Before and After Permeation

Sample	Weight Before (grams)	Saturated Surface Dry Weight (grams)	Dimensions Before (inches)	Dimensions After (inches)
A	97.5	172.4	1.9x3.2	1.9x3.2
B	107.3	N/A	1.9x3.5	N/A