WestVirginiaUniversity
THE RESEARCH REPOSITORY @ WVU

Graduate Theses, Dissertations, and Problem Reports

2010

Nonwoven Geotextile Filtration Performance with Coal Refuse

Rajesh Tolikonda
West Virginia University

Follow this and additional works at: https://researchrepository.wvu.edu/etd

Recommended Citation

Tolikonda, Rajesh, "Nonwoven Geotextile Filtration Performance with Coal Refuse" (2010). *Graduate Theses, Dissertations, and Problem Reports*. 4665.
https://researchrepository.wvu.edu/etd/4665

This Thesis is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Thesis has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

Nonwoven Geotextile Filtration Performance with Coal Refuse

Rajesh Tolikonda

Thesis submitted to the
College of Engineering and Mineral Resources
at
West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Civil and Environmental Engineering

Dr. John D. Quaranta, Ph.D., Chair
Dr. Hema Siriwardane, Ph.D.
Dr. Xinchao Wei, Ph.D.

Department of Civil and Environmental Engineering

Morgantown, West Virginia

2010

KEYWORDS: Clogging; Hydraulic Conductivity; Grain Size Distribution; Coal refuse; Rigid wall; Nonwoven Geotextile; Apparent Opening Size (AOS).

ABSTRACT

Nonwoven Geotextile Filtration Performance with Coal Refuse

Rajesh Tolikonda

This project investigated aspects of geosynthetic geotextile filter retention, permittivity, and clogging potential due to coal slurry particle intrusion and blinding. The project objective was to investigate the geotextile filtration performance when used in combination with coal refuse.

The project involved bench scale testing investigating geotextile filter clogging by fine particle intrusion and fabric blinding from coarse and fine coal refuse with nonwoven geotextile filter fabric. The research explored the fine particle distribution through the refuse material and interfacial contact with the geotextile. The coal refuse was obtained from an active mining and coal waste impoundment operation located in Boone County, WV. The research involved testing of non-woven geotextiles with coarse and fine coal refuse under standard and reduced compaction energies in order to simulate field performance of the fabric to the effects of loose compaction conditions, such as direct end dumping, compared with a maximum compaction effort, standard Proctor, occurring in field conditions.

The laboratory testing program consisted of performing compaction mold permeameter testing having different compaction densities, nonwoven geotextile thicknesses, and different mix proportions of coarse and fine coal refuse. Data was obtained on fine particle grain-size distribution through the compacted coal refuse specimens, and hydraulic conductivity variations with time.

Engineering evaluation of the data results was based on comparing the laboratory results with the filtration requirements presented by the US Mine Safety and Health Administration (MSHA) guidelines presented in the Engineering and Design Manual: Coal Refuse Disposal Facilities (MSHA, 2009). The MSHA manual details the filtration design requirements for the use of nonwoven geotextiles as filter media in combination with coal refuse. Engineering calculations were performed to compare the MSHA and other published guidelines for geotextile selection and performance.

Conclusions of the research identified several key findings. During the compaction of the rigid wall permeameter samples the refuse experiences crushing and slaking effects which for a coarse grained refuse will produce an increase in the percentage of fines. This effect occurs at compaction energies ranging from optimum to reduced (13,288 to 1,417 ft-lb/ft^3). The percentage of fines produced appeared to be a consistent percentage increase of approximately 32%. The characteristics of the grain size shift can result in filtration concerns when evaluating the D_{15} criteria used in the clogging evaluations.

Graphs of the hydraulic conductivity versus time indicated that there was no stable filter developed within the coarse coal refuse specimens. The GSE Lining Corporation's NW 6 nonwoven geotextile was selected as the "worst case" filter for comparison of the soil-geotextile system because it has the largest Apparent Opening Size (AOS) of 0.212 mm. Results indicated that for both the initial (non-compacted) and the compacted refuse at all compaction density ranges that the Retention and Permeability Criteria were met (passed) both the MSHA and Giroud design criteria. The corresponding results of the Clogging criteria indicated that the refuse failed under non-critical conditions.

Blends of fine and coarse coal refuse were developed in the laboratory which provided for a uniformly graded grain size distribution. This distribution was at 80% coarse to 20% fines (80/20) and at 60% coarse to 40% fines (60/40) which passed the No. 100 sieve. Results of the post compaction grain size distributions for the blended refuse samples identified that the crushed particles formed aggregates and

produced a shift in the shape of the curve which resembled more of a coarse refuse material. The aggregation of the fine particles was consistent across all tested samples and exhibited similar ranges of increases to the D_{85}, D_{60}, D_{15} and D_{10} particle sizes.

Considering the FCR 80/20 mix, no apparent reduction in the hydraulic conductivity or development of a stable filter media was observed under the ranges of the test parameters. The reasons for this effect may be similar to the coarse coal refuse test results. For 60/40 FCR material passing No.100 sieve, a stable filter was formed after 75 hours of testing and the stable filter was continued throughout the end of the test. For the 80/20 and 60/40 blended refuse samples passed the Retention Criteria and Permeability Criteria. The samples failed the Clogging Criteria under non-critical conditions.

A series of rigid wall permeability tests were conducted on Coarse Coal Refuse and Blended 80/20 and 60/40 refuse samples using a strong pH 2, sulfuric acid. Results of the Coarse Coal Refuse and the Blended 80/20 and 60/40 mix, the hydraulic conductivity versus time showed a one-order of magnitude decrease when compared to the water permeated samples at similar testing parameters. For the acid permeated Coarse Coal and 80/20 Blended samples the post grain size distribution indicated that the acid does not alter the Retention, Permeability, or Clogging criteria. For the 60/40 Blended samples the post grain size analysis indicated that specimen passed the Clogging criteria.

The following recommendations are presented for the use of nonwoven geotextiles in non-critical conditions. Post grain size distribution tests should be performed on specimens at the optimum compaction level to observe changes in D_{85} for meeting the Retention Criteria requirements. This will take the particle crushing and slaking effects into consideration. It should be noted that the continued or repetitive compaction of the CCR material may reduce the particle diameter to less than the geotextile's Apparent Opening Size (AOS) which then renders potential failure in achieving the Retention Criteria.

It is suggested to use a geotextile having a permittivity value greater than 0.5 s^{-1} in order to pass the Permittivity Criteria. Installation of the geotextile in a field application having only Coarse Coal Refuse should be performed at the optimum compaction (energy value 13,288 ft-lb/ft^3) level. This is preferred over a reduced compaction (end dump) condition in order to increase the potential to satisfy the permeability criteria due to the increase in fines, when the permeability criteria is critical.

For Clogging Criteria, the post grain size distribution tests should be performed on specimens at the optimum compaction level to observe changes in D_{15}. This will take the soil particle size into consideration when comparing to the fabric AOS, ($AOS \geq 3*D_{15}$) (Non-critical Conditions). The increase in refuse fines percentage tends to develop a stable internal filter thereby tending to reduce potential geotextile clogging.

Research was performed to investigate the chemical composition of the coal refuse and to determine alternative approaches to track the fine particle movements of refuse amended with fine particle metal beads. This attempted to develop a particle tracking method for coal refuse and determine geosynthetic filter clogging characteristics. Photo microscopy was used to obtain visual images of sample nonwoven geotextile filters impacted with coal refuse material. The results of this work indicate that the mobility of the metals in the cell depends on the size of the metal beads added, their relative density, and intrinsic solubility in the water used to treat the cells. The use of metal beads appears to have excellent potential as a particulate tracking method that could be applied to evaluation of clogging of geotextile fabrics. Of the metal beads added, the tungsten (W), molybdenum (Mo), and chromium (Cr) showed the most promise based on where the concentrations were maximized.

ACKNOWLEDGMENTS

I would like to gratefully acknowledge the enthusiastic supervision of Dr. John D. Quaranta, a great teacher and advisor who was abundantly helpful and offered invaluable assistance, support and guidance to accomplish this research project. His technical insight was priceless.

I wish to thank Mr. Jeremi Stawovy, Mr. James Matthew Dudley, Mr. Eric Baker, and Mr. Srinivas Majjiga for assistance in the laboratory testing.

I gratefully acknowledge the financial support provided by National Technology Transfer Center at Wheeling Jesuit University through a grant from the Mine Safety and Health Administration. I also acknowledge J. Davitt McAteer, Program Director of the Coal Impoundment Project. I wish to thank the MSHA Pittsburgh Safety and Health Technology Center—Mine Waste and Geotechnical Engineering Division for their involvement and support of this work. I also wish to thank the engineers and staff members from Patriot Coal Corporation who provided in-kind supported the program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION AND BACKGROUND

1.1. Introduction

Following the breakthrough and release of coal slurry from the Martin County Coal Corporation impoundment near Inez, Kentucky on October 11, 2000 the United States Congress requested the National Research Council (NRC) to examine ways to reduce these types of accidents. The NRC completed their study titled "Coal Waste Impoundments" which identified numerous areas of concern and the committee presented recommendations for improving the design, operation, and safety of coal slurry impoundments. The contents of this research prepared by West Virginia University Department of Civil and Environmental Engineering are to support the National Technology Transfer Center (NTTC) on the Coal Slurry Impoundment Project.

This project investigated aspects of geosynthetic geotextile filter clogging due to coal slurry particle intrusion and filter blinding. The project was designed into multiple tasks. The first task included a literature review of current industry and regulatory practices for geotextile selection and performance evaluation; followed by a second task that involved limited bench testing investigating geotextile filter clogging by fine particle intrusion and fabric blinding. The third task explored the use of analytical microscopy to assess particle blinding and intrusion within the micro-structure of the geotextile fabrics. Work on this project was performed at West Virginia University by the Department of Civil and Environmental Engineering and the Bennett Department of Chemistry.

1.2. Research purpose and objectives

1.2.1. Purpose

The purpose of this research is to investigate the filtration performance of the coal refuse-geotextile system in geotextile wrapped drains in coal impoundments. The geotextile clogging potential was evaluated by performing various laboratory tests and correlating the data with actual field constructed systems from WV Department of Environmental Protection permit files. The research involved testing of non-woven geotextiles with coarse coal refuse and fine coal refuse under standard and reduced compaction energies. This approach attempted to simulate field placement of refuse against the geotextile fabrics to model different compaction densities such as loose compaction by direct end dumping, and a maximum compaction effort in the field. Different mix proportions of coarse coal refuse and fine coal refuse were used to assess the clogging effects occurring either at the interface of the soil and geotextile; within the soil; and within the geotextile fabric. Different conditions in coal impoundments such as acid mine drainage were considered by performing the tests with a strong sulfuric acid (H_2SO_4) as permeant.

1.2.2. Objectives

The objectives of this research are to investigate the performance of non-woven geotextile fabrics for use in coarse coal refuse filtration and separation applications where rock drain structures are used for reducing piezometric head levels within embankments. This research will investigate the mechanical, physical, and chemical effects of coarse coal fine particle clogging and blinding of the geotextile fabric filters.

The mechanical and physical testing will focus on fabric clogging by fine particle intrusion. The chemical testing will investigate physical changes of coarse coal overburden materials through deterioration and development of oxide armoring occurring at the geotextile and overburden interface.

1.3. Scope of work

The scope of the work gives the method followed throughout this research. The proposed project tasks are discussed in brief in the following paragraphs.

1.3.1. Task 1: Literature review and test plan development

A literature review will be performed that identifies current problems in field application of geotextiles for filtration in drainage applications at coal slurry impoundments. Information was sought from the US Mine Safety and Health Administration (MSHA) concerning filtration applications and conditions of use, and design specifications of filter systems. Review of existing literature was performed to identify types and specifications of geotextiles that have been applied for coarse coal mine refuse filtration. Specific information to be sought includes published data concerning compaction values of coarse coal refuse adjoining filter fabric application locations, refuse installation densities and particle grain size distributions, and permeant liquid properties (pH, Specific Conductance, etc..).

A project test plan will be developed as a Methods document providing detail for performing the laboratory testing, data analysis and reduction, and reporting formats.

1.3.2. Task 2: Bench scale filtration and chemical testing

The testing phase was structured in a tiered structure presented below.

The First Tier Testing addresses base-line parameter assessment and testing of the selected coarse coal refuse from exposure to permeants including water and mild to harsh acid. The second tier of testing will address performance based parameters following ASTM compliant testing to evaluate geotextile performance from benign coarse refuse permeants to assess particle intrusion and clogging; and tier three will continue performance testing using with chemical permeants with coarse coal refuse to identify accelerated deterioration potential and filtration impact of armoring and intrusion developing at the fabric interface. Each of the three tiers is discussed below:

Tier One Testing: Base-Line Index Testing, Parameter Assessment, & Protocol Evaluation

This research involved establishing the base-line index parameters of the coarse coal refuse following the ASTM testing procedures. The physical index property tests to be performed are listed below in Table 1.1. The coarse coal refuse specimens were obtained from two working coal impoundments in West Virginia.

Selection of the coarse coal refuse was based on the ASTM requirements for each individual test. The maximum particle size tested was the fine-gravel size ranging ¾ " (20mm) to No. 4 sieve (4mm), then to include other fine particles through to the clay size fraction (< No. 200 sieve). A Hydrometer analysis was performed to identify clay size particles.

Table 1.1: Geotechnical material property tests

TEST NAME	**ASTM**
Physical properties	
Moisture Content	D-2216
Sieve / Hydrometer	D-422
Atterberg Limits (LL, PL)	D-4318
Specific Gravity of Soils	D-854
Compaction	
Standard Proctor	D-698
Modified Proctor	D-1557
Relative Density	D-4253 D-4254
Permeability	
Clays & Low-Permeability Soils	D-5084
Constant Head (Soils & Silts)	D-2434

Protocols used for testing were documented for standardizing sample preparation based on the uniqueness of the coarse refuse material.

Tier Two Testing: Geotextile Performance Testing for Permittivity (Filtration) Drainage

Performance testing will be performed on selected non-woven geotextiles with coarse coal refuse to establish filtration (permittivity-drainage) rates. Experimentation will be based on following ASTM D-5856 *Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a*

Rigid-Wall, Compaction-Mold Permeameter and ASTM D -2434 *Test Method for Permeability of Granular Soils (Constant Head).* Selection of the seepage permeant consisted of test water prepared in accordance with ASTM – Type 18, low ionic, organic free, de-aired water. Various geotextile weight fabrics will be tested.

Sample filter media was evaluated pre- and post- exposure to the coarse coal refuse to investigate entrained particle weight changes and filtration reduction. Information relating to the intrusion of coal fines into the micro-structure of the geotextile will be reported.

Physical property testing of the coarse coal refuse was performed at the beginning and at the end of each test in order to evaluate material property changes due to permeant influences or particle filtration and piping effects occurring.

Tier Three Testing: Chemically Enhanced Permeant Performance Testing

The third tier testing program focused on the chemical deterioration of the refuse and armoring effects occurring at the geotextile fabric interface. The test program was similar to the techniques of Tier One and Two, but with the introduction of a low pH solution of sulfuric acid (H_2SO_4) as permeant. This low pH solution was intended to emulate a harsh saturated environment and accelerate refuse deterioration by minimizing buffering through constant pore volume exchanges in the permeameters. The selection of this acidic permeant was to assist with investigating a weathered / aged refuse which may exist in an acid mine drainage (AMD) environment.

Chemical testing of the permeant fluids at post exposure was performed to assay the respective ion release or stripping of ions from the refuse materials. Physical index testing of the reformed coarse refuse post flushing was performed to assess ion exchange extents. Testing frequency was performed in triplicate.

1.3.3. Task 3 Analytical Microscopy

In collaboration with Task 2 testing, retrieved geotextile specimens were studied using several microscopic techniques for evaluation of particle trapping characteristics. For this work, thin-sections of filters were prepared using quick-freeze/thin slicing and chemical mounting techniques. Thin sections were selected using standard random sampling design to insure representative characterization of the filters.

1.4. Thesis organization

The report is organized into the following four sections as discussed in the following text.

1.4.1. Literature review

Literature review was performed on coal refuse, seepage and its problems in coal refuse impoundments. This section also concentrates on the study of installation of geotextiles in drains in coal impoundments for filtration and the problems associated with it. Literature also focuses on the design criteria of the geotextile installation which are mentioned by MSHA and WVDEP and other literature.

1.4.2. Laboratory experimentation program

Laboratory experimentation program was performed on different coal refuse samples collected from West Virginia. Various physical and geotechnical tests were performed. Hydraulic conductivity testing was conducted on coal refuse samples with selected non-woven geotextiles to find the filtration performance. Different percentages of fine coal refuse were blended with coarse coal refuse to increase the clogging potential and the permittivity-drainage rates were determined. To evaluate the acid mine drainage effect on the geotextile in the coal impoundments, acid was used as permeant. Analytical microscopy was also performed on the samples to track the particle movement within the sample.

1.4.3. Data reduction and Results

Data from laboratory experiments was reduced using sigma plot. Data reduced from the laboratory experimentation program, the results from literature review, Mine safety and health administration (MSHA), and West Virginia division of environmental protection (WVDEP) are combined and presented. The results are used to provide the information useful for the future research in installing the geotextiles in coal impoundments for filtration.

1.4.4. Appendix

All data, tables are incorporated in appendix.

2. LITERATURE REVIEW

This literature review focused on identifying the current state of practice used for the design and specification of geotextiles for separation and filtration applications at coal slurry impoundments. This review was performed and is presented in three stages. The first stage concentrates in defining coal refuse; the materials physical, geotechnical properties, and processed properties affecting its placement and use in engineered slopes. The information researched includes data defining particle size distributions, compaction values and densities of coal refuse and variability of coal refuse properties which, in turn, impact the clogging behavior of geotextiles as filtering media in coal refuse impoundments and embankments. The second stage of the literature review focused on identifying the types and specifications of geotextiles that have been applied to coal mine refuse filtration designs and that are referenced by both federal and state regulatory agencies permitting impoundments. This review was also focused on the applications of geotextiles in coal refuse embankments and in the application of the drainage control drains in the coal refuse impoundments in the field.

The third stage of literature review addressed the study of microscopic techniques, which in turn, helps in determining the clogging potential of the coal refuse in the geotextiles. Certain methods which are used for the determination of the constriction size, apparent opening size of geotextiles were also studied which helps in finding the filtration performance of the geotextiles.

2.1. Coal refuse background and properties

Under this section the types of coal refuse, properties and variability of the material were studied. This section includes discussions on the types of coal refuse transport. The coal refuse properties are reported from the major work compiled by the Mine Safety Health Administration (MSHA).

2.1.1. Coal refuse and types

B.R. Stewart and W.L. Daniels defined coal refuse as material which is cleaned from the coal at a preparation plant. The coal refuse can be found in various forms such as: tailings, spoil, gob, slate, and colliery waste. Coal refuse is a by-product obtained from mining and preparation of coal (R.A. Busch, R. R. Baker, L. A. Atkins 1985 and D'Appolonia 1976) and generally consists of two types: i). coarse coal refuse (CCR) and ii) fine coal refuse (FCR). Coarse coal refuse mainly consists of coal and soil; it is also used as the primary engineered fill for the construction of impoundments or impounding structures. CCR is also used to construct the dams and to serve as the embankment to retain fine coal refuse and water slurries. FCR consists of coal, water and dust and soil mixture. The carbon content is higher in FCR when compared with the CCR. The typical structure of a coal refuse impoundments is similar to an earthen fill dam, differing mainly by the material used for construction. MSHA (2009) states that coal refuse is composed of materials such as shale and variable amounts of coal which makes the coal refuse typical kind of soil having lower specific gravity and densities than the other soils.

2.1.2. Production of coal refuse from preparation plant

Coal refuse is the by-product of coal processing. Coal is a sedimentary rock consisting of elements of carbon, hydrogen and oxygen. MSHA (2009) provides details of the coal refuse produced from coal preparation plants. The main production of coal refuse is from the mining and preparation plants. Coal refuse is comprised of rock, minerals and coal unavoidably removed from the earth during the coal mining process. The proportion of coal and associated minerals depends on geologic formation of coal stratum, geochemical properties of coal and adjacent minerals, process used to separate coal from refuse. The primary source of the rocks and minerals that are associated with the coal refuse are from the formations from coal seam and sediments within the coal seam.

2.1.3. Refuse transport and disposal placement

Prior to Buffalo Creek failure, there was very little technical information available for the design of coal refuse disposal facilities. After Buffalo Creek dam failure accident, the safety in disposal and the technical effort was highly increased. The transport and disposal of coal refuse is very important because due to the material's typical nature, coal refuse may undergo changes in its engineering properties which in turn may affect the life of the disposal facility. MSHA (2009) provides the details of the coal refuse transport systems that are generally used. Depending on method of refuse transport and disposal, the geotechnical characteristics of coal refuse varies. The compaction effort used for the disposal of coal refuse is one of the main points to be considered.

Transport of the coal refuse is generally done by trucks, scrapers, and conveyors. For the transport of slurry or fine refuse pipelines are used. The type of transport depends on several factors which include: the distance between preparation plant and disposal area; production rate of coal refuse supply; properties of the coal refuse and or grain size; and finally the aerial extent and type of disposal facility. Generally tractor dozers are used for spreading the coal refuse in the disposal facility. If proper care is taken while placing the coal refuse, tractor dozers can effectively spread in horizontal layers. Discharge of fine coal refuse should be such that the discharge point is relatively low on the impoundment side or upstream face of embankment. Compaction equipment is mainly used for the uniformity of coal refuse in disposal facility. The compaction effort that is used for the refuse placement is critical because it controls the material's density and the associated strength of the piles as well as the hydraulic conductivity. The compaction effort changes the grain size distribution of particles which is a primary concern during construction. The compaction equipment typically used for the construction of the structural fill includes rubber-tired hauling units, vibratory rollers (smooth drum or sheepsfoot) and non-vibratory rollers.

2.1.4. Coal refuse properties

Various physical and chemical properties and geotechnical properties which include index properties and engineering properties are to be investigated because it will help in designing coal refuse disposal dams and impoundments. The clogging effect of filter is also based on these properties. Particle size distribution is one of the important properties to be considered as the clogging nature is based on the fine particle intrusion.

Physical and chemical properties

Coal refuse will have several properties similar to the properties of the parent coal seam. The rocks present in coal wastes include sedimentary rocks such as sand stone, quartz, clay composed rocks and other blends of rock with high percentages of shale and carbonous shale. Rocks with clay compositions are present in higher percentages than other rocks. The main minerals that are present in the coal refuse are sulfur, carbonates, quartz. Pyrite is also present in the considerable amounts in coal refuse. The other minerals that are present in clay rocks are also present in coal refuse such as illite, kaolinite, chlorite, etc. Quartz is present in higher percentages in coarse refuse than in fine refuse. The oxidation effect of coal refuse can cause various problems to the environment because of the pyrite and the sulfur present. These materials when in contact with air and water react to form acids.

Chemical properties are considered important because they may produce adverse environmental effects and, or destroy the construction material (borrow materials). The main chemical components that are present in the coal refuse are silica (SiO_2) and alumina (Al_2O_3). Other chemicals include ferric oxide and potassium oxide. The main chemical properties such as pH, ash content, corrosivity, pyrite content helps to assess the chemical behavior of coal refuse. B.R. Stewart and W.L. Daniels provide ranges of pH values for coal refuse from Southwest Virginia. The pH varied from 3.0 to 8.3. Jacek Libicki, Stephen R. Wassersug, and Ronald D. Hill presented the different properties of coal solid wastes from a disposal site in Poland, Table 2.1

Table 2.1: pH and conductivity values of Coal waste from Poland site.

Property	Maximum	Minimum	Average
pH	9.9	7.3	8.4
Conductivity	2140	500	1500

Geotechnical properties

The geotechnical properties of any soil can be classified into index properties and engineering properties. The index properties are the moisture content, specific gravity, particle size distribution, Atterberg limits, and unit weight. The engineering properties of coal refuse include hydraulic conductivity and strength.

Y. A. Hegazy, A. G. Cushing and C.J. Lewis provide discussions on the physical, mechanical and hydraulic properties and relationships of coal refuse used for the slurry impoundment design. The properties of CCR and FCR are critical in designing the coal refuse disposal dams and impoundments for both static and seismic stability. The authors state that CCR is used to construct dams to retain slurry of FCR and water whereas FCR is used for the prediction of seepage conditions, designing internal drains and evaluating static and seismic upstream slope stability.

A database for the properties of CCR and FCR was developed using data from coal refusal disposal sites in Western Pennsylvania, USA, and England (Chen 1976). The variability of each material properties were evaluated using the coefficient of variation (COV) and then a simple first order statistical method was used to determine the reliability using the average material properties for different geotechnical aspects. Table 2.2 presents a summary of the grain size distribution data collected by Y. A. Hegazy, A.G. Cushing and C.J. Lewis for coarse and fine coal refuse respectively.

Table 2.2: Summary of CCR and FCR sieve analysis

Percent Finer	CCR	FCR
D_{10} (mm)	< 0.075	0.010
D_{30} (mm)	0.35	0.037
D_{50} (mm)	1.23	0.127
D_{60} (mm)	2.02	0.196
Passing #200 sieve	19.76%	57.7%
Specific Gravity (G_s)	2.02	1.52

MSHA (2009) illustrates the typical grain size distribution of coarse and fine coal refuse that are being disposed into impoundments. The grain size distribution of both coarse and fine coal refuse is important because it will affect the clogging nature and the fine particle intrusion into the filter. Generally coarse coal refuse is a well-graded material and its properties are similar to well-graded rock and soil fill. The particle size of CCR ranges from 4.75 mm to a size of 3 inches and the fines percentage vary from less than 10 percent to 20 percent. Typical classification of CCR is silty, clayey sand with gravel to clayey, silty gravel with sand. Fine coal refuse typically has particle sizes less than 1 mm and fines content ranging 30 to 80 percent. Samples of FCR collected close to the discharge point or delta area on an impoundment are more of the sand and silt-size material and the samples collected towards the pool area of the impoundment tent to be of the silt and clay-size materials.

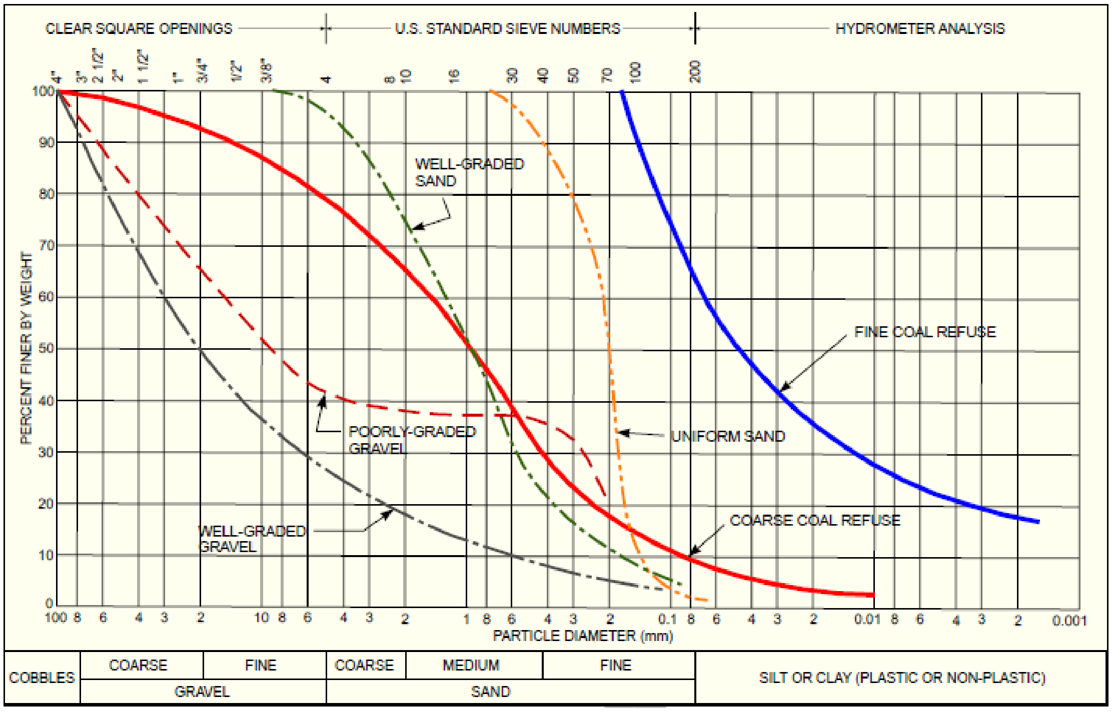


Figure 2.1: GSD of Coarse and Fine coal refuse specified by MSHA (2009)

Representative Geotechnical properties of the coal refuse are given in below Table 2.3 and Table 2.4.

Table 2.3: Coarse coal refuse Properties by Y. A. Hegazy, A.G.Cushing, & C.J. Lewis

Coarse Coal Refuse Properties			
Property	Average	Standard Deviation	COV
Dry Density, γd(KN/m3)	19.7	0.93	0.047
Specific Gravity, Gs	2.02	0.31	0.154
Water Content, %	6.4	1.6	0.252
D10 (mm)*			
D30 (mm)	0.35	0.25	0.71
D50 (mm)	1.23	0.62	0.5
D60 (mm)	2.02	0.89	0.44
Passing No. 200	19.76%	10.79	0.55

Table 2.4: Fine coal refuse Properties by Y. A. Hegazy, A.G.Cushing, & C.J. Lewis

Fine Coal Refuse Properties			
Property	Average	Standard Deviation	COV
Dry Density, γd(KN/m3)	9	1.46	0.162
Specific Gravity, Gs	1.52	0.25	0.165
LL	31.20%	5.2	0.17
PL	20.10%	3.4	0.17
PI	11.2	3.1	0.28
Water for Atterberg Limits	33	11.5	0.35
D10 (mm)	0.01	0.015	1.5
D30 (mm)	0.037	0.055	1.49
D50 (mm)	0.127	0.128	1.01
D60 (mm)	0.196	0.209	1.07
Passing No. 200	57.70%	25	0.43

MSHA (2009) states that coal refuse contains various kinds of material which affect the specific gravity values of coal refuse. MSHA specifies the specific gravity values for coarse coal refuse ranging from 1.5 to 2.8 and fine coal refuse ranging from 1.4 to 2.3. Based on various observations and field tests MSHA (2009) gives the range of hydraulic conductivity for coarse coal refuse ranging from 10^{-6} to 10^{-2} cm/sec.

2.1.5. Variability of coal refuse properties

Estimating the variability of coal refuse properties assists with assessing the safety of coal refuse disposal facilities. Variability encountered in the coal refuse properties is a major source of uncertainty encountered by the geotechnical engineers during the material selection, site characterization, analysis and design (S.C. Cheng and M.A. Usmen 1987). The true values of geotechnical parameters cannot be determined with full accuracy. These values can be estimated using representative numbers of laboratory tests and from field tests. The inconsistencies of the test results are attributable to the inherent heterogeneity of the materials as well as the errors arising from the sampling, testing and human judgment (P. Lumb 1974).

Coal refuse is produced in significant quantities in United States and also all over the world. The disposal of the coal refuse has been a problem from many years. Coal refuse impoundments are constructed for the safe and efficient disposal of refuse. The traditional approach to the assessment of the safety of a coal refuse disposal facility as a part of design processes has been the use of a deterministic factor of safety (FS), which can be obtained by the use of a single value for each of those material properties considered. The single value can be taken as uncertainty of the true value (S.C. Cheng and M.A. Usmen). Recently, considerable interest has been focused on the use of probability and statistics (P. Lumb, 1974 and M. E. Harr, 1984) in the analysis and design of geotechnical structures to account for the variabilities and uncertainties associated with the input parameters.

Variations in the properties of coal refuse may be attributed to: mineral composition, different kinds of soils present; geologic process such as erosion, weathering, transportation, depositional changes, which cause heterogeneity and anisotropy (property which changes with direction, e.g., permeability). Variability of coal refuse properties can be measured by first considering the appropriate sample size for the data reduction and determining the following statistical parameters: the average, standard deviation (SD) and the coefficient of variation (COV). COV is defined as the normalized dispersion of the set of data points around the mean, which is the ratio of standard deviation to the mean. Table 2.5 illustrates the variability of properties of the coarse and fine coal refuse in terms of average, standard deviation and COV.

The index properties and the engineering properties are critical in designing the coal refuse disposal dams and embankments. The variability of these design properties should be investigated. Typically the ranges of COV below 10% is thought to be low, between 10% and 30% are thought to be moderate, and above 30% are considered as high (Harr, 1987). Table 2.5 indicates the natural water content has "high" coefficients of variation for both coarse coal refuse (CCR) and fine coal refuse (FCR), specific gravity and *in-situ* dry density have moderate coefficients of variation for both CCR and FCR, whereas permeability has a very high coefficient of variation for both CCR and FCR. This comparison illustrates that engineering properties are significantly more variable than index properties.

Reliability and risk assessment of coal refuse

S.C. Cheng, M.A. Usmen (1987) presented a method for assessing the reliability and risk of coal refuse due to variability of coal refuse properties. The safety of coal refuse disposal facilities is conventionally measured by a deterministic factor of safety. The Factor of Safety is determined by using single valued geotechnical properties of coal refuse, the foundation profile (subsurface exploration), and an estimate of pore water pressure conditions (Phreatic line) and the disposal facility geometry. The factor of safety alone does not identify the risk associated with the designing disposal facilities; therefore a probabilistic approach where alternative parameters such as the reliability index or probability of low factor of safety are required.

Table 2.5 Variability of Coal Refuse Properties

Type of Refuse	Natural Water Content, %			Specific Gravity			In-situ Dry Density, pcf			Permeability 10-4 cm/sec			References
	X	COV	N	X	COV	n	X	COV	n	X	COV	n	
Coarse Coal Refuse	6.1	22	9	2	10	9	90.6	9.8	9	1.38	105.6	10	R1
	5.5	26	6	2.2	2.7	6	92.2	18	6				
	7.2	14	5	1.9	9	5	88.6	9.8	5				
	9.6	35	122	1.7	1	21	98.1	11	122				R2
	5.9	51	80	1.2	5.7	8	98.9	8.4	80				
	10	59	93	2.3	-	1	101	13	93				
				2	14	47	93.2	14	47				
Fine Coal Refuse	54	8.6	15	1.6	4.4	15	52.1	5.2	15	0.07	209.2	15	R3
	49	32	13	1.7	10	13	52.5	7.9	13	4.22	244.3	13	
	30	42	19	1.5	7.3	19	53.9	13	19				
	31	23	11	1.8	9.7	11	62.4	11	11	8.7	221.7	19	R4
	13	29	4	1.5	3.6	10	49.7	6.7	4				
				1.6	14	49	56.2	17	49				
										1.31	143.7	10	R3

R1- R.A. Busch, R. R. Baker, L. A. Atkins 1985.
R2- Files of West Virginia Department of Natural Resources, West Virginia.
R3- R.A. Busch, R. R. Baker, L. A. Atkins 1975.
R4- R.A. Busch, R. R. Baker, L. A. Atkins 1977.

By using the sample size, mean, standard deviation, the Factor of Safety (FS) is determined using the point estimate method (PEM) (E. Rosenblueth, 1975). The Reliability index is a term used for the determining the reliability of the geotechnical structure. The Reliability index (β) indicates the normalized distance between best estimate of FS and the nominal impending failure mode of 1.0 in terms of the SD. The higher the β value, the higher the reliability of the geotechnical structure. It is generally agreed that a minimum deterministic factor of safety of 1.5 must be attained in coal refuse disposal facilities (S.C. Cheng, M.A. Usmen).

MSHA specifies that the test results data should be verified and validated before using the data for the design process. Engineering properties should be quantified. Correlation should be developed on the basis of large data set and the main point to be known is that correlation will be based on data upon which it is used. The minimum factor of safety for the coal embankment design provided by MSHA is 1.3. The factor of safety was based on strength properties of coal refuse.

2.2. Coal refuse disposal facilities

Coal refuse disposal facilities are constructed for the primary purpose of disposing of coal wastes produced from mining processes. The safety of these coal refuse disposal facilities is major concern. According to MSHA (2009), the Buffalo Creek dam failure which occurred in 1972 in Logan County, West Virginia was due to severe rainfall and inconsistent construction methods. The rainfall caused the upstream impoundment, of a three tiered diked coal refuse disposal facility, to overtop and cascade the coal slurry into the lower two slurry ponds. The lower ponds subsequently failed and lead to devastation in the downstream valley. Prior to the Buffalo Creek accident little attention was taken for the design and maintenance of the coal refuse impoundments. After that incident, coal refuse disposal facilities were upgraded in terms of design, inspection and safety standards. Standards were developed and research initiated to help the coal industry, public, and regulatory agencies construct safe impounding structures.

According to MSHA (2009) coal refuse disposal facilities are classified depending on their configuration, they are: 1. Impounding facilities, 2. Non-impounding facilities, 3. Slurry cell facilities, and 4. Underground injection facilities. An impounding facility is defined as a structure which will have the potential for holding water and slurry to a specified height. A non-impounding facility will have the embankment fill such that no liquids (water or slurry) may be impounded. These non-impounding facilities are used for the disposal of coarse coal refuse and fine coal refuse but not liquid slurry.

2.2.1. Failures in coal refuse impoundments

The main problems associated with the failure of the embankment are as follows:

- Seepage
- Slope stability
- Drainage

Design criteria and methodology are similar for earthen dams and coal waste impoundments. Both of these types of engineered facilities are susceptible to water damaging events. Many water retaining structures have inherent seepage challenges associated with their as-built construction. Slope failure and internal erosion are some of the detrimental problems caused by seepage. Internal erosion or piping can lead to uncontrolled seepage and drainage system failure which may further develop into embankment failure.

2.2.2. Seepage

Any water retaining structure will be associated with seepage problems. Seepage is the important concern in the design of embankment with an impoundment. Seepage through the foundation materials is also very important which needs to be controlled. Seepage may cause progression of erosion through the embankment or foundation of an impoundment. Piping is the phenomenon which occurs due to increase in the seepage. FEMA (2008) state that process of piping failure (which is caused by seepage) in earthen dams is divided into four phases. They are: 1) initiation, 2) continuation of erosion, 3) progression to form a pipe, 4) formation of breach. Suffusion is the other phenomenon develops due to the seepage and internal erosion. Suffusion is washing away of finer particles due to internal instability of the soils. FEMA presents the different types of models for the development of failure by piping and internal erosion. They are: 1) Backward erosion piping in the embankment, 2) concentrated leak piping in the embankment, 3) piping in the foundation and 4) piping from embankment to foundation.

Methods of controlling seepage

Seepage in the coal refuse embankments is controlled by installing the internal drains which are associated with the filters. The reason for installing drains is to increase the stability of coal refuse embankment by reducing the phreatic surface low and to control the seepage that leaves the embankment. Seepage in the foundation of an impoundment is collected by providing a collection system. The collection system consists of trenches or horizontal drains which are allied with filters. If the seepage in the foundation is not controlled, stability of the embankment reduces because of the excessive pore pressure built in the foundation. If seepage is high, the soils particles get erode away from embankment and also from foundation.

2.2.3. Geotextile application for seepage control

FEMA and MSHA suggest that one way of controlling seepage and internal erosion is by introduction of filters and high permeability zones within the embankment. Geotextiles are used as filters in coal refuse impoundments as per MSHA (2009). There are two main functions of filters: 1) they must allow water to flow through, and 2) prevent soil particles to pass through, or clog or blind the filter. According to FEMA (2007), the graded granular filter design criteria for embankments and foundations includes determining the following items: : 1) they must have appropriate openings or particle size distributions, 2) they must offer sufficient internal stability, as finer particles should not erode away from the filter due to seepage flows, 3) filters must have sufficient permeability and thickness, 4) they should have good survivability criteria for installation and operation, and 5) be resistant to segregation and breaking during installation, compaction.

Seepage flow in coal refuse embankments can be controlled by reducing the phreatic surface level of the impounded liquids and by reducing the phreatic levels within the embankment matrix. This can be achieved by installing internal drains within the embankment at critical locations. These drains should be incorporated with fine particle filters to mitigate the movement of fine particles into the drain (to prevent the clogging) and allow the seep to free flow into the drain and away from the embankment.

Problems associated with filters (geotextiles) in coal impoundments

Problems associated with geotextiles used in coal waste impoundment applications can include the following items:

1. Damage during installation
2. Long-term reliability of Geotextile to function without clogging.
3. Geotextile placement location – geotextile should be placed where it is accessible to repair.
4. A difference in compaction efforts cause damages to geotextiles.
5. Chemical deterioration (leaching) of the geotextiles due to chemicals present in the coal refuse.

Installation of geotextiles

Geotextiles which are byproduct of geosynthetics are used for the separation of granular drain material from the coal refuse and also as a replacement of graded granular filters. Nation Dam Safety Review Board currently recommends that geotextiles not be used as filters in locations where they would be critical to the safety of an embankment dam, citing concerns about the long-term capability of the geotextile to function without deterioration or clogging. But in most of the drainage and filtration applications, geotextiles are used as a replacement of graded granular filters because of economical advantage of geotextiles over granular filters. For the installation of geotextiles, appropriate engineering design is required or else they may cause serious problems. While installing geotextiles, flow conditions, piping resistance, clogging resistance and strength parameters should be properly specified.

The installation of geotextile in the foundation of Hughes Hollow Slurry impoundment (WVDEP, 2002) is shown in the following picture and the installation process is explained as below:

- Picture 1: Main centre drain (looking upstream) in the foundation.
- Picture 2: Filter fabric (geotextile) placement.
- Picture 3: Main centre drain (looking downstream) in the foundation.
- Picture 4: Coarse filter material placement in main drain.
- Picture 5: 24-inch metal corrugated pipe installed, filter fabric and coarse fill material.
- Picture 6: Fine filter material placement (looking upstream).
- Picture 7: complete filling of fine material.
- Picture 8: Main center drain looking downstream.

- Picture 9: wrapping of geotextile prior to soil placement.
- Picture 10: Placement of soil.

The installation of geoextile in the foundation drain of Hughes Hollow slurry impoundment is shown in Figure 2.2 and Figure 2.3.

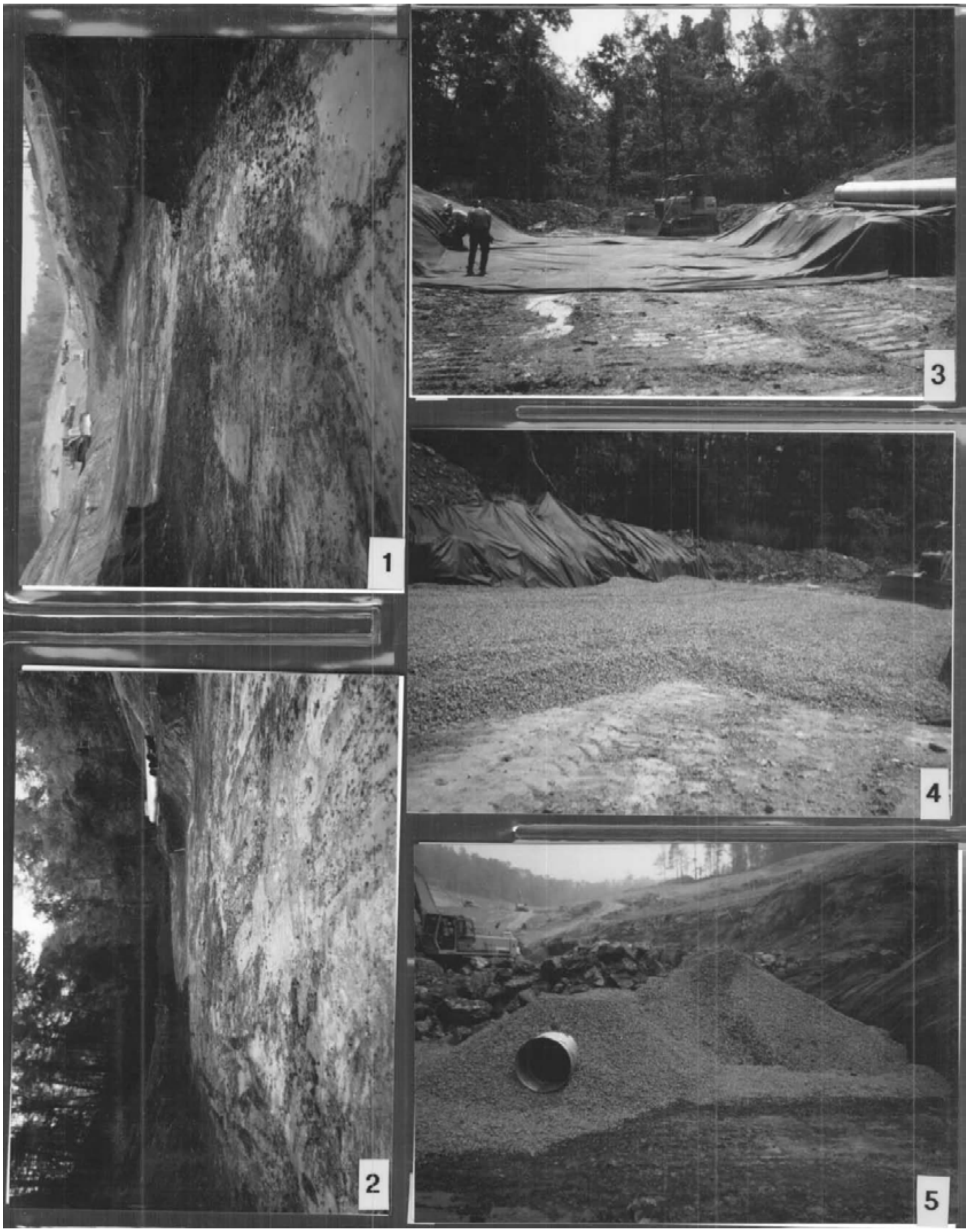


Figure 2.2: Installation of Geotextile in the foundation drain of Hughes Hollow slurry impoundment (Reproduced from WVDEP) - part I

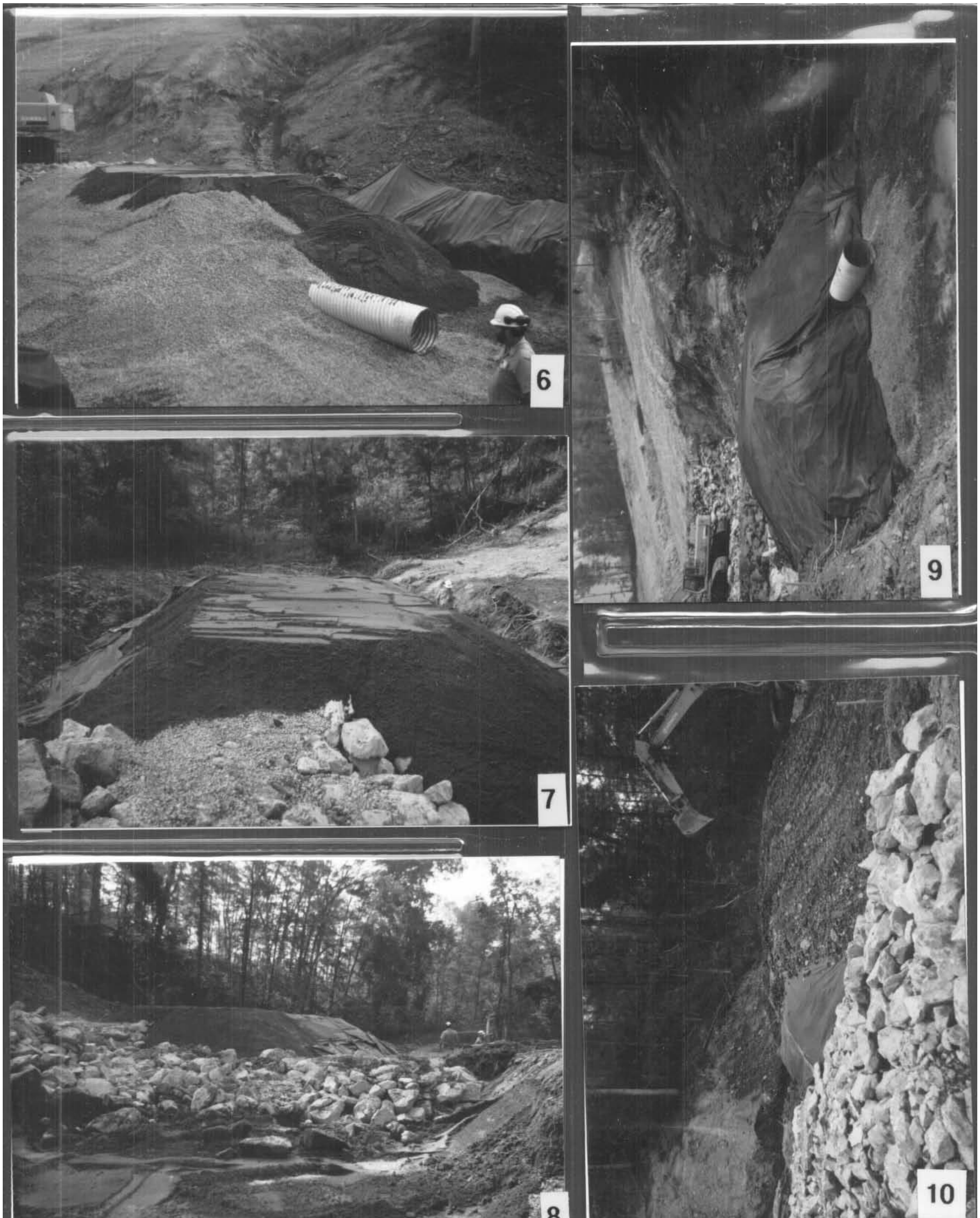


Figure 2.3: Installation of Geotextile in the foundation drain of Hughes Hollow slurry impoundment (Reproduced from WVDEP) - part II

2.3. Photo microscopy

<u>Overview of instrumental and analytical methods</u>

<u>Microscopy</u>

Three types of microscopy were utilized for this project. First was stereomicroscopy utilizing a Criac QDSII system capable of variable magnification from 5-57x. Images were captures using a PixiLink camera system. This is a reflection-type microscope suitable for viewing and imaging items such as the geotextile fabric recovered from the bottom of the cells. For the thin sections of the textiles, a transmission microscope was used (Olympus CX31) and images were captured using a Canon Powershot A620.

The third and final type of microscope used was a JOEL JSM6490LV scanning electron microscope (SEM) operating in the low vacuum mode. The SEM has a functional magnification range up to ~ 1,000,000x although such extreme magnifications were not needed or utilized in the project. The low vacuum mode allowed for imaging of materials such as polymeric mounting materials which are electrical insulators. Under electron beam bombardment, such materials build up a surface charge that overwhelms any useful image collection. With the low vacuum feature, a small amount of air is bled in, allowing for the formation of ions that neutralize the surface charge and allow for collection of good images.

The inductively coupled mass spectrometer (ICPMS) was used for elemental analysis and characterization of the coal refuse. This instrument, an Agilent 7500CX, draws liquid samples (prepared by acid digestion) into the plasma where atomization and ionization occurs. Ions, principally atomic such as Mg^{2+}, Fe^{2+}, etc. are then separated in the mass spectrometer to yield qualitative and quantitative information regarding elements present and concentration. In this project, the ICPMS was operated in a semi-quantitative mode, so results cannot be interpreted as exact, but rather as estimates. Most, but not all elements on the periodic table can be detected using ICPMS. In this project, a subset of elements was selected based on initial screenings. Those elements which were detected in the parts-per-billion range (~ 200ppb or above) in the solutions were selected for further evaluation and semi-quantitative analysis. An example of typical results is shown below in Table 2.6: ICPMS Screening Levels; concentrations listed here are for the solution, not the coal refuse itself. Elements such as sodium (Na) and potassium (K) were not evaluated given their typically high concentration as environmental background.

Table 2.6: ICPMS Screening Levels

Semi-Quantitation Report - Detailed (Text Only)
File Name : 006SMPL.D
File Path : C:\ICPCHEM\1\DATA\10B09S00.B\
Method : c:\ICPCHEM\1\DATA\09E08p00.B\SemiQNT.M
Acq Time : Feb 9 2010 06:44 pm
Sample Name : 020310 D2
Sample Type : Sample
Comments : HCl 1:10
Prep Dilution : 124.8 = (50.00 / 20.03) * 50.00
Auto Dilution : Undiluted
Total Dilution : 124.8
Operator Name: XZ
Acq Mode : Spectrum
Bkg File : --------
Bkg Rejected Masses: --------
Interference Correction : OFF
ISTD Correction: OFF
ISTD File : --------
ISTD Element 1 : --------
ISTD Element 2 : --------
ISTD Element 3 : --------
ISTD Element 4 : --------
Blank File : --------
Tune Step : #1

Mass	Conc.	Counts(CPS)	Bkg count	Time(sec)	
Li 7	180.0 ppb	180.0130	---	0.1	
Be 9	59.00 ppb	60.00399	---	0.1	
B 11	220.0 ppb	100.0050	---	0.1	
C 12	16,000 ppb	192,795.3	---	0.1	
N 14	No Data	---	---	---	
Na 23	36,000 ppb	406,472.4	---	0.1	
Mg 24	5,200 ppb	24,375.16	---	0.1	
Al 27	52,000 ppb	77,432.03	---	0.1	
Si 28	39,000 ppb	37,563.76	---	0.1	DCHARGE
P 31	4,200 ppb	550.0771	---	0.1	
S 34	51,000 ppb	1,040.167	---	0.1	DCHARGE
Cl 35	1.500E+8 ppb	2,278,198	---	0.1	
K 39	35,000 ppb	115,650.4	---	0.1	
Ca 42	120,000 ppb	5,422.532	---	0.1	
Sc 45	120.0 ppb	1,420.355	---	0.1	
Ti 47	460.0 ppb	360.0457	---	0.1	DCHARGE
V 51	190.0 ppb	3,862.601	---	0.1	OXIDE
Cr 52	260.0 ppb	5,854.830	---	0.1	
Mn 55	2,500 ppb	29,808.79	---	0.1	
Fe 56	430,000 ppb	5,603,231	---	0.1	

Co 59	910.0 ppb	14,567.83	---	0.1	
Ni 60	12,000 ppb	53,176.85	---	0.1	
Cu 63	13,000 ppb	140,922.5	---	0.1	
Zn 66	180,000 ppb	348,502.6	---	0.1	
Ga 69	1,700 ppb	10,393.29	---	0.1	
Ge 72	57.00 ppb	90.00565	---	0.1	
As 75	4,400 ppb	4,705.699	---	0.1	
Se 78	510.0 ppb	100.0062	---	0.1	DIMER
Br 79	26,000 ppb	3,581.009	---	0.1	
Rb 85	1,000 ppb	5,456.507	---	0.1	
Sr 88	11,000 ppb	74,425.55	---	0.1	
Y 89	590.0 ppb	7,303.944	---	0.1	
Zr 90	390.0 ppb	3,771.836	---	0.1	
Nb 93	<3.000 ppb	20.00104	---	0.1	
Mo 95	280,000 ppb	1,185,960	---	0.1	
Ru 101	<8.800 ppb	20.00104	---	0.1	
Rh 103	<1.500 ppb	10.00052	---	0.1	
Pd 105	<7.200 ppb	0.0000000	---	0.1	
Ag 107	9.700 ppb	150.0079	---	0.1	
Cd 111	64.00 ppb	170.0152	---	0.1	OXIDE
In 115	9.200 ppb	160.0094	---	0.1	
Sn 118	200.0 ppb	1,070.280	---	0.1	
Sb 121	33.00 ppb	180.0168	---	0.1	
Te 125	<190.0 ppb	10.00053	---	0.1	

I 127	71.00 ppb	250.0174	---	0.1
Cs 133	28.00 ppb	490.0703	---	0.1
Ba 137	7,900 ppb	22,355.98	---	0.1
La 139	220.0 ppb	7,453.552	---	0.1
Ce 140	570.0 ppb	22,525.83	---	0.1
Pr 141	86.00 ppb	3,473.229	---	0.1
Nd 146	340.0 ppb	2,621.946	---	0.1
Sm 147	130.0 ppb	800.1904	---	0.1
Eu 153	26.00 ppb	560.0949	---	0.1
Gd 157	110.0 ppb	930.2805	---	0.1
Tb 159	17.00 ppb	780.1967	---	0.1
Dy 163	100.0 ppb	1,060.388	---	0.1
Ho 165	12.00 ppb	520.0975	---	0.1
Er 166	37.00 ppb	510.0883	---	0.1
Tm 169	4.300 ppb	180.0204	---	0.1
Yb 172	25.00 ppb	240.0258	---	0.1
Lu 175	5.900 ppb	160.0107	---	0.1
Hf 178	15.00 ppb	150.0091	---	0.1
Ta 181	<1.300 ppb	30.00162	---	0.1
W 182	510.0 ppb	5,072.522	---	0.1
Re 185	<4.300 ppb	0.0000000	---	0.1
Os 189	<6.000 ppb	10.00054	---	0.1
Ir 193	<2.900 ppb	20.00109	---	0.1
Pt 195	<7.600 ppb	20.00109	---	0.1

Au 197	<6.000 ppb	10.00054	---	0.1
Hg 202	<21.00 ppb	40.00217	---	0.1
Tl 205	64.00 ppb	970.2304	---	0.1
Pb 208	3,900 ppb	40,439.50	---	0.1
Bi 209	110.0 ppb	1,700.486	---	0.1
Th 232	370.0 ppb	7,104.982	---	0.1
U 238	120.0 ppb	2,391.338	---	0.1
End of Report				
		Wed Feb 10 14:47:11 2010		

2.4. SigmaPlot

The software that has been used for the data reduction throughout the research was SigmaPlot 11. SigmaPlot 11 is a graphical and data analysis software package used to create graphs. SigmaPlot 11 has compatibility for Microsoft Office 2007, which means that Microsoft Office files can be directly imported into SigmaPlot without any conversions. For the statistical analysis also, SigmaPlot 11 was used. SigmaPlot 11 has complete advisory statistical analysis features.

3. APPROACH, MATERIALS AND METHODS

This chapter addresses the research testing approach, field materials used, and the testing methods followed for the project. The testing presented in this research was performed in conformance with the American Society of Testing and Materials (ASTM) standards.

The complete research analysis was primarily based on the two tests, hydraulic conductivity and grain size distribution. Figure 3.1 shows the picture of the complete research based on hydraulic conductivity and grain size distribution. Hydraulic conductivity testing program is explained in the figure 3.2 as a flowchart. ASTM D 5856 rigid wall compaction mold permeameter test is used for the hydraulic conductivity testing. Post grain size distribution tests are performed on hydraulic conductivity specimens. After the analysis of the laboratory testing, appropriate parameters are used for the geotextile design (using the MSHA criteria) for retention, permittivity and clogging criteria.

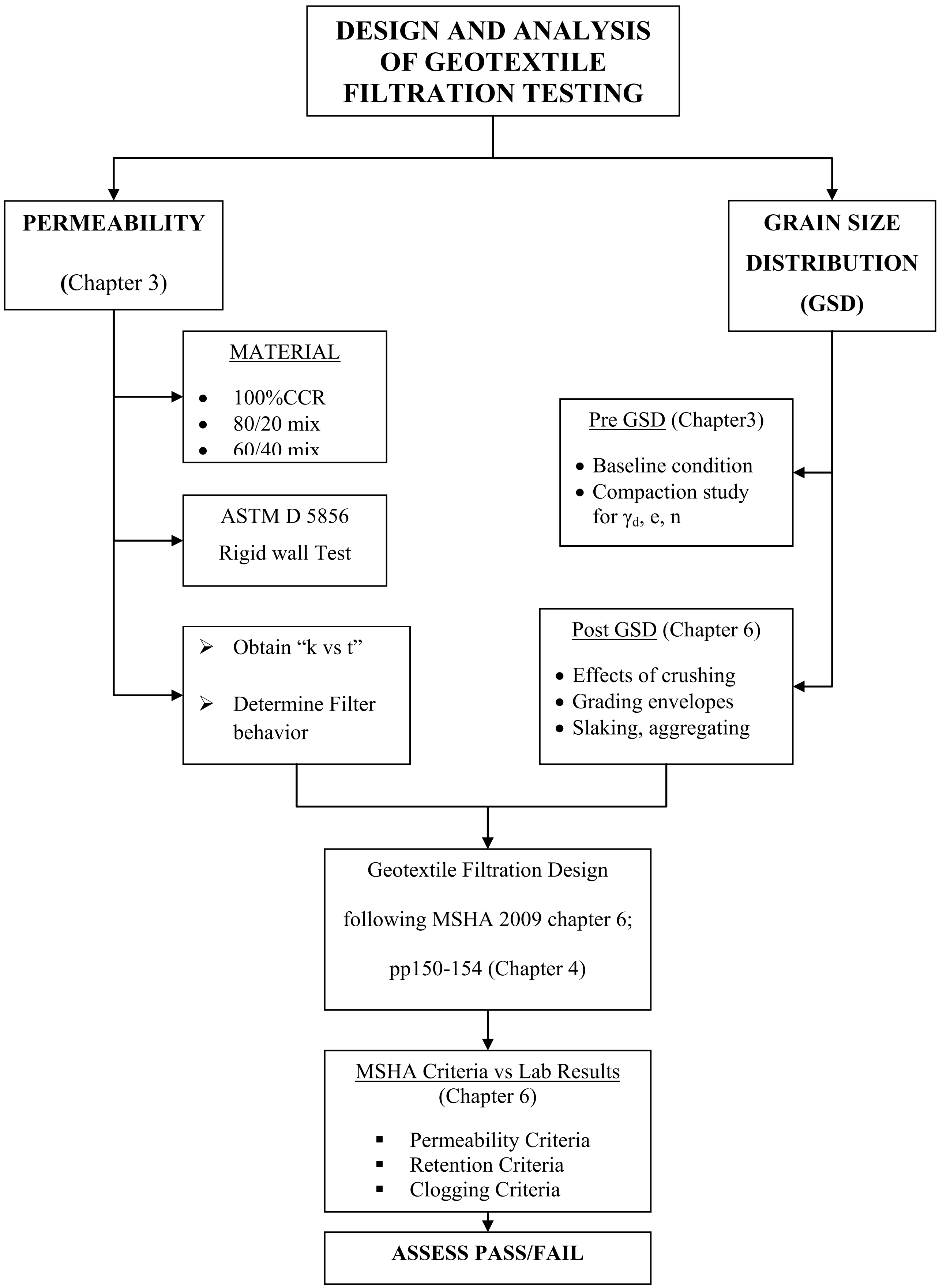


Figure 3.1: Research plan depending on permeability and GSD tests

3.1. Laboratory testing Overview

The laboratory testing program for this research was approached in three phases. The first phase consists of geotechnical material property testing of coal refuse in which various physical properties and engineering properties were determined. Second phase of laboratory testing was performed in different stages; the second phase consists of testing of non-woven geotextiles with coarse coal refuse to identify the fine particle intrusion (clogging) and the filtration performance (permittivity-drainage) of geotextiles. The coal refuse selected for the second phase testing was the same coal refuse tested in first phase. Second phase was done by carrying a standard test method for measurement of hydraulic conductivity of coal refuse. In second phase, coal refuse sample were compacted to different densities and the geotextile was used to find the filtration performance of coal refuse-geotextile system. Different seepage permeants and different geotextile were used. The chemical deterioration of coal refuse and armoring effects occurring at the geotextile fabric interface was also evaluated by using acid as permeant for hydraulic conductivity testing. The third phase of the testing program concentrates on photo microscopy testing on the geotextiles which were used for hydraulic conductivity testing from second phase. Laboratory testing of the samples was performed in the soil mechanics lab in Evansdale campus of West Virginia University. The third phase testing was performed in chemistry department lab in Oglebey hall in West Virginia University.

3.1.1. Phase-I:

In this stage, Geotechnical material property testing was carried out to find out the physical and engineering properties of the sample that were necessary for the research on geotextile testing. The materials tested in this research include both coarse coal refuse and fine coal refuse. Physical property testing of coal refuse was performed at the beginning and ending of the each test of the hydraulic conductivity testing in second phase in order to evaluate the material property changes due to particle filtration and piping effects. The main physical property that is evaluated in the second phase and compared with the first stage results is grain-size distribution.

3.1.2. Phase-II:

The second phase mainly concentrates on the geotextile testing with coal refuse to find the filtration performance of the geotextile. The geotextiles that are used all along this project are non-woven geotextiles. Different geotextiles i.e., having different openings were used The coal refuse used in this stage is coarse coal refuse and blended refuse which is mix of coarse coal refuse and fine coal refuse. Different mix proportions are used for the blended refuse. The selection of seepage permeant was based on ASTM requirements. The experimentation for this stage was performed based on the hydraulic conductivity test. Coal refuse was compacted to a certain density and the geotextile was placed beneath the compacted specimen and at certain gradient, seepage was allowed to flow through the specimen. The hydraulic conductivity of coal refuse geotextile system was calculated by measuring the outflow at certain intervals of time. Different compaction energies (or different compaction densities) were used for the hydraulic conductivity testing. Grain-size distribution was performed on the hydraulic conductivity samples after the test. Pre and post evaluation testing of the hydraulic conductivity samples was performed in this phase. Different criteria relating to geotextile such as retention criteria, permeability criteria and clogging criteria were evaluated based on the hydraulic conductivity test results and compared with field conditions where geotextiles are used for the filtration and drainage applications.

3.1.3. Phase-III:

This phase concentrates on the characteristics of non-woven geotextile that were used in the second phase for the hydraulic conductivity testing. This phase also mainly concentrates on coal refuse particle intrusion into the geotextile. To attain the particle tracking in the hydraulic conductivity specimens, the specimens were tested by using the microscopy testing in which the sample will undergo a testing method called core-cutting.

Analytical microscopy was also performed on the selected geotextiles that were used for hydraulic conductivity testing. The geotextiles were made into thin-sections of filters by using quick-freeze/thin slicing and chemical mounting techniques.

The summary of the hydraulic conductivity laboratory research plan is shown in Figure 3.2

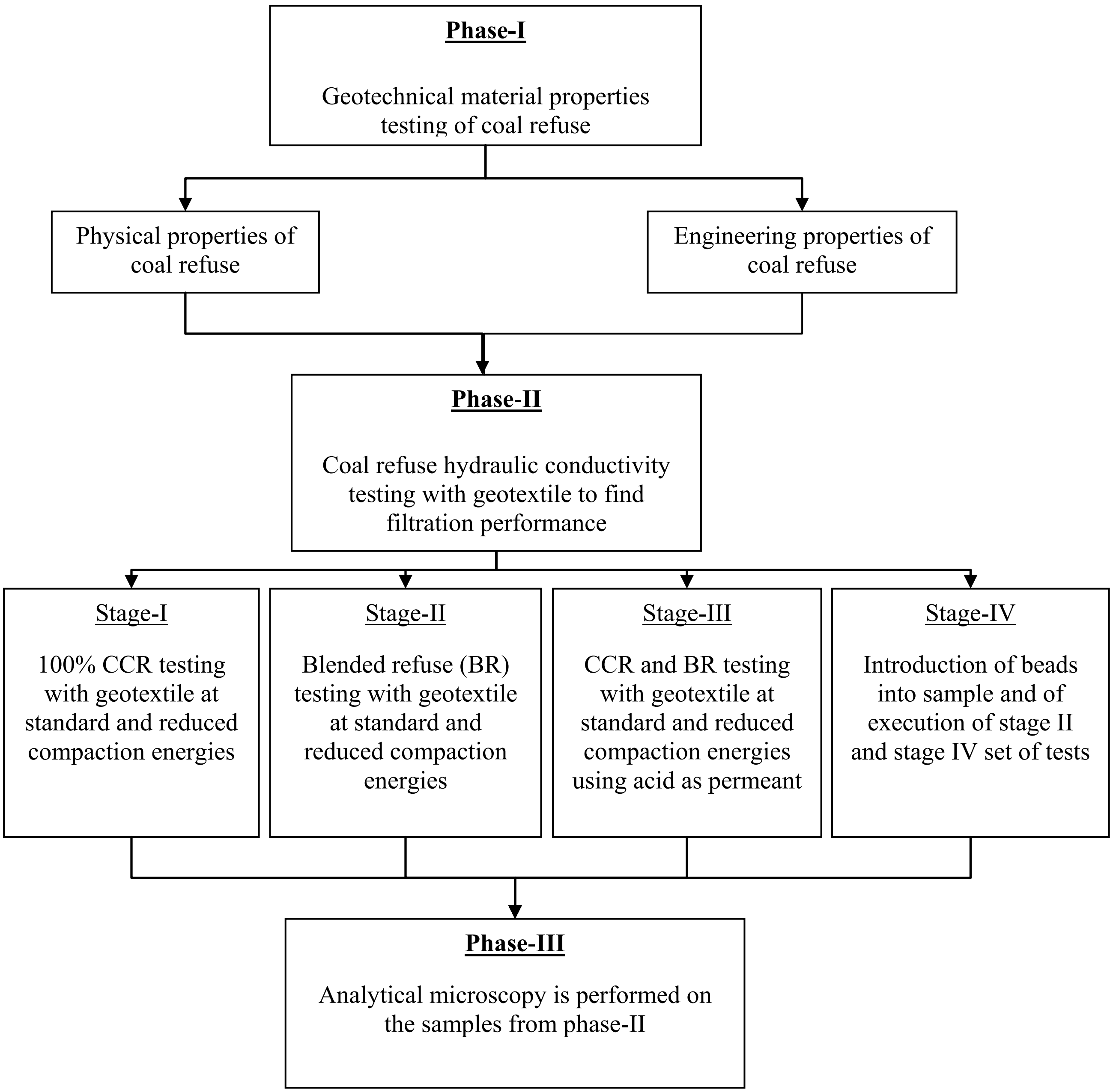


Figure 3.2: Summary of hydraulic conductivity laboratory research plan

3.2. Materials

The materials that were used for this research include coarse coal refuse, fine coal refuse and non-woven geotextiles. The other materials used for the research consists of filter paper, porous stone. The seepage permeant used in the third stage of second phase was acid with pH equals to 2.

3.2.1. Coal refuse

Two types of coal refuse are used for this research. They are coarse coal refuse (CCR) fine coal refuse (FCR). Both CCR and FCR were obtained from underground mining in Boone County, West Virginia, USA. The samples of coal refuse were obtained from randomly placed end dump piles and fine coal refuse was obtained from the preparation plant prior to pumping to the coal refuse impoundment at the mine. One set of coarse coal refuse was provided by WVDEP (West Virginia Department of Environmental Protection) and one set of fine coal refuse was provided by Mineral Laboratories, INC from Shoemaker, West Virginia, USA. The maximum particle size of the coarse coal refuse specimen was selected based on the scope of research. The as-received coarse coal refuse samples and fine coal refuse samples are shown in following Figure 3.3 and Figure 3.4 respectively.

Figure 3.3: Coarse Coal refuse

Figure 3.4: Fine Coal refuse

3.2.2. Non-woven geotextiles

The non-woven geotextile fabric samples were provided by the GSE Lining Technology Inc. and Propex Corporation. The list of non-woven geotextiles that were used for this research are listed below in the following Table 3.1.

Table 3.1: List of Non-woven geotextiles used

Apparent opening size	Geotextile type		
	NW 6	NW 16	NW 601
U.S. Standard Sieve	70	100	70
mm	0.212	0.15	0.212

3.2.3. Porous stone and filter paper

The filter papers that were used in this research followed ASTM requirements. The filter papers were bought from Fisher Scientific Company. The porous stones were obtained from the soils lab in West Virginia University.

3.2.4. Acid permeant

The seepage permeants used in the research were de-aired water and a sulfuric acid permeant having a pH equal to 2.

3.3. Methods

The ex perimental r esearch was p erformed i n t hree p hases. The f irst p hase was t he execution o f geotechnical material property tests for the coarse and fine coal refuse samples. The second phase was the testing of coal refuse specimen with geotextile by performing a hydraulic conductivity test using different permeants such as water, acid. The third phase will be testing of selected non-woven geotextiles that were tested in second phase using different techniques such as electron microscopy.

3.3.1. Phase-I: Geotechnical Material Property Testing

Geotechnical material property testing was carried out to find out the physical and engineering properties of the sample that were necessary for the research on geotextile testing. Physical property testing of coal refuse w as pe rformed a t t he be ginning a nd e nding of t he e ach t est i n o rder t o ev aluate t he material property changes due to particle used for filtration and piping effects. Various physical property tests and engineering property tests that were performed are listed in Table 3.2 and Table 3.3 respectively. All the geotechnical material property testing of coal refuse was performed in Soils lab in Evansdale campus of West Virginia University.

Table 3.2: Physical property tests

Physical Properties	
Test	ASTM
Moisture Content	D-2216
Sieve Analysis / Hydrometer	D-422
Atterberg Limits (LL, PL)	D-4318
Specific Gravity	D-854

Table 3.3: Engineering Property tests

Engineering Properties	
Test	ASTM
Standard Proctor	D-698
Modified Proctor	D-1557

Physical properties and engineering properties of coal refuse were required for the application of geotextile t esting i n seco nd st age. I n a ddition t o t he ab ove t ests, h ydrometer an alysis t est was al so performed t o i dentify c ohesive pa rticle pr operties. These t ests were p erformed b ased o n the r espective method that ASTM specifies.

The scope of work for this research gives the selection of maximum particle size of coarse coal refuse as per ASTM requirements. The maximum particle size tested will be fine-gravel ranging from ¾" (20mm) to No. 4 sieve (4mm). Inclusion of other fine particles was carried out to encourage clogging.

1. <u>Moisture Content</u>

The ASTM D 2216-05, method A (dry method) was used to determine the coal refuse moisture content in accordance with MSHA (2009). Highlights of the standard are that the coarse refuse samples were dried at 110^{o}C for 24 hours and then the dry weight measurements were taken. Moisture content test was performed in order to establish material phase relations of air, water and solids.

Typically, coal refuse is not significantly affected by oven drying process (MSHA 2009). The field collection of the coal refuse samples were performed on rainy days and the initial moisture content was not collected and the samples were not sealed from the ambient air-conditioning within the WVU geotechnical laboratory. Samples were air-dried for several days before moisture content tests were performed. Slight variations in the results of the moisture content tests were noted and are discussed later in this Data analysis section

Representative samples of coarse refuse were placed in containers as illustrated below in Figure 3.5 for determining the moisture content.

Figure 3.5: Containers and coal refuse sample for Moisture content test

2. *Specific Gravity*

Specific gravity is defined as the ratio of unit weight of given material to the unit weight of distilled water at 4°C. The method used for the determination of specific gravity was ASTM D 854 - Method A in which a water pycnometer was used. The specific gravity test followed the ASTM protocol without deviation. Briefly, the test was done by weighing the pycnometer containing coal refuse particles suspended in distilled water and taking the weight of equal volume of water in same pycnometer. An air vacuum was applied for 2 hours during the test.

Specific gravity test is performed because it is useful in finding the dry density, void ratio, and degree of saturation and is also used in the hydrometer analysis calculations. This test is also used to classify coal refuse because it is different from soils. Generally it is lower because of the presence of the carbon in higher percentages. As the carbon content increases, the specific gravity decreases which results in lower densities. So the specific gravity for fine coal refuse is much lower than the coarse coal refuse. MSHA (2009) gives the typical range of specific gravity values for coarse and fine coal refuse. For coarse refuse the range of specific gravity is 1.9 to 2.4 and for fine refuse it is 1.4 to 2.3. The apparatus that was used for the specific gravity test is shown in Figure 3.6.

Figure 3.6: Water Pycnometer and the sample for Specific gravity Test

The coarse refuse sample used for the specific gravity test was the sample passing No. 4 Sieve (as per ASTM D 854method A)

3. Atterberg Limits

Atterberg limits are the limits of water content used to define soil behavior (plastic/liquid). Atterberg limits are also used to classify the soil. Increasing water content in soil will progress from the solid state to semi-solid, plastic and finally liquid states respectively. The limits that are used to define the soil behavior are liquid limit (LL), plastic limit (PL) and shrinkage limit (SL). The liquid limit is defined as the water content at which soil becomes as liquid. Plastic limit is defined as the water content at which soil crumbles when rolled into 1/8 inch diameter threads. The liquidity and plasticity of coal refuse depends on the place where coal refuse was collected in impoundment. As the clay content will be high in slurry discharge point than other points in the impoundment, the plasticity and liquidity differs.

The ASTM D 4318 method was used to determine the Atterberg Limits for this research. Coal refuse samples for testing was selected as per the method. Certain water contents were taken to blend with sample. The blend is placed in liquid limit apparatus and a standard width groove was made using the tool and the cup is dropped until the groove closes and the number of blows was counted. The moisture content at which 25 blows was defined as liquid limit. Plastic limit test was carried using certain amount of coal refuse as per ASTM and blending with water. The water content at which the coal refuse begins to crumbles when rolled into 1/8 inch diameter is plastic limit. Plasticity Index (PI) is another property which is defined as difference of liquid limit and plastic limit. PI is useful in the classification of soil. The apparatus that was used for the liquid limit test is shown in Figure 3.7.

Figure 3.7: Liquid limit device

4. <u>Grain-size distribution and Hydrometer analysis</u>

Grain-size distribution is considered as one of the important properties of the soil. Grain-size distribution is useful in estimating hydraulic conductivity and also in finding the engineering properties of soil. The ASTM method used for the grain-size distribution was ASTM D 422. Grain-size distribution was carried using the sieve shaker. Certain representative sample of coal refuse was taken and it was sieved at least five minutes. The scope of this research gives the selection of maximum size of particle which was passing No. 4 sieve; the sieve analysis was mainly carried on the coal refuse particles passing No. 4 sieve. Table 3.4 gives the list of sieves used for the sieve analysis throughout this research.

Grain-size distribution can be used to design the filters to prevent piping in water-retaining structures (MSHA 2009) such as coal impoundments. Uniformity of soil is defined using terms uniformity coefficient (C_u) and coefficient of curvature (C_c). C_u is defined as the ratio of D_{60} to D_{10}, where D_{60} is the particle diameter at which 60 percent of soil weight is finer and D_{10} is the particle diameter at which 10 percent of soil weight is finer. C_c is expressed in terms of D_{10}, D_{60} and D_{30}. Sieves were cleaned each time after sieving. Sieve shaker used for sieving is shown in Figure 3.8.

Table 3.4: List of Sieves used

Sieve No.	Particle diameter(mm)
No. 4	4.75
No. 10	2.0
No. 30	0.595
No. 50	0.297
No. 60	0.25
No.100	0.149
No.140	0.105
No. 200	0.074

Figure 3.8: Sieve shaker with sieves in it

Sieve analysis, particle diameters were used to classify the coal refuse. USCS classification was used to classify the coal refuse with the sieve analysis. Grain-size distribution of Coal refuse particles finer than No. 200 sieve was carried out using hydrometer test as per ASTM method. Specific gravity was one of the main property needed while performing hydrometer test. Hydrometer test was carried out by making a blend of coal refuse sample passing No. 200 sieve and measuring the suspension of the particles in that blend using calibrated hydrometer. Dispersing agent sodium meta phosphate was used in hydrometer test. Two 1000ml flasks were used for the test. After each reading the hydrometer should be kept in other 1000ml flask and stirred so that particles attached to it go out. The hydrometer analysis apparatus is shown in Figure 3.9.

Figure 3.9: Hydrometer analysis with two 1000 ml flasks

Grain-size distribution was very important because it was performed at the beginning and ending of each rigid-wall permeameters test to evaluate the material property changes due to filtration.

5. Compaction test

In coal refuse impoundments, coal refuse is compacted to in design densities and used as structural fill. Compaction helps in reducing the seepage, constructing the earth dams. In coal refuse impoundments, compaction can be done by using rollers. Compaction test was also used to determine the engineering properties of the soil such as hydraulic conductivity. Standard proctor test was used for the compaction test. The ASTM method used for compaction was ASTM D 698. The objective of compaction test was to determine the optimum moisture content and maximum dry density of coal refuse within a given compactive effort. The sample used for the compaction test depends on the grain-size distribution of the coal refuse. ASTM D 698 gives the maximum size of the coal refuse material needed for the compaction test. The coal refuse sample used for the standard proctor test was material passing No. 4 sieve. Laboratory compaction testing can be evaluated with the field compaction using the standard proctor test.

The method used for the compaction was method A as per ASTM D 698. The procedure used for standard compaction test was to apply a standard effort of energy of 12,400 ft-lb/ft^3 (600 kN-mm^3) for the compaction of the coal refuse. The apparatus used for the standard compaction test was 4" diameter compaction mold with removable collar and base, rammer, and mixer for mixing the coal refuse with water and a jack to remove compacted sample from mold. The required coal refuse sample mass for one compaction test was about 25 pounds. Coal refuse sample was taken and then mixed with certain percentages of water. The point near optimum water content should be determined by visual judgment. Typically, the soil at optimum water content can be squeezed into lump and stick together when hand pressure is released and breaks into sections when bent. At least five specimens were prepared using different water contents. One should be at point near optimum and two specimens wet and other two dry side of optimum water content. For the standard compaction test, previously compacted coal refuse sample should not be reused.

Coal refuse samples were mixed with water and compacted in three layers with 25 blows /layer following the ASTM method. After the compaction the collar was removed and excess sample was trimmed to the surface of the mold. The empty weight of mold and weight of mold with compacted sample was taken. Degree of compaction of coal refuse was measured in terms of its dry density. Same procedure was followed with other water contents and then graph between water content and respective dry densities were drawn. The graph presents the optimum water content and the maximum dry density of the sample. Zero-air void curve was also determined and provides a check to the compaction results that no dry density curve should plot to the right of zero-air void curve.

MSHA (2009) gives the specifications for construction of compacted fill in coal refuse embankments and coal impoundments. MSHA described that density attained in the field be equal to or greater than certain percentage o f maximum density at tained i n t he l aboratory co mpaction t ests. No rmally f or st ructural embankment zones, MSHA recommends a (MSHA 2009) 95 percent of maximum dry density at optimum moisture content from standard proctor test will be used. MSHA specifications also include the water content should be near the optimum in range from 2 percent below or 3 percent above. The figures of compaction mold, mixer, rammer and jack are shown in Figure 3.10.

Figure 3.10: Compaction mold with removable collar and Rammer

After the compaction test the mold was taken out and discrete moisture contents of each specimen were taken by cutting the specimen into three equal parts or layer and collecting the small amount of sample from top, middle and bottom layers. Removal of compacted specimen form hydraulic Jack is shown in Figure 3.11. The figure of the mold for moisture content is shown below in Figure 3.12.

Figure 3.11: Removal of compacted specimen from mold using Jack

Figure 3.12: Layers of compaction mold specimen for moisture content

The density values obtained from the compaction curve were used for the compaction of the coal refuse in the rigid wall permeameter. Typically, the maximum density obtained from the compaction curve was considered and 95 percent of that maximum density at the corresponding water content was used for the compaction of the samples in rigid-wall permeameter. To evaluate the clogging effect and also fine particle movement of the sample in the rigid-wall sometimes under compaction energy is used. The compactive effort for the 95 percent density compacted samples and the under compacted samples was calculated using the compactive energy formula. The compaction energy formula uses the number of blows and the volume of the compaction mold to find the compactive effort. Compactive effort of each sample which was compacted in rigid-wall permeameter was taken.

3.3.2. Phase-II: Hydraulic conductivity testing of coal refuse with geotextile

The main experimental part of this research is the hydraulic conductivity testing of coal refuse samples which are associated with the geotextiles. The geotextiles filtration performance and the clogging effects were evaluated and estimated based on the hydraulic conductivity tests. Hydraulic conductivity is defined as the rate at which water or any other permeant flows through the soil of unit cross-section area of porous medium under particular head (pressure) and standard temperature conditions. The experimentation of hydraulic conductivity was based on following ASTM D-5856 *Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter* and ASTM D-2434 *Test Method for Permeability of Granular Soils (Constant Head).* ASTM D-5856 was selected rather than the gradient ratio test (ASTM D-5101) because it was considered as the best reflection of the condition of geotextile and refuse interface contact promoting clogging. Moreover, ASTM D-5856 applies to one-dimensional, laminar flow of permeant (water or acid) within laboratory compacted materials such as soils. In ASTM D-5856, using other permeant such as chemical wastes or acids can be accomplished using similar procedures.

Phase-II testing was performed in four stages. Stage one describes the hydraulic conductivity testing of only coarse coal refuse with non-woven geotextiles. Stage Two describes the hydraulic conductivity testing of blended refuse (BR) which was made using coarse coal refuse and fine coal refuse by using a special technique. The Third stage illustrates the hydraulic conductivity testing of both CCR and BR using acid as the permeant. The Forth stage demonstrates the set of tests performed in second and third stage with the introduction of metal filament shavings (beads) in the hydraulic conductivity testing specimen.

Stage I: Geotextile Testing with Coarse coal refuse

Hydraulic conductivity was measured in the laboratory by percolating permeant through a coal refuse sample of known density and volume. The testing in this stage follows ASTM D-5856 without any deviation. Prior to the hydraulic conductivity experimentation various physical property and engineering property tests were performed in Phase-I. The main properties that assist in this stage are grain-size distribution and compaction. Grain-size distribution can be used to estimate the hydraulic conductivity of the coal refuse and also in design of filters in coal impoundments.

Apparatus

For the hydraulic conductivity testing throughout the research the same testing apparatus were used and are shown below:

Constant head (pressure):

A system which was capable of maintaining a constant hydraulic pressure or head with in ±5% tolerance on the soil specimen was used. A panel board having pressure gauges installed was used to measure the hydraulic pressure and is shown in Figure 3.13, below.

Figure 3.13: Pressure board for Hydraulic conductivity test

Flow measurement system:

The flow measurement system includes the measuring structures for inflow and outflow of the system. For the inflow of the permeant, reservoirs were used and had volumes scale to monitor the accuracy of the permeant volume. One inflow reservoir held a volume of 4000ml. Outflow volumes were measured using graduated cylinders on the outflow port of the permeameter. The graduated cylinder and inflow reservoir are shown in Figure 3.14.

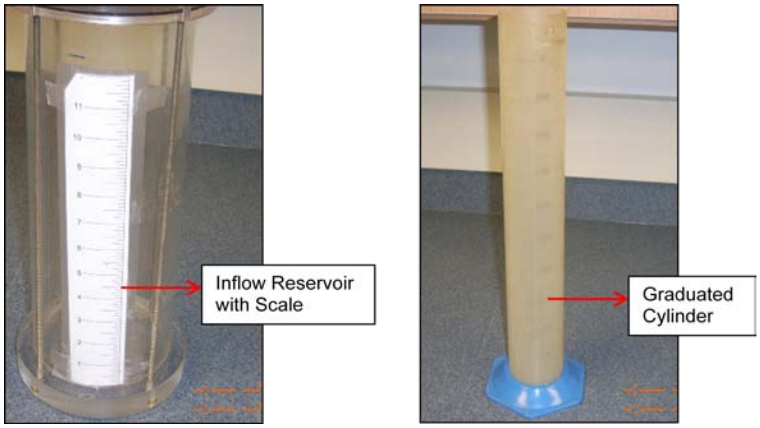


Figure 3.14 : Reservoir and Graduated cylinder

The flow accuracy for the flow measurement system was maintained over an interval of time of ±5% or better.

Permeameter cell:

The testing apparatus permeameter consists of rigid-wall permeameter in which the coal refuse is compacted. The complete permeameter should consist of rigid-wall cell, two end plates one at the top and one at the bottom to control inflow and outflow of the permeant. The rigid-wall apparatus is shown below in Figure 3.15.

Figure 3.15: Rigid-wall permeameter cell

Other apparatus:

The other apparatus or materials used for the hydraulic conductivity system are top plate, bottom plate, filter paper, porous stone, O-rings, Glue, scale, oven, balances, compaction equipment, tubing with 1/8” and ¼” diameter, and clamping rods which are associated with permeameter cell.

Permeant water:

The permeant used in this stage was de-aired water and was made by applying vacuum to the distilled water until the water stopped yielding bubbles. After de-airing, the reservoir was closed in order to prevent the dissolution of air back into the water.

Procedure:

The scope of the research gives the selection of coarse coal refuse for the hydraulic conductivity testing is the material passing No. 4 sieve (4.75mm). The setup of compaction mold permeameter is explained as follows: Coarse coal refuse materials were compacted in the compaction mold. On the base plate of the permeameter cell, porous stone will be placed. The base plate and the top plate were sealed with O-rings by applying glue to prevent leakage. Selected geotextile fabrics were placed between the bottom porous stone and the compacted sample. Two filter papers were used; one was placed at the top of the compacted sample between specimen and the top porous stone and the other filter paper was placed between geotextile and the bottom porous stone. The setup of the permeability cell followed ASTM protocol with no deviations. The schematic view of permeability cell is shown in Figure 3.16.

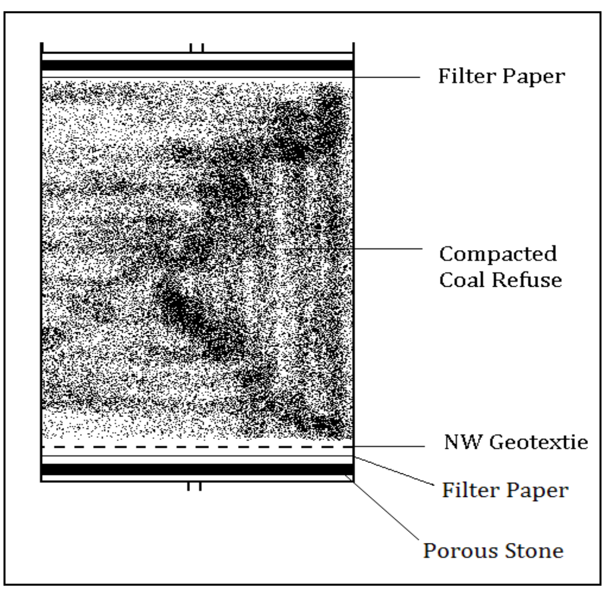


Figure 3.16 Permeability cell setup

An upset test was performed on the experimental setup to check the head losses in the system (tubes, porous stones, filter paper). The upset test was performed by assembling the permeameter cell without any specimen inside but with porous stones, filter paper at the top and bottom and then hydraulic system filled. The head to the system was applied with an accuracy of ±5%. For upset test was constant rate of flow was used. After the upset test (i.e. when leakages were not present in the system) the specimen set-up was executed. Prior to the compaction of the coal refuse, filter papers were cut to approximately the same shape as the cross section of the test specimen. Both filter papers and porous stones were soaked in the de-aired water prior to the test. The major purpose of filters papers was to prevent the clogging of the porous stones.

Rigid-wall permeameter was cleaned well prior to the compaction. To compensate for the placing of porous stone and geotextile layer in the rigid-wall setup a porous stone was placed at the bottom of the compaction mold while before compaction. Prior to the compaction, the dimensions and the mass of the compaction ring were determined using a balance. Coarse coal refuse passing No. 4 sieve was selected for the compaction. The coarse coal refuse materials were compacted to specified densities by varying the water content and compaction energy in the permeability cell. The coal refuse was compacted in layers, and for every layer the surface was lightly scarified with an appropriate object. For the compaction of coal refuse standard test method ASTM D 698 was followed. After the compaction of coarse coal refuse, the mass of the compaction ring with the compacted specimen was determined. The mass of the compacted specimen (M) was determined by subtracting the mass of the compaction mold from the mass of the compaction mold plus test specimen. The compaction energy (E) used for the compaction of coal refuse was calculated by using the equation as shown below:

$$E = \frac{[(No.of\ blows\ per\ layer)*(No.of\ layers)*(Weight\ of\ hammer)*(Height\ of\ hammer)]}{Volume\ of\ mold} \ldots\ldots (3.1)$$

The weight of the hammer and the height of the hammer were constant for any specimen. So the compaction energy was mainly calculated based on volume of mold, number of layers, and the number of blows. The water content of the compacted material was calculated in accordance to ASTM D 2216. The calculation of moisture content (w) helps in finding the dry density of the compacted specimen. The total volume of the test specimen (V) was calculated using the length (L), radius (R) of the specimen as follows:

$$V = \Pi R^2 L \ldots\ldots (3.2)$$

The dry density (γ_d) and the porosity (n) of the compacted specimen was calculated using the formulae

$$\gamma_d = \frac{M}{(1+w)V} \quad (3.3)$$

$$n = 1 - \frac{\gamma_d}{G_s \gamma_w} \quad (3.4)$$

Where,

γ_w= unit weight of water

G_s= specific gravity of the coarse coal refuse

The pore volume in the test specimen was calculated using the formula as shown below:

$$V_p = nV \quad (3.5)$$

Where,

n= porosity

V= total volume of the test specimen

V_p= pore volume

For the geotextile clogging tests using coarse coal refuse the selected non-woven geotextile was cut to the circular profile of the permeameter cross section; a porous stone and filter paper layer were next placed in contact with the compacted refuse specimen. After setup, the specimen was saturated for a certain period of time using de-aired water. The seepage water initiated from the bottom ports for upward saturation and for venting of the entrained air. After saturation, the test was started with hydraulic gradients initially ranging from 5 to 7 and that were consistent with the ASTM standard. The permeant volumes of inflow and outflow were measured periodically and the experiment was conducted until completion of at least one reservoir volume which is about 4300 ml. The hydraulic conductivity apparatus setup is shown below in Figure 3.17.

Figure 3.17: Hydraulic Conductivity apparatus

The hydraulic conductivity was calculated on the following form of Darcy's law:

$$k = \frac{QL}{Ath} \qquad (3.6)$$

Where:

k= hydraulic conductivity, m/s,

Q= volume of outflow, m^3,

L= length of the specimen, m,

A= cross-sectional area specimen, m^2,

t= interval of time in which Q occurs, s,

h= hydraulic gradient

After the experimentation of the CCR at standard compaction energies the CCR was tested at reduced compaction energies. The compaction energies were reduced in order to simulate filed conditions and to simulate an increasing clogging effect at refuse-geotextile interface due to mobilized or piping of the fines. Several different compaction energies were tested to model a range of placement densities from optimum to loose (end dump) conditions. These compaction energies are shown in Table 3.5.

Table 3.5: Compaction energies

Configuration of Permeameter Compaction	Compaction Energy kJ/m^3 (ft-lb/ft^3)
Standard Proctor (ASTM D698)	592.5 (12375)
25 Blows/layer, 3 layers	636.21 (13288)
4 Blows/layer, 2 layers	67.84 (1417)
8 Blows/layer, 2 layers	135.73(2835)
12 Blows/layer, 2 layers	203.58 (4252)

The grain size distribution of the coal refuse within the permeameter was evaluated at the end of the permeability test. This testing involved removal of the refuse specimen using a hydraulic piston jack then segregating the specimen into four parts: top and middle 1/3, then one-half of the remaining bottom 1/3. The extracted refuse specimens were dried and then grain size distribution analysis was determined. The grain-size distribution of specimen at the beginning and at the end of the test were compared in order to evaluate the potential material property changes; such as an increase in fine particle percentages resulting from the compaction process with varying energy efforts, as well as the potential of fine particle movement within the specimen matrix in the direction of seepage flow. The post grain size distribution depends on the drying time of the specimen and the compaction effort used. The crushing effort on specimen for post grain size distribution was executed such that individual grain size should be less than 4.75 mm. All permeameters were prepared following ASTM procedures where the maximum particle size was passed the No. 4 sieve (4.75 mm).

<u>Stage II: Geotextile testing with blended refuse</u>

The experimentation performed in this stage was similar to Stage I. The difference between Stages I and II was that a blended refuse (BR) was used for hydraulic conductivity test. The blended refuse was selected to increase the particle fines to promote clogging. . The blended refuse specimens were prepared by mixing the coarse coal refuse with increasing percentages of fine coal refuse. The fine coal refuse (FCR) was obtained from a coal preparation plant at the slurry line circuit prior to pumping up to the impoundment. The fine coal refuse was transported to the WVU Civil and Environmental Engineering Department's Geotechnical Lab using sealed 5 gallons plastic buckets.

The candidate slurry used for blending was well stirred in the bucket then dried. The dried slurry was pulverized into small grain sizes using a pestle and then sieved.

Blending of FCR with CCR

Two proportions were used for the blending of FCR. One mix proportion was 80% CCR and 20% FCR. The second mix proportion used was 60% CCR and 40% FCR.

Blending of 80% CCR and 20% FCR:

Blended refuse proportions followed method presented by Windisch (1996) with proportions of 80% (CCR) and 20% (fines). This method was selected in order to obtain a uniform gradation that would provide percentages of different sized fines to promote piping and clogging. Windisch (1996) discussed the procedure which was simple, rapid and efficient to blend different aggregates. This method used a mathematical function for the combination process in which grain-size distributions of known materials are the sets of known constants represented as vectors A_i in terms of fractions passing given sieves:

$$[A_i] = [a_{i1}, a_{i2}, \dots \dots \dots, a_{in}], i = 1 \ to \ m \quad (3.7)$$

Where

a_{ij}= percentage of material i finer than sieve size j, j= 1 to n,

m= number of materials to be combined, and

n= number of sieve sizes.

X is the proportion to which the m different material is combined. X is represented in vector form as:

$$[X] = [x_1, x_2, \dots \dots \dots, x_m] \quad (3.8)$$

x_1 will be the proportion of material 1 to be combined and x_2 will be the proportion of material 2 to be combined. The resulting combination gradation curve is given by the equation:

$$c_j = \sum_{i=0}^{m} a_{ij} \ x_j \quad (3.9)$$

The C vector is represented as $[C] = [c_1, c_2, \dots \dots, c_n$. To get the desired gradation of the combined analysis, the target curve is set to known constant elements which are represented as vector D.

$$[D] = [d_1, d_2, \dots \dots., d_3] \quad (3.10)$$

Where d_j = desired percentage of material finer than sieve size j. To get the desired gradation, the combined curve C should be close to target curve D; therefore the difference between curves C and D are minimal, which is defined by convenient error function z on basis of squares of errors.

$$z = \sum_{j=1}^{n}(c_j - d_j)^2 \quad (3.11)$$

Table 3.6 presents example for the grain size distribution of blended refuse. Where a_1, a_2 are the percent of materials passing for coarse and fine coal refuse respectively. C_1 is the 80 percent blend for coarse refuse and C_2 is the 20 percent for fine refuse and C is the gradation of the combined refuse. There was a minimal difference in the calculated gradation and the actual gradation because of the percent of fines present in the coarse refuse and due to material slaking from the pulverizing effort (D'Appolonia 1980).

Table 3.6: Blending of coarse and fine coal refuse (80% coarse, 20% fines)

Mm	0.074	0.25	0.297	0.595	2	4.75
a_1	5.81	11.08	16.26	27.83	61.89	99.55
a_2	15.61	46.3	52.51	67.12	93.86	100
C_1	4.648	8.864	13.008	22.264	49.512	79.64
C_2	3.122	9.26	10.502	13.424	18.772	20
C	7.77	18.124	23.51	35.688	68.284	99.64

Blending of 60% CCR and 40% FCR:

To increase the clogging effect, the fines percentage was increased in this mix proportion. The fine coal refuse used for blending in this case was the fine coal refuse passing No. 100 sieve. For the compaction, 60% CCR (passing No.4 sieve), 40% FCR (passing No.100 sieve) was mixed and then sample was compacted.

Procedure:

The hydraulic conductivity testing of blended refuse follow the same method ASTM D 5856 used in Stage-I. A standard Proctor curve was developed for the 80-20 mix proportion to obtain the maximum dry density value of blended refuse. The blended refuse hydraulic conductivity specimens were compacted with reduced energies. Increased fines percentage made the blended refuse specimens dense.

To increase the clogging effect and to track fine particle migration within the blended refuse lower compaction energy was used. The lower compaction energies were anticipated to model the loose dump conditions of refuse in coal impoundments. The 60-40 mix was intended to promote the clogging effect.

Different reduced compaction energies were used for the hydraulic conductivity test of blended refuse samples rather than standard compaction energies. Standard proctor for 60-40 mix was not developed as the main purpose was to assist in clogging. The reduced compaction energies used for the blended refuse are shown below in Table 3.7.

Table 3.7: compaction energies used for the Blended refuse

Configuration of Permeameter Compaction	Compaction Energy kJ/m^3 ($ft\text{-}lb/ft^3$)
Standard Proctor (ASTM D698)	592.5 (12375)
25 Blows/layer, 3 layers	636.21 (13288)
15 Blows/layer, 1 layer	127.26 (2658)
15 Blows/layer, 3 layers	381.73 (7973)
4 Blows/layer, 3 layers	102.17 (2134)

After blending the coarse coal refuse with fine coal refuse at different mix proportions the hydraulic conductivity testing was performed on the BR samples. After the hydraulic conductivity testing, the post grain-size distribution test was performed as described for Stage I. The formula for calculating the specific gravity for blended refuse samples are shown below:

$$Combined\ G_s = \sum_{i=1}^{n} P_i / \sum_{i=1}^{n} \left(\frac{P_i}{Gs_i}\right) \qquad (3.12)$$

Where

P_i= percentage of the material used for the proportion

Gs_i= specific gravity of the material used for proportion.

Stage III- Geotextile testing of CCR and BR using Acid as permeant:

Stage III reflects on the testing of coal refuse geotextile system using acid as permeant. The research scope also focuses on the chemical deterioration of the refuse and the armoring effects occurring at the interface of geotextile. The selection of this acidic permeant was to assist with investigating a weathered / aged refuse which may exist in an acid mine drainage (AMD) environment. Permeation with Acid and other liquids was accomplished using ASTM D -5856 *Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter*. The test program and the method were similar to the methods followed in Stage I and Stage II. The acid in this stage was solution of sulfuric acid with pH value of 2. Sulfuric acid was selected as the surrogate for acid mine discharge leachate. The low pH solution was intended to emulate a harsh saturated environment and accelerate refuse deterioration by minimizing buffering through constant pore volume exchanges in the permeameters. The acid solution was prepared by mixing de-ionized water with the concentrated H_2SO_4. Volumetric calculations were performed to get the H_2SO_4 acid solution of pH 2. For 2.3 ml of concentrated H2SO4 acid approximately 4280 ml of de-aired was added to get the solution to a pH value of 2. Although it was hard to get the acid solution to exact pH value of 2, efforts were made to get the acid solution close to 2; volumetric calculations were carried as shown below:

$$V_A = \frac{(M_{DI} * MW)}{D} \qquad (3.13)$$

V_A= Volume of Concentrated H_2SO_4 Acid (mL)

MW= Molecular weight of H_2SO_4 Acid (gram/mol)

D= Density of H_2SO_4 Acid (g/mL)

M_{DI}= Molar concentration of De-ionized water for pH 2 (mol)

$$M_{DI} = (V_w * pH_c) \qquad (3.14)$$

V_w= Volume of De-ionized water (L)

pH_c= concentration for pH 2 (mol/L)

The pH concentration calculations are explained in the following Table 3.8.

Table 3.8: Example for Volumetric Calculations of Acid

pH Concentration Calculations	
Volume (L)	4.28
pH 2 Concentration (mol/L)	0.01
Density of Acid (g/mL)	1.84
Molecular weight of Acid (g/mol)	98
Volume of DI water for pH2 (mol)	0.0428
Volume of Acid (mL)	2.28

The molarity of the acid was calculated using the molecular weight and the volume of the acid. Molarity is defined as the number of moles of solute per liter of solution. The molarity of the acid was calculated using the equations as described below:

$$M = \frac{n}{(V_A * V_w)} * 1000 \quad (3.15)$$

M= Molarity of the Acid

V_A= Volume of Concentrated H_2SO_4 Acid (mL)

V_w= Volume of De-ionized water (L)

n= number of moles

$$n = \left(\frac{m_A}{MW_A}\right) \quad (3.16)$$

m_A= Mass of Acid

$$m_A = V_A * D \quad (3.17)$$

MW_A= Molecular Weight of Acid

The molarity calculation is shown in the following Table 3.9:

Table 3.9: Molarity Calculation for the Acid

Molarity of Acid	
Volume of DI Water (ml)	4280
Molecular weight of H2SO4 (g/mol)	98
Volume of Acid (ml)	2.3
Density of Acid (g/ml)	1.84
Mass of Acid (g)	4.232
No. of Moles (mol)	0.043
Molarity of Acid (mol/L)	0.01

The experimentation in this stage was similar to the Stage I and Stage II by performing hydraulic conductivity testing of coal refuse-geotextile system using Acid permeant. The testing was performed on selected coarse coal refuse and Blended refuse samples. Before the start of test the refuse samples were saturated with Acid permeant for approximately 24 hours.

During the test, the permeant fluid was collected in viles at the outlet to perform the pH and specific conductivity testing. The pH and specific Conductance values of fluid before and after the test were determined and then analyzed. This was performed to assay the respective ion release or stripping of ions from the refuse materials. Physical index testing of the reformed coal refuse post flushing was performed to assess ion exchange extents. This was achieved by carrying the grain-size distribution on the refuse material.

<u>Stage IV- Introduction of Beads into hydraulic conductivity sample to track fine particle movement</u>

Movement of fine particles in the rigid wall cell during the hydraulic conductivity test was achieved by introducing the metal beads into the sample during the compaction. Beads were introduced into the blended refuse sample with 60% coarse coal refuse and 40% fine coal refuse. The compaction effort used for this sample was 2216 lb-ft/ft^3 and the mode of compaction was 4 blows 3 layers.

Three types of beads were introduced onto the top of each sample layer in between the respective compaction layer. Metal beads were spaced (from the top of compaction cell towards) at the top of the coal refuse, next at approximately 1.5 inch, then again at approximately 3inches from the top of the sample. The beads used are listed as follows:

- Tungsten
- Mixture of Tantalum and Molybdenum
- Mixture of Nickel and Stainless steel

The distribution of metal beads is as follows: 1 gram of Nickel/Stainless steel beads were placed at the first layer (bottom) of compaction; 1 gram of Tantalum/Molybdenum beads were placed at the second layer (middle) of compaction; and 1 gram of Tungsten beads were placed at the third layer (Top) of the Mold. Metals beads were placed in a 1" diameter spread located at the center line of the sample and they were placed according to the higher specific gravity value material at the top of the soil specimen. The schematic view of metals in the refuse sample along with geotextile is shown in the following Figure 3.18.

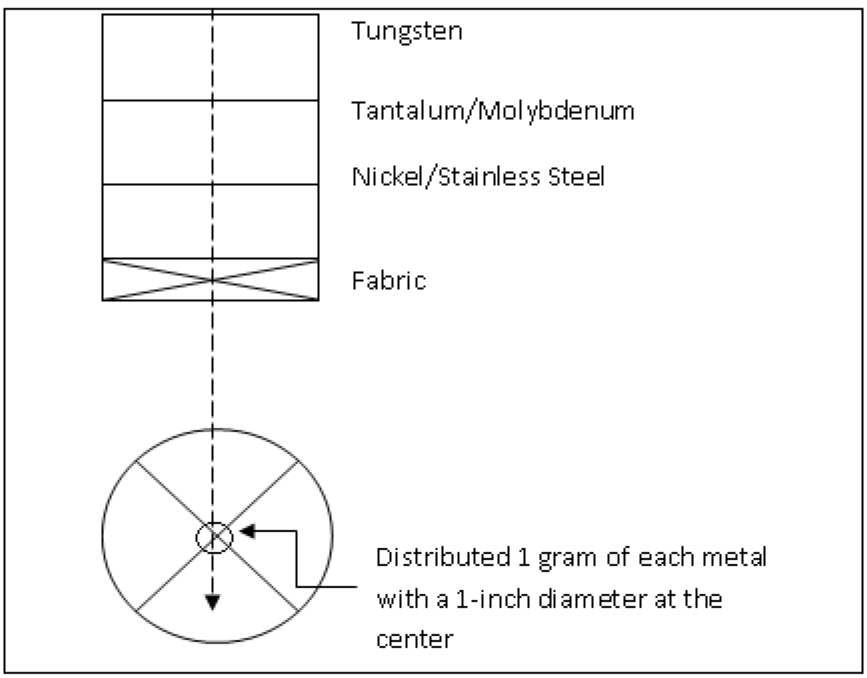


Figure 3.18: Schematic view of Metal Beads in the Sample

After the introduction of the metal beads into the sample, hydraulic conductivity testing was performed. Two types of samples were used for testing in which one was tested using de aired water as permeant and the other with sulfuric acid with pH 2 as permeant. The method of testing for these samples was the hydraulic conductivity which follows the methods described in stages I, II and III. After the hydraulic conductivity test, samples were sent to chemistry department to analyze the fine particle movement within the samples. Some of the samples were tested by technique called analytical microscopy.

3.3.3. Phase-III: Photo Microscopy and its Method of Testing

The initial intent of the microscopy work was to visualize particulates trapped in textile fibers and to infer aspects of clogging behavior accordingly. Three options were explored: visible and polarizing light microscopy using prepared thin sections; scanning electron microscopy, and stereomicroscopy. To use traditional (transmission) light microscopes, the samples must be thin enough for light to penetrate which in turn requires that thin sections be cut from the fabrics. However, since these are flexible and soft, any semblance of normal particle distribution will be lost. To preserve as much of this as possible, studies were made of different mounting media. In general, these media are organic solutions of polymeric precursors that when combined, polymerize to form a clear solid or semi-solid that can be accurately and thinly sliced for slide mounts. Because the polymer flows gently into the fabric matrix, particulate displacement was expected to be minimized.

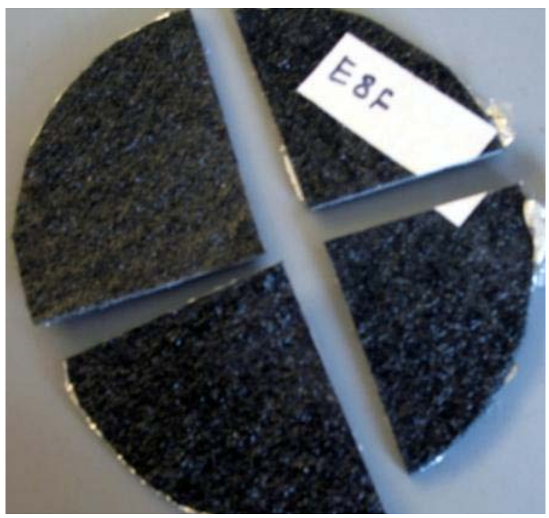


Figure 3.19: Slices of geotextile with Aluminum foil wrapped

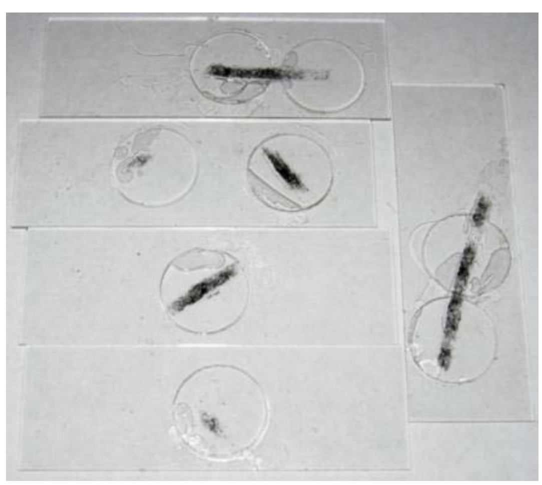


Figure 3.20: Polymerized material from the geotextile

After several trials, the material selected was Arddite 502 polymer system, a four-component mixture that polymerizes with gentle overnight heating. Briefly, the textile circles were laid on aluminum foil and placed in a foil pan to which the mixture was added to the fabric and allowed to gently permeate. This procedure minimized the disturbance of embedded particles. The pan was placed in an oven overnight at 60°C. The next day, the pan was removed and allowed to cool, yielding the polymerized material as shown above in Figure 3.19 and Figure 3.20.

Next, the circles were cut into quarter sections and sliced thinly using a manual microtome and mounted on microscope slides. Problems arose at this stage. To obtain good transmittance, the slices must be very thin (< 1mm), but the process of cutting these very thin sections put significant shear force on the fibers, resulting in distortion and breakage. Even though it was possible to capture good micrographic images, it is felt that these could not be interpreted as true representations of the original particle distribution in the textile fabric. Microscopic images of geotextiles are shown in Figure 3.21and Figure 3.22.

Figure 3.21: Micrographic image (1) of Geotextile

Figure 3.22: Micrographic image (2) of Geotextile

Attempts were also made to image the mounted textiles using scanning electron microscopy (SEM) operating under low vacuum conditions. This approach would afford greater depth of field, thus eliminating the need for thin sections. A mounted quarter section was placed in the SEM and images were successfully obtained, but under the electron beam, the polymer appeared opaque rather than clear as shown below in Figure 3.23.

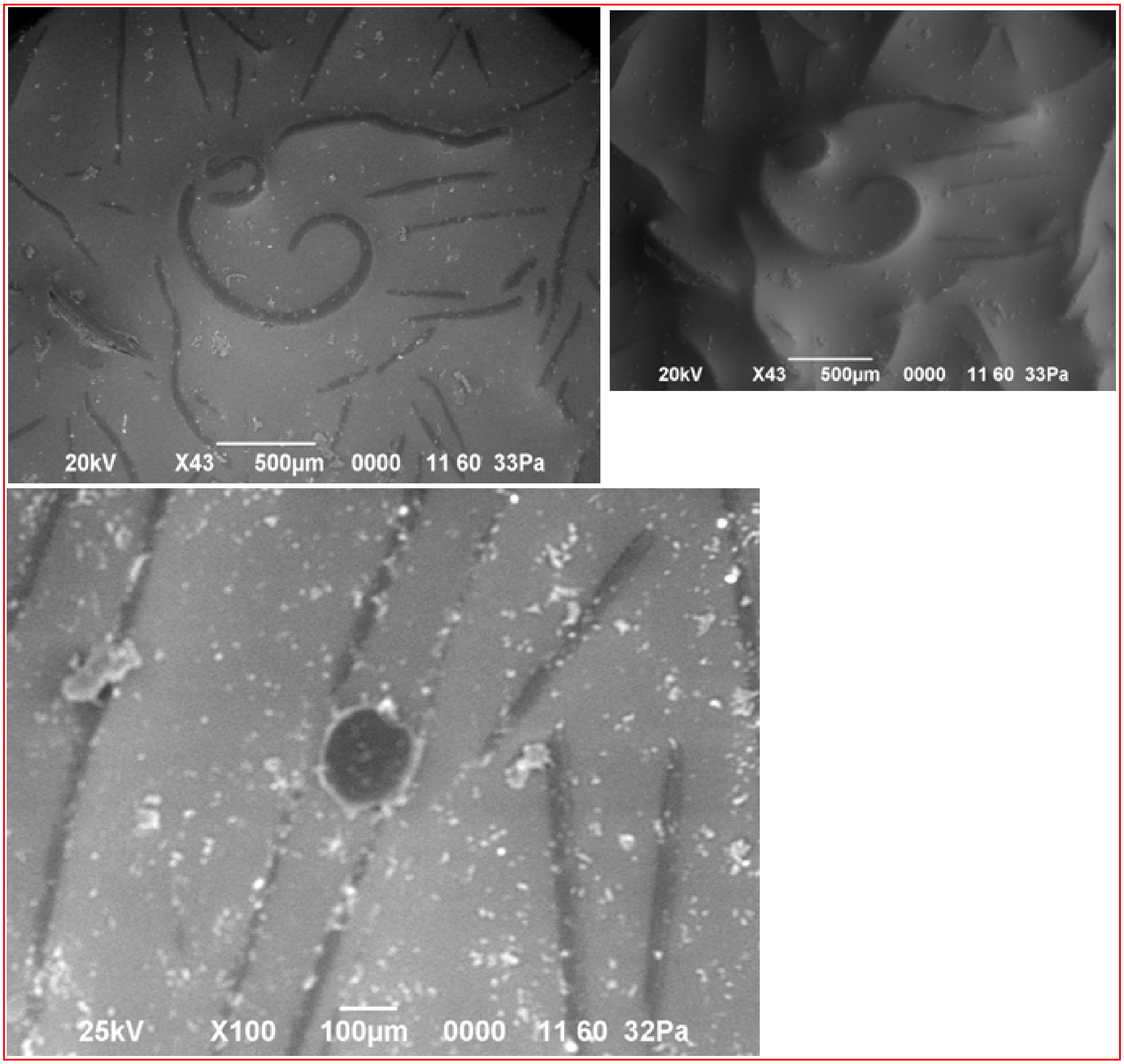


Figure 3.23: Scanning Electron Microscopy images of Geotextile

The final aspect of the analytical microscopy was the use of stereomicroscopy, which will be discussed below in the section describing the particle tracking experiments.

Laboratory Measurements

pH and Specific Conductance

Liquid samples delivered to the laboratory were tested for pH and specific conductance. Standard instrumentation, calibration, and performance check protocols were utilized. The instrumentation used was a Hach HQ14d Conductivity meter and probe and a VWR SympHony pH meter and electrode.

ICPMS

Analysis of refuse from two cells was analyzed using inductively coupled plasma mass spectrometry (ICPMS, Agilent 7500 Series). A screening method was used which covers a wide range of elements and yield semi-quantitative results. This means that the concentrations reported are estimates and while trends and general observations are possible, the values should not be interpreted as exact values with a defined uncertainty.

The general method of sample preparation was to transfer refuse to a plastic extraction tube which was weighed before and after this process to determine the net weight of refuse. A solution of 10% hydrochloric acid in distilled water was added, followed by a small amount of concentrated nitric acid. The amount of solution prepared was typically 50 mL. This solution was then diluted again by a factor of 50 in most cases and then introduced into the instrument by aspiration. Estimated concentrations are provided as ppb (ug/L) in the solution and this value was converted to the equivalent ppm (mg/kg) in the soil refuse using volume of extraction, sample weight, and dilution factors.

The complete process of sample preparation from cell to reported data is described in the particle tracking section.

Particle tracking experiments

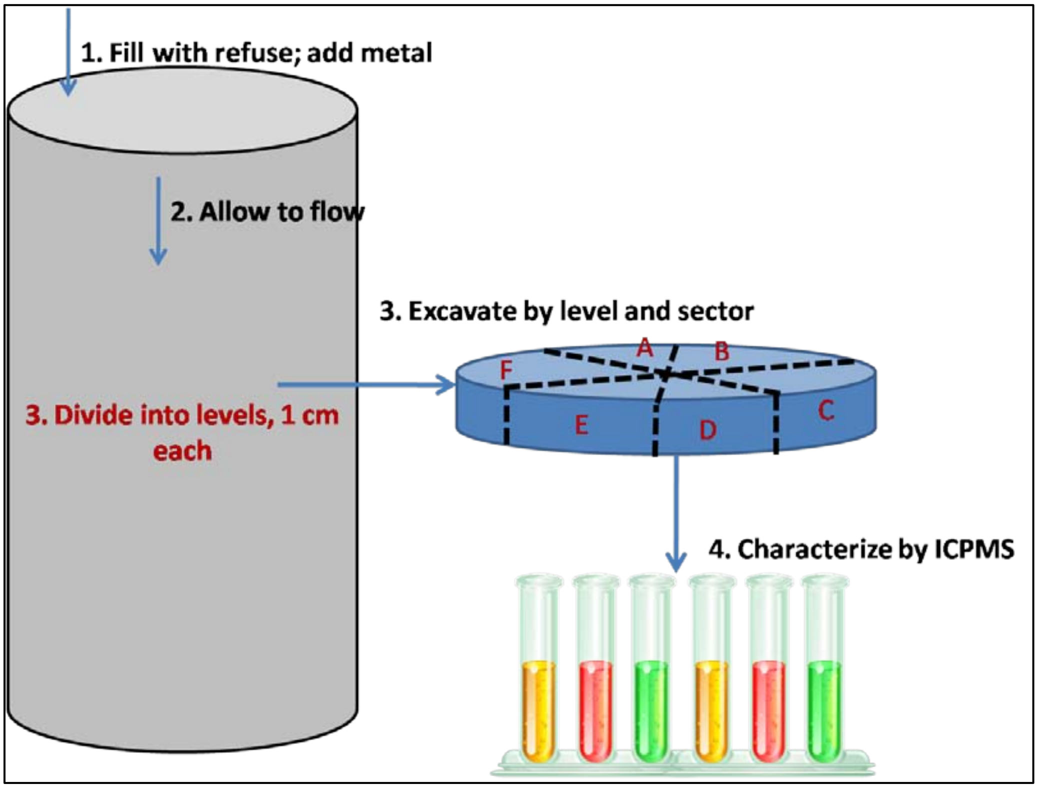


Figure 3.24: Picture representing the particle tracking experiment concept

The goal of this work was to attempt to model how dissolved materials move through a refuse cell by adding known amounts of pure metal particulates to the cells in known positions and tracking movement by extracting defined regions in the cell and analyzing using ICP-MS. Because the metals are soluble using the extraction method described above, the concentration of these metals will be elevated in any region of refuse in which they were trapped. The concept is summarized in the above Figure 3.24. The metals used were tungsten, molybdenum, stainless steel, nickel, and tantalum. Although a detailed assay for the stainless steel was not available, typical steels contain iron, chromium, and nickel. The selection of metals was based on a series of dissolution experiments and the metals most soluble in the acid extraction system described above were used.

Round 1: Cell NW 6

For the first round, a soil sampling tube was driven down into the center of the cell and used as a reference point. The cylinder was marked such that 6 roughly equal sections were created as shown in the Figure 3.25and Figure 3.26. The refuse was then carefully dug out from each of the six sections in layers of approximately 1 cm. This produced 10 layers within the cell and 60 separate vials containing refuse. The weight of each sample was recorded and the vial labeled by level (1-10) and by letter (A-F). The sequence of excavation is shown in photo series on the following page in Figure 3.27 and Figure 3.28 without tool and with tool respectively. As the photos show, the most challenging problem was keeping the dry material from collapsing into adjacent grid locations.

Figure 3.25: special tool designed for the particle tracking experiments

To address this, a special tool was designed and fabricated to stabilize the six triangular sections of the cell. The tool consists of a central core region and a sharpened end that facilitated the movement of the tool downward into the packed refuse with minimal disturbance. The six blades were also sharpened on the bottom edge for the same reason. Using this approach it was possible to drive the tool completely into the cell and preserve the vertical boundaries between designated layers. Note that the top of the tool is flattened to allow for hammering, which was necessary to penetrate the hard-packed refuse.

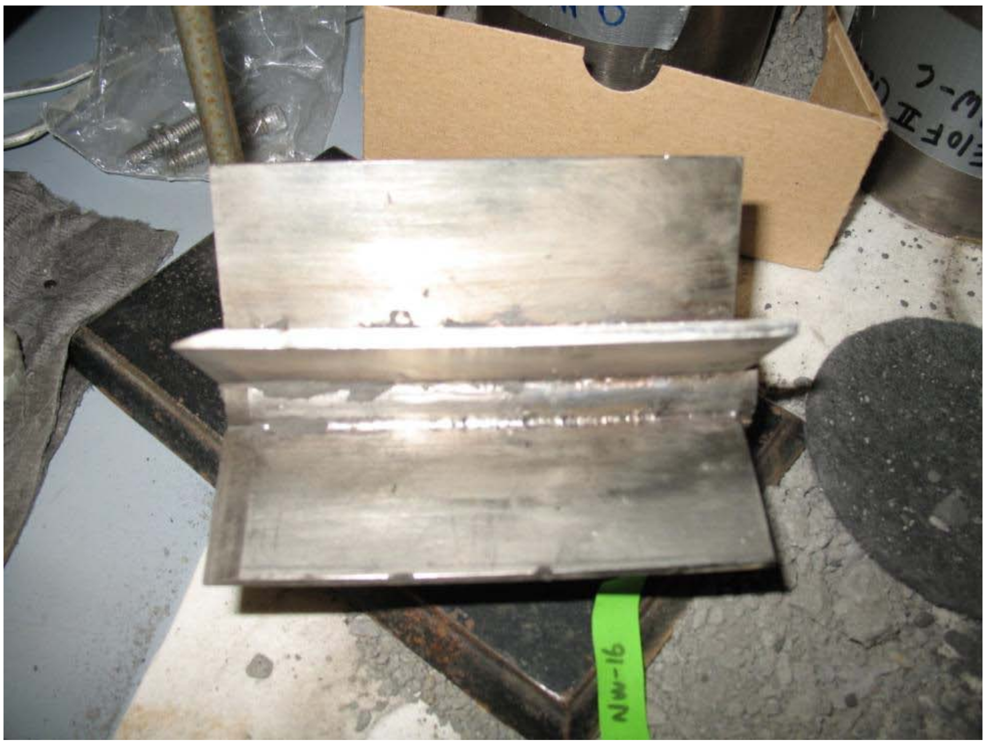


Figure 3.26: Sharp edges of the special tool

Initial set-up; driving in of the center reference tube

Completed excavation

Figure 3.27: Sequence of excavation without tool for particle tracking experiment

Sequence of excavation: With tool

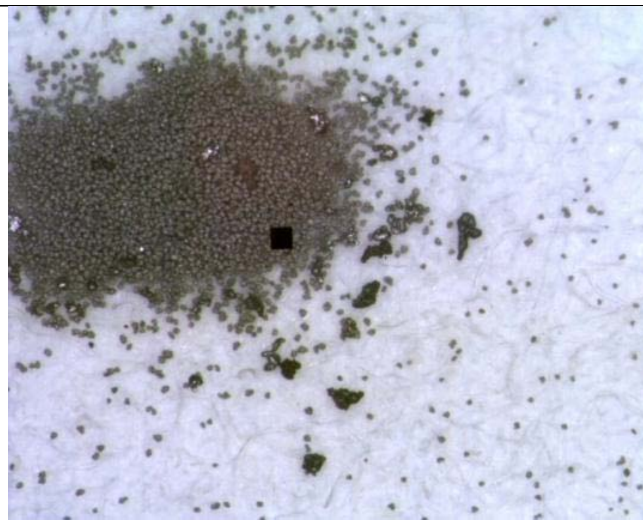
Figure 3.28: Sequence of excavation with tool for particle tracking experiments

Figure 3.29: Tool completely inserted into the sample

The particle tracking experiment with tool is shown in Figure 3.29. The textile on the bottom was removed and evaluated using stereomicroscopy and imaging, with the hope of being able to see some of the remaining metal fragments that had been added to cell originally. If so, this means that the particle was picked up and carried all the way through the cell and this could be correlated with particle sizes to learn about particulate transport within the cell.

To assist in the visual identification process, images of each of the metals were obtained and used as reference. In the images below, the small black square is an aperture on the center of the microscope and is not part of image or sample. In the filter images, there are particles seen that are consistent with the appearance of the metal particles, but the refuse mix is so variable, it is not possible to confirm these identifications based on observation alone. Images were collected at various magnifications (4-56x) using a Leica stereomicroscope. Figure 3.30 gives the visual concentration of metals in samples.

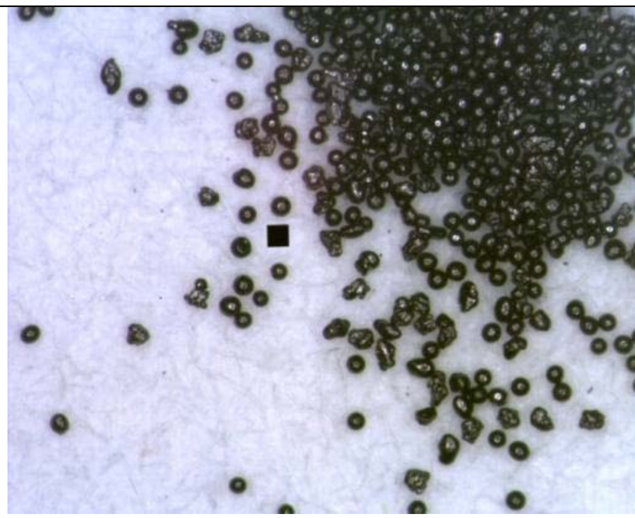
Molybdenum (Mo)



Nickel (Ni)

Stainless steel (Fe, Co, Ni)

Tantalum (Ta)



Tungsten (W)

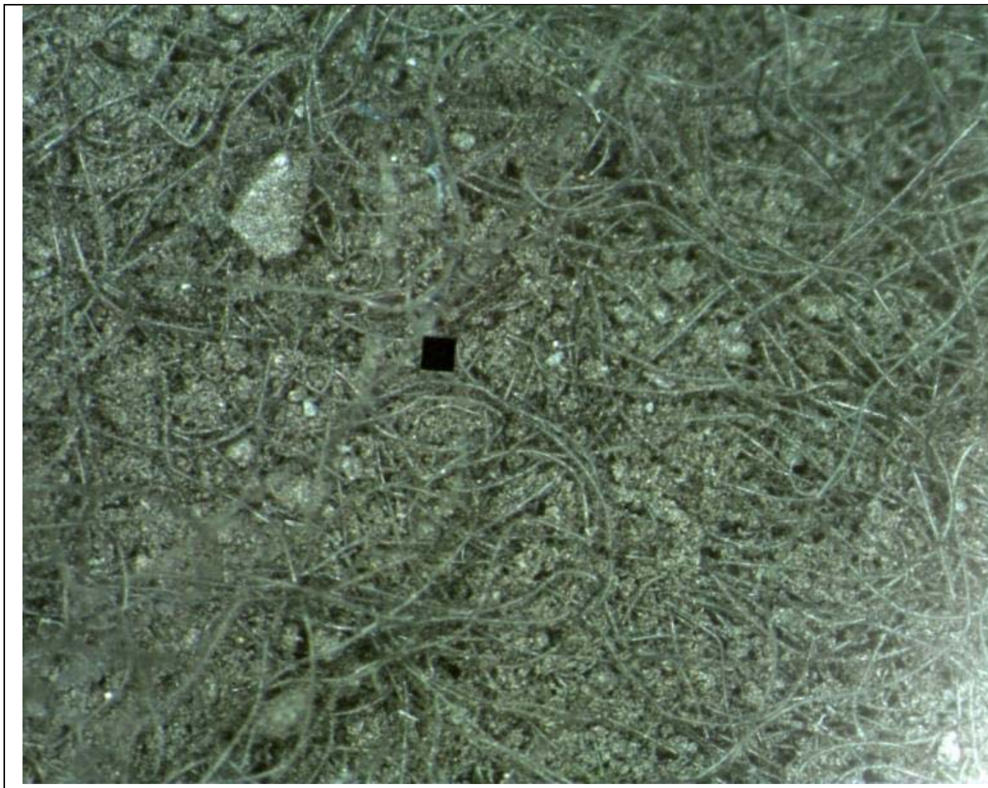
Figure 3.30: Picture representing the visual concentration of metals

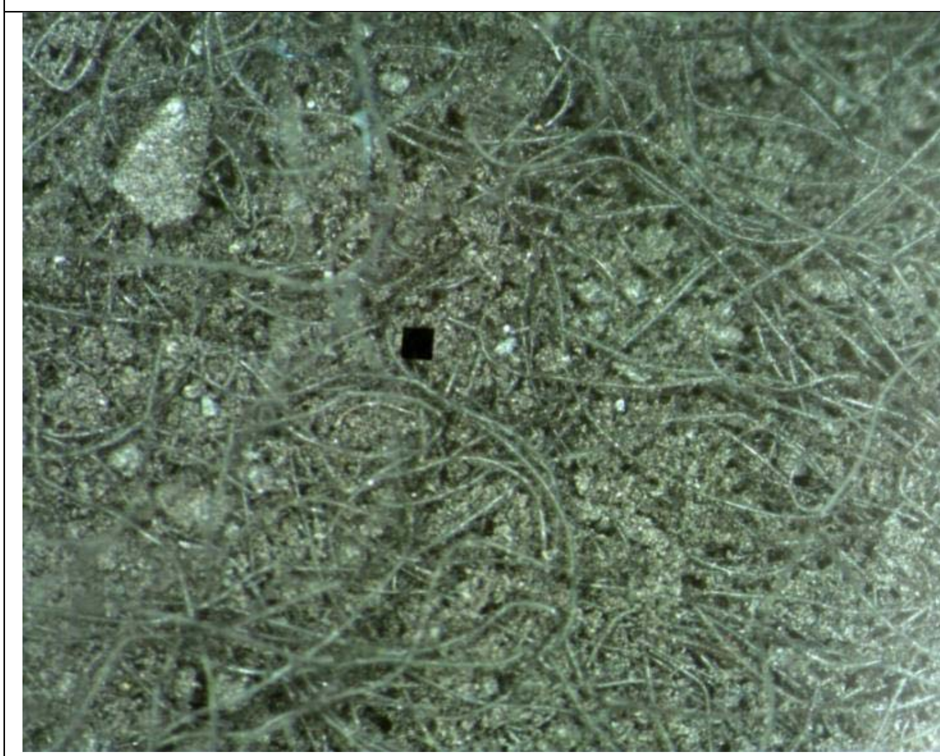
The fabric remove with coal refuse on its surface is shown in Figure 3.31.

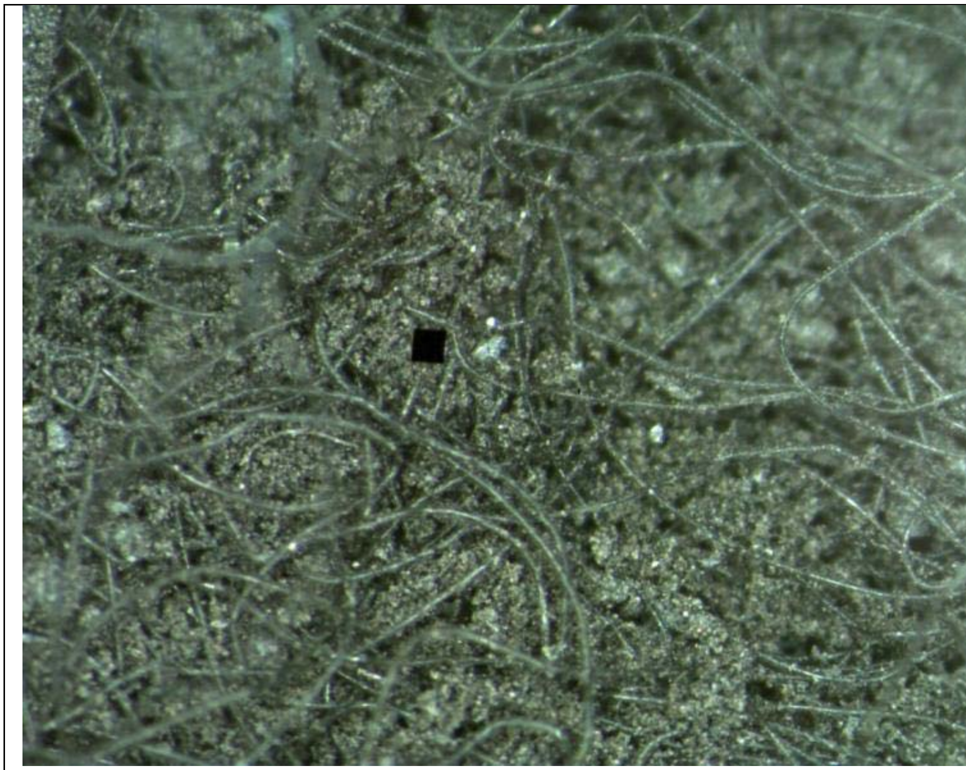
Figure 3.31: Fabric removed from excavation

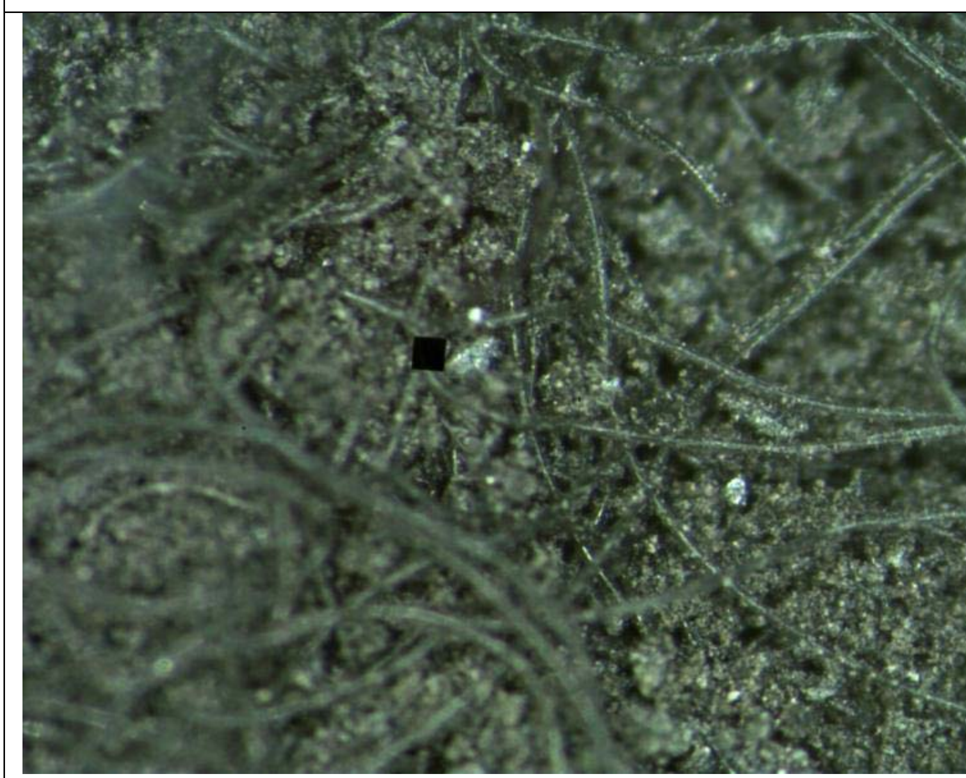
Fabric removed from excavation of the original sample.

Tape markes boundaries of the A-F zones.









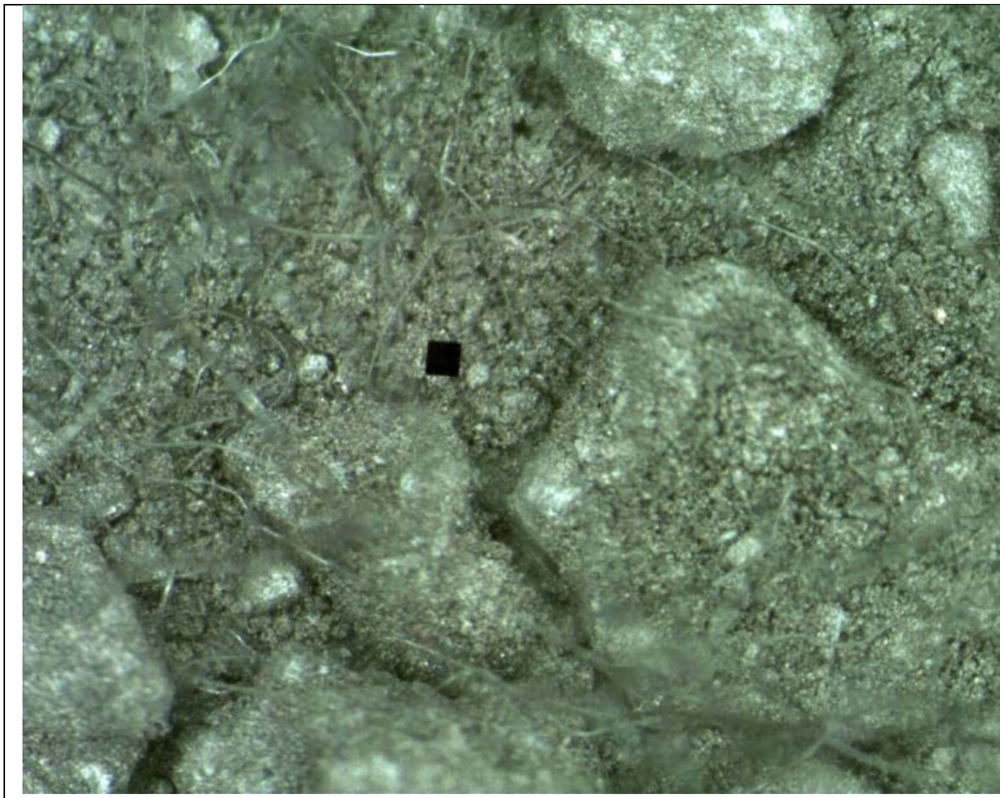


Figure 3.32: Microscopic images of geotextile

The microscopic images of removed geotextile are shown in Figure 3.32.

ICP-MS Results of Particle Tracking Experiments

The analysis of refuse from two cells spike with metal beads (hereafter, "original" and "duplicate") produced an enormous amount of data for nearly 100 samples and dozens of elemental constituents. From initial characterizations of the coal refuse alone, a subset of elements was selected for study as summarized in the table below. Results presented in figures to follow are given in ppm or mg/kg of the metal per kg of coal refuse material. It is worth reemphasizing that the data associated with these studies is semi-quantitative in nature and should not be interpreted as a complete and accurate quantitative assay of the refuse. The data is ideally suited to observe trends and movement within a cell and for identifying a large portion of the metals present in the refuse. However, the digestion procedure was not exhaustive (which would have required the use of hydrofluoric and perchloric acids) and therefore provides only a partial snapshot of the coal refuse composition. Although the metals in the beads are also expected to be present in the coal refuse, the amount of beads added insures that any such concentrations would be overwhelmed by that arising from dissolution of the beads. List of elements examined for concentration in sample is shown in Table 3.10: list of elements in coal refuse and beads.

Table 3.10: list of elements in coal refuse and beads

Elements in coal refuse only	Elements in beads added to cells
Magnesium (Mg)	Chromium (Cr)
Aluminum (Al)	Iron (Fe)
Titanium (Ti)	Nickel (Ni)
Vanadium (V)	Molybdenum (Mo)
Manganese (Mn)	Tungsten(W)
Cobalt (Co)	
Copper (Cu)	
Zinc (Zn)	
Arsenic (As)	
Strontium (Sr)	
Barium (Ba)	

For the original sample, the excavation proceeded through ten levels with six sections per level as shown in the table above. For the duplicate sample, this was consolidated to four levels. For consistency, the data from the original sample was also combined into four levels for comparison purposes, but retaining the ten level data for additional study.

For the original sample, ten layers were excavated and analyzed, allowing for tracking of elements, both from the refuse and from the added metal beads, as a function of depth. The results are summarized graphically below. For the metals added, one set of graphs depicts the associated error bars based on the 95% confidence interval. The data used to generate these quantities were the elemental data for all sectors and levels consolidated into four levels. This allowed comparison between the original (ten excavated levels consolidated into 4) and duplicate sample (four levels excavated).

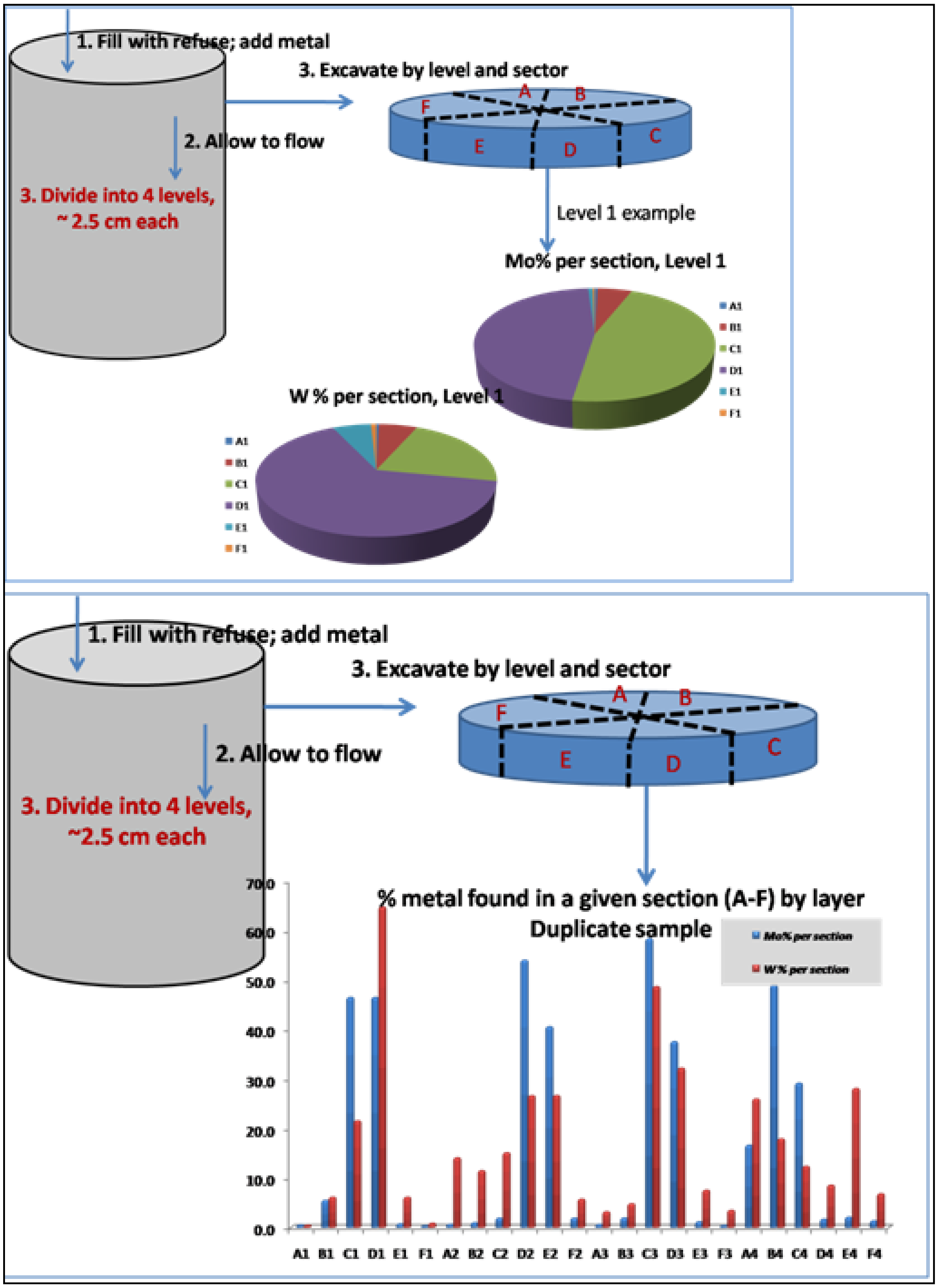


Figure 3.33: Concentration of elements with pie chart and bargraph

The analytical data was also useful for correlations and study of concentrations across sections within a given level. For example, as shown in the figure below, it was possible to determine in which sectors (A-F) the highest concentration of spiked metal was located. In this Figure 3.33: Concentration of elements with pie chart and bargraph, the relative % of a metal found in a given level is plotted as a function of sector. Thus, in Level 1, the molybdenum was found in roughly equal proportions in sectors C and D while the tungsten (W) was predominately located in sector D. Such information can be used to map lateral flow to complement the vertical flow measurements described in the previous section. In this instance, the tungsten appears to spread out with depth while the molybdenum seems to stay relatively centered within the refuse column. Another method of examining this trend is shown in the figure below. Here, the relative percentage is depicted in a pie chart form. The bulk of both metals was found in the C and D sectors.

<u>Miscellaneous Procedures</u>

Two additional procedures were explored to assist in characterization of the coal refuse cells to which metal beads were added. First was separation by density in which the excavated refuse samples were placed in a separatory funnel containing a dense organmetallic liquid as shown in Figure 3.34. Separation of the particulates occurs based on relative density. Several attempts resulted in poor separation and significant consumption of the expensive high density liquid. As a result, this approach was abandoned.

Figure 3.34: Funnel with organic liquid to characterize coal refuse

The second procedure attempted was a magnetic separation. In this approach, the refuse was placed in device that shook the sample while directing it over an electromagnet. The reasoning was that the magnetic metals (iron for example) would be separable from the bulk of the coal refuse, greatly simplifying the needed chemical processing prior to ICPMS sample preparation and analysis. This method also failed to provide significant separation and proved to be very time and labor intensive and was abandoned for this reason. The method is shown in Figure 3.35.

Figure 3.35: Magnetic separation for coal refuse characterization

3.4. Laboratory Experimentation Summary

The experimentation program was performed in three phases. First phase was the geotechnical material property testing of coal refuse samples. The geotechnical material property test includes different physical property tests of coarse coal refuse and blended refuse. The main experimentation of this research was performed in second phase, which includes the hydraulic conductivity testing of coal refuse-geotextile system. Different mix proportions, various geotextiles and different compaction energies and different gradients were used for testing in this phase. Third phase deals with the photo microscopy testing of coal refuse samples and the geotextiles that were tested in phase II.

4. SEEPAGE CRITERIA AND FILTRATION ANALYSIS

4.1. Seepage Analysis

A primary engineering concern with the structural stability of coal impoundments are seepage, slope stability and drainage. Seepage and drainage are primary concerns because of the permeable nature of the refuse material and water seepage. MSHA states the reasons for the seepage concern in coal refuse impoundments, particularly in embankments and foundations of coal impoundments, are: 1. excessive pore water pressure in the embankment and foundation effecting stability; 2) excessive hydraulic gradients at the embankment slope, at drain interfaces, at the toe area leading to internal particle erosion and piping, and 3.) water lost through or under the foundation structure. . The main parameters that helps in the estimation of seepage analysis in coal impoundments are hydraulic conductivity, soil particle size and anisotropy ratios. The typical profile of coal refuse embankments is similar to earthen dams. The seepage analysis for coal refuse embankments is performed by flow-net analysis and analyzed using graphical methods to identify zones of differing hydraulic conductivity, seepage flow lines, seepage vectors, and isotropy. To determine the rate of seepage using the flow net method, the following form of Darcy's law is used.

$$q = k\,h\,\left(\frac{N_f}{N_d}\right) \qquad (4.1)$$

Where:

q= seepage flow per unit width ($length^2$/time)

k= permeability of the embankment material (length/time)

h= total head across the system (length)

N_f= Number of flows

N_d= Number of drops

The equation used for the seepage analysis through the porous media such as coal refuse is given by Darcy's equation:

$$Q = k\,i\,a \qquad (4.2)$$

Where,

Q= flow rate (volume/time)

k= coefficient of hydraulic conductivity (length/time)

i= hydraulic gradient (dimensionless)

a= cross-sectional area through which flow occurs ($length^2$)

Seepage Control

Pore water pressure develops if the saturation in the coal refuse due to seepage causes a strength loss in the refuse. Seepage forces can be controlled by internal drains within the embankments.

Geotextile filter fabrics have been used the interface between the coal refuse and drains surface. The function of geotextile is to prevent the fine particle movement, i.e., soil retention, and to allow water to pass through, drainage.

Geotextile application for seepage control

The geotextile design for the subsurface drainage systems is same as the design of the graded granular filters. FEMA and MSHA suggest that one way of controlling seepage and internal erosion is by introduction of filters and high permeability zones within the embankment. Geotextiles are the permeable geosynthetics material made using textiles. They are made of polymers such as polypropylene and polyester. Geotextiles are widely used in foundations and earth retaining structures. Geotextiles typically involve two main types; i) woven-geotextiles and ii) non-woven geotextiles. Woven geotextiles are used for reinforcement and separation, and non-wovens are intended for filtration and drainage applications.

Non-woven geotextiles have been designed and permitted for installation as filtration components in coal refuse impoundments by the West Virginia Department of Environmental Protection and MSHA.

There are two main functions of any kind of filter: 1) allow water to flow through, and 2) prevent soil particles to pass (retention). According to FEMA (2007), filter must have following criteria to install in embankments and foundations. They are: 1) have appropriate openings or particle size distributions, 2) have sufficient internal stability, finer particles should not erode away from filter due to seepage pressure and flows, 3) have sufficient permeability and thickness, 4) have good survivability criteria, and 5) be resistant to segregation and breaking during installation.

Seepage flow in coal refuse embankments can be controlled by reducing the internal phreatic surface level. This can be achieved by installing internal lateral drains within the embankment. Drains are incorporated with filters.

Characteristics of geotextiles

The characteristics of geotextiles that affect the filtration performance of the geotextiles relative to the soil are apparent opening size (AOS), percent open area (POA), pore opening size distribution (PSD), constriction size (CS), and permittivity of the geotextile.

1. Apparent opening size (AOS): It is defined as the pore diameter measure in the geotextile. It is denoted by "O_{95}", which means 95 % of the opening sizes of the geotextile are smaller than apparent opening size (O_{95}).
2. Percent open area (POA): POA is defined as the ratio of the percent open area of geotextile to the total area of the geotextile.
3. Permittivity: The rate at which the geotextile allows the soil particles on it to pass through perpendicular or cross-plane to the flow.
4. Pore opening size distribution: defines how the pores are distributed in the geotextile.

Problems associated with filters (geotextiles) in coal impoundments

There are some problems associated with geotextiles while installing in coal impoundments. They are:

1. Damage during installation
2. Long-term reliability of Geotextile to function without clogging.
3. Geotextile placement location – geotextile should be placed where it is accessible to repair.
4. A difference in compaction efforts cause damages to geotextiles.
5. Chemical deterioration (leaching) of the geotextiles due to chemicals present in the coal refuse.

4.2. Design criteria for Geotextiles in coal refuse impoundments

Current design criteria given by Holtz et al., (1998), J.P. Giroud (1988) and FHWA (1985) depends mainly on ratios of certain apparent opening size parameters and the grain size distribution of the soil. Geotextiles act as a transition zone between an embankment material and a drainage zone. Geotextiles prevent the movement of fine particles and embankment materials into the drainage zone reducing the clogging potential. When the grain-size distribution of the embankment material varies widely, the fine particles will tend to move into the pores of coarser particles promoting the piping effect. To prevent this piping effect, filters are used. The main points considered in applications of geotextiles are flow requirements, piping, clogging potential.

The criteria required for the geotextiles installation are:

- Retention criteria- geotextile should retain the larger particles which are larger than largest opening size of geotextile.
- Hydraulic conductivity criteria- geotextile should be able to pass liquid to pass through it.
- Clogging resistance criteria- geotextile should not clog even it is installed for high period of time.
- Survivability criteria- geotextile should be resistant and have higher strength so that it will survive for long time.

4.2.1. Filter design criteria

The filter design criteria described here are for non-woven geotextile-wrapped type drains. There are different criteria proposed by both different organizations and different authors.

The following are the parameters given by respective authors required for the design criteria of geotextile for installing around drains given in Table 4.1.

Table 4.1: Parameters required for the design of geotextiles

PARAMETERS FOR GEOTEXTILE DESIGN	
Soil Parameters	**Geotextile Parameters**
D_{85}, D_{60}, D_{10}, D_{50}, D_{15} of soil	AOS (O_{95}) of geotextile
k_{soil}	$k_{geotextile}$
Coefficient of Uniformity (C_u)	Permittivity (Ψ) of geotextile
Percent passing No.200 Sieve	Porosity (n) of geotextile

RETENTION CRITERIA:

1. MSHA:

   1.1 Steady state flow conditions:

$$AOS\ (O_{95}) \leq\ B * D_{85} \quad (4.3)$$

For sands, gravelly sands, silty sands, and clayey sands which have less than 50% passing 0.075 mm sieve B is defined as follows

$C_u \leq 2$ or ≥ 8	B=1
$2 \leq C_u \leq 4$	B= 0.5 C_u
$4 < C_u < 8$	B=8/C_u

For silts and clays which have more than 50% passing 0.075 mm sieve, B is a function of type of geotextile.

For Woven, B=1 and for Non-Woven, B= 1.8

1.2 Dynamic flow conditions:

$$AOS\ (O_{95}) \leq\ 0.5 * D_{85} \quad (4.4)$$

2. J.P. Giroud's and FHWA:

$$O_{\ 95} <\ \lambda_R\ D_{85} \quad (4.5)$$

Where D_{85}= $Cu^{0.7}$ D_{50} (Giroud's definition)

J.P. Giroud Criteria for λ_R		
	Loose soil	Dense soil
$1 < C_u < 3$	λ_R= $C_u^{0.3}$	λ_R=9 $C_u^{-1.7}$
C_u >3	λ_R= 2 $C_u^{0.3}$	λ_R=18 $C_u^{-1.7}$

FHWA Criteria for λ_R	
$1 < C_u < 2$	λ_R= 1
$2 < C_u < 4$	λ_R= 0.5 C_u
$4 < C_u < 8$	λ_R= 8/C_u
$C_u > 8$	λ_R=1

PERMEABILITY OR PERMITTIVITY CRITERIA:

1. MSHA:

   1.1 Permeability:

   For less critical applications and less severe conditions,

$$k_{geotextile} \geq k_{soil} \quad \ldots\ldots (4.6)$$

   For critical applications and severe conditions,

$$k_{geotextile} \geq 10\, k_{soil} \quad \ldots\ldots (4.7)$$

   1.2 Permittivity:

   $\Psi \geq 0.5\ sec^{-1}$ for <15% passing 0.075 mm sieve

   $\Psi \geq 0.2\ sec^{-1}$ for 15 to 50% passing 0.075 mm sieve

   $\Psi \geq 0.1\ sec^{-1}$ for >50% passing 0.075 mm sieve

2. J.P. Giroud's and FHWA:

Giroud	FHWA
$k_{geotextile} \geq k_{soil}/10$	$k_{geotextile} > k_{soil}$ for small gradients and stable soils
	$k_{geotextile} > 10\ k_{soil}$ for high gradients and unstable soils

CLOGGING RESISTANCE:

1. MSHA:

For non-critical conditions, and for soils with Cu > 3

$$AOS\ (O_{95}) \geq\ 3 * D_{15} \qquad (4.8)$$

For soils with $C_u \leq 3$, select geotextile from retention criteria.

$$k_{geotextile}\ \geq 10 * k_{soil} \qquad (4.9)$$

When flow capacity is sufficient and there is no problem pertaining to flow conditions, the hydraulic conductivity criteria changes. This is the condition where geotextiles are wrapped along drainage pipes.

$$q_{required}\ =\ q_{geotextile}\ * (\frac{A_g}{A_t}) \qquad (4.10)$$

Where:

A_g= geotextile area available for flow

A_t= total geotextile area

2. FEMA:

$$k_{geoetxtile}\ = 10\ to\ 100 * k_{soil} \qquad (4.11)$$

3. WVDEP:

$$O_{95} < B_{85} \qquad (4.12)$$

SURVIVABILITY CRITERIA:

The survivability criteria of geotextiles are based on empirical data from previous geotextile applications. MSHA (2009) provides the following criteria for survivability and various strength parameters as follows:

Table 4.2: Survivability criteria from MSHA (2009)

Property (units)	Geotextile Class 2 (Class 2 is default selection)	
	Elongation	
	< 50%	≥ 50%
Grab Strength (N)	1100	700
Sewn Seam Strength (N)	990	630
Tear Strength (N)	400	250
Puncture Strength (N)	400	250
Burst Strength (kPa)	2700	1300

4.3. Geotextile Information

The ge otextiles t hat w ere us ed f or t ests a re pr ovided by di fferent manufacturers. T he i nformation of geotextiles are given in the table

Table 4.3: Information of Geotextiles used for testing

Manufacturer	Propex			GSE Lining Tech.	
Geotextile	Geotex 401	Geotex 601	Geotex 801	NW 6	NW 16
Apparent Opening Size (mm)	0.212	0.212	0.18	0.212	0.15
Permeability (cm/s)	-	-	-	0.30	0.27
Permittivity (s^{-1})	2	1.3	1.5	1.5	0.6

For most of the hydraulic conductivity tests, the geotextile used was NW 6. The properties of geotextiles that are mentioned in the above table are used for the evaluation of design criteria. The coal refuse sample used for the geotextile design was passing No.4 (4.75mm) sieve.

5. EXPERIMENTATION RESULTS

5.1. Geotechnical Material properties

Different geotechnical material property test were performed on the coarse coal refuse, fine coal refuse (coal slurry) and blended coal refuse.

5.1.1. Moisture content

Table 5.1: Moisture content test results for Coarse Coal Refuse

Moisture Content-Sample E (CCR)			
Test	Test 1	Test 2	Test 3
Container No.	E1	E2	E3
Container Mass(g), M_c	33.55	26.58	32.02
Container+Moist Specimen Mass(g), M_{cms}	100.06	98.6	66.89
Oven Temperature	110^o C	110^o C	110^o C
Date/Time in Oven	3/20/2009	3/20/2009	3/20/2009
Initial Container+Oven Dry Specimen Mass(g), M_{cds}	97.67	95.81	65.28
Date/Time out of Oven	3/21/2009	3/21/2009	3/21/2009
Mass of Water(g), $M_w= M_{cms}-M_{cds}$	2.39	2.79	1.61
Mass of Solids(g), $M_s= M_{cds}-M_c$	64.12	69.23	33.26
Water Content, % W= (M_w/M_s)x100	**3.73**	**4.03**	**4.84**
Note: Moisture Content was taken After Air Drying for 1 Day. The filed collection of coal refuse samples was performed on rainy day.			

5.1.2. Specific gravity

Table 5.2: Specific Gravity test results for Coarse Coal Refuse

Specific Gravity- Sample E (CCR)			
	E1	E2	E3
Wt. of Pycnometer(g)	166.15	167.80	163.68
Sample+Pycnomter+Water(g)	715.29	717.45	703.73
Pycnometer+Water(g)	663.57	665.69	661.04
Wt. of Sample(g)	85.21	86.16	70.4
Specific Gravity	**2.544**	**2.505**	**2.541**

Table 5.3: Specific Gravity test results for Dried Coal slurry

Specific Gravity- Coal slurry	
Wt. of Pycnometer(g)	105.80
Sample+Pycnomter+Water(g)	370.79
Pycnometer+Water(g)	354.46
Wt. of Sample(g)	35.00
Specific Gravity	**1.875**

Table 5.4: Specific Gravity Calculations for Blended Refuse

Combined Specific Gravity				
	Slurry	CCR(F)	Slurry	CCR(F)
Percentages	20	80	40	60
Gs	1.874	2.450	1.874	2.450
Combined Gs	**2.308**		**2.182**	

5.1.3. Sieve analysis

Coarse Coal Refuse

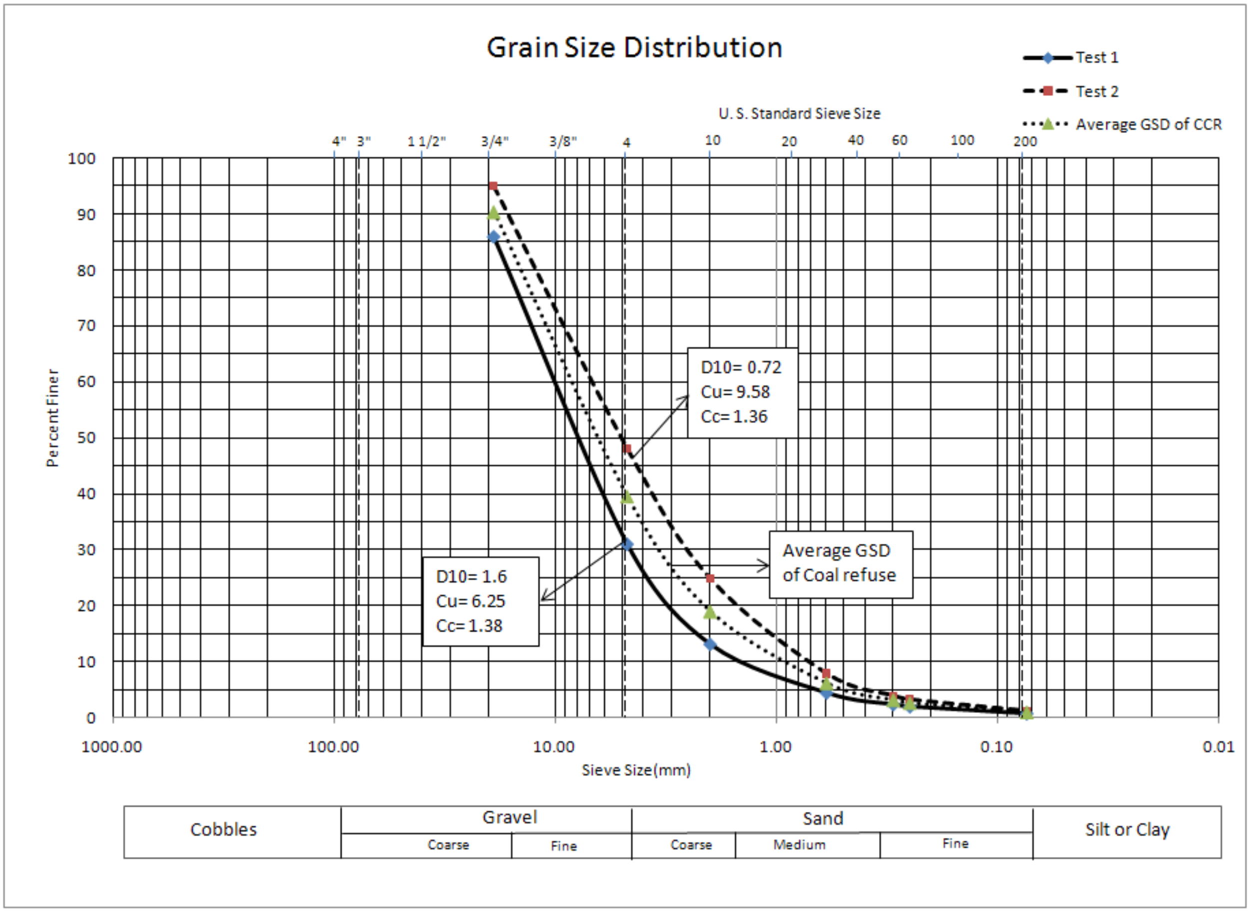
Table 5.5: Sieve Analysis test results of entire Coarse Coal Refuse

Coarse Coal Refuse (E)- Sieve Analysis											
Sieve No.	Particle dia	Wt Retained+ pan		Wt Retained		% Retained		Cumulative %		Percent Finer	
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
3/4"	19.05	713.51	607.40	158.46	52.35	14.18	5.08	14.18	5.08	85.82	94.92
No. 4	4.75	1122.60	992.47	612.28	482.16	54.79	46.83	68.97	51.92	31.03	48.08
No. 10	2.00	671.36	711.23	199.42	239.29	17.85	23.24	86.82	75.16	13.18	24.84
No. 30	0.60	578.36	655.88	96.96	174.49	8.68	16.95	95.49	92.11	4.51	7.89
No. 50	0.30	394.44	412.33	22.98	40.87	2.06	3.97	97.55	96.08	2.45	3.92
No. 60	0.25	370.61	373.48	4.17	7.05	0.37	0.68	97.92	96.77	2.08	3.23
No. 200	0.07	351.46	358.30	14.15	20.99	1.27	2.04	99.19	98.81	0.81	1.19
Pan		380.20	382.92	8.43	11.15	0.75	1.08	99.94	99.89	0.06	0.11
			Total	1116.85	1028.35						

Coarse coal refuse Passing No.4 Sieve

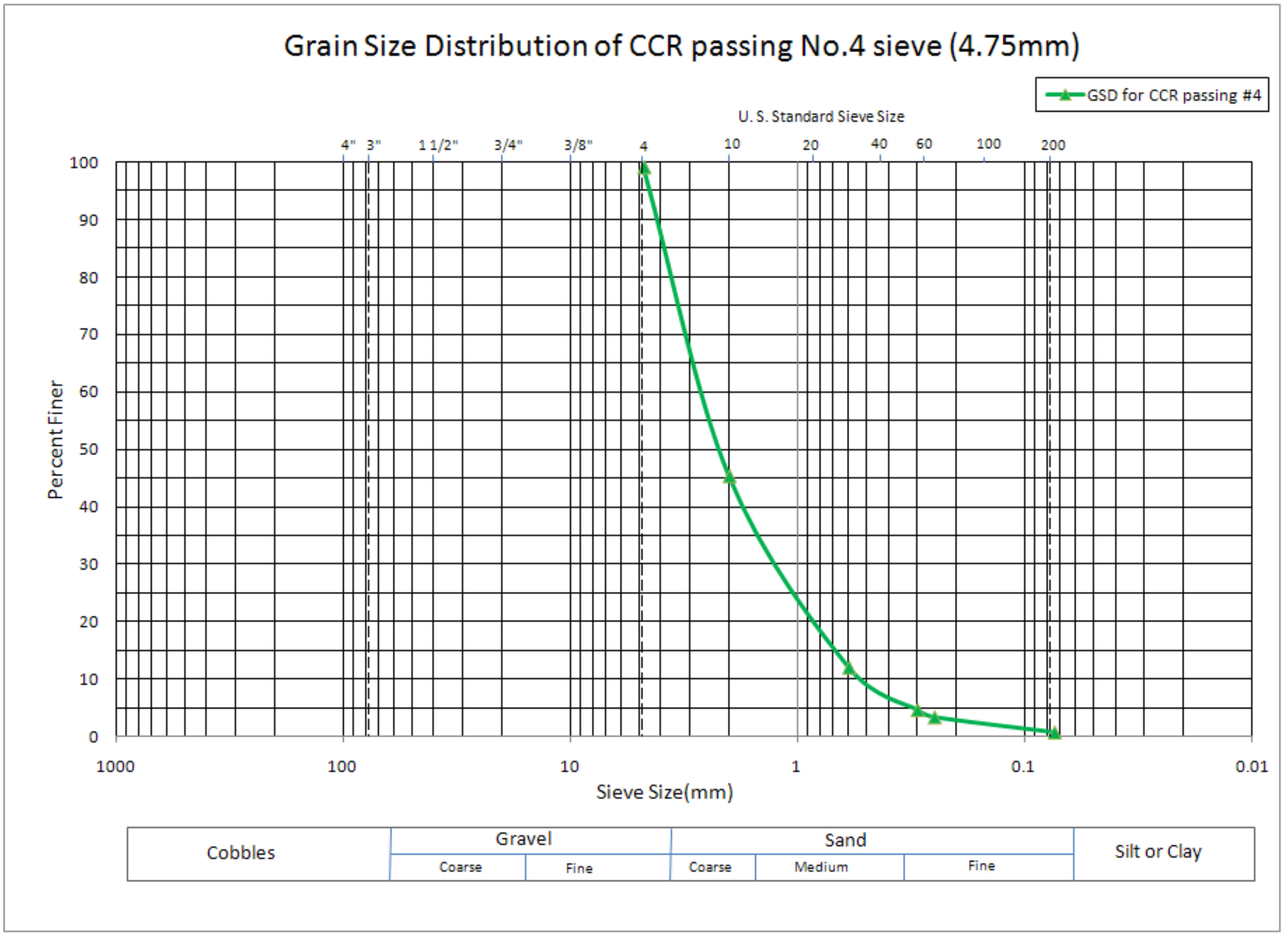
Table 5.6: Sieve Analysis results of Coarse Coal Refuse material passing No. 4 (4.75 mm) Sieve

Sieve analysis of CCR passing #4 sieve					
sieve No.	Particle dia	Wt. retained	% Retained	Cumulative %	Percent Finer
No. 4	4.75	10.61	1.00	1.00	99.00
No. 10	2.0	568.56	53.67	54.67	45.33
No. 30	0.595	352.22	33.25	87.91	12.09
No. 50	0.297	78.34	7.39	95.31	4.69
No. 60	0.25	13.48	1.27	96.58	3.42
No. 200	0.074	28.02	2.64	99.22	0.78
Pan		8.22	0.78	100.00	0.00
	Total	1059.45			



Results- Sample E Sieve Analysis		
	Raw Sample	
	Test 1	Test 2
D90	-	17
D60	10	6.9
D50	8	5
D30	4.7	2.6
D25	3.9	2
Effective Size, D10	1.6	0.72
Uniformity Coefficient, Cu	6.25	9.58
Coefficient of Curvature, Cc	1.38	1.36

Figure 5.1: Sieve Analysis Graph and Data of Coarse Coal refuse



Results- sieve analysis for CCR Initial GSD for passing No.4 sieve	
D_{85}	3.9
D_{60}	2.7
D_{50}	2.2
D_{30}	1.3
D_{25}	1.1
D_{15}	0.68
D_{10}	0.53
C_u	5.09
C_c	1.18

Figure 5.2: Sieve Analysis Graph and Data of CCR material Passing No.4 (4.75mm) Sieve

<u>Blended Refuse (80% CCR- 20 % FCR)</u>

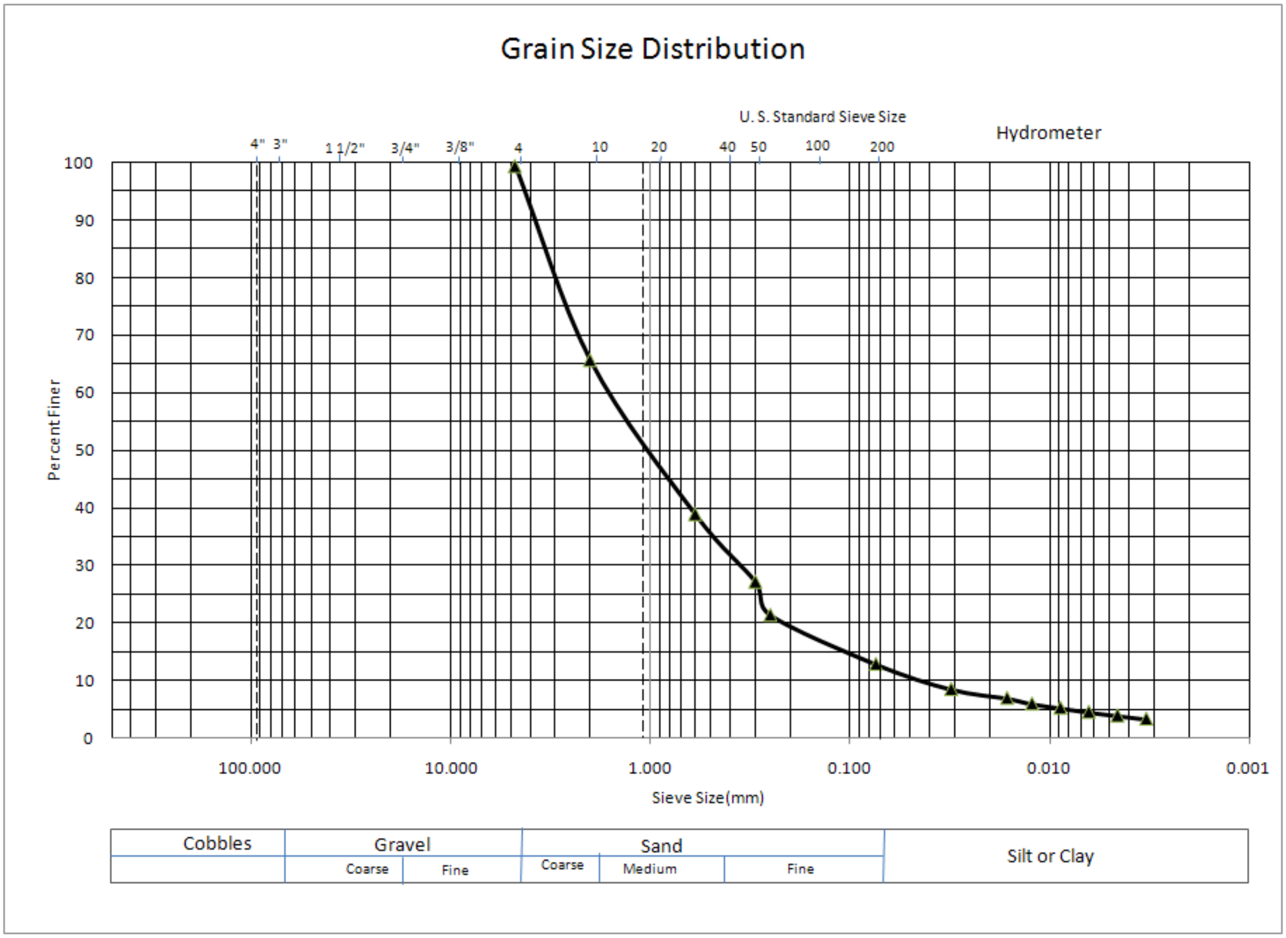
Table 5.7: Sieve Analysis test results for Blended refuse (80/20 Mix)

Blend using mix					
Combined Analysis (20% Fine - 80% Refuse)					
sieve No.	Particle dia	Wt. retained	% Retained	Cumulative %	Percent Finer
No. 4	4.75	5.3	0.53	0.53	99.47
No. 10	2.0	336.66	33.76	34.29	65.71
No. 30	0.595	266.91	26.77	61.06	38.94
No. 50	0.297	117.06	11.74	72.80	2 7.20
No. 60	0.25	57.52	5.77	78.57	21.43
No. 200	0.074	85.11	8.54	87.10	12.90
Pan		128.59	12.90	100.00	0.00

<u>Hydrometer Analysis of 80/20 BR</u>

Table 5.8: Hydrometer test results for Blended refuse (80/20 Mix)

Hydrometer Analysis- Blended refuse (80/20 Mix)														
Sample Wt	Time(T)	Hydrometer reading	Meniscus Correction, Cm	Corrected R	Eff Depth, L	Correction Factor(K)	Dia(mm)	Cd	R-Cd	Temp Correction, m	R-Cd+m	Percent Finer	Adjusted Finer
50	2	35.5	0	35.5	10.478	0.01357	0.0311	1.5	34	1.3	35.3	70.60	8.54
50	8	29	0	29	11.544	0.01357	0.0163	1.5	27.5	1.3	28.8	57.60	6.96
50	15	25	0	25	12.2	0.01357	0.0122	1.5	23.5	1.3	24.8	49.60	6.00
50	30	22	0	22	12.692	0.01357	0.0088	1.5	20.5	1.3	21.8	43.60	5.27
50	60	19	0	19	13.184	0.01357	0.0064	1.5	17.5	1.3	18.8	37.60	4.55
50	120	16.5	0	16.5	13.594	0.01357	0.0046	1.5	15	1.3	16.3	32.60	3.94
50	240	14	0	14	14.004	0.01357	0.0033	1.5	12.5	1.3	13.8	27.60	3.34



BR Initial GSD (80%CRR, 20% FCR)- Results	
D_{85}	3.5
D_{60}	1.6
D_{50}	1.1
D_{30}	0.35
D_{25}	0.28
D_{15}	0.12
D_{10}	0.045
C_u	35.56
C_c	1.70

Figure 5.3: Sieve Analysis graph and Data of Blended Refuse material (80/20 mix)

<u>Blended Refuse (60% CCR- 40 % FCR passing No.100 sieve)</u>

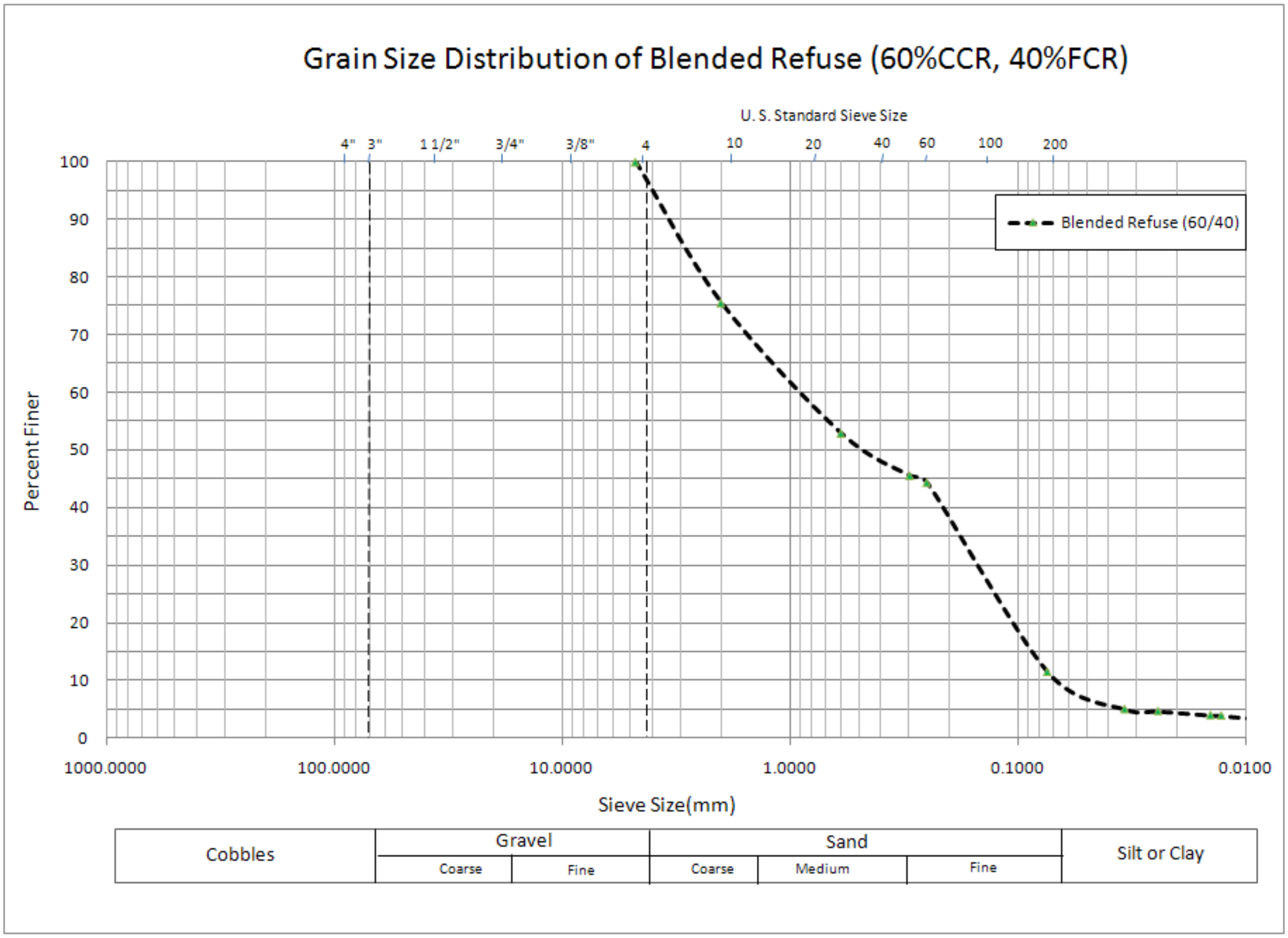
Table 5.9: Sieve Analysis test results for Blended refuse (60/40 Mix)

Sieve Analysis- Blended Refuse (60% CCR, 40% FCR passing No.100)							
Sieve No.	Particle dia	Empty Pan	Wt Retained+pan	Wt Retained	% Retained	Cumulative %	Percent Finer
3/4"	19.05	551.42	551.42	0.00	0.00	0.00	100.00
No. 4	4.75	525.25	526.30	1.05	0.06	0.06	99.94
No. 10	2.00	479.12	919.94	440.82	24.45	24.50	75.50
No. 30	0.60	476.99	885.28	408.29	22.64	47.15	52.85
No. 50	0.30	441.61	574.05	132.44	7.34	54.49	45.51
No. 60	0.25	317.85	339.28	21.43	1.19	55.68	44.32
No. 200	0.07	294.20	886.11	591.91	32.82	88.50	11.50
Pan		372.54	579.85	207.31	11.50	100.00	0.00
				1803.25			

<u>Hydrometer analysis of 60/40 BR</u>

Table 5.10: Hydrometer test results for Blended refuse (60/40 Mix)

Hydrometer Analysis- BR (60/40)												
Sample Wt	Time(T)	Hydrometer reading	Meniscus Correction, Cm	Corrected R	Eff Depth, L	Correction Factor(K)	Dia(mm)	Cd	R-Cd	Temp Correction, m	R-Cd+m	Percent Finer
50	2	23.5	0.1	23.6	12.4296	0.01357	0.033829	3	20.6	1.3	21.9	43.80
50	4	22	0.1	22.1	12.6756	0.01357	0.024157	3	19.1	1.3	20.4	40.80
50	12	19	0.1	19.1	13.1676	0.01357	0.014215	3	16.1	1.3	17.4	34.80
50	15	18.5	0.1	18.6	13.2496	0.01357	0.012754	3	15.6	1.3	16.9	33.80
50	30	16.5	0.1	16.6	13.5776	0.01357	0.009129	3	13.6	1.3	14.9	29.80
50	65	14	0.1	14.1	13.9876	0.01357	0.006295	3	11.1	1.3	12.4	24.80
50	125	12	0.1	12.1	14.3156	0.01357	0.004592	3	9.1	1.3	10.4	20.80



BR (60% CCR, 40% FCR passing No.100)-Results	
D_{85}	2.9
D_{60}	0.9
D_{50}	0.5
D_{30}	0.16
D_{25}	0.14
D_{15}	0.086
D_{10}	0.069
C_u	13.04
C_c	0.41

Figure 5.4: Sieve Analysis graph and Data of Blended Refuse material (60/40 mix)

5.1.4. Atterberg Limits

Table 5.11: Atterberg test Results of Coarse Coal refuse

Sample E- Coarse Coal Refuse						
	Liquid Limit test			Plastic Limit test		
Container Mass(g), M_c	30.34	37.22	37.36	37.11	33.08	37.32
Container+Moist Specimen Mass(g), M_{cms}	39.42	43.44	45.33	39.14	36.21	40.26
Container+Oven Dry Specimen Mass(g), M_{cds}	37.51	42.04	43.45	38.76	35.75	39.71
Mass of Water(g), $M_w = M_{cms} - M_{cds}$	1.91	1.4	1.88	0.38	0.46	0.55
Mass of Solids(g), $M_s = M_{cds} - M_c$	7.17	4.82	6.09	1.65	2.67	2.39
Water Content, % $W = (M_w/M_s) \times 100$	26.64	29.05	30.87	23.03	17.23	23.01
No. of Blows	30	23	13	PL =	21.09	

Coarse Coal Refuse (E)	LL	PL	PI
	28.40	21.09	7.31

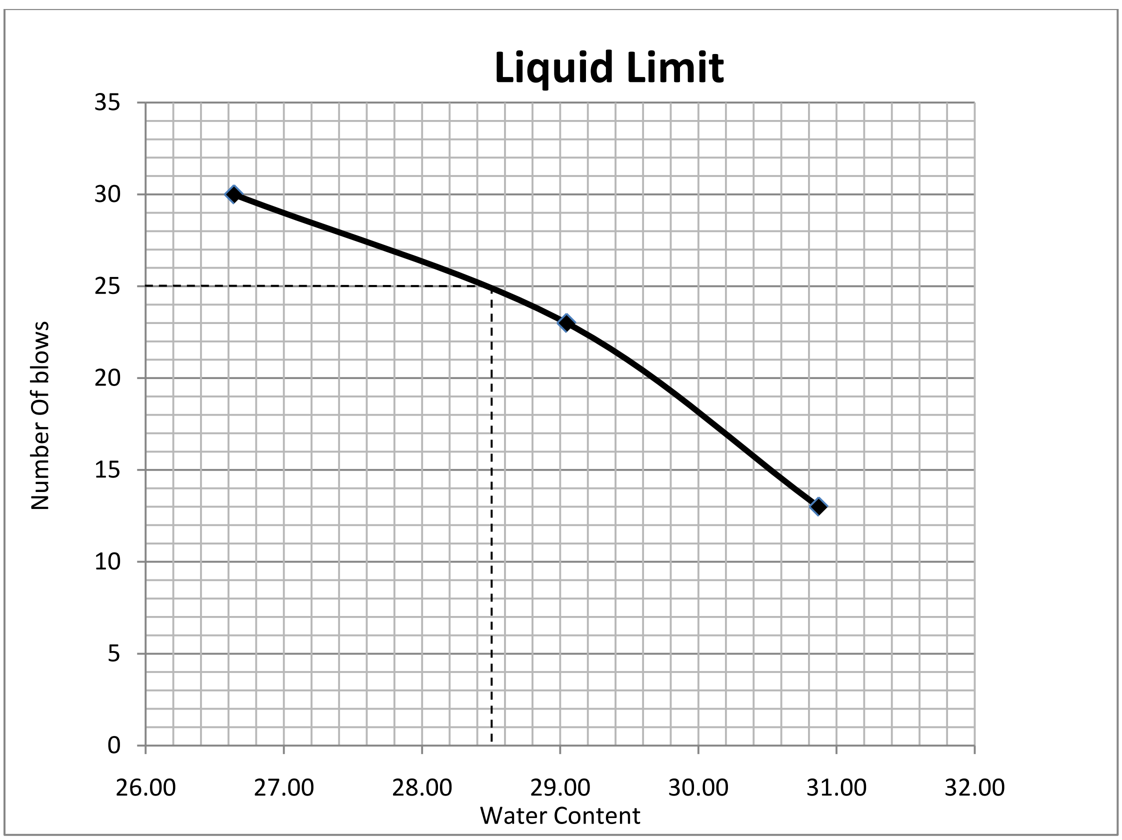


Figure 5.5: Liquid limit graph of Coarse Coal refuse

5.2. Compaction tests

5.2.1. Standard compaction (coarse coal refuse)

Sample E-Density Results					
Test No.	E1	E2	E3	E4	E5
Water Content, % W	4.00	5.00	6.00	7.00	8.00
Mold Weight(g), M_{md}	2075.30	2075.30	2075.30	2075.30	2075.30
Specimen+Mold Weight(g), M_t	3846.50	3919.00	3945.52	4006.52	3889.00
Volume of Mold(cm^3), V	904.00	904.00	904.00	904.00	904.00
Specific Gravity of Soil, G_s	2.530	2.530	2.530	2.530	2.530
Unit Weight of Water @ 20°C(KN/m^3), γ_w	9.79	9.79	9.79	9.79	9.79
Moist Unit Weight of Compacted Specimen(g/cm^3), γ_m	1.96	2.04	2.07	2.14	2.01
Dry Unit Weight of Compacted Specimen(g/cm^3), γ_d	1.88	1.94	1.95	2.00	1.86
Dry Unit Weight of Compacted Specimen(KN/m^3), γ_d	18.48	19.05	19.14	19.58	18.22
Dry Unit Weight of Compacted Specimen(lb/ft^3), γ_d	**117.61**	**121.26**	**121.85**	**124.64**	**115.98**
Void Ratio, $e=((Gs*\gamma_w)/\gamma_d)-1$	0.34	0.30	0.29	0.26	0.36
Degree of Saturation (%), S=Gs*w/e	29.71	42.15	51.65	66.87	56.32
W_{sat}	13.46	11.86	11.62	10.47	14.21

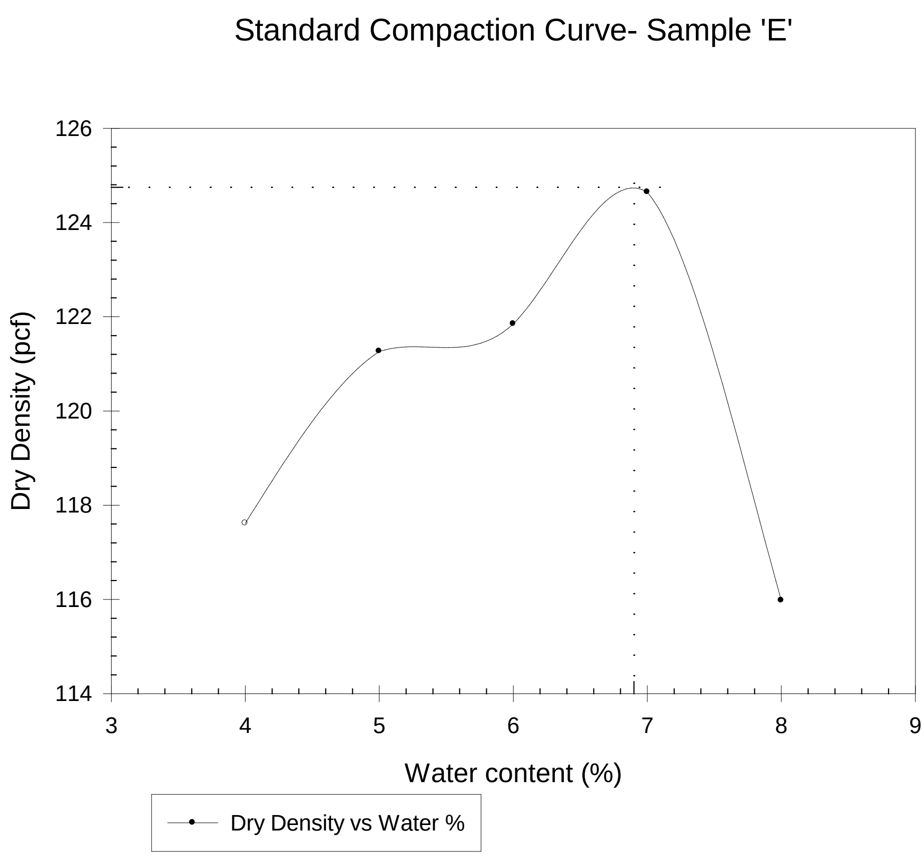


Figure 5.6: Standard Compaction test results and Graph of CCR material passing No.4 sieve

5.2.2. Reduced compaction (CCR) - 12 Blows 2 layers

Sample E reduced compaction (12 blows 2 layers)-Density Results					
Water Content, % W	5.11	8.43	8.98	10.00	11.94
Mold Weight(g), M_{md}	2048.94	2048.94	2048.94	2048.94	2048.94
Specimen+Mold Weight(g), M_t	3693.00	3868.00	3875.00	3900.00	3911.00
Volume of Mold(cm^3), V	904.00	904.00	904.00	904.00	904.00
Specific Gravity of Soil, G_s	2.530	2.530	2.530	2.530	2.530
Unit Weight of Water @ $20^oC(KN/m^3)$, γ_w	9.79	9.79	9.79	9.79	9.79
Moist Unit Weight of Compacted Specimen(g/cm^3), γ_m	1.82	2.01	2.02	2.05	2.06
Dry Unit Weight of Compacted Specimen(g/cm^3), γ_d	1.73	1.86	1.85	1.86	1.84
Dry Unit Weight of Compacted Specimen(KN/m^3), γ_d	16.97	18.20	18.18	18.25	18.05
Dry Unit Weight of Compacted Specimen(lb/ft^3), $\square_d$	**108.02**	**115.86**	**115.71**	**116.21**	**114.88**
Void Ratio, $e=((Gs*\gamma_w)/\gamma_d)-1$	0.46	0.36	0.36	0.36	0.37
Degree of Saturation (%), S=Gs*w/e	28.11	59.10	62.71	70.96	81.11
W_{sat}	18.17	14.26	14.33	14.10	14.72

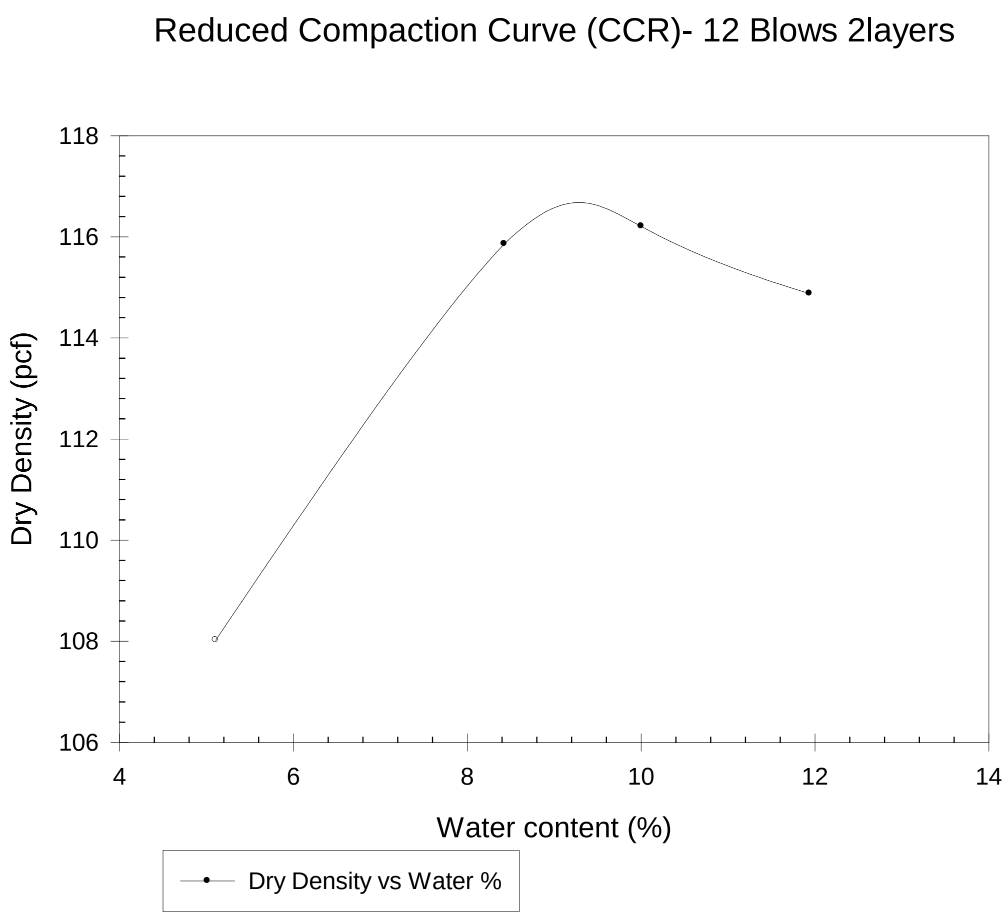


Figure 5.7: 12 blows 2layers Compaction test results and Graph

5.2.3. Reduced compaction (CCR) - 8 Blows 2 layers

Sample E reduced compaction (8 blows 2 layers)-Density Results					
Water Content, % W	4.70	7.09	8.92	10.76	11.46
Mold Weight(g), M_{md}	2049.32	1917.22	1888.41	1921.85	2049.32
Specimen+Mold Weight(g), M_t	3642.00	3482.50	3623.00	3707.50	3884.00
Volume of Mold(cm^3), V	904.00	874.00	874.00	874.00	904.00
Specific Gravity of Soil, G_s	2.530	2.530	2.530	2.530	2.530
Unit Weight of Water @ 20°C(KN/m^3), γ_w	9.79	9.79	9.79	9.79	9.79
Moist Unit Weight of Compacted Specimen(g/cm^3), γ_m	1.76	1.79	1.98	2.04	2.03
Dry Unit Weight of Compacted Specimen(g/cm^3), γ_d	1.68	1.67	1.82	1.84	1.82
Dry Unit Weight of Compacted Specimen(KN/m^3), γ_d	16.50	16.40	17.87	18.09	17.86
Dry Unit Weight of Compacted Specimen(lb/ft^3), γ_d	**105.05**	**104.40**	**113.75**	**115.16**	**113.67**
Void Ratio, $e=((Gs*\gamma_w)/\gamma_d)-1$	0.50	0.51	0.39	0.37	0.39
Degree of Saturation (%), S=Gs*w/e	23.75	35.18	58.50	73.78	74.96
W_{sat}	19.80	20.16	15.26	14.59	15.30

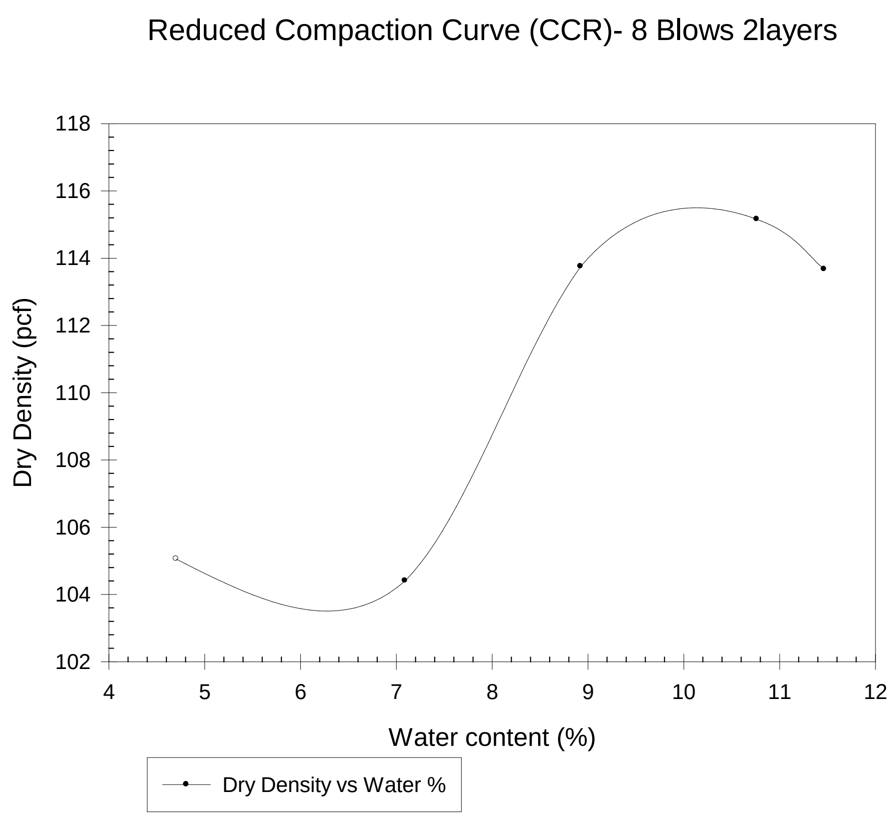


Figure 5.8: Reduced Compaction (8 blows 2layers) test results and Graph

5.2.4. Reduced compaction (CCR) - 4 Blows 2 layers

Sample E reduced compaction (4 blows 2 layers)-Density Results				
Water Content, % W	5.39	7.38	9.14	11.01
Mold Weight(g), M_{md}	2048.96	616.73	614.05	619.22
Specimen+Mold Weight(g), M_t	3597.00	2156.82	2298.72	2335.58
Volume of Mold(cm^3), V	904.00	874.00	874.00	874.00
Specific Gravity of Soil, G_s	2.530	2.530	2.530	2.530
Unit Weight of Water @ 20°C(KN/m^3), γ_w	9.79	9.79	9.79	9.79
Moist Unit Weight of Compacted Specimen(g/cm^3), γ_m	1.71	1.76	1.93	1.96
Dry Unit Weight of Compacted Specimen(g/cm^3), γ_d	1.62	1.64	1.77	1.77
Dry Unit Weight of Compacted Specimen(KN/m^3), γ_d	15.93	16.09	17.32	17.35
Dry Unit Weight of Compacted Specimen(lb/ft^3), γ_d	**101.44**	**102.45**	**110.25**	**110.44**
Void Ratio, $e=((Gs*\gamma_w)/\gamma_d)-1$	0.55	0.54	0.43	0.43
Degree of Saturation (%), S=Gs*w/e	24.60	34.64	53.81	65.15
W_{sat}	21.91	21.30	16.99	16.90

Reduced Compaction Curve (CCR)- 4 Blows 2layers

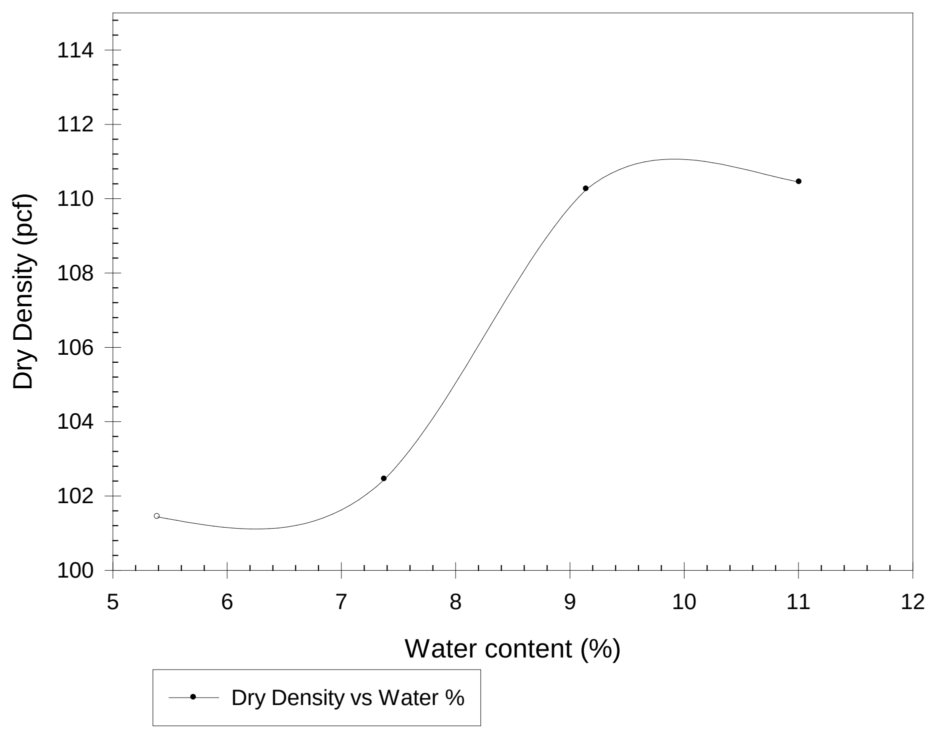


Figure 5.9: Reduced Compaction (4 blows 2layers) test results and Graph

5.2.5. Standard compaction (Blended refuse-80/20 mix)

Sample F-Density Results						
Test No.	F1	F2	F3	F4	F5	F6
Water Content, % W	5.99	7.78	9.58	11.11	12.04	12.71
Mold Weight(g), M_{md}	2049.27	2049.27	2049.27	2049.27	2049.27	2049.27
Specimen+Mold Weight(g), M_t	3772.00	3811.00	3901.00	3920.00	3899.00	3839.00
Volume of Mold(cm^3), V	904.00	904.00	904.00	904.00	904.00	904.00
Specific Gravity of Soil, G_s	2.300	2.300	2.300	2.300	2.300	2.300
Unit Weight of Water @ 20^oC(KN/m^3), γ_w	9.79	9.79	9.79	9.79	9.79	9.79
Moist Unit Weight of Compacted Specimen(g/cm^3), γ_m	1.91	1.95	2.05	2.07	2.05	1.98
Dry Unit Weight of Compacted Specimen(g/cm^3), γ_d	1.80	1.81	1.87	1.86	1.83	1.76
Dry Unit Weight of Compacted Specimen(KN/m^3), γ_d	17.63	17.73	18.33	18.27	17.91	17.23
Dry Unit Weight of Compacted Specimen(lb/ft^3), γ_d	**112.24**	**112.88**	**116.70**	**116.27**	**114.01**	**109.66**
Void Ratio, $e=((Gs*\gamma_w)/\gamma_d)-1$	0.28	0.27	0.23	0.23	0.26	0.31
Degree of Saturation (%), S=Gs*w/e	49.76	66.34	96.57	109.83	107.73	95.22
W_{sat}	12.05	11.72	9.92	10.12	11.18	13.35

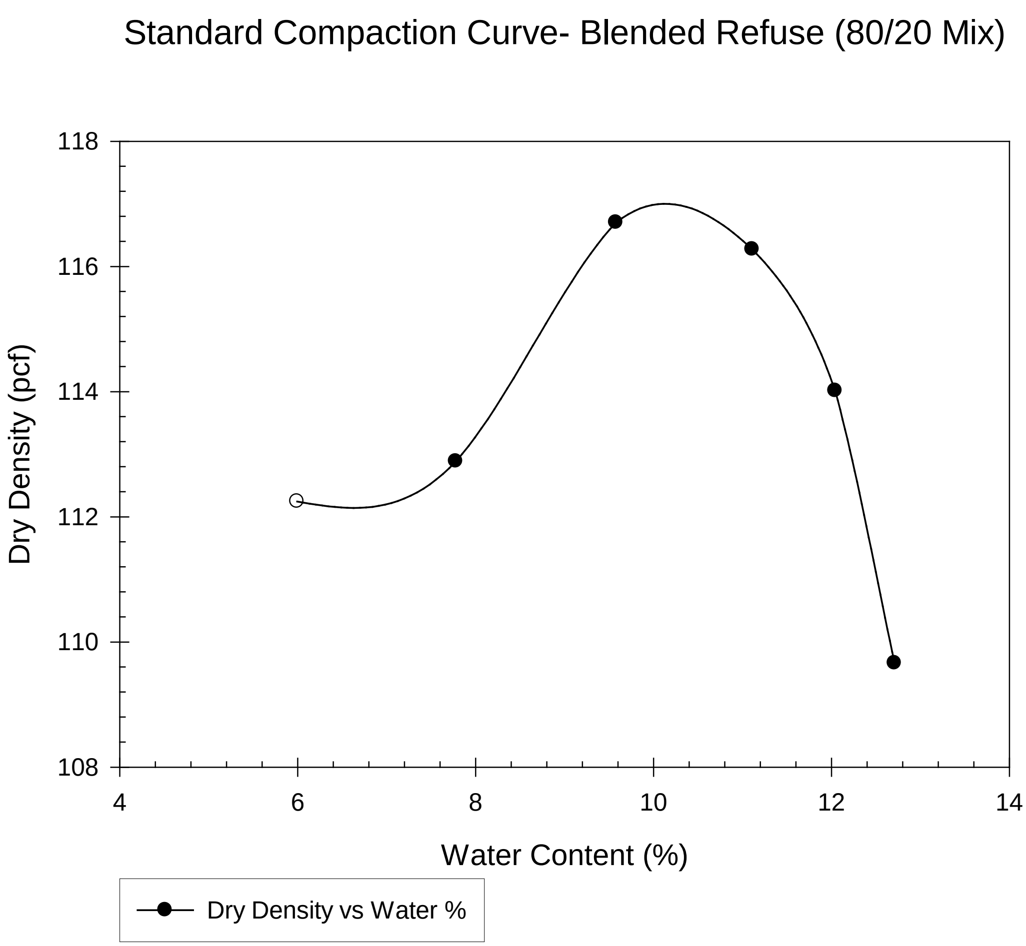


Figure 5.10: Standard Compaction test results and Graph of Blended refuse (80/20 mix)

5.2.6. Reduced compaction (BR) - 15 Blows 1 layers

Sample F-Density Results						
Test No.	6%	8%	10%	11%	12%	13%
Water Content, % W	5.85	7.53	9.95	11.18	12.02	13.06
Mold Weight(g), M_{md}	2049.36	2049.39	2049.36	2049.36	2049.36	2049.36
Specimen+Mold Weight(g), M_t	3547.00	3547.00	3642.00	3733.00	3771.00	3298
Volume of Mold(cm^3), V	904.00	904.00	904.00	904.00	904.00	904.00
Specific Gravity of Soil, G_s	2.300	2.300	2.300	2.300	2.300	2.300
Unit Weight of Water @ 20°C(KN/m^3), γ_w	9.79	9.79	9.79	9.79	9.79	9.79
Moist Unit Weight of Compacted Specimen(g/cm^3), γ_m	1.66	1.66	1.76	1.86	1.90	1.38
Dry Unit Weight of Compacted Specimen(g/cm^3), γ_d	1.57	1.54	1.60	1.68	1.70	1.22
Dry Unit Weight of Compacted Specimen(KN/m^3), γ_d	15.35	15.11	15.71	16.43	16.67	11.98
Dry Unit Weight of Compacted Specimen(lb/ft^3), γ_d	**97.71**	**96.18**	**100.03**	**104.58**	**106.14**	**76.27**
Void Ratio, $e=((Gs*\gamma_w)/\gamma_d)-1$	0.47	0.49	0.43	0.37	0.35	0.88
Degree of Saturation (%), S=Gs*w/e	28.81	35.32	52.88	69.41	78.91	34.17
W_{sat}	20.30	21.31	18.82	16.11	15.23	38.23

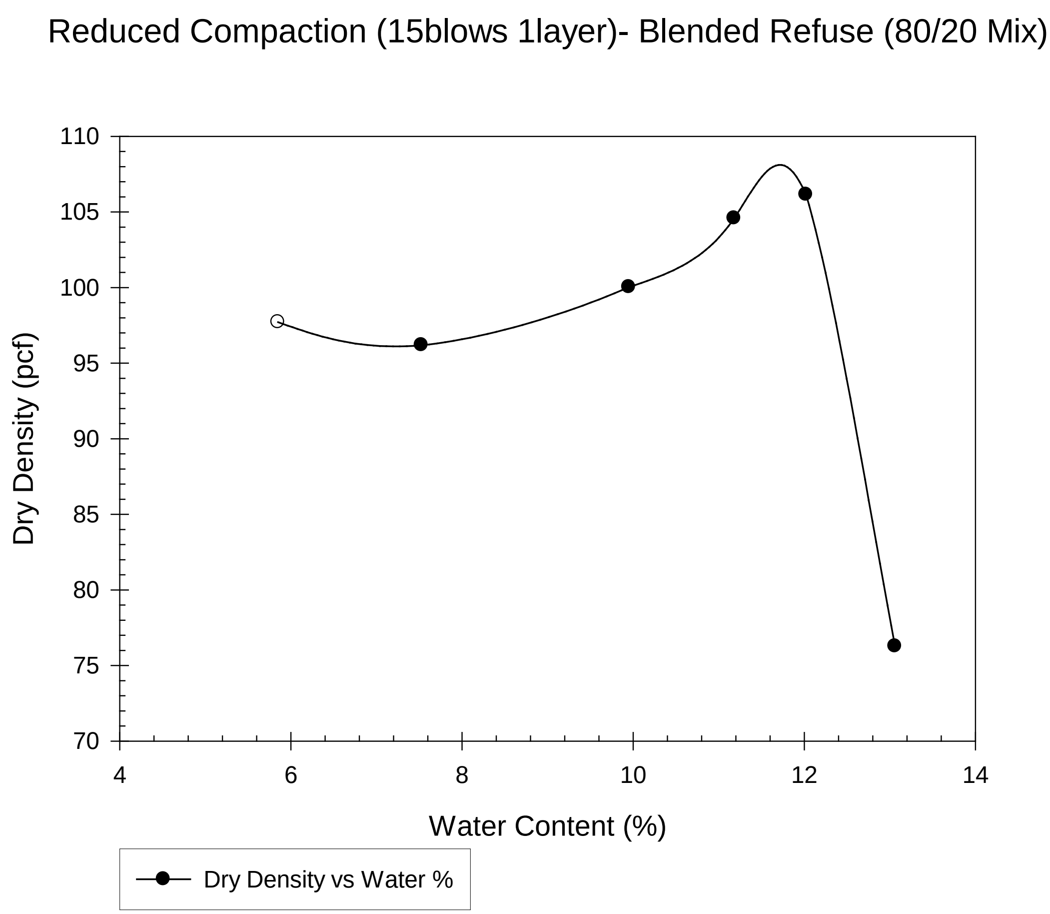


Figure 5.11: Reduced compaction (15 blows and 1 layer) test results of BR (80/20 mix)

5.3. Hydraulic Conductivity Results

5.3.1. Coarse Coal Refuse (CCR) Samples

<u>Hydraulic conductivity for CCR without geotextile (standard compaction)</u>

	CCR
Dry Density, kN/m^3 (pcf)	18.83 (119.84)
Compaction Energy, kJ/m^3 ($ft\text{-}lb/ft^3$)	636.21
Number of Blows/Layer	25 Blows,3layers
Geotextile	---------
AOS (mm)	---------
Gradient	5
Test Duration (hours)	5
Average k (m/sec)	5.06e-6
Standard Deviation for k	1.12e-6
Void Ratio, e	0.32
Porosity, n	0.24
Cumulative Permeant Volume (ml)	3640
Pore volume, pV (ml)	209.67

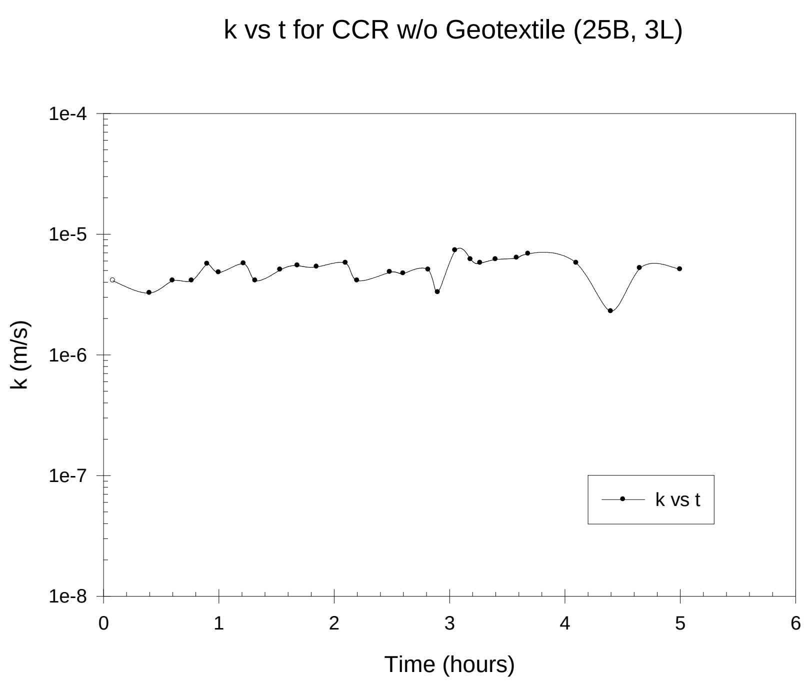


Figure 5.12: HC test data of CCR sample (standard compaction) and k vs. t graph

Hydraulic conductivity for CCR without geotextile (12blows 2layers)

	CCR
Dry Density, kN/m^3 (pcf)	16.49 (104.94)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	203.58 (4252)
Number of Blows/Layer	12 Blows, 2layers
Geotextile	---------
AOS (mm)	---------
Gradient	5
Test Duration (hours)	5.58
Average k (m/sec)	5.82e-6
Standard Deviation for k	1.60e-6
Void Ratio, e	0.50
Porosity, n	0.33
Cumulative Permeant Volume (ml)	3665
Pore volume, pV (ml)	292.31

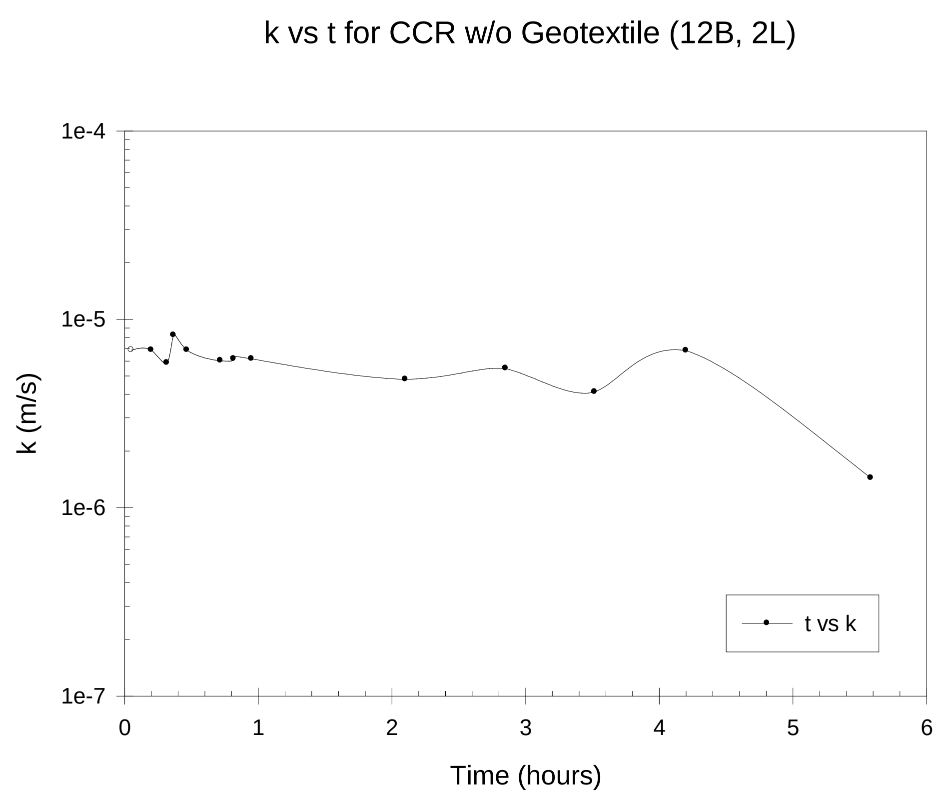


Figure 5.13: HC test data of CCR (12blows 2layers) W/O Geotextile and k vs. t graph

Hydraulic conductivity for CCR without geotextile (4blows 2layers)

	CCR
Dry Density, kN/m^3 (pcf)	14.76 (93.97)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	67.84 (1417)
Number of Blows/Layer	4 Blows, 2layers
Geotextile	---------
AOS (mm)	---------
Gradient	5
Test Duration (hours)	2.92
Average k (m/sec)	1.43e-5
Standard Deviation for k	1.90e-5
Void Ratio, e	0.68
Porosity, n	0.40
Cumulative Permeant Volume (ml)	3250
Pore volume, pV (ml)	353.42

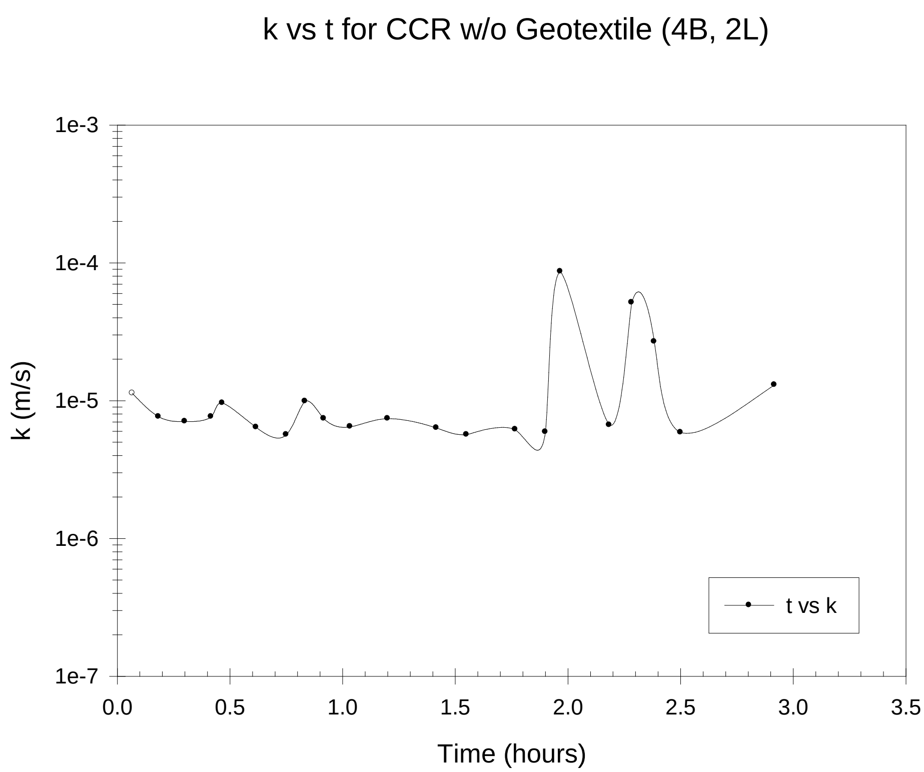


Figure 5.14: HC test data (4blows 2layers) W/O Geotextile and k vs. t graph of CCR

Hydraulic conductivity for CCR without geotextile (8blows 2layers)

	CCR
Dry Density, kN/m^3 (pcf)	15.90 (101.23)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	135.73 (2835)
Number of Blows/Layer	8 Blows, 2layers
Geotextile	---------
AOS (mm)	---------
Gradient	5
Test Duration (hours)	3.57
Average k (m/sec)	1.05e-5
Standard Deviation for k	1.36e-5
Void Ratio, e	0.56
Porosity, n	0.36
Cumulative Permeant Volume (ml)	4620
Pore volume, pV (ml)	353.42

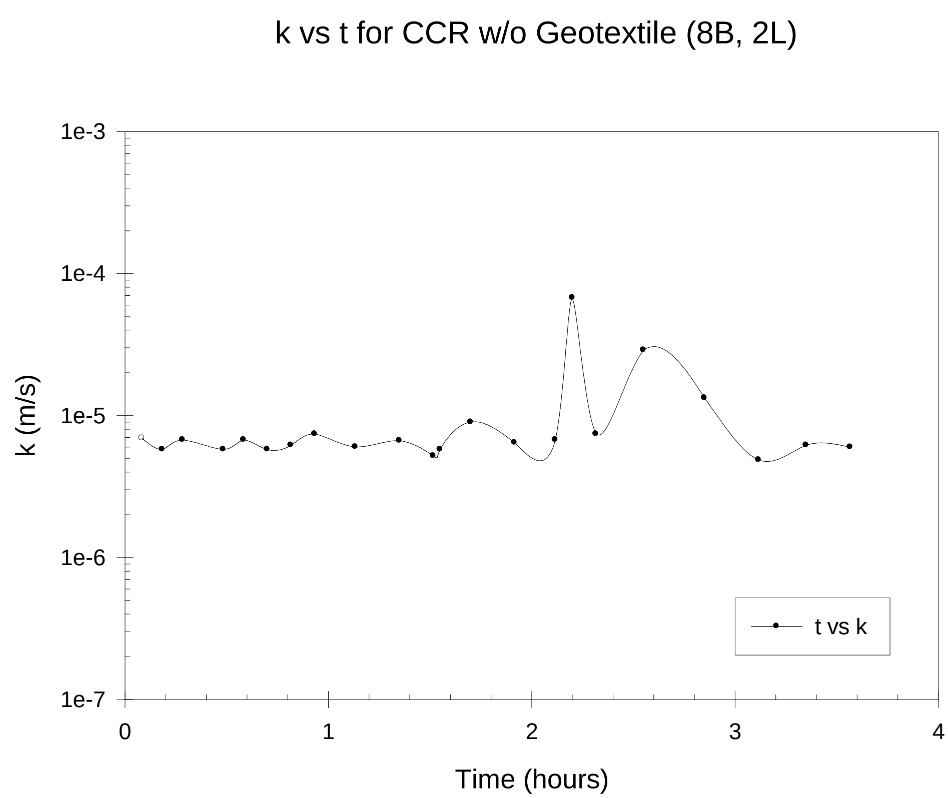


Figure 5.15: HC test data (8blows 2layers) W/O Geotextile and k vs. t graph of CCR

Hydraulic conductivity for E7, E8, E9

	E7	E8	E9
Dry Density, kN/m^3 (pcf)	19.66 (125.14)	18.97 (120.79)	18.82 (120.02)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	636.21	636.21	636.21
Number of Blows/Layer	25 Blows,3layers	25 Blows,3layers	25 Blows,3 layers
Geotextile	NW-601	NW-401	NW-801
AOS (mm)	0.212	0.212	0.180
Gradient	5	5	5
Test Duration (hours)	8	10.82	10.8
Average k (m/sec)	3.69 e-7	1.81 e-6	2.35 e -6
Standard Deviation for k	7.96 e-8	1.14 e-6	7.35 e -7
Void Ratio, e	0.26	0.31	0.32
Porosity, n	0.21	0.23	0.24
Cumulative Permeant Volume (ml)	430	2750	3755
Pore volume, pV (ml)	180.35	204.72	210.025

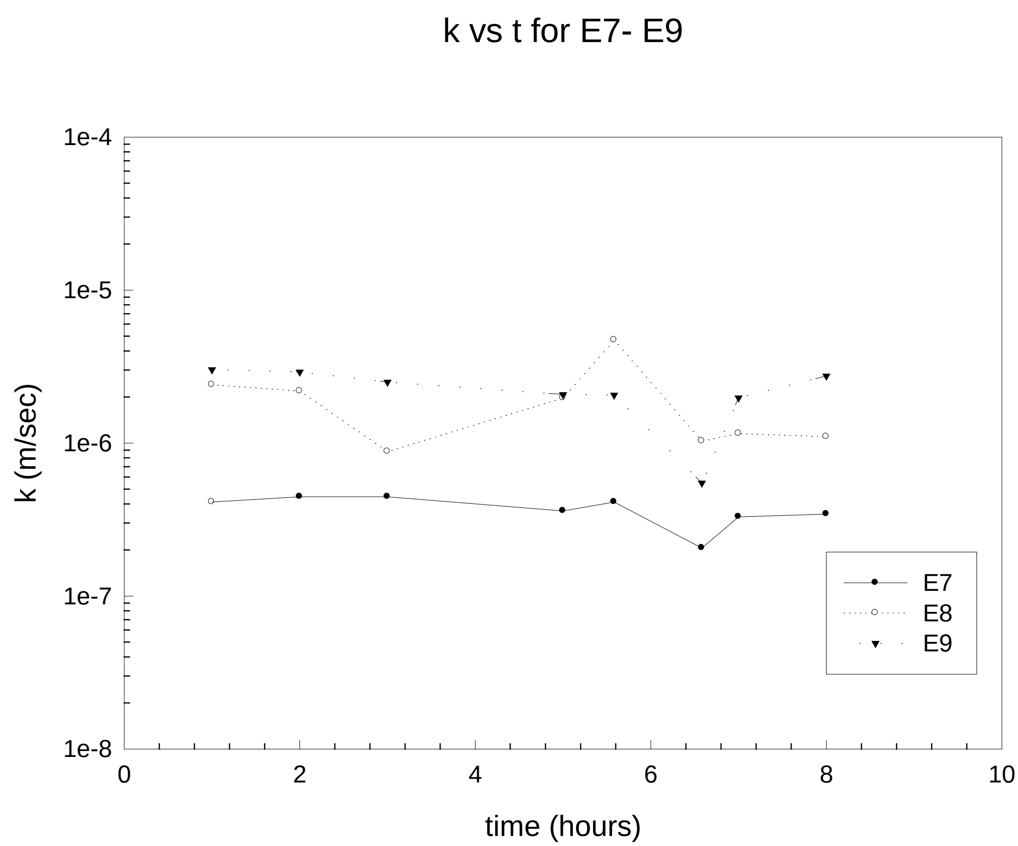


Figure 5.16: Hydraulic conductivity data and graph of sample E7-E9

Hydraulic conductivity for E7, E8, E9 (Duplicate)

	E7-II	E8-II	E9-II
Dry Density, kN/m^3 (pcf)	19.65 (125.06)	18.98 (120.83)	18.78 (119.56)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	636.21	636.21	636.21
Number of Blows/Layer	25 Blows,3layers	25 Blows,3layers	25 Blows,3layers
Geotextile	NW-601	NW-401	NW-801
AOS (mm)	0.212	0.212	0.180
Gradient	5	5	5
Test Duration (hours)	6.10	5.30	2.50
Average k (m/sec)	4.66 e-6	5.62 e-6	1.22 e -5
Standard Deviation for k	6.57 e-7	1.18 e-6	2.14 e -6
Void Ratio, e	0.26	0.30	0.32
Porosity, n	0.21	0.23	0.24
Cumulative Permeant Volume (ml)	4110	4224	4293
Pore volume, pV (ml)	180.70	204.37	211.43

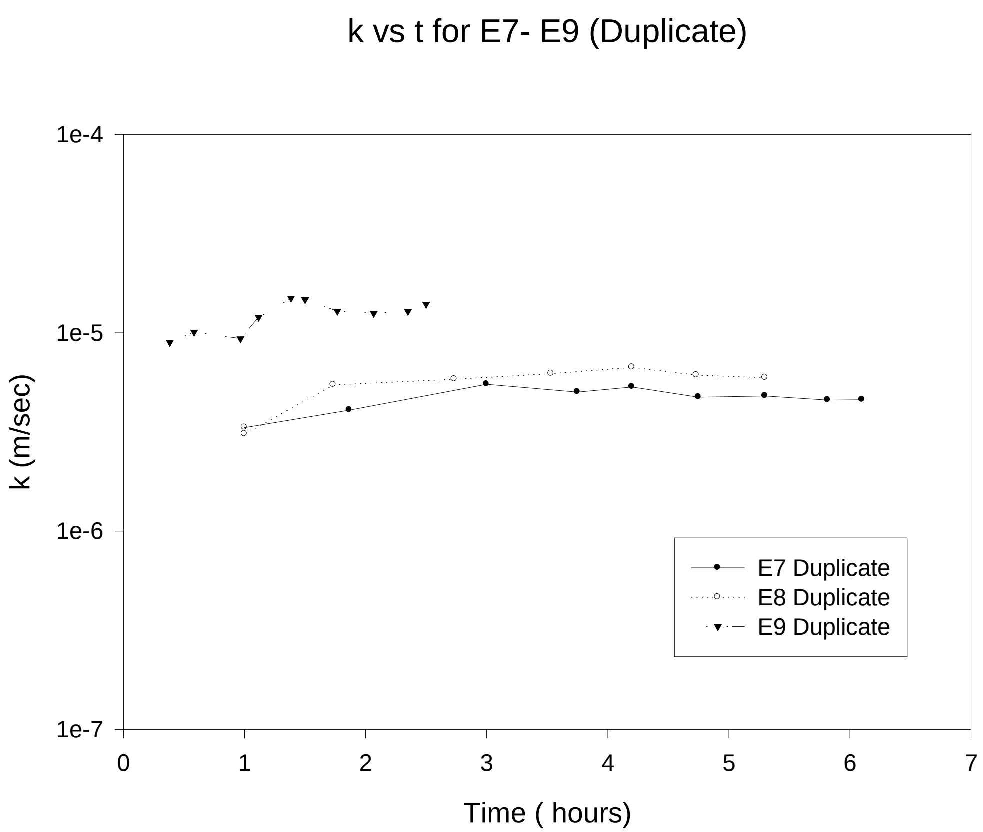


Figure 5.17: Hydraulic conductivity data and graph of sample E7-E9 (Duplicate)

Hydraulic conductivity for E7, E8, E9 (Triplicate)

	E7-III	E8-III	E9-III
Dry Density, kN/m^3 (pcf)	19.61(124.82)	18.95 (120.60)	18.87 (120.10)
Compaction Energy, kJ/m^3 ($ft\text{-}lb/ft^3$)	636.21	636.21	636.21
Number of Blows/Layer	25 Blows,3layers	25 Blows,3layers	25 Blows,3layers
Geotextile	NW-601	NW-401	NW-801
AOS (mm)	0.212	0.212	0.180
Gradient	5	5	5
Test Duration (hours)	3.30	3.32	2.50
Average k (m/sec)	7.85 e-6	7.16 e-6	1.18 e -5
Standard Deviation for k	1.60 e-7	1.07 e-6	2.23 e -6
Void Ratio, e	0.26	0.31	0.31
Porosity, n	0.21	0.23	0.24
Cumulative Permeant Volume (ml)	3750	3508	4293
Pore volume, pV (ml)	182.12	205.43	208.25

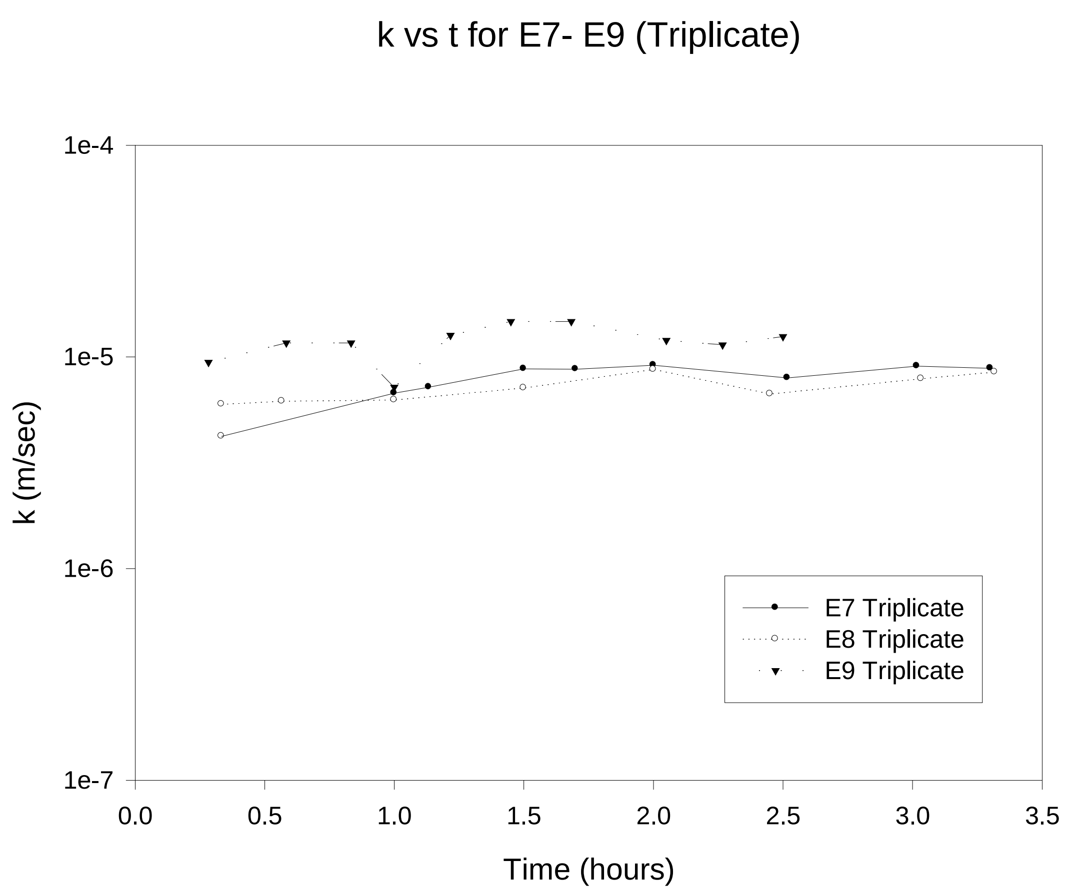
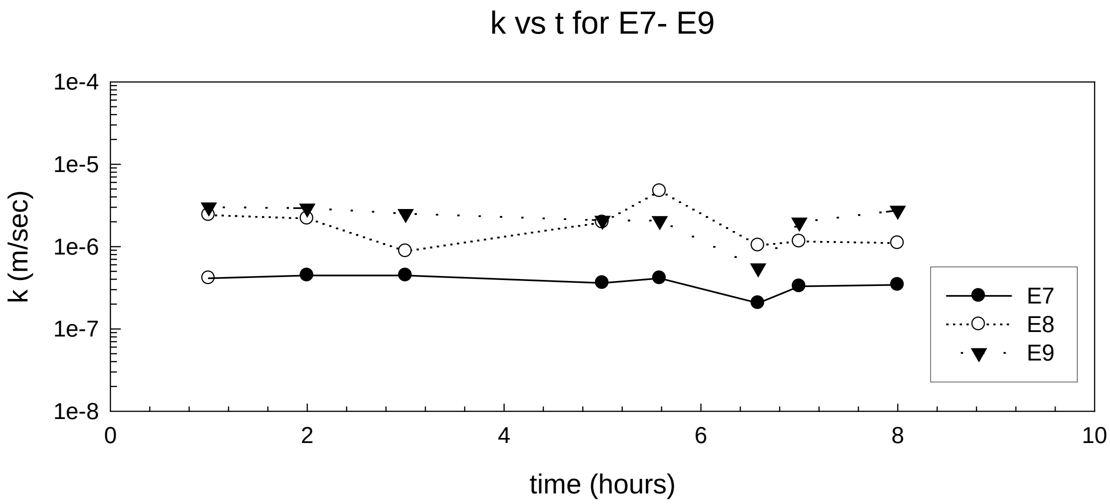
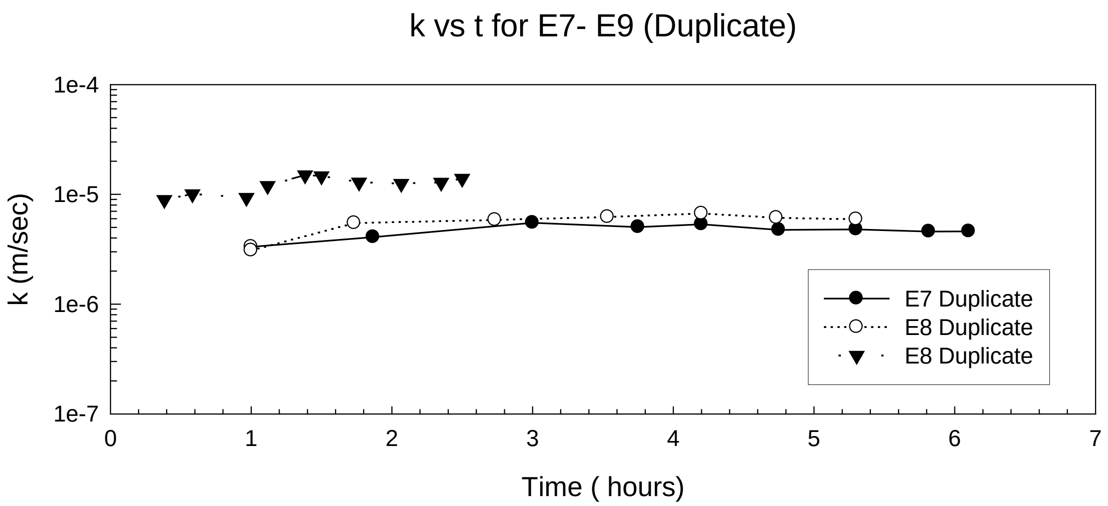
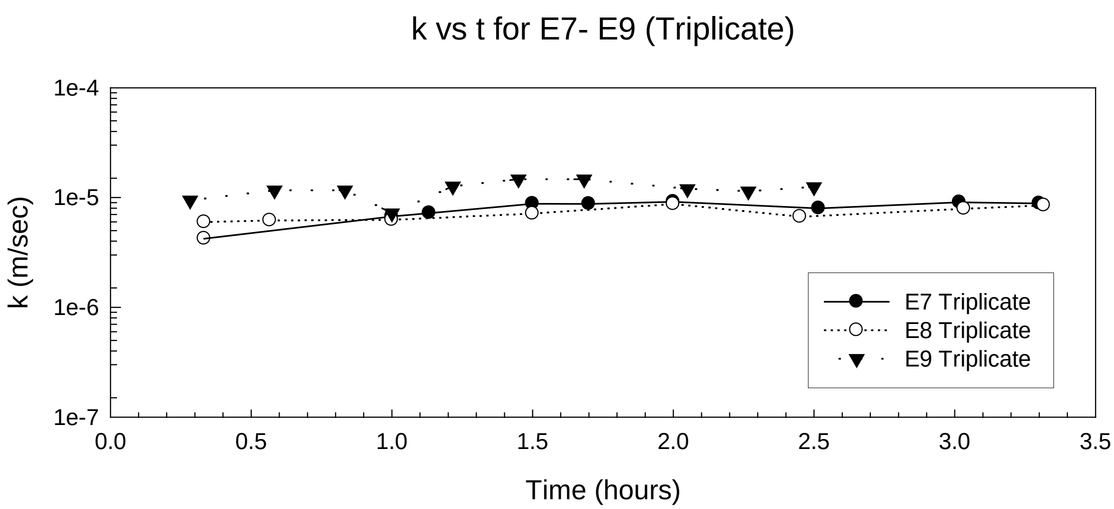


Figure 5.18: Hydraulic conductivity data and graph of sample E7-E9 (Triplicate)

<u>Overall Hydraulic Conductivity graphs of E7-E9</u>







5.19: Overall HC graphs of samples E7-E9

Hydraulic conductivity for E10, E11

	E10	E11
Dry Density, kN/m^3 (pcf)	19.02 (121.11)	18.95 (120.63)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	636.21	636.21
Number of Blows/Layer	25 Blows,3layers	25 Blows,3 layers
Geotextile	NW 6	NW 16
AOS (mm)	0.212	0.150
Gradient	5	5
Test Duration (hours)	4.70	6.37
Average k (m/sec)	6.56 e-6	1.73 e-6
Standard Deviation for k	1.14 e-6	4.69 e-7
Void Ratio, e	0.30	0.31
Porosity, n	0.23	0.23
Cumulative Permeant Volume (ml)	4404	1835
Pore volume, pV (ml)	202.95	205.43

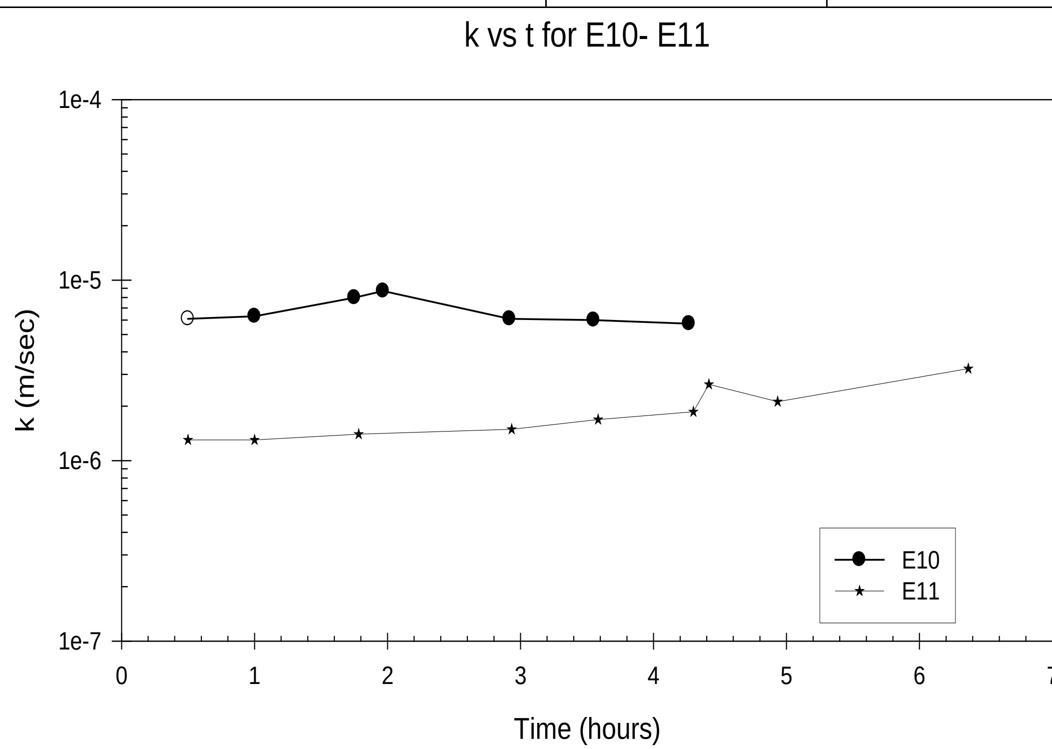


Figure 5.20: Hydraulic conductivity data and graph of sample E10-E11

Hydraulic conductivity for E10, E11 (Duplicate)

	E10-II	E11-II
Dry Density, kN/m^3 (pcf)	19.66 (125.13)	19.56 (124.54)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	636.21	636.21
Number of Blows/Layer	25 Blows,3layers	25 Blows,3layers
Geotextile	NW 6	NW 16
AOS (mm)	0.212	0.150
Gradient	5	5
Test Duration (hours)	10.48	8.10
Average k (m/sec)	7.86 e-7	3.30 e-6
Standard Deviation for k	3.02 e-7	5.04 e-7
Void Ratio, e	0.26	0.27
Porosity, n	0.21	0.21
Cumulative Permeant Volume (ml)	1110	3930
Pore volume, pV (ml)	180.35	183.88

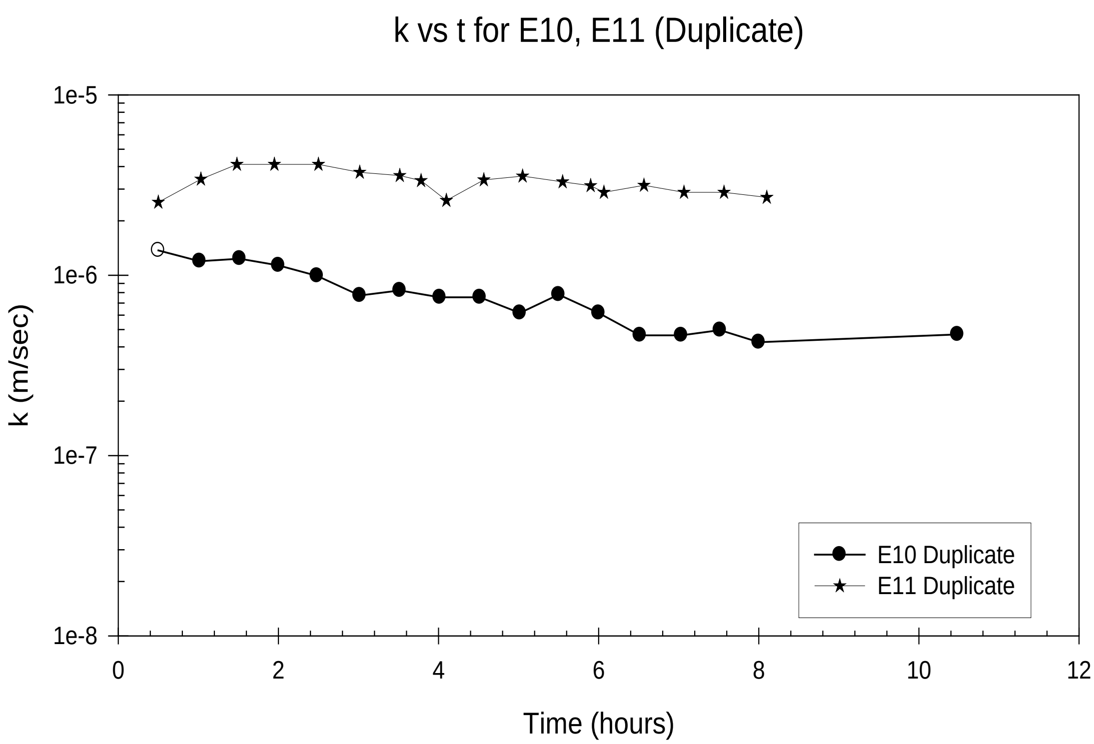


Figure 5.21: Hydraulic conductivity data and graph of sample E10-E11 (Duplicate)

Overall Hydraulic Conductivity graphs of E10-E11

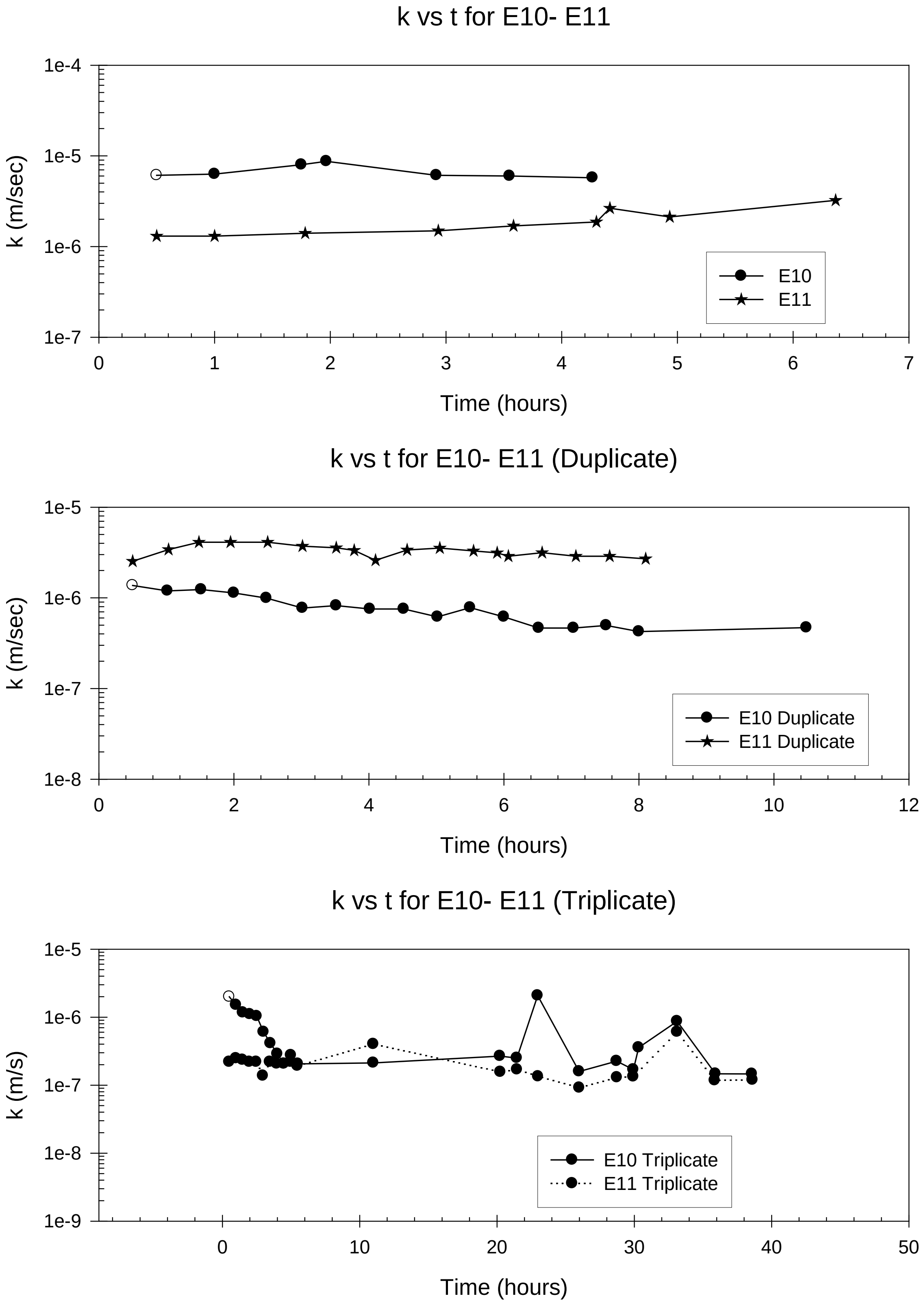


Figure 5.22: Overall HC graphs of samples E10-E11

Hydraulic conductivity for E10, E11 (Triplicate)

	E10-III	E11-III
Dry Density, kN/m^3 (pcf)	19.63 (124.97)	19.33 (123.05)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	636.21	636.21
Number of Blows/Layer	25 Blows,3layers	25 Blows,3layers
Geotextile	NW 6	NW 16
AOS (mm)	0.212	0.150
Gradient	5	5
Test Duration (hours)	38.58	42.73
Average k (m/sec)	6.21 e-7	2.15 e-7
Standard Deviation for k	6.05 e-7	1.10 e-7
Void Ratio, e	0.26	0.28
Porosity, n	0.21	0.22
Cumulative Permeant Volume (ml)	2357	1050
Pore volume, pV (ml)	181.41	192.01

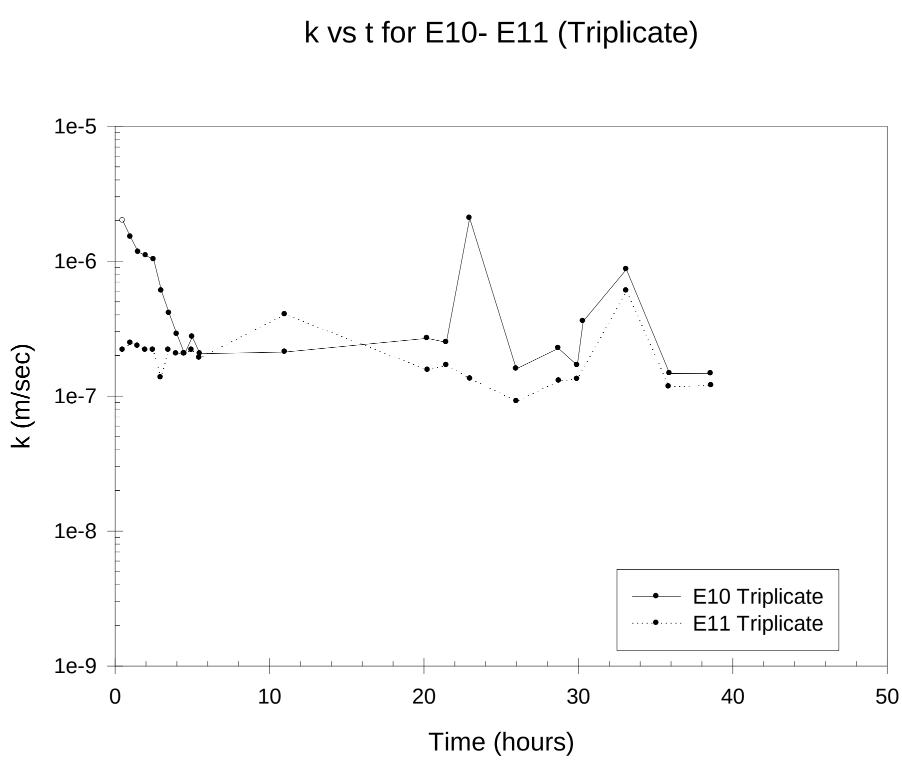


Figure 5.23: Hydraulic conductivity data and graph of sample E10-E11 (Triplicate)

Hydraulic conductivity for E12, E13, E14

	E12	E13	E14
Dry Density, kN/m^3 (pcf)	18.77 (110.49)	18.99 (120.88)	18.62 (118.55)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	203.58 (4252)	203.58 (4252)	203.58 (4252)
Number of Blows/Layer	12 Blows,2layers	12 Blows,2layers	12 Blows,2layers
Geotextile	NW 6	NW 6	NW 6
AOS (mm)	0.212	0.212	0.212
Gradient	5	5	5
Test Duration (hours)	14.87	9.57	4.83
Average k (m/sec)	1.94 e-6	3.24 e-6	6.44 e -6
Standard Deviation for k	5.87 e-7	1.09 e-6	1.39 e -7
Void Ratio, e	0.32	0.30	0.33
Porosity, n	0.24	0.23	0.25
Cumulative Permeant Volume (ml)	3650	4250	4515
Pore volume, pV (ml)	211.78	204.01	217.08

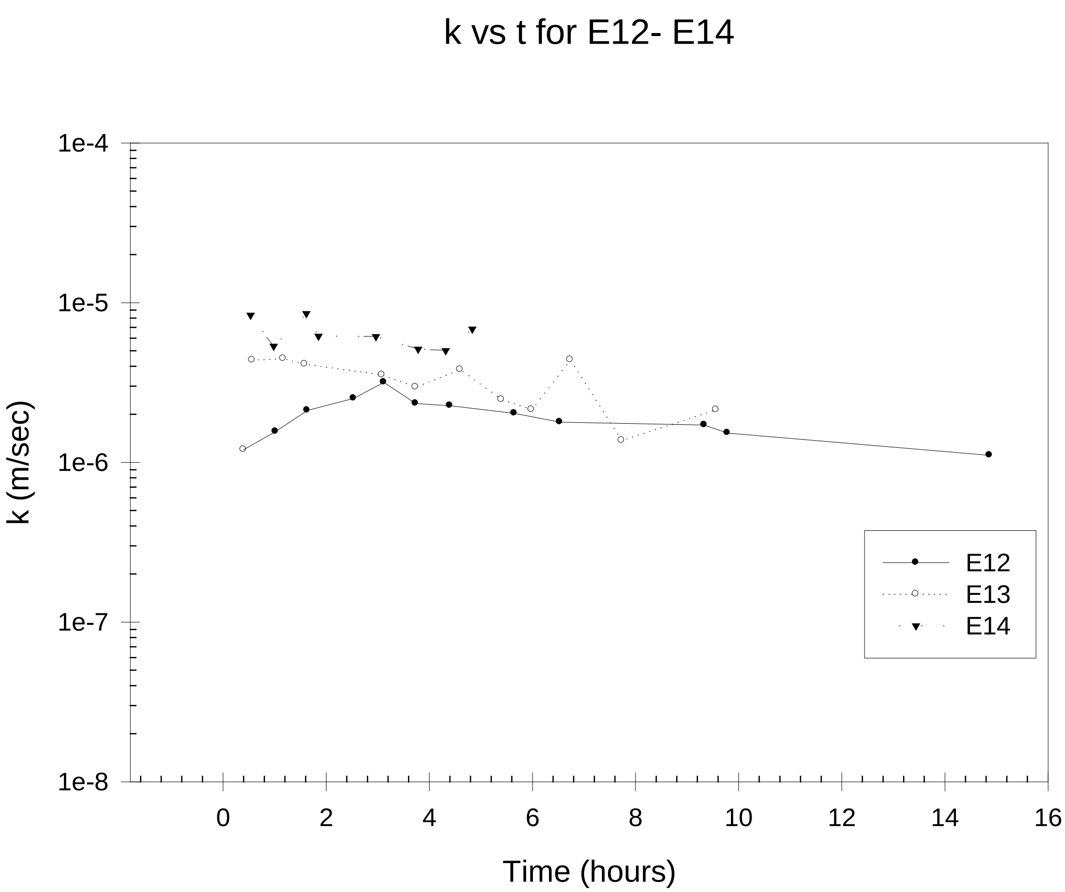


Figure 5.24: Hydraulic conductivity data and graph of sample E12-E14

Hydraulic conductivity for E15, E16, E17

	E15	E16	E17
Dry Density, kN/m^3 (pcf)	16.08 (102.36)	17.30 (110.16)	17.33 (110.15)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	67.84 (1417)	67.84 (1417)	67.84 (1417)
Number of Blows/Layer	4 Blows,2layers	4 Blows,2layers	4 Blows,2layers
Geotextile	NW 6	NW 6	NW 6
AOS (mm)	0.212	0.212	0.212
Gradient	5	5	5
Test Duration (hours)	13.77	18.28	8.53
Average k (m/sec)	6.73 e-6	5.56 e-6	1.06 e-5
Standard Deviation for k	1.65 e-6	1.18 e-6	1.65 e -6
Void Ratio, e	0.54	0.43	0.43
Porosity, n	0.35	0.30	0.30
Cumulative Permeant Volume (ml)	13310	13270	13000
Pore volume, pV (ml)	306.80	263.70	262.65

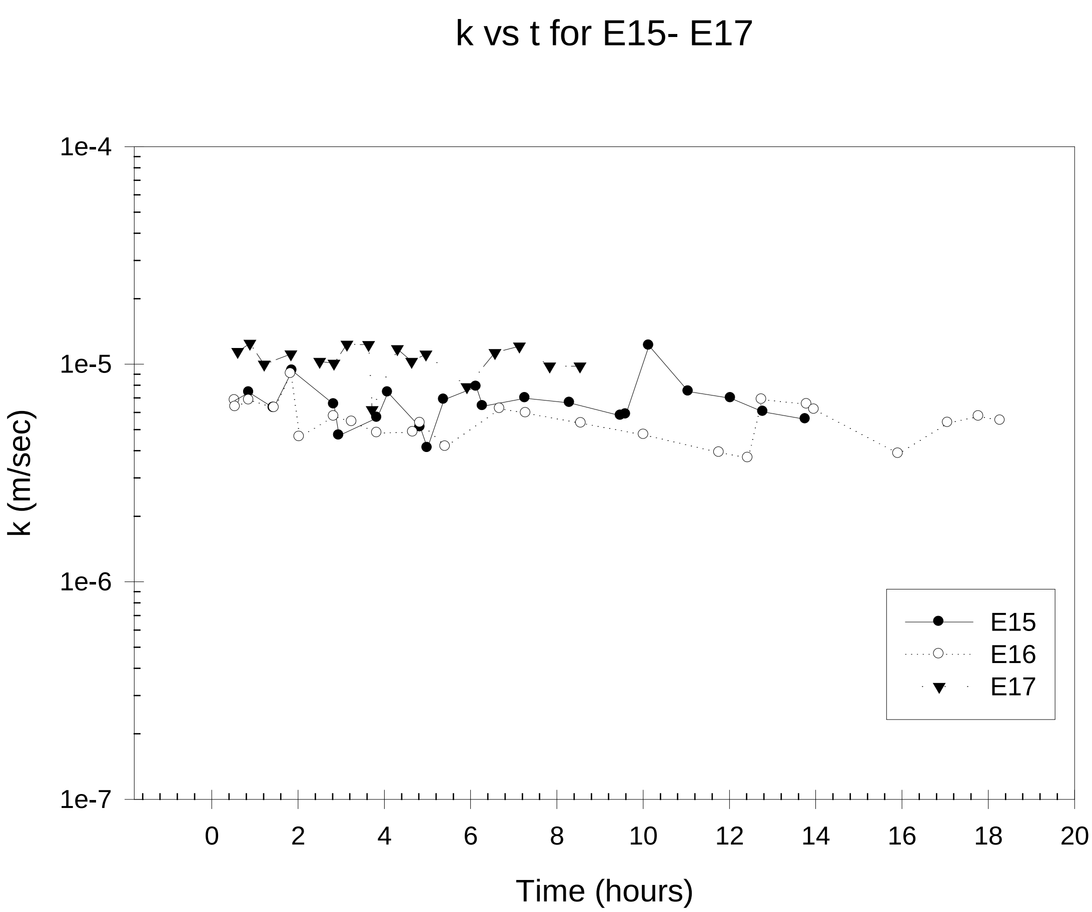


Figure 5.25: Hydraulic conductivity data and graph of sample E15-E17

Hydraulic conductivity for E18, E19, E20

	E18	E19	E20
Dry Density, kN/m^3 (pcf)	16.39 (104.32)	17.85 (113.65)	18.07 (115.06)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	135.73 (2835)	135.73 (2835)	135.73 (2835)
Number of Blows/Layer	8 Blows,2layers	8 Blows,2layers	8 Blows,2layers
Geotextile	NW 6	NW 6	NW 6
AOS (mm)	0.212	0.212	0.212
Gradient	7.14	7.14	7.14
Test Duration (hours)	15.08	9.77	16.17
Average k (m/sec)	4.39 e-6	6.50 e-6	4.05 e-6
Standard Deviation for k	5.48 e-7	9.52 e-7	7.99 e-7
Void Ratio, e	0.51	0.39	0.37
Porosity, n	0.34	0.28	0.27
Cumulative Permeant Volume (ml)	13650	13425	13450
Pore volume, pV (ml)	295.85	244.28	236.51

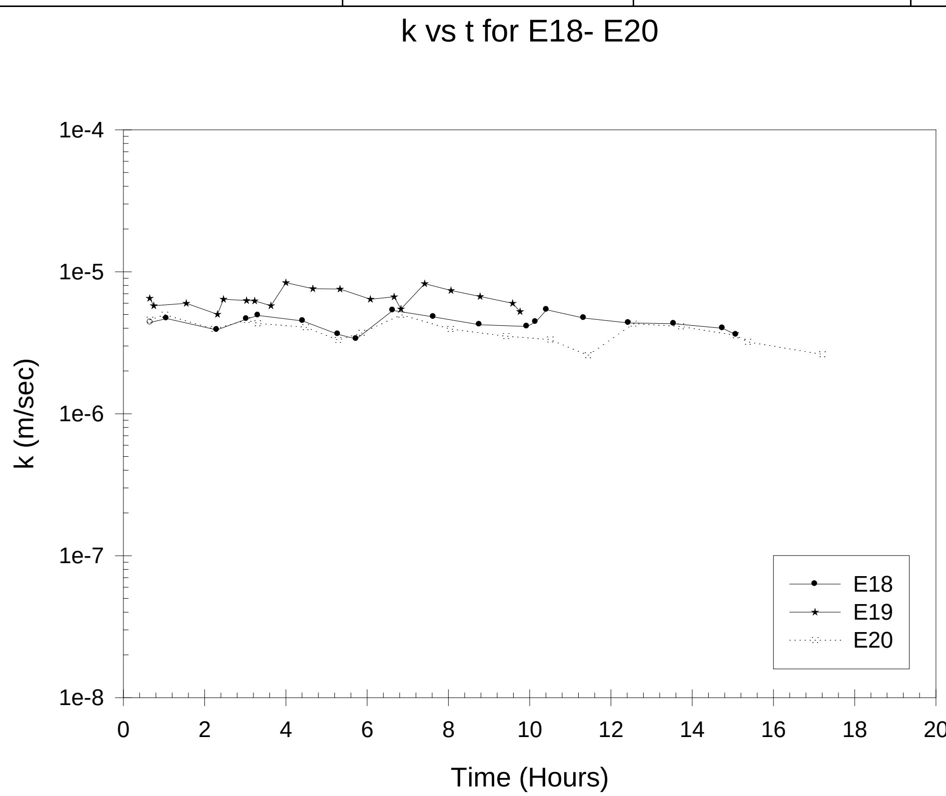


Figure 5.26: Hydraulic conductivity data and graph of sample E18-E20

5.3.2. Blended Refuse (BR) Samples

Hydraulic conductivity for F4, F5, F6

	F4	F5	F6
Dry Density, kN/m^3 (pcf)	16.08 (102.38)	16.77 (106.74)	16.64 (105.94)
Compaction Energy, kJ/m^3 ($ft\text{-}lb/ft^3$)	381.73 (7973)	381.73 (7973)	381.73 (7973)
Number of Blows/Layer	15 Blows,3layers	15 Blows,3layers	15 Blows,3layers
Geotextile	NW 6	NW 6	NW 6
AOS (mm)	0.212	0.212	0.212
Gradient	32.5	32.5	32.5
Test Duration (hours)	195.67	195.78	195.77
Average k (m/sec)	1.74 e-8	1.27 e-8	9.50 e-9
Standard Deviation for k	4.14 e-9	2.12 e-9	3.93 e-9
Void Ratio, e	0.40	0.34	0.35
Porosity, n	0.29	0.26	0.26
Cumulative Permeant Volume (ml)	3147	2324	1675
Pore volume, pV (ml)	250.0	223.19	228.24

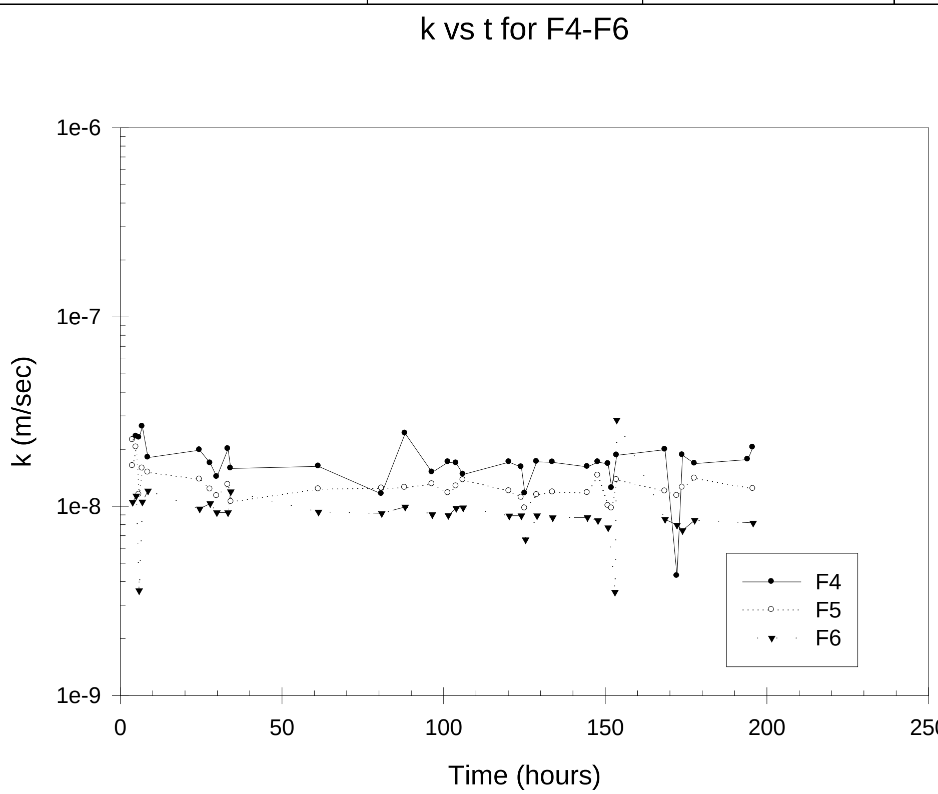


Figure 5.27: Hydraulic conductivity data and graph of sample F4-F6

Hydraulic conductivity for F7, F8, F9

	F7	F8	F9
Dry Density, kN/m^3 (pcf)	15.41(98.09)	14.92 (94.95)	15.27(97.24)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	127.26 (2658)	127.26 (2658)	127.26 (2658)
Number of Blows/Layer	15 Blows,1layer	15 Blows,1layer	15 Blows,1layer
Geotextile	NW 6	NW 6	NW 6
AOS (mm)	0.212	0.212	0.212
Gradient	15	15	15
Test Duration (hours)	6.28	7.63	7.32
Average k (m/sec)	3.37 e-6	4.65 e-6	2.90 e-6
Standard Deviation for k	1.07 e-6	2.23 e-6	8.59 e-7
Void Ratio, e	0.46	0.61	0.57
Porosity, n	0.32	0.38	0.36
Cumulative Permeant Volume (ml)	8887	13685	9050
Pore volume, pV (ml)	276.03	330.56	317.79

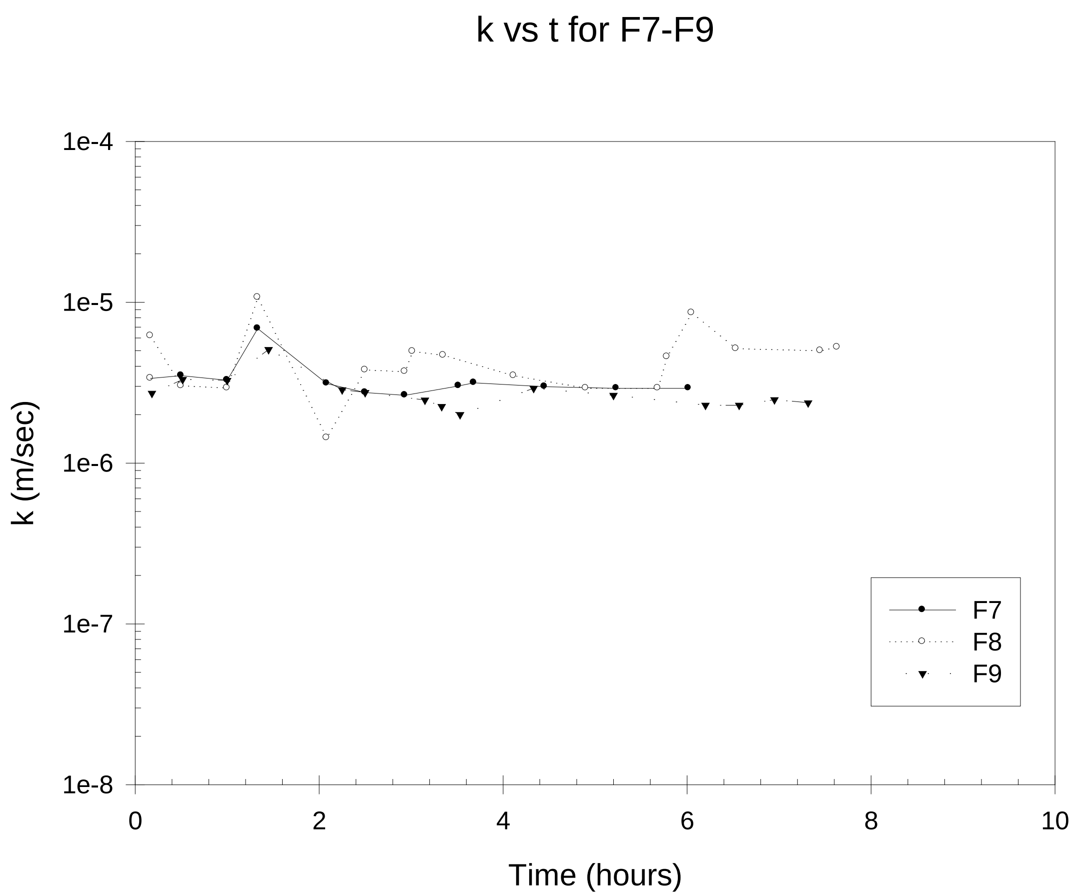


Figure 5.28: Hydraulic conductivity data and graph of sample F7-F9

Hydraulic conductivity for F10, F11, F12

	F10	F11	F12
Dry Density, kN/m^3 (pcf)	14.75 (93.88)	14.84 (94.49)	14.86 (94.57)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	127.26 (2658)	127.26 (2658)	127.26 (2658)
Number of Blows/Layer	15 Blows,1layer	15 Blows,1layer	15 Blows,1layer
Geotextile	NW 16	NW 16	NW 16
AOS (mm)	0.150	0.150	0.150
Gradient	15	15	15
Test Duration (hours)	8.25	8.25	8.27
Average k (m/sec)	8.63 e-7	5.96 e-7	1.05 e-6
Standard Deviation for k	2.32 e-7	1.05 e-7	7.54 e-7
Void Ratio, e	0.53	0.52	0.52
Porosity, n	0.34	0.34	0.34
Cumulative Permeant Volume (ml)	2990	2113	3660
Pore volume, pV (ml)	301.67	298.18	297.40

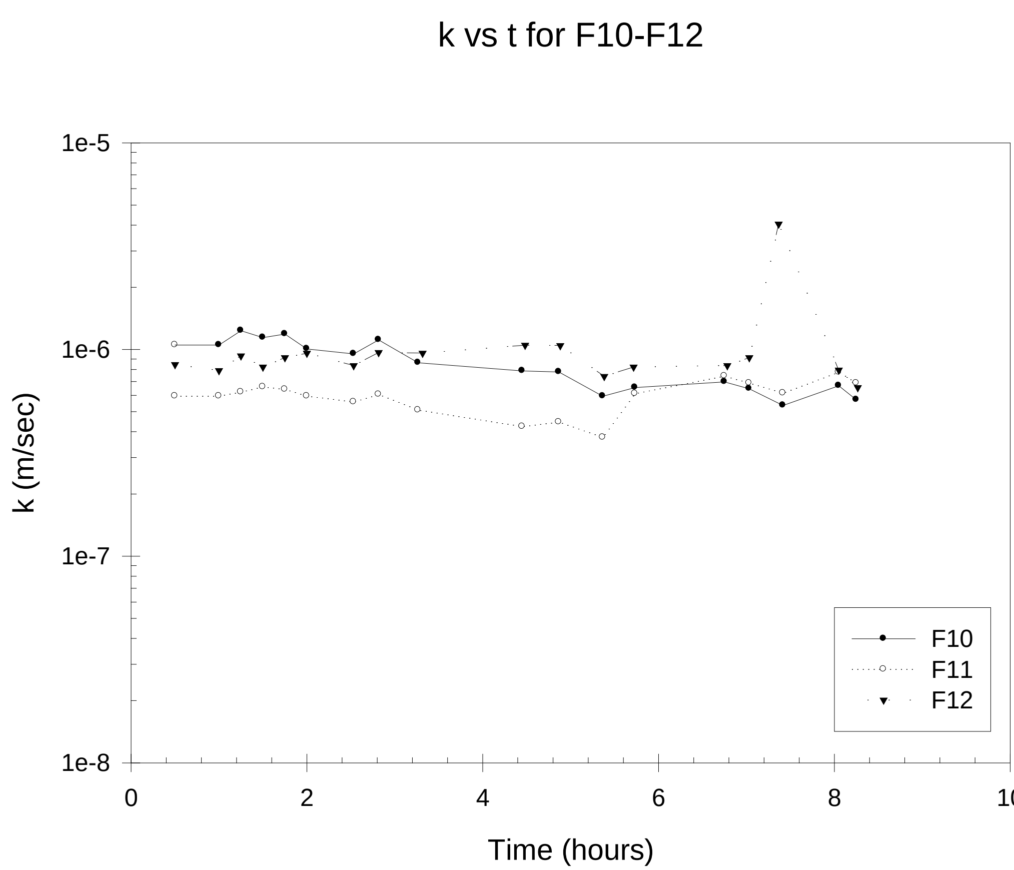


Figure 5.29: Hydraulic conductivity data and graph of sample F10-F12

Hydraulic conductivity for F13, F14 (No Geotextile)

	F13	F14
Dry Density, kN/m^3 (pcf)	15.69 (99.87)	15.78 (100.48)
Compaction Energy, kJ/m^3 ($ft\text{-}lb/ft^3$)	127.26 (2658)	127.26 (2658)
Number of Blows/Layer	15 Blows,1layer	15 Blows,1layer
Geotextile	----	----
AOS (mm)	----	----
Gradient	15	15
Test Duration (hours)	11.93	23.36
Average k (m/sec)	6.42 e-7	4.63 e-7
Standard Deviation for k	4.87 e-7	4.12 e-7
Void Ratio, e	0.43	0.43
Porosity, n	0.30	0.30
Cumulative Permeant Volume (ml)	2857	4271
Pore volume, pV (ml)	265.15	261.66

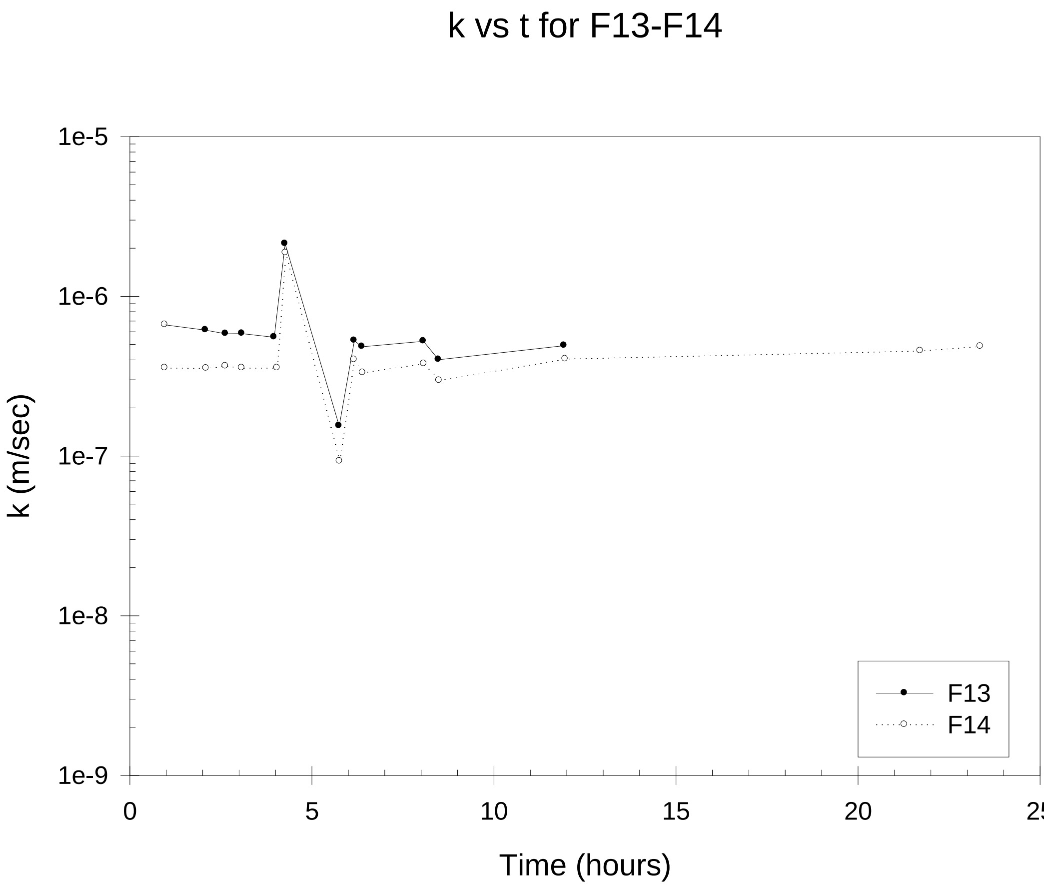


Figure 5.30: HC data and graph of Blended Refuse sample W/O Geotextile F13-F14

Hydraulic conductivity for F15

	F15
Dry Density, kN/m^3 (pcf)	13.56 (86.34)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	102.17 (2134)
Number of Blows/Layer	4 Blows,3layers
Geotextile	NW 6
AOS (mm)	0.212
Gradient	32.5
Test Duration (hours)	342.33
Average k (m/sec)	2.44 e-7
Standard Deviation for k	3.56 e-7
Void Ratio, e	0.57
Porosity, n	0.36
Cumulative Permeant Volume (ml)	29359
Pore volume, pV (ml)	318.91

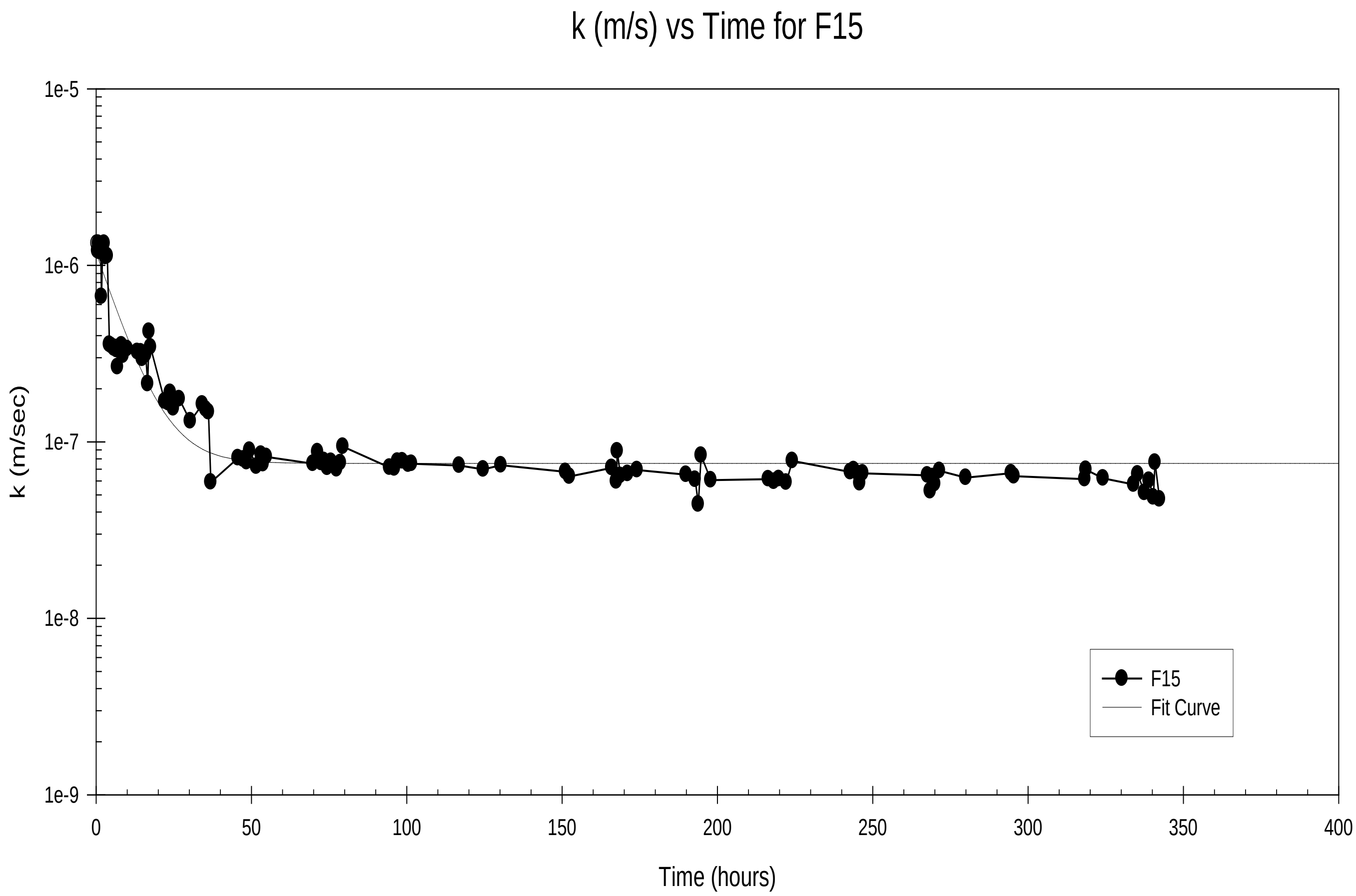


Figure 5.31: Hydraulic conductivity data and graph of BR (60/40) sample F15

6. DATA ANALYSIS & RESULTS

6.1. Results

6.1.1. Coal Refuse Properties

The geotechnical material property laboratory results for the coarse coal refuse (CCR) and fine coal refuse (FCR) data are presented below in Table 6.1, Table 6.2 and Table 6.3.

Coarse Coal refuse

Table 6.1: CCR Data Comparison

Comparison of Coarse Coal Refuse (CCR) DATA					
	R1	R2	R3	R4	**RESEARCH DATA**
G_s	2, 2.2, 1.9	1.7, 1.2, 2.3	2.02	1.5-2.8	**2.54**
LL	--	--	--	25-35 %	**28.40%**
PI	--	--	--	< 12 %	**7.34%**
γ_d (Pcf)	90.6, 92.2, 88.6	98.1, 98.9, 101	115	--	**115.98 - 124.64**
k (cm/s)	$1.38 * 10^{-4}$	--	--	10^{-6} to 10^{-2}	**$5.06 * 10^{-4}$**

R1- R.A. Busch, R. R. Baker, L. A. Atkins (1985)
R2- Files of West Virginia Department of Natural Resources, West Virginia
R3- Hegazy et al. (2004)
R4- MSHA (2009)

Fine Coal Refuse

Table 6.2: FCR Data Comparison

Comparison of Fine Coal Refuse (FCR) DATA					
	R5	R6	R3	R4	**RESEARCH DATA**
G_s	1.6, 1.7, 1.5	1.8, 1.5, 1.6	1.52	1.4-2.3	**1.875**

R3- Hegazy et al. (2004)
R4- MSHA (2009)
R5- R.A. Busch, R. R. Baker, L. A. Atkins (1975)
R6- R.A. Busch, R. R. Baker, L. A. Atkins (1977)

Grain Size Distribution

Table 6.3: GSD Data Comparison of CCR and FCR

Comparison of Grain Size Distribution DATA						
	R1		R2	**RESEARCH DATA**		
	CCR	FCR	CCR	**CCR**	**BR (80/20)**	**BR (60/40)**
D_{50}	1.23	0.127	0.9	**2.2**	**1.1**	**0.5**
D_{15}	---	---	0.15	**0.68**	**0.12**	**0.086**
D_{10}	< 0.075	0.01	0.09	**0.53**	**0.045**	**0.069**
C_u	---	19.6	17.77	**5.09**	**35.56**	**13.04**

R1- Hegazy et al. (2004)
R2- MSHA (2009)

Evaluation of this tabulated data tends to indicate the following observations:

- The specific gravity of both coarse coal refuse (2.54) and fine coal refuse (1.87) are within the range of the published references.
- The dry density values of coarse coal refuse (115 pcf-124 pcf) are within the published limits.
- The Atterberg limits of coarse coal refuse (LL-28.4, PL-21.06 and PI-7.34) are within the range specified by MSHA.
- The average Hydraulic conductivity values of coarse coal refuse (5.06 $*10^{-4}$ cm/s) are within range of published reference.
- In Table 6.3, the D_{50}, D_{15}, D_{10}, C_u values of coarse coal refuse used for research are larger in particle diameter compared to the references. Comparison of the differences indicates that the CCR used for the research contained less fine particles.
- The research data for the fine coal refuse had a higher fines percentage compared with the range of the published values.

Unified Soil Classification of CCR and FCR

Soil classification was performed following the Unified Soil Classification System (USCS) (ASTM D-2487). Results of the classification for the refuse materials used in this study are presented below:

Material Description: Coarse Coal Refuse as received from field

Group Symbol: GW Group Name: Well Graded Gravel with Sand

Coarse Coal Refuse passing No. 4 Sieve (laboratory tested material)

Group Symbol: SP Group Name: Poorly Graded Sand

Material Description: Blended Refuse (% coarse coal refuse + % fine coal refuse)

80/20 mix:

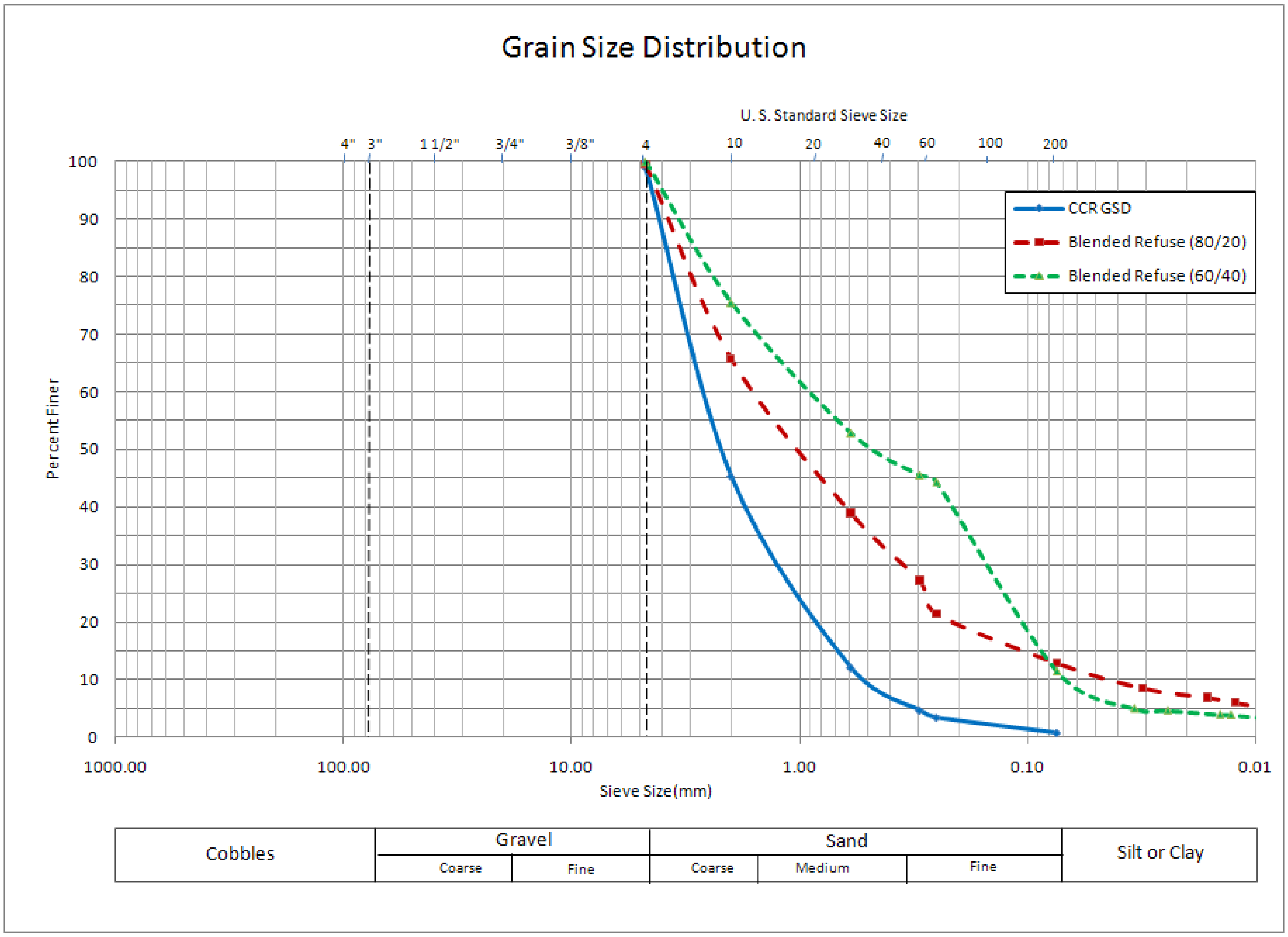
Group Symbol: SC Group Name: Clayey Sand

60/40 mix:

Group Symbol: SC Group Name: Clayey Sand

Grain-Size Distribution Data Analysis

The initial grain-size distribution of coarse coal refuse material passing No.4 sieve and the two blended fine coal refuse specimens are illustrated below in Figure 6.1 along with the corresponding data analysis.



	CCR	BR (80% CCR, 20% FCR)	BR (60% CCR, 40% FCR passing No.100)
D_{85}	3.9	3.5	2.9
D_{60}	2.7	1.6	0.9
D_{50}	2.2	1.1	0.5
D_{30}	1.3	0.35	0.16
D_{25}	1.1	0.28	0.14
D_{15}	0.68	0.12	0.086
D_{10}	0.53	0.045	0.069
C_u	5.09	35.56	13.04
C_c	1.18	1.70	0.41

Figure 6.1: Initial GSD graphs and data of CCR, BR samples

6.1.2. Different compaction energies for CCR

Figure 6.2 is a graph presenting the results of four coarse coal refuse compaction density curves. The curves illustrate the dry density vs. moisture content percentage for the tested material ranging from optimum compaction energy of 13,288 ft-lb/ft^3 to reduced compaction energy of 1,417 ft-lb/ft^3.

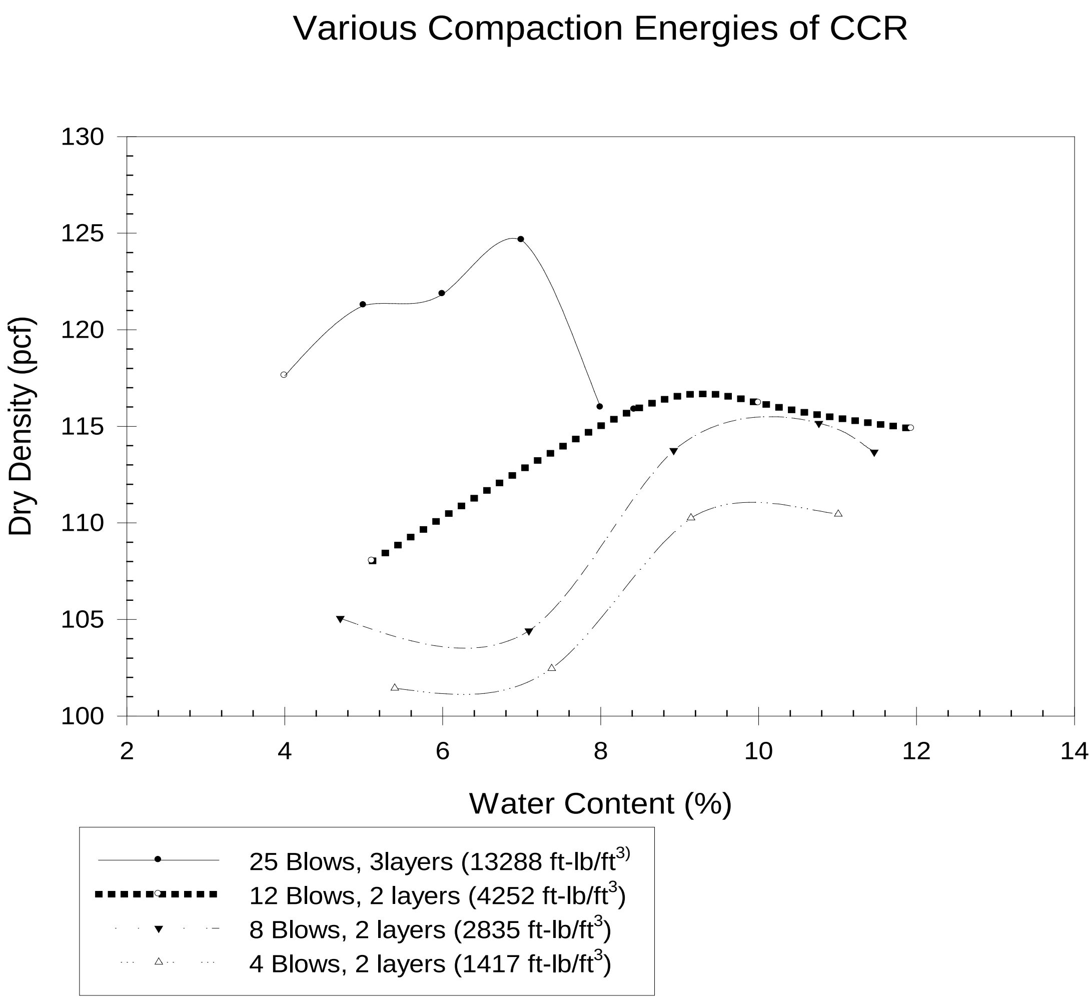


Figure 6.2: Different Compaction Energies graphs of CCR

Results:

- The graph for the optimum compaction was plotted as a double peak because the liquid limit (LL) value was calculated less than 30.
- The reduced compaction curves show a one and one-half peak also consistent with LL<30 soil. The increase in the full peak is expected because of the capillary tension effect occurring from the increase in moisture content.

6.1.3. Different compaction energies for BR (80/20 mix)

Figure 6.3 shows the results of compaction curves of blended refuse (80/20 mix) at optimum and reduced compaction energy levels. Two different compaction energies were used ranging from optimum 13,288 ft-lb/ft^3 to low compaction energy of 2,658 ft-lb/ft^3.

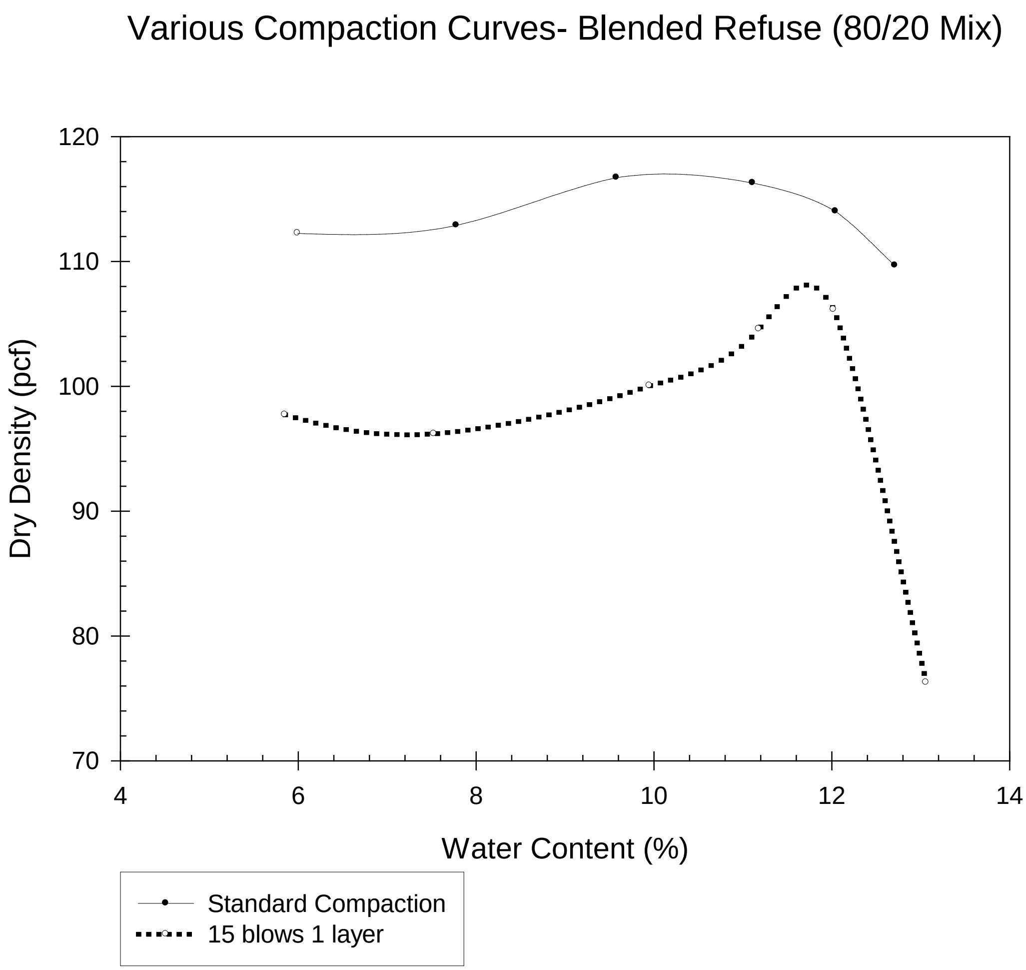


Figure 6.3: Different Compaction Energies graphs of BR (80/20 mix)

The reduced compaction curves show a one and one-half peak because of the capillary tension occurring from the increased fine percentage and water content.

6.1.4. Hydraulic Conductivity Graphs of CCR (combined)

The hydraulic conductivity of coarse coal refuse samples compacted at different compaction energies are shown in Figure 6.4.

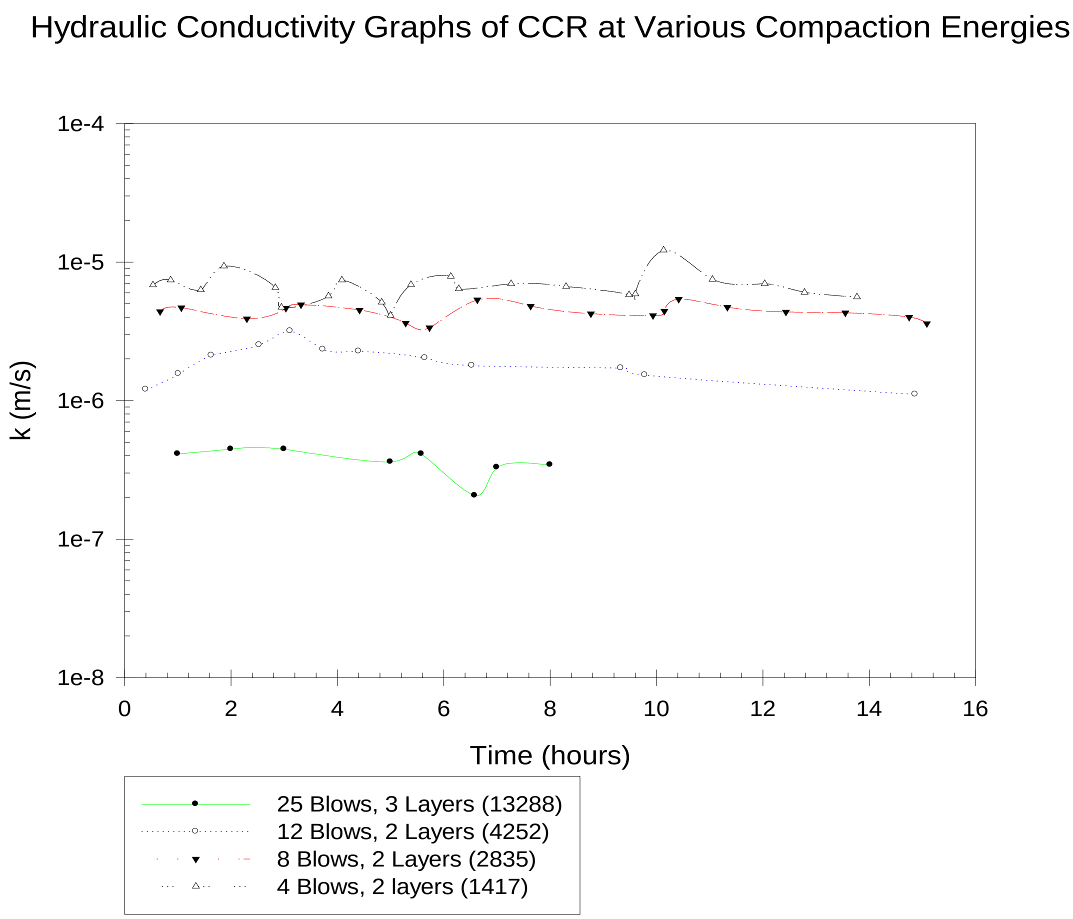


Figure 6.4: Hydraulic Conductivity Graphs of CCR at Various Compaction Energies

Evaluation of the graphed data in Figure 6.4 tends to indicate the following observations:

- For all compaction densities it appears that no natural filter was formed as evidenced by little to no reduction in hydraulic conductivity being observed. This trend indicates that the filter fabric clogging was not occurring.
- As per Rao, et.al 1991, the permeability of the optimum compacted refuse is one order of magnitude ($2.35 * 10^{-6}$ m/s) lower than the reduced compaction. The trend in k tends to indicate an unstable filter condition exists during the test duration and that a stable equilibrium condition was not reached during the testing period.
- No filter stability appeared to develop even after 10 hours of permeation for any of the coarse coal refuse samples.

6.1.5. Hydraulic Conductivity Graphs of BR (80/20 mix)

The gr aph s howing t he Hydraulic c onductivity of bl ended refuse sa mples wh ich ar e co mpacted at different compaction energies is shown in Figure 6.5.

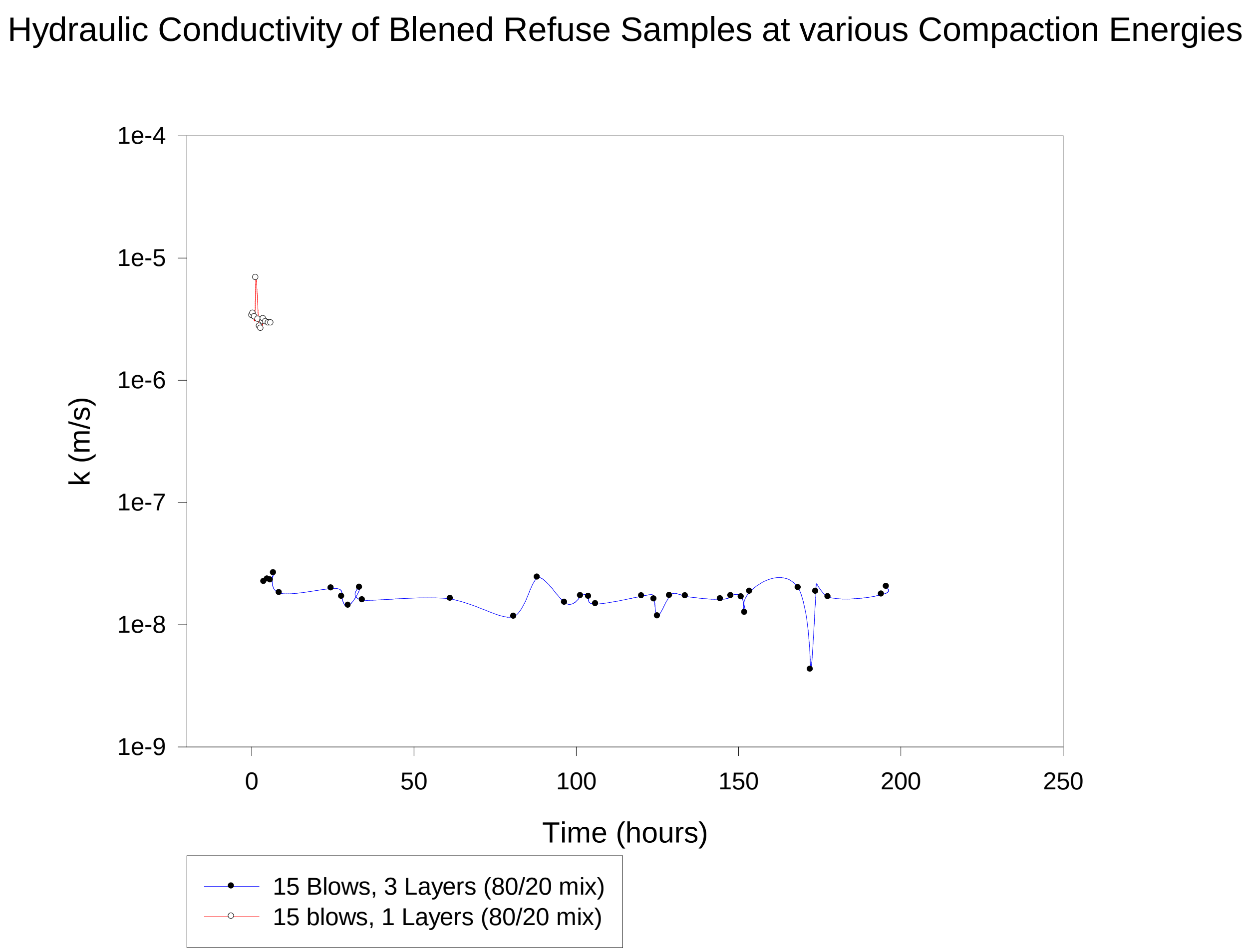


Figure 6.5: Hydraulic Conductivity Graphs of BR samples at Different Compaction Energies

The Figure 6.5 tends to indicate the following observations:

- Reduction in hydraulic conductivity of the blended refuse 80/20 mix samples was not observed which indicates that no filter stability developed even with a 20% increase in fines.
- No c hange i n h ydraulic conductivity of the blended r efuse sa mples developed even at l ower compaction e nergies t ending t o i ndicate minimal movement o f particle f ines f or t he s elected hydraulic gradient.

6.1.6. Hydraulic Conductivity Graphs of BR (60/40 mix)

Hydraulic conductivity of blended refuse 60/40 mix samples is shown in Figure 6.6

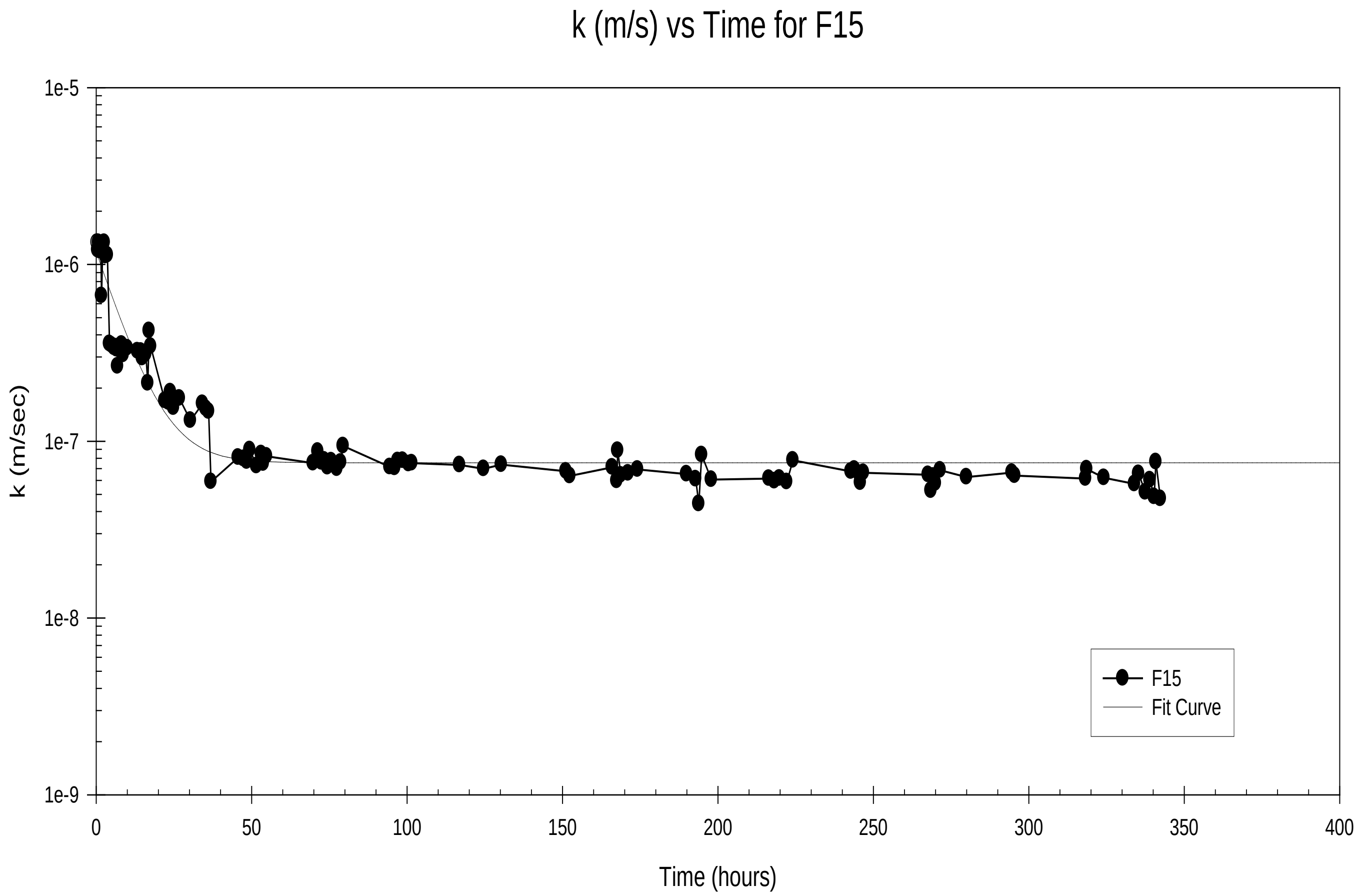


Figure 6.6: Hydraulic Conductivity Graph of BR 60/40 mix sample.

Evaluation of the graph in the Figure 6.6 leads to following observations:

- A stable filter was formed after 75 hours of test and continued at the same rate for approximately 350 hours at which time the test ended.
- Hydraulic conductivity values reduce from an initial value on the order of $1 * 10^{-6}$ m/s and stabilize to a value of $1 * 10^{-7}$ m/s.
- Filter stability was achieved due to the increase in fines percentage.

6.1.7. Hydraulic Conductivity testing with Acid as Permeant

Hydraulic conductivity for E15, E15A-I, E15A-II

	E15	E15A-I	E15A-II
Dry Density, kN/m^3 (pcf)	16.08 (102.36)	14.84 (94.48)	14.66 (93.31)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	67.84 (1417)	67.84 (1417)	67.84 (1417)
Number of Blows/Layer	4 Blows,2layers	4 Blows,2layers	4 Blows,2layers
Geotextile	NW 6	NW 6	NW 6
AOS (mm)	0.212	0.212	0.212
Gradient	5	5	5
Test Duration (hours)	13.77	3.60	8.55
Average k (m/sec)	6.73 e-6	1.38 e-5	1.69 e-5
Standard Deviation for k	1.65 e-6	1.47 e-6	2.15 e-5
Void Ratio, e	0.54	0.67	0.69
Porosity, n	0.35	0.40	0.41
Cumulative Permeant Volume (ml)	13310	7258	12390
Pore volume, pV (ml)	306.80	353.31	359.76

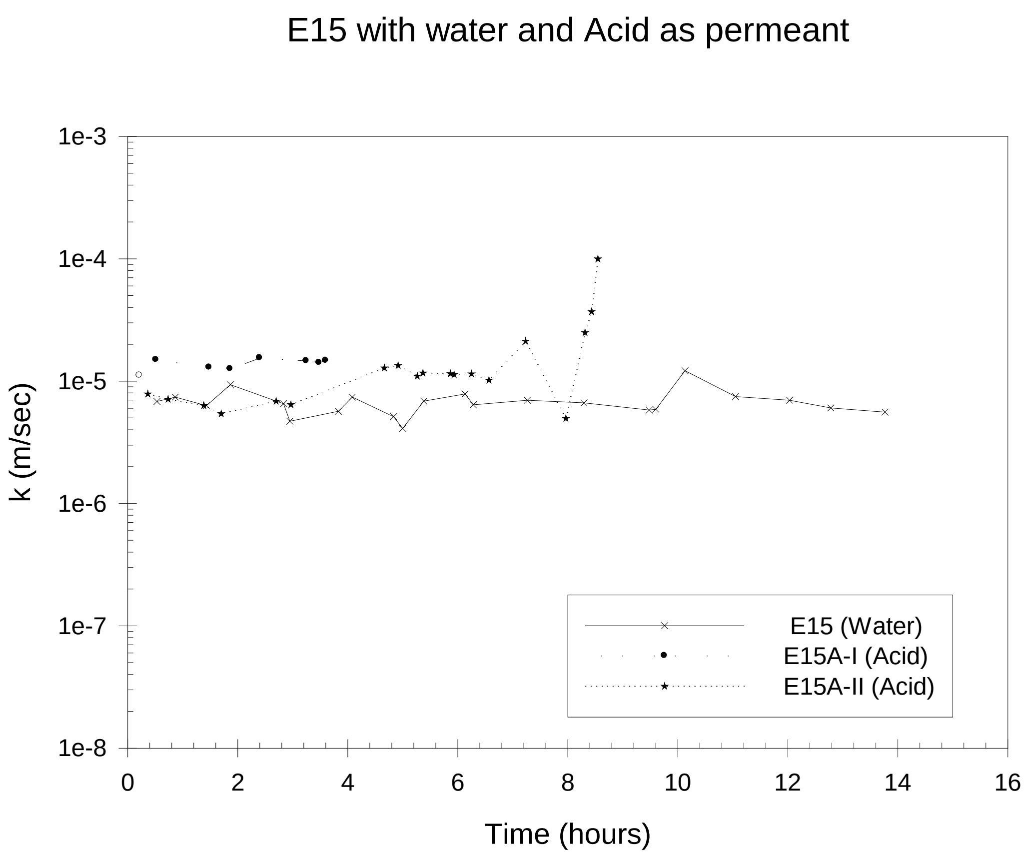


Figure 6.7: HC Data and Graphs of CCR samples with Water and Acid permeants

Hydraulic conductivity for F11A, F11A-I, F11A-II

	F11	F11A-I	F11A-II
Dry Density, kN/m^3 (pcf)	14.84 (94.49)	14.11 (89.84)	14.47 (92.11)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	127.26 (2658)	127.26 (2658)	127.26 (2658)
Number of Blows/Layer	15 Blows,1layer	15 Blows,1layer	15 Blows,1layer
Geotextile	NW 16	NW 16	NW 16
AOS (mm)	0.150	0.150	0.150
Gradient	15	13.68	13.68
Test Duration (hours)	8.25	5.75	4.77
Average k (m/sec)	5.96 e-7	7.97 e-6	6.31 e-6
Standard Deviation for k	1.05 e-7	2.68 e-6	9.52 e-7
Void Ratio, e	0.52	0.59	0.55
Porosity, n	0.34	0.37	0.35
Cumulative Permeant Volume (ml)	2113	17465	15040
Pore volume, pV (ml)	298.18	327.175	313.33

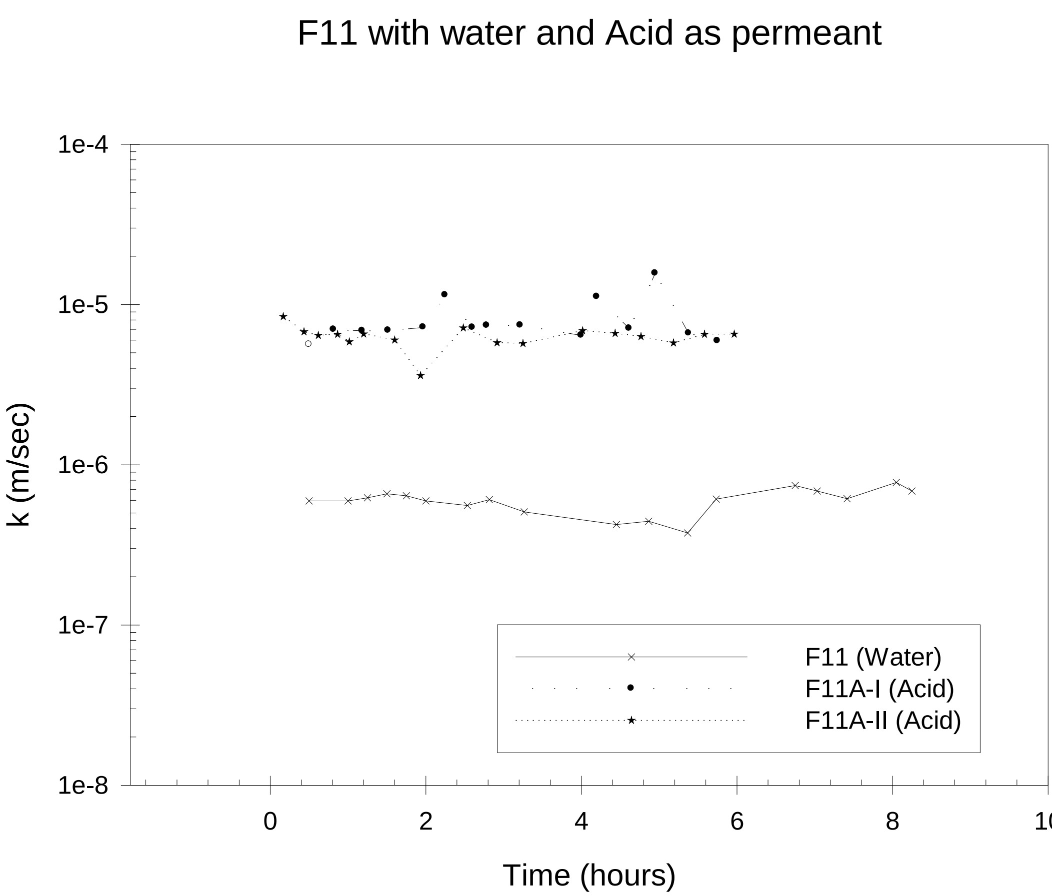


Figure 6.8: HC Data and Graphs of BR samples with Water and Acid permeants

Hydraulic conductivity for F15A (with beads)

	F15	F15A-I
Dry Density, kN/m^3 (pcf)	13.56 (86.34)	13.22 (84.14)
Compaction Energy, kJ/m^3 (ft-lb/ft^3)	102.17 (2134)	102.17 (2134)
Number of Blows/Layer	4 Blows,3layers	4 Blows,3layers
Geotextile	NW 6	NW 6
AOS (mm)	0.212	0.212
Gradient	32.5	32.5
Test Duration (hours)	342.33	170.72
Average k (m/sec)	2.44 e-7	5.46 e-7
Standard Deviation for k	3.56 e-7	6.25 e-7
Void Ratio, e	0.57	0.61
Porosity, n	0.36	0.38
Cumulative Permeant Volume (ml)	29359	31408
Pore volume, pV (ml)	318.91	338.62

F15 with water and acid as permeant (with beads)

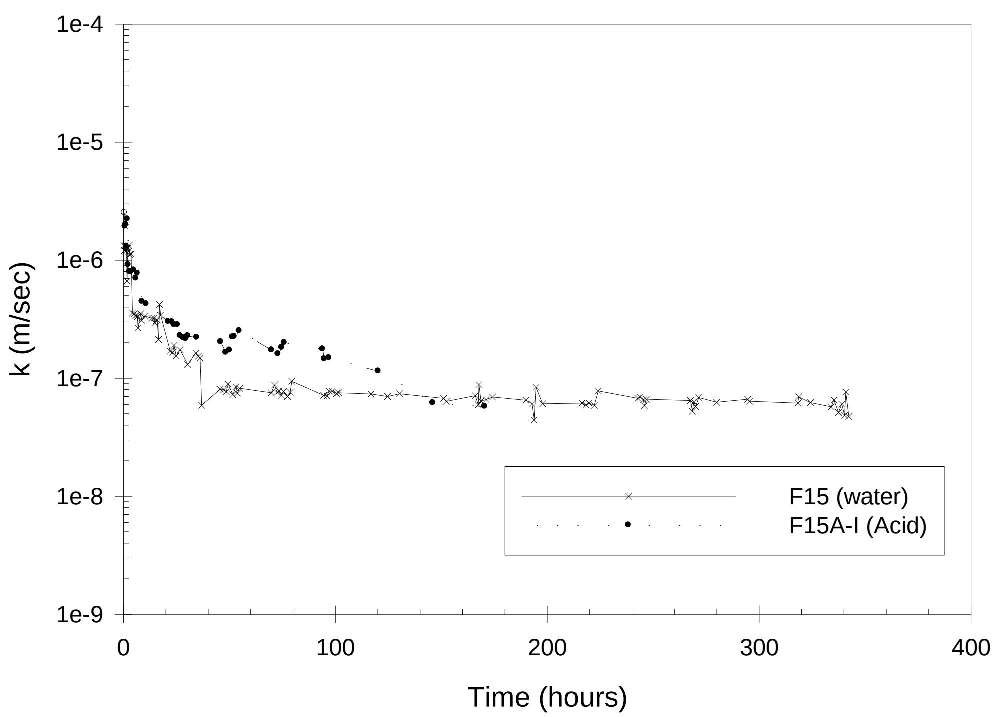


Figure 6.9: HC Data and Graphs of BR samples with Water and Acid permeants (with beads)

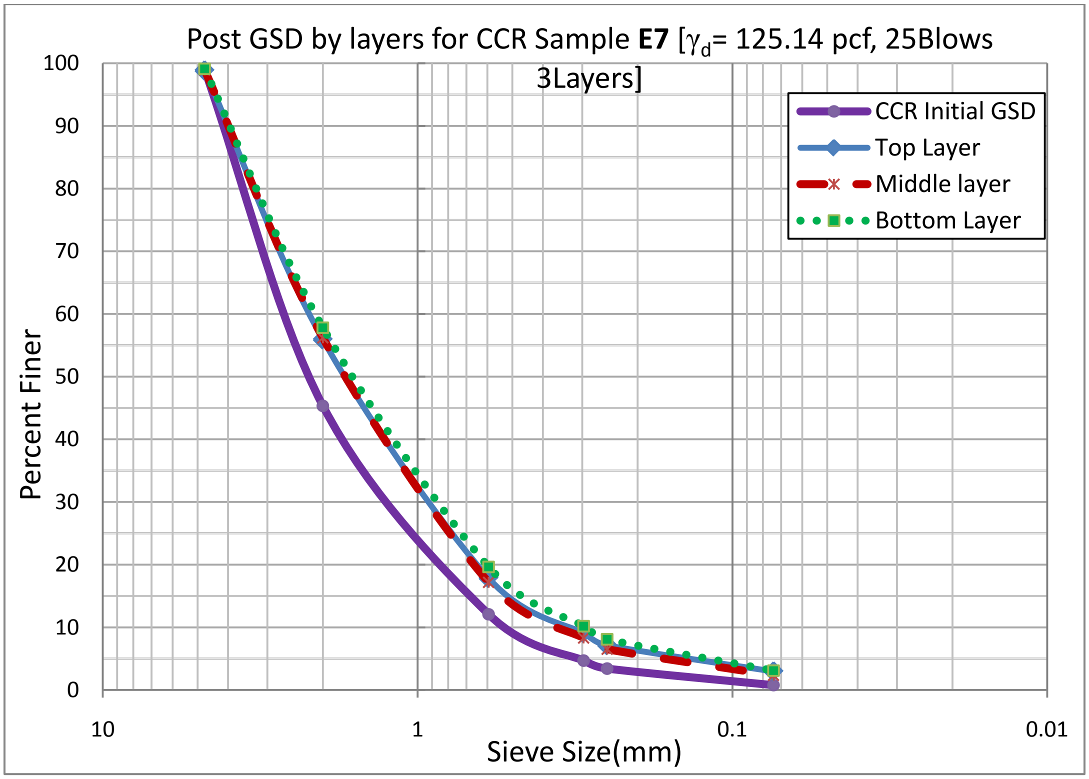
The results of these permeability tests shown in Figures 6.7 to 6.9 indicate an increase in the hydraulic conductivity. This increase is attributed to the low pH value causing flocculation of the fine particles consistent with previous research (Bowders, 1989)

6.1.8. Post Grain Size Distribution

Post grain-size distribution of coarse coal refuse samples was performed for the compacted samples. Post grain si ze sieve analysis was performed in F igures 6. 11 t o 6. 20 to an alyze t he p ercentage o f f ines increased due to compaction.

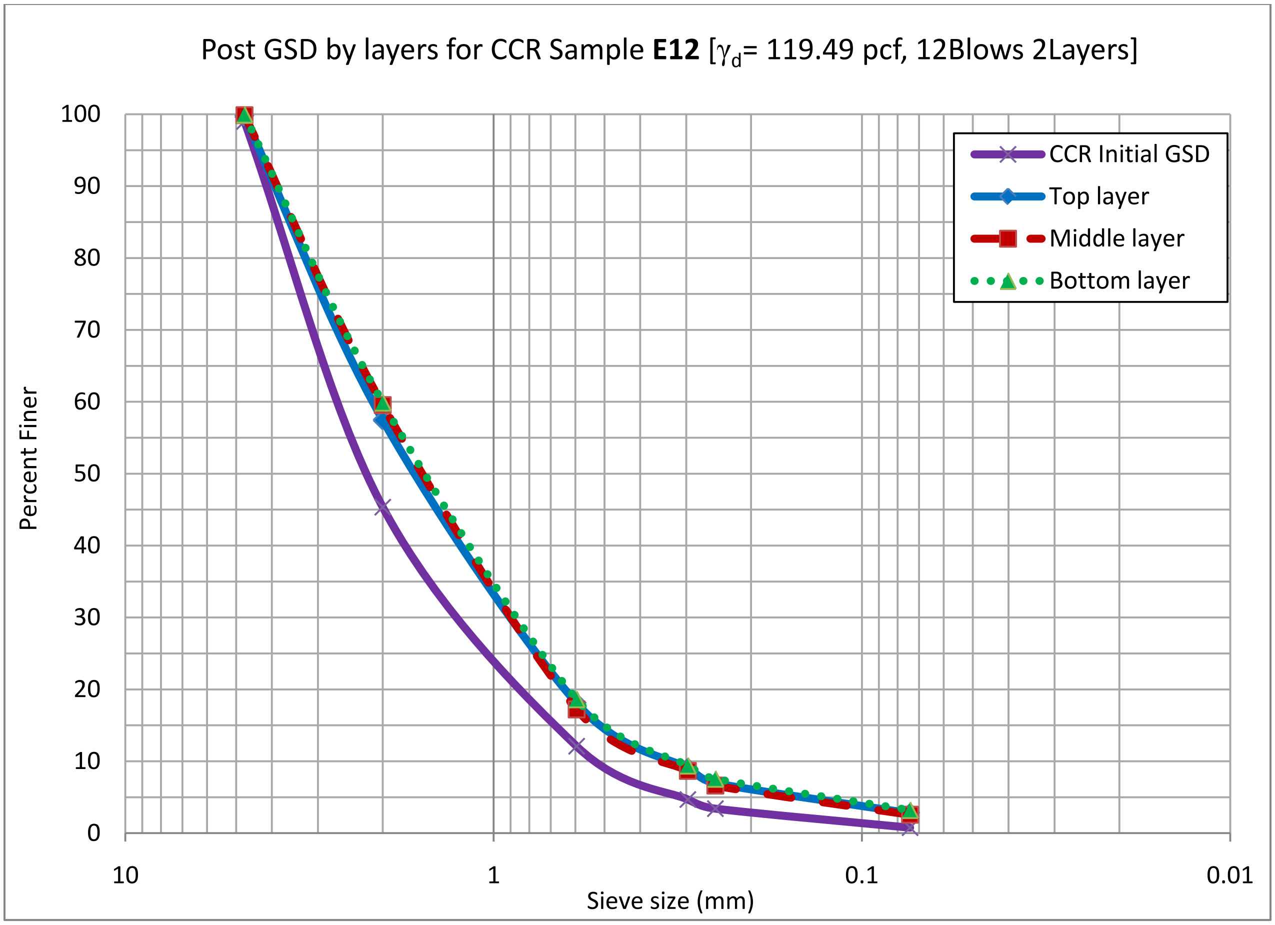
Coarse coal refuse samples

The post GSD of coarse coal refuse samples are shown from Figure 6.10 to Figure 6.19.



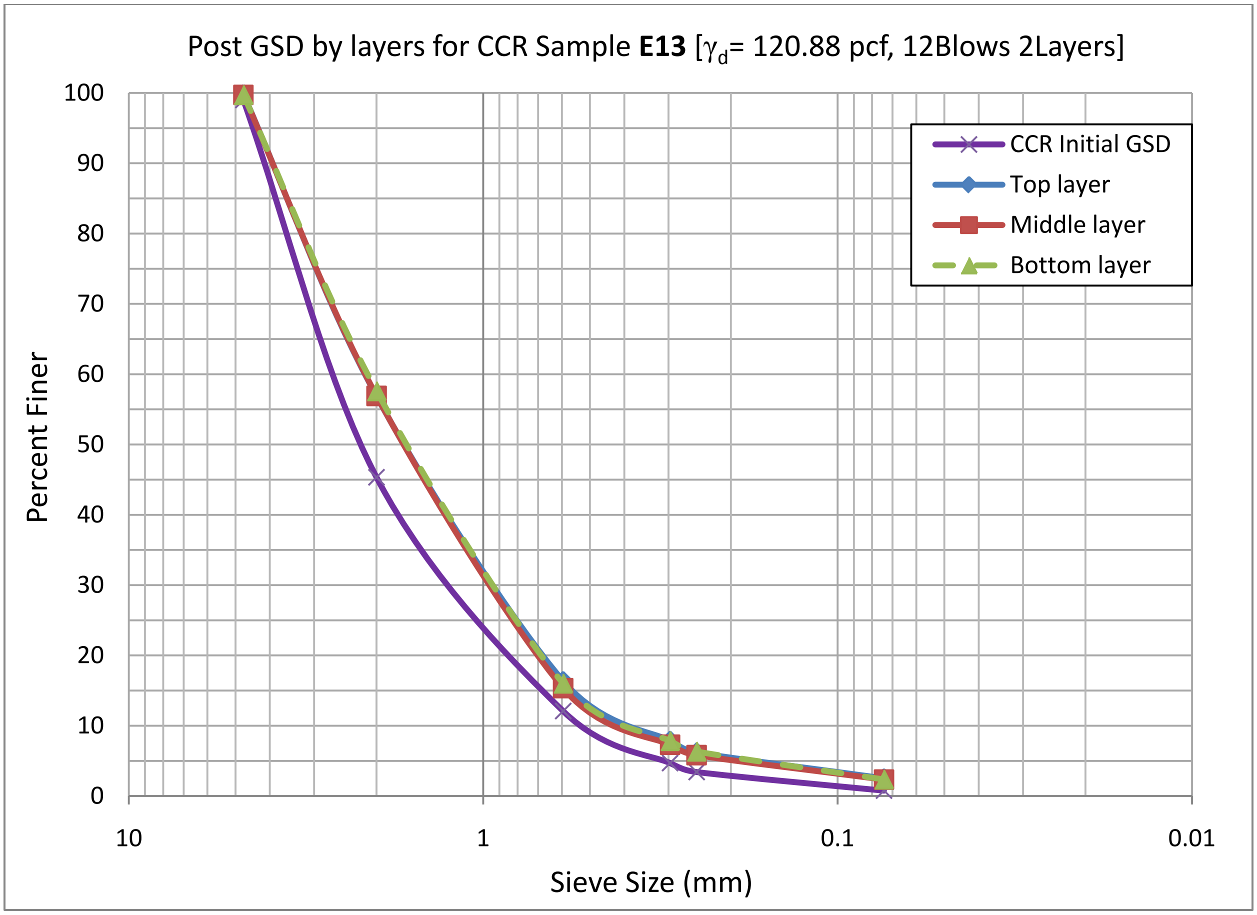
	CCR Initial GSD	CCR Post GSD (E7)		
		Top	Middle	Bottom
D_{85}	3.9	3.7	3.7	3.7
D_{60}	2.7	2.2	2.2	2.1
D_{50}	2.2	1.75	1.75	1.7
D_{30}	1.3	0.93	0.93	0.87
D_{25}	1.1	0.79	0.79	0.72
D_{15}	0.68	0.54	0.52	0.56
D_{10}	0.53	0.36	0.33	0.29
C_u	5.09	6.11	6.67	7.24
C_c	1.18	1.09	1.19	1.24

Figure 6.10: Post GSD Data and graphs of E7 Sample



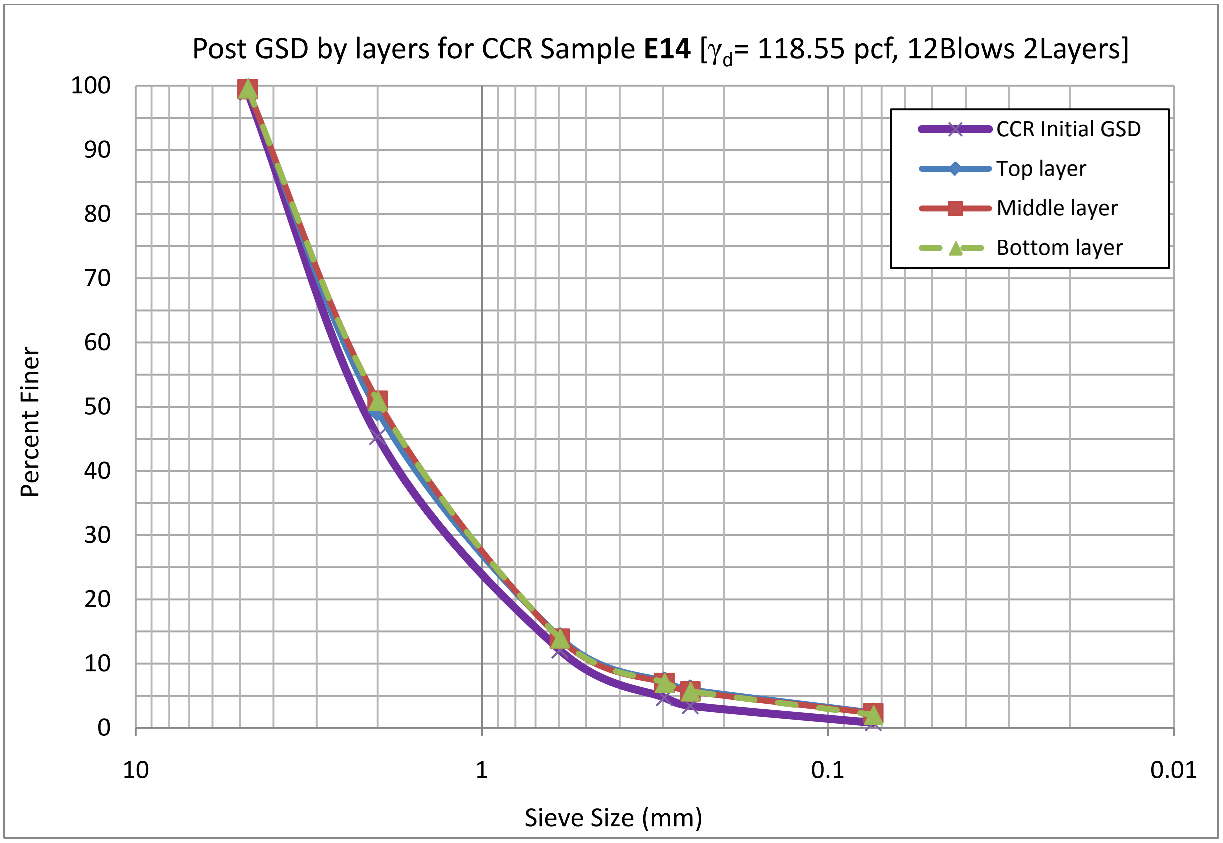
	CCR Initial GSD	CCR Post GSD (E12)		
		Top	Middle	Bottom
D_{85}	3.9	3.7	3.7	3.6
D_{60}	2.7	2.2	2	2
D_{50}	2.2	1.7	1.65	1.65
D_{30}	1.3	0.9	0.9	0.89
D_{25}	1.1	0.76	0.75	0.75
D_{15}	0.68	0.55	0.52	0.52
D_{10}	0.53	0.33	0.36	0.32
C_u	5.09	6.67	5.56	6.25
C_c	1.18	1.12	1.13	1.24

Figure 6.11: Post GSD Data and graphs of E12 Sample



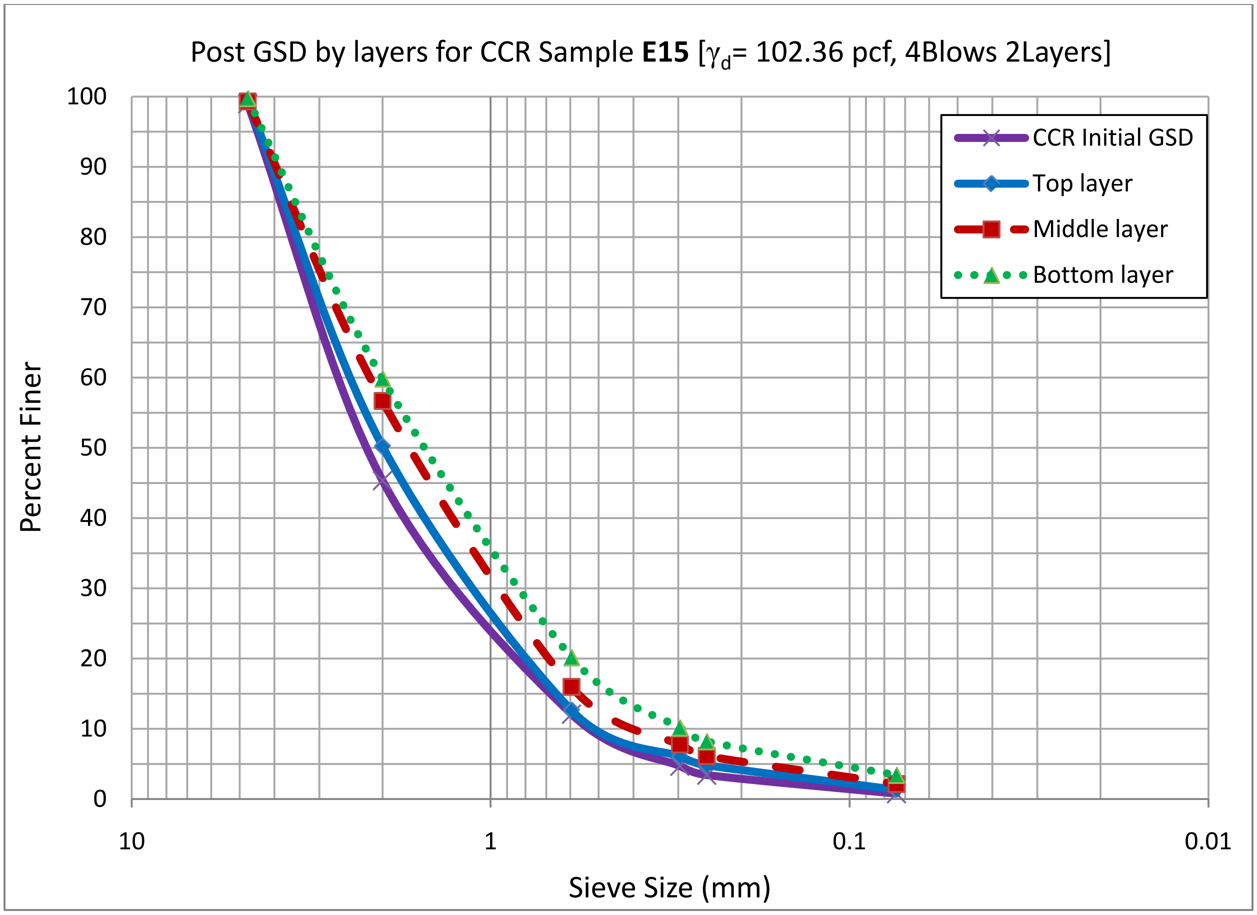
	CCR Initial GSD	CCR Post GSD (E13)		
		Top	Middle	Bottom
D_{85}	3.9	3.6	3.6	3.6
D_{60}	2.7	2.2	2.2	2.2
D_{50}	2.2	1.75	1.75	1.75
D_{30}	1.3	1.2	1.2	1.2
D_{25}	1.1	0.93	0.93	0.93
D_{15}	0.68	0.62	0.62	0.62
D_{10}	0.53	0.40	0.40	0.40
C_u	5.09	5.50	5.50	5.50
C_c	1.18	1.64	1.64	1.64

Figure 6.12: Post GSD Data and graphs of E13 Sample



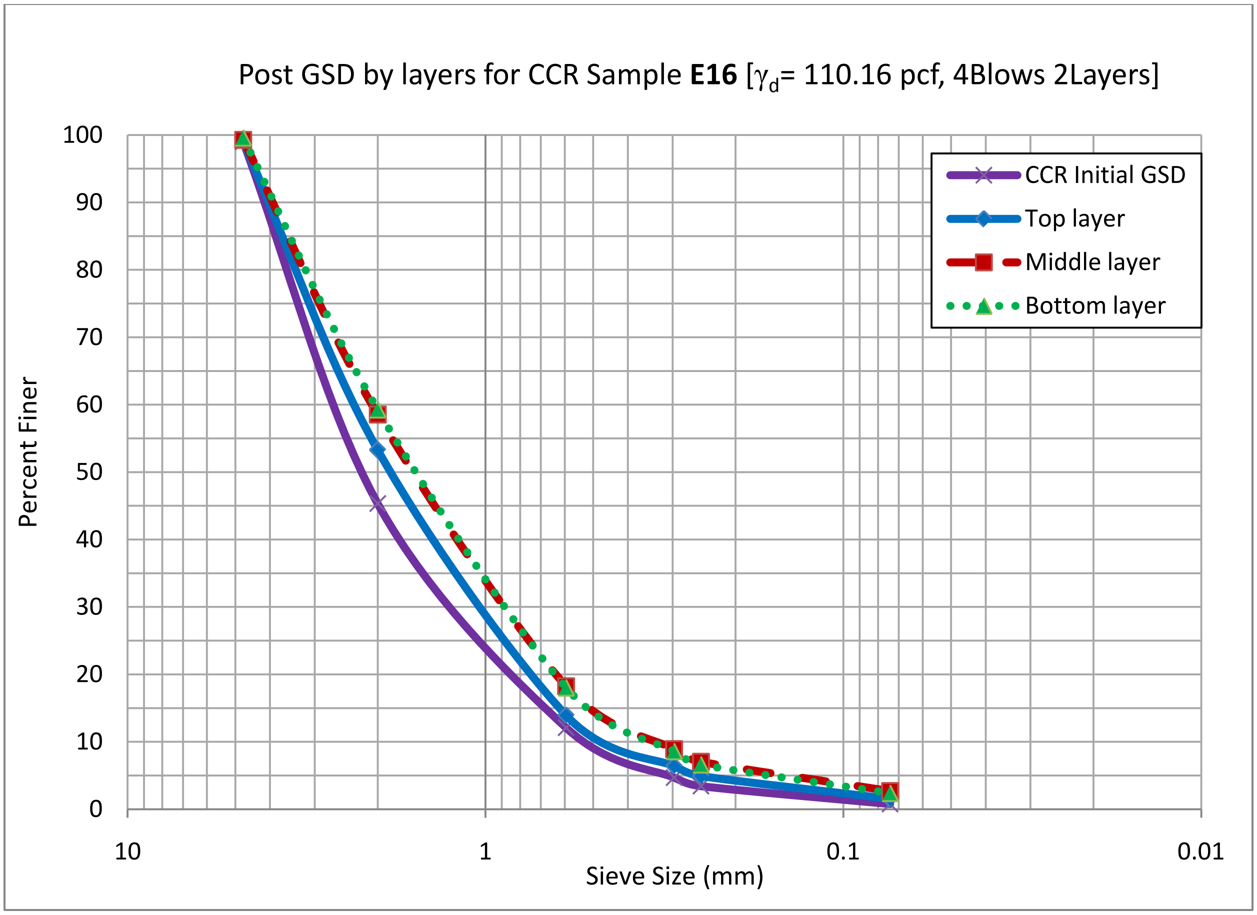
	CCR Initial GSD	CCR Post GSD (E14)		
		Top	Middle	Bottom
D_{85}	3.9	3.8	3.8	3.8
D_{60}	2.7	2.5	2.5	2.5
D_{50}	2.2	2	2	2
D_{30}	1.3	0.95	0.95	0.95
D_{25}	1.1	0.69	0.69	0.69
D_{15}	0.68	0.57	0.57	0.57
D_{10}	0.53	0.47	0.47	0.47
C_u	5.09	5.32	5.32	5.32
C_c	1.18	0.77	0.77	0.77

Figure 6.13: Post GSD Data and graphs of E14 Sample



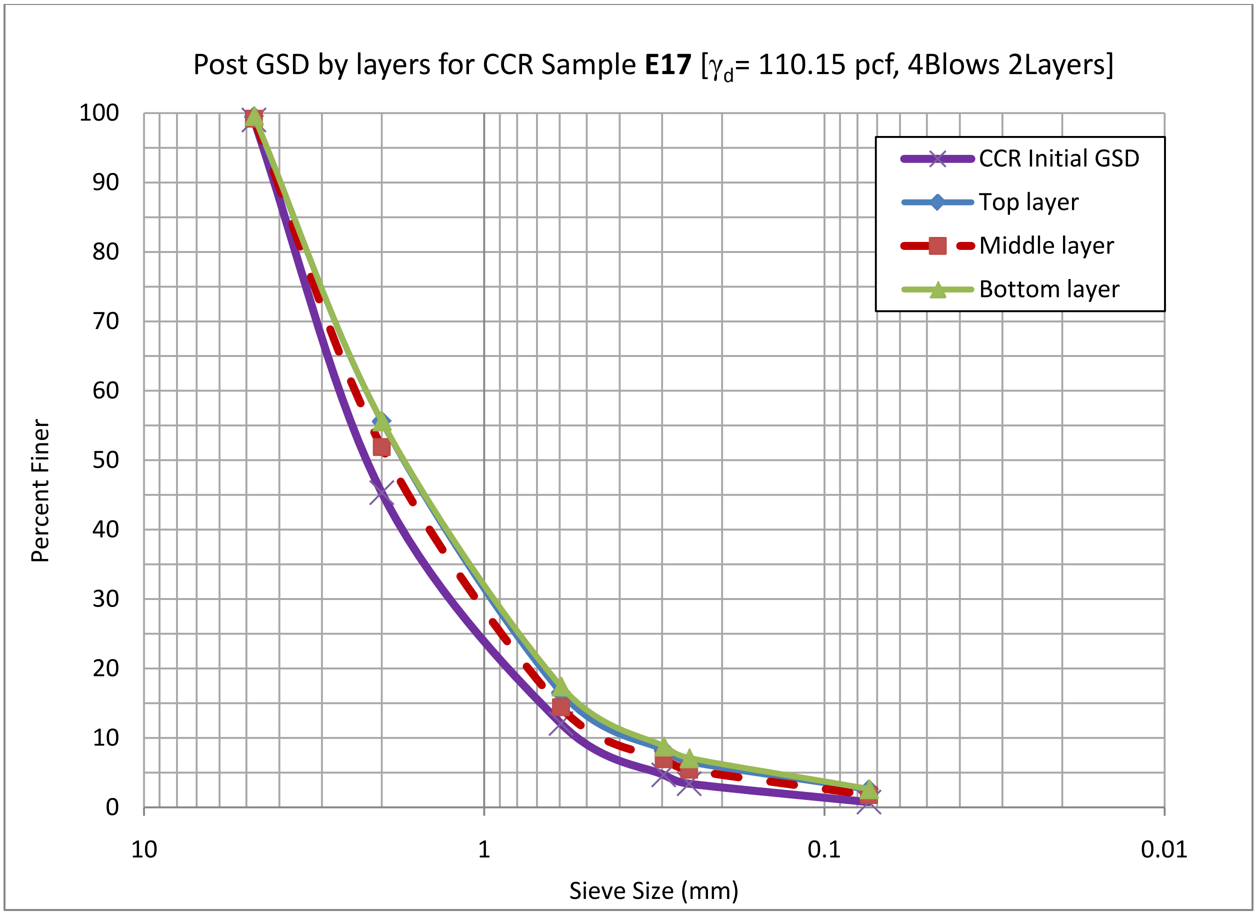
	CCR Initial GSD	CCR Post GSD (E15)		
		Top	Middle	Bottom
D_{85}	3.9	3.8	3.7	3.6
D_{60}	2.7	2.5	2.2	2
D_{50}	2.2	2	1.7	1.6
D_{30}	1.3	1.2	0.95	0.84
D_{25}	1.1	0.95	0.81	0.7
D_{15}	0.68	0.66	0.57	0.46
D_{10}	0.53	0.52	0.40	0.29
C_u	5.09	4.81	5.50	6.90
C_c	1.18	1.11	1.03	1.22

Figure 6.14: Post GSD Data and graphs of E15 Sample



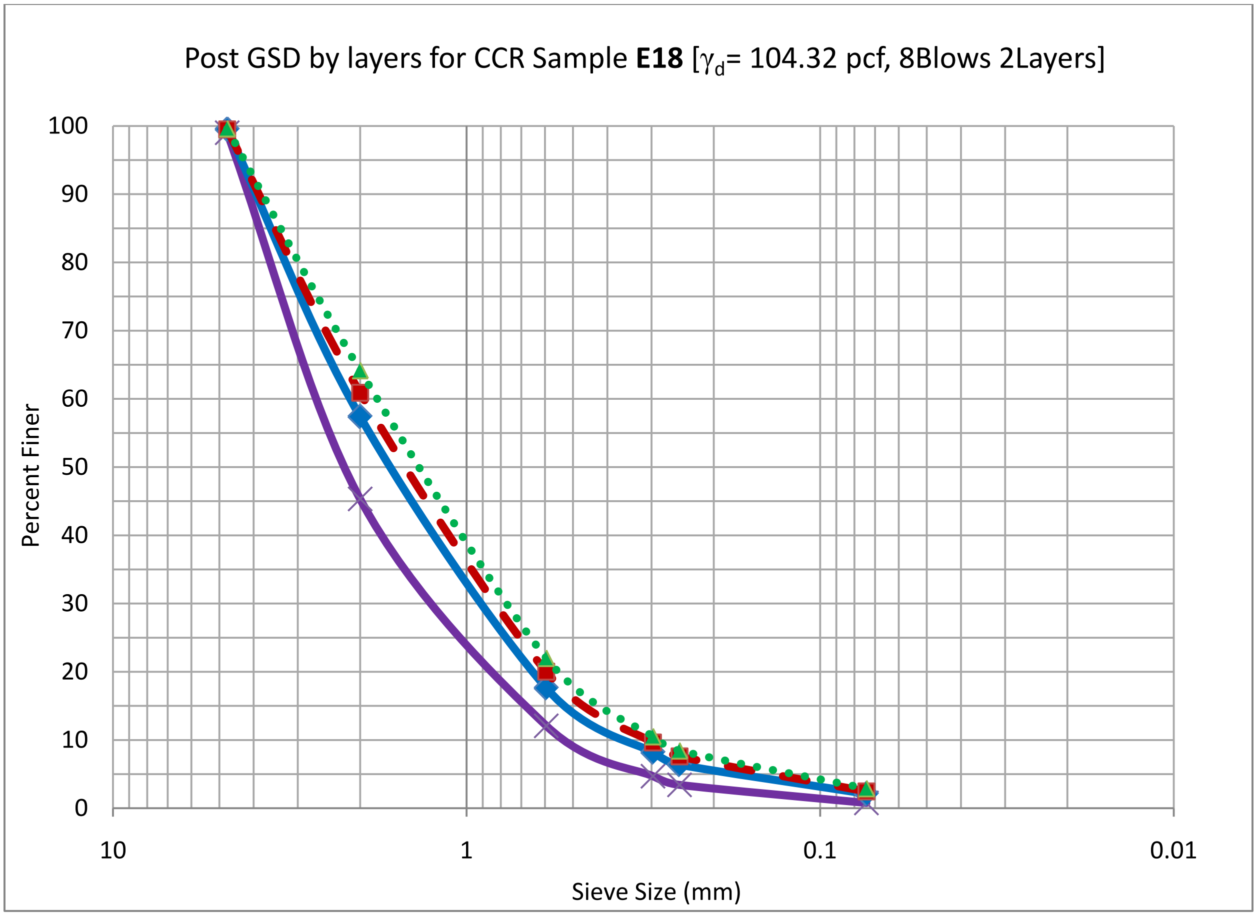
	CCR Initial GSD	CCR Post GSD (E16)		
		Top	Middle	Bottom
D_{85}	3.9	3.7	3.6	3.6
D_{60}	2.7	2.4	2.1	2.1
D_{50}	2.2	1.85	1.6	1.6
D_{30}	1.3	1.1	0.89	0.89
D_{25}	1.1	0.89	0.75	0.75
D_{15}	0.68	0.62	0.50	0.50
D_{10}	0.53	0.49	0.35	0.35
C_u	5.09	4.90	6.00	6.00
C_c	1.18	1.03	1.08	1.08

Figure 6.15: Post GSD Data and graphs of E16 Sample



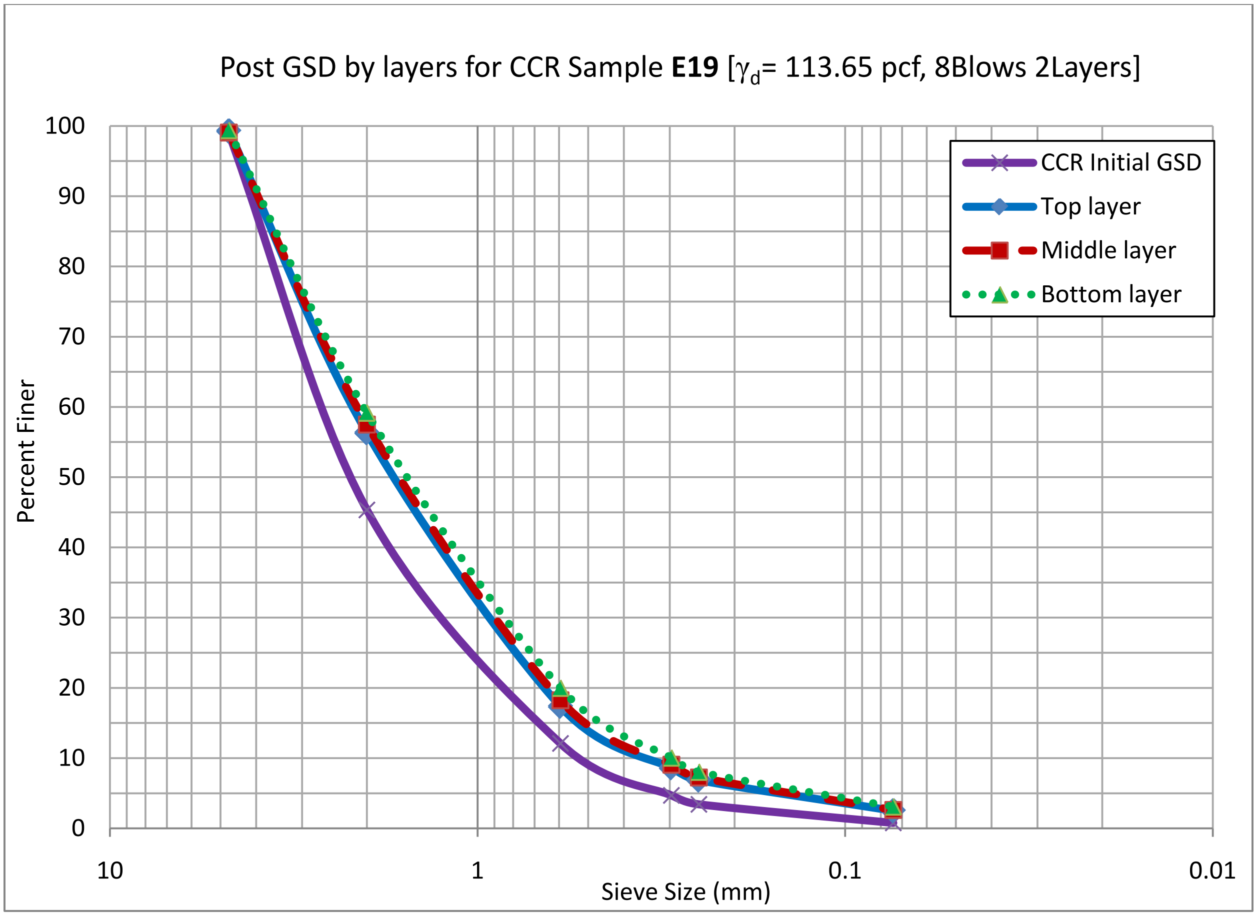
	CCR Initial GSD	CCR Post GSD (E17)		
		Top	Middle	Bottom
D_{85}	3.9	3.7	3.6	3.6
D_{60}	2.7	2.4	2.1	2.3
D_{50}	2.2	1.85	1.6	1.75
D_{30}	1.3	1.1	0.89	0.94
D_{25}	1.1	0.89	0.75	0.79
D_{15}	0.68	0.62	0.50	0.30
D_{10}	0.53	0.49	0.35	0.34
C_u	5.09	4.90	6.00	6.76
C_c	1.18	1.03	1.08	1.13

Figure 6.16: Post GSD Data and graphs of E17 Sample



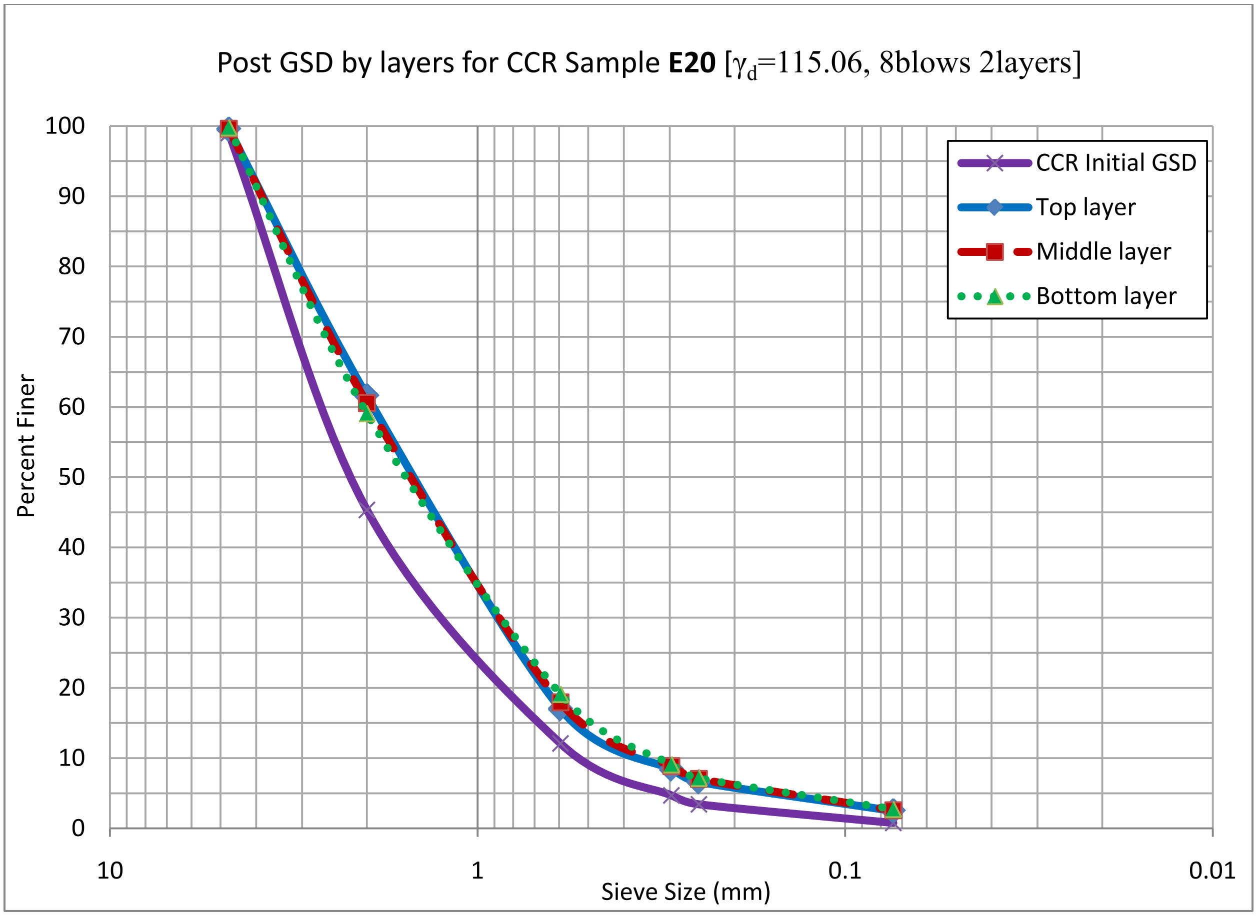
	CCR Initial GSD	CCR Post GSD (E18)		
		Top	Middle	Bottom
D_{85}	3.9	3.6	3.5	3.4
D_{60}	2.7	2.1	1.95	1.85
D_{50}	2.2	1.65	1.55	1.4
D_{30}	1.3	0.9	0.83	0.77
D_{25}	1.1	0.78	0.71	0.66
D_{15}	0.68	0.54	0.48	0.42
D_{10}	0.53	0.37	0.30	0.29
C_u	5.09	5.68	6.50	6.38
C_c	1.18	1.04	1.18	1.11

Figure 6.17: Post GSD Data and graphs of E18 Sample



	CCR Initial GSD	CCR Post GSD (E19)		
		Top	Middle	Bottom
D_{85}	3.9	3.6	3.6	3.6
D_{60}	2.7	2.2	2.2	2.05
D_{50}	2.2	1.7	1.7	1.6
D_{30}	1.3	0.92	0.89	0.85
D_{25}	1.1	0.78	0.76	0.72
D_{15}	0.68	0.54	0.51	0.47
D_{10}	0.53	0.35	0.33	0.30
C_u	5.09	6.29	6.67	6.83
C_c	1.18	1.10	1.09	1.17

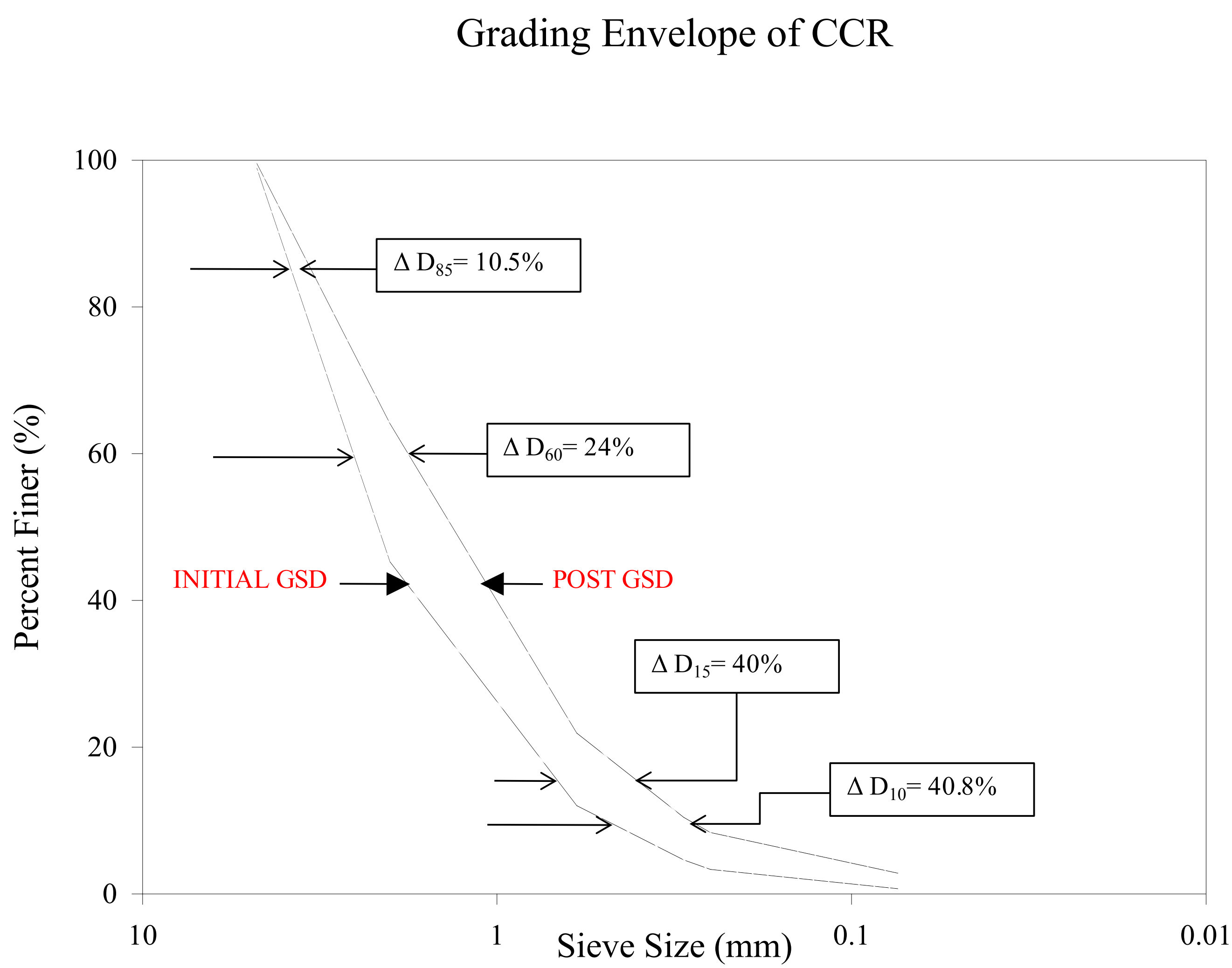
Figure 6.18: Post GSD Data and graphs of E19 Sample



	CCR Initial GSD	CCR Post GSD (E20)		
		Top	Middle	Bottom
D_{85}	3.9	3.5	3.5	3.5
D_{60}	2.7	2	2	2
D_{50}	2.2	1.6	1.6	1.6
D_{30}	1.3	0.88	0.88	0.88
D_{25}	1.1	0.75	0.75	0.75
D_{15}	0.68	0.55	0.52	0.50
D_{10}	0.53	0.36	0.35	0.33
C_u	5.09	5.56	5.71	6.06
C_c	1.18	1.08	1.11	1.17

Figure 6.19: Post GSD Data and graphs of E20 Sample

Grading envelope of CCR



GRAVEL	SAND			SILT or CLAY
	Coarse	Medium	Fine	

Analysis of post GSD graphs of coarse coal refuse (CCR) specimens leads to following observations:

- There is an overall and consistent movement in the grain-size distribution curves for the compacted samples of coarse coal refuse.
- The fines increase range was approximately constant for the different compaction energies.
- There appears to be similar amount of fines percentage between loose compacted samples and the optimum compacted samples.
- For example, the percentage variation in the particle size is a minimum at 8.82% and a maximum at 31% for the different particle sizes.
- The shift of post grain-size distribution curve to the right indicates that fines are increased due to compaction effort which causes a crushing of the particles.

<u>Coal Refuse Particle Disintegration</u>

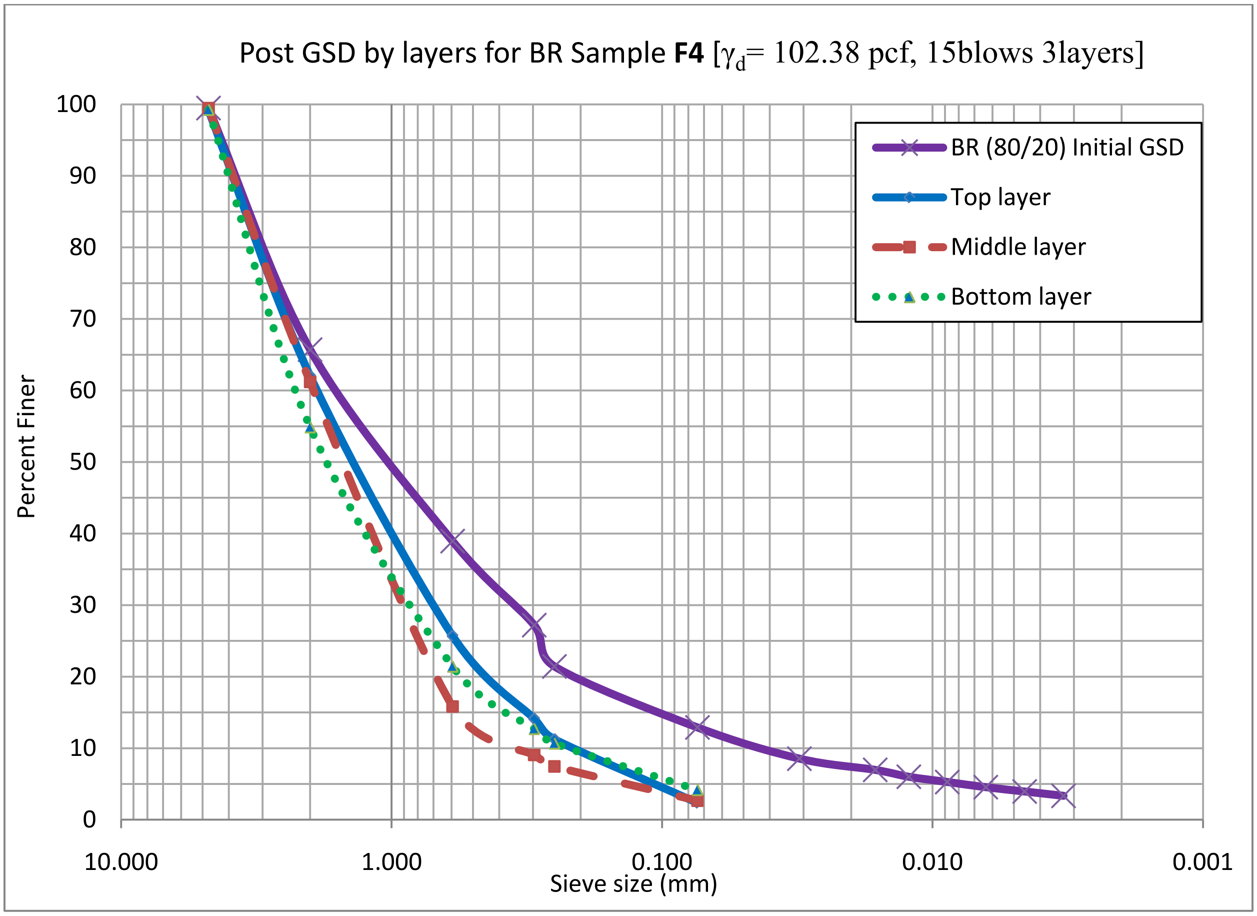
Observations showing the increases in the fine particle percentages of the compacted refuse occurs due to the following reasons: i) inter-granular crushing of the refuse from the compaction effort and ii) slaking of the fine particles leading to disintegration.

Inter-granular particle crushing of the refuse particles occurs in the coarse and fine fraction. This occurs from the compaction effort applied to the material causing particle stresses that reduce particle diameters.

Slaking is the crumbling and disintegration of materials when exposed to air or water. Previous research by D'Appolonia (1980) reported that the mechanisms of slaking occur from breaking of dried clay when saturated with water due either to compression of entrapped air by inward migrating capillary water or progressive swelling. D' Appolonia discusses that slaking is the short term disintegration process which occurs in geologic material due to internal stress increases. The physical and chemical characteristics of the geologic material significantly increase the probability of slaking in common sedimentary materials, such as coal refuse. The release of confining stresses due to mining and post material processing create partial openings and cracking along weak planes. Factors affecting slaking include the particle size of fine-grained sediments.

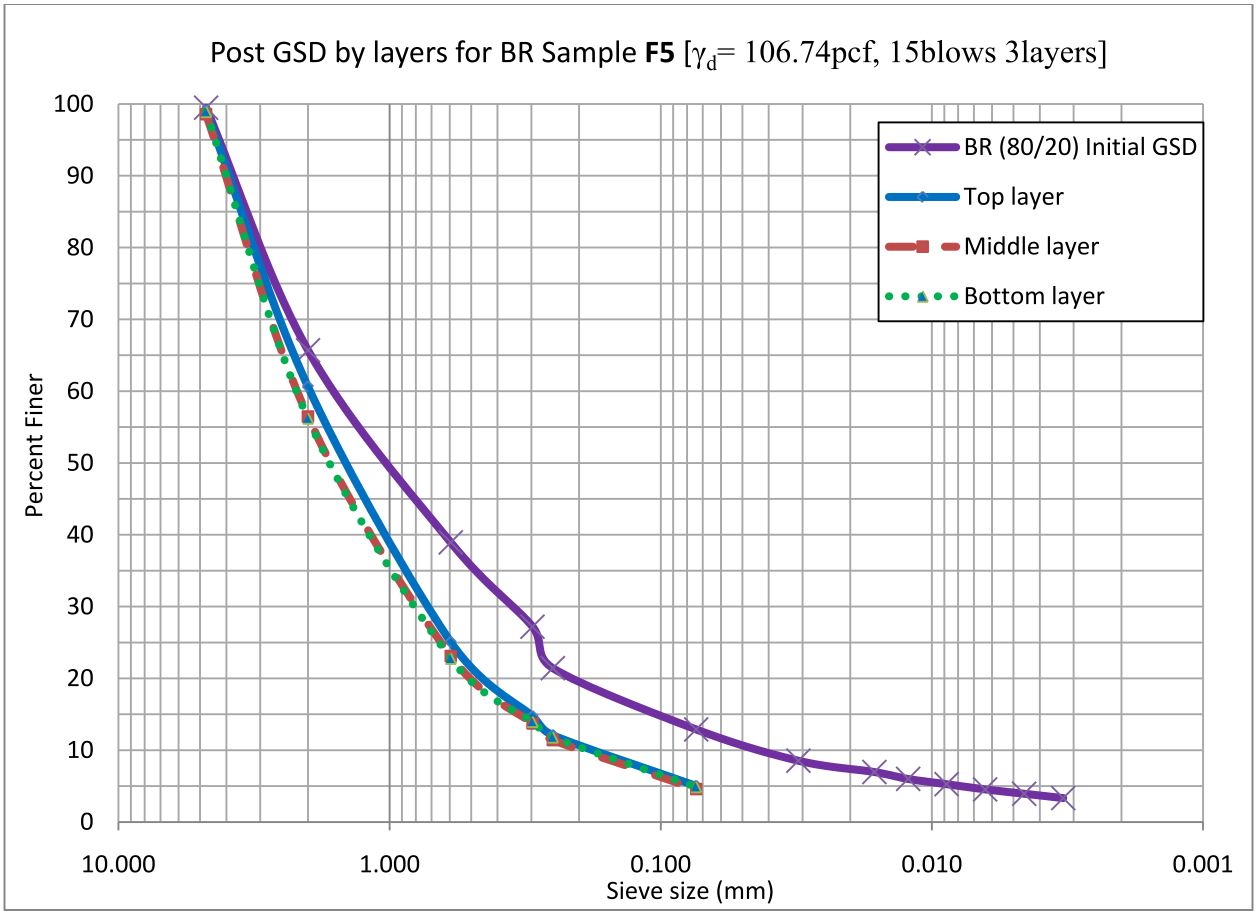
Blended refuse samples

The post GSD of coarse coal refuse samples are shown from Figure 6.10 to Figure 6.22.



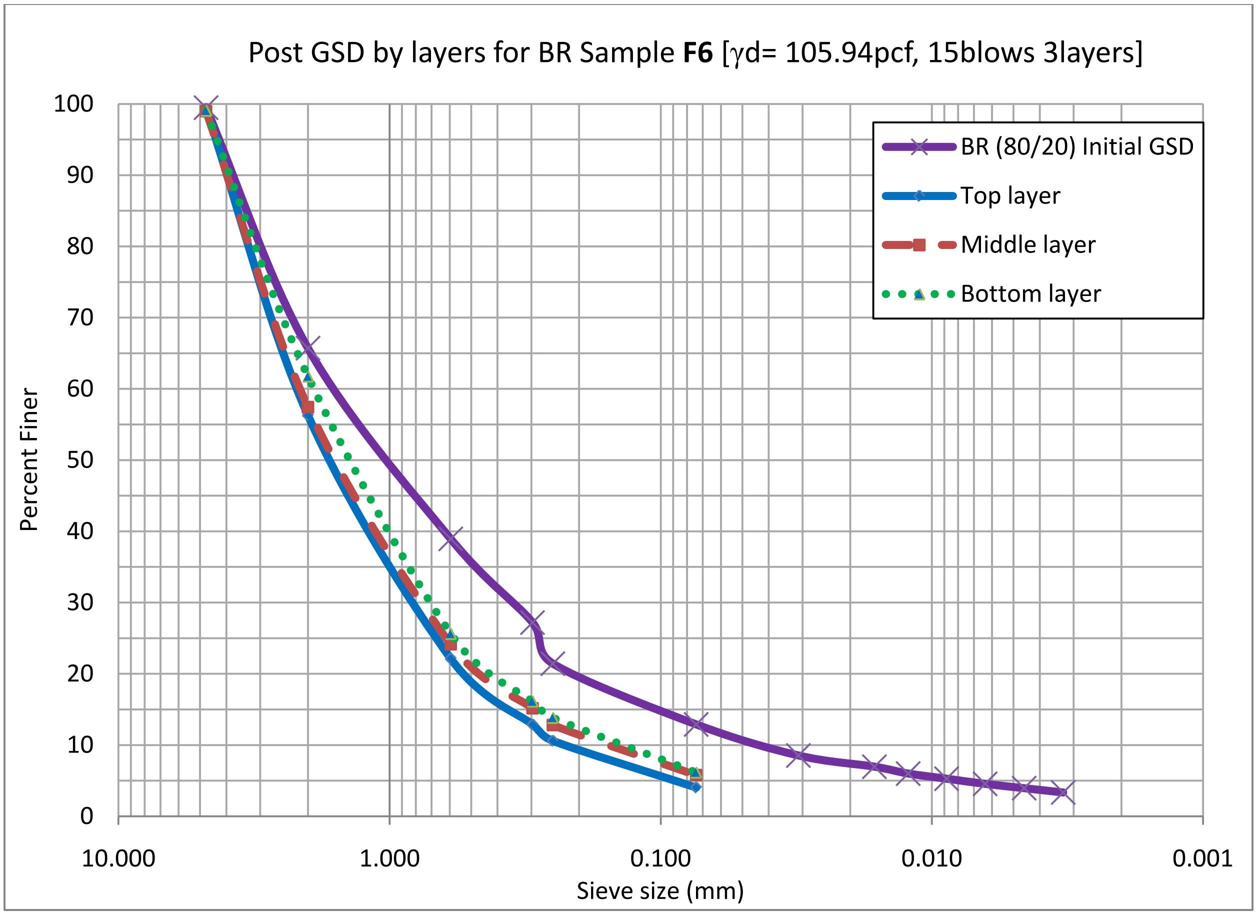
	BR Initial GSD	BR Post GSD (F4)		
		Top	Middle	Bottom
D_{85}	3.5	3.5	3.5	3.6
D_{60}	1.6	1.9	1.9	2.3
D_{50}	1.1	1.5	1.6	1.8
D_{30}	0.35	0.7	0.9	0.88
D_{25}	0.28	0.6	0.8	0.7
D_{15}	0.12	0.32	0.59	0.39
D_{10}	0.045	0.23	0.36	0.23
C_u	35.56	8.26	5.28	10.00
C_c	1.70	1.12	1.18	1.46

Figure 6.20: Post GSD Data and graphs of F4 Sample



	BR Initial GSD	BR Post GSD (F5)		
		Top	Middle	Bottom
D_{85}	3.5	3.5	3.5	3.5
D_{60}	1.6	1.9	2.2	2.2
D_{50}	1.1	1.5	1.7	1.7
D_{30}	0.35	0.7	0.8	0.8
D_{25}	0.28	0.6	0.65	0.65
D_{15}	0.12	0.30	0.33	0.33
D_{10}	0.045	0.19	0.19	0.19
C_u	35.56	10.00	11.58	11.58
C_c	1.70	1.36	1.53	1.53

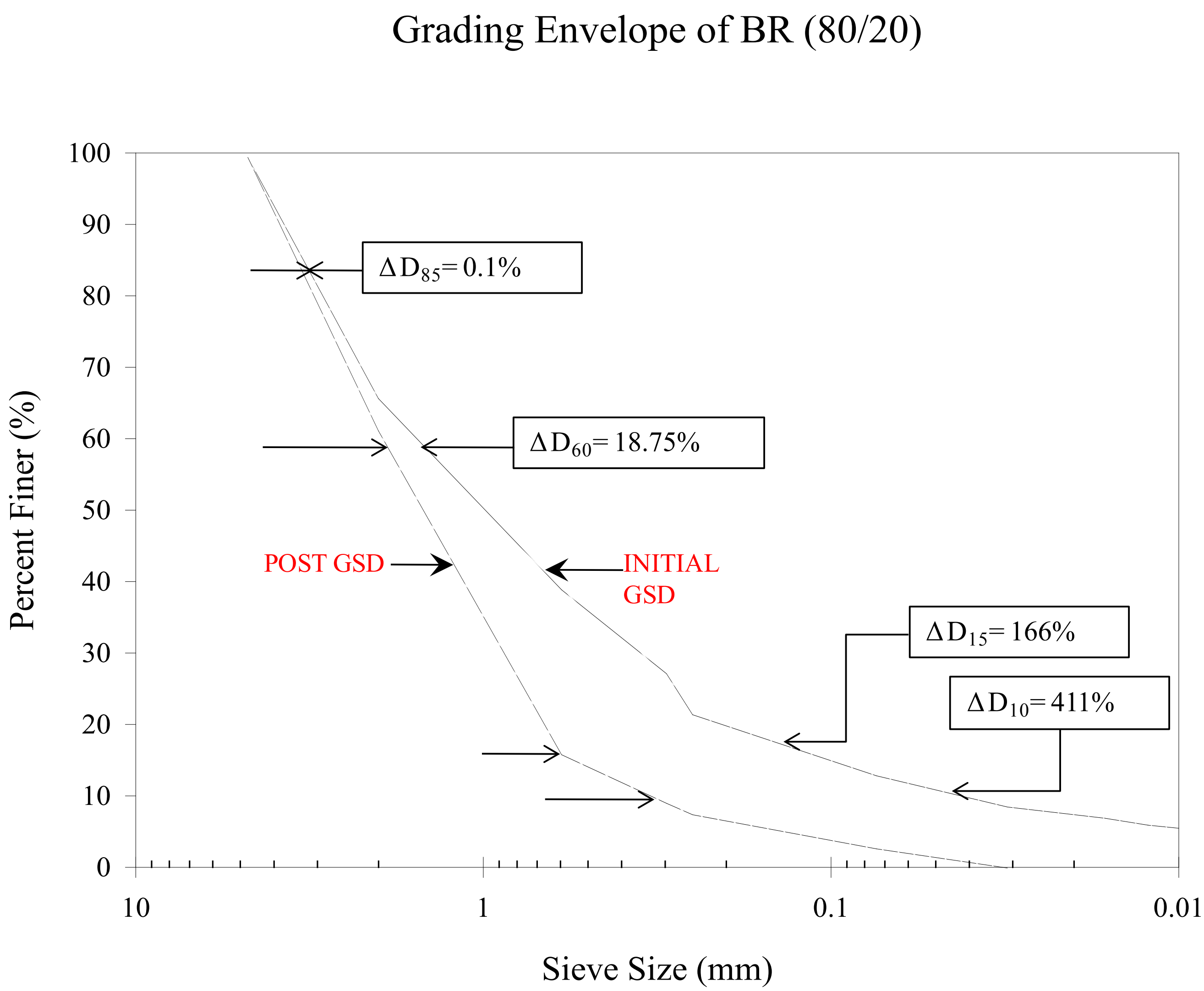
Figure 6.21: Post GSD Data and graphs of F5 Sample



	BR Initial GSD	BR Post GSD (F6)		
		Top	Middle	Bottom
D_{85}	3.5	3.6	3.6	3.5
D_{60}	1.6	2.2	2.1	1.9
D_{50}	1.1	1.7	1.6	1.4
D_{30}	0.35	0.84	0.76	0.7
D_{25}	0.28	0.69	0.62	0.59
D_{15}	0.12	0.38	0.30	0.29
D_{10}	0.045	0.23	0.16	0.15
C_u	35.56	9.57	13.13	12.67
C_c	1.70	1.39	1.72	1.72

Figure 6.22: Post GSD Data and graphs of F6 Sample

Grading envelope of BR (80/20)



GRAVEL	SAND			SILT or CLAY
	Coarse	Medium	Fine	

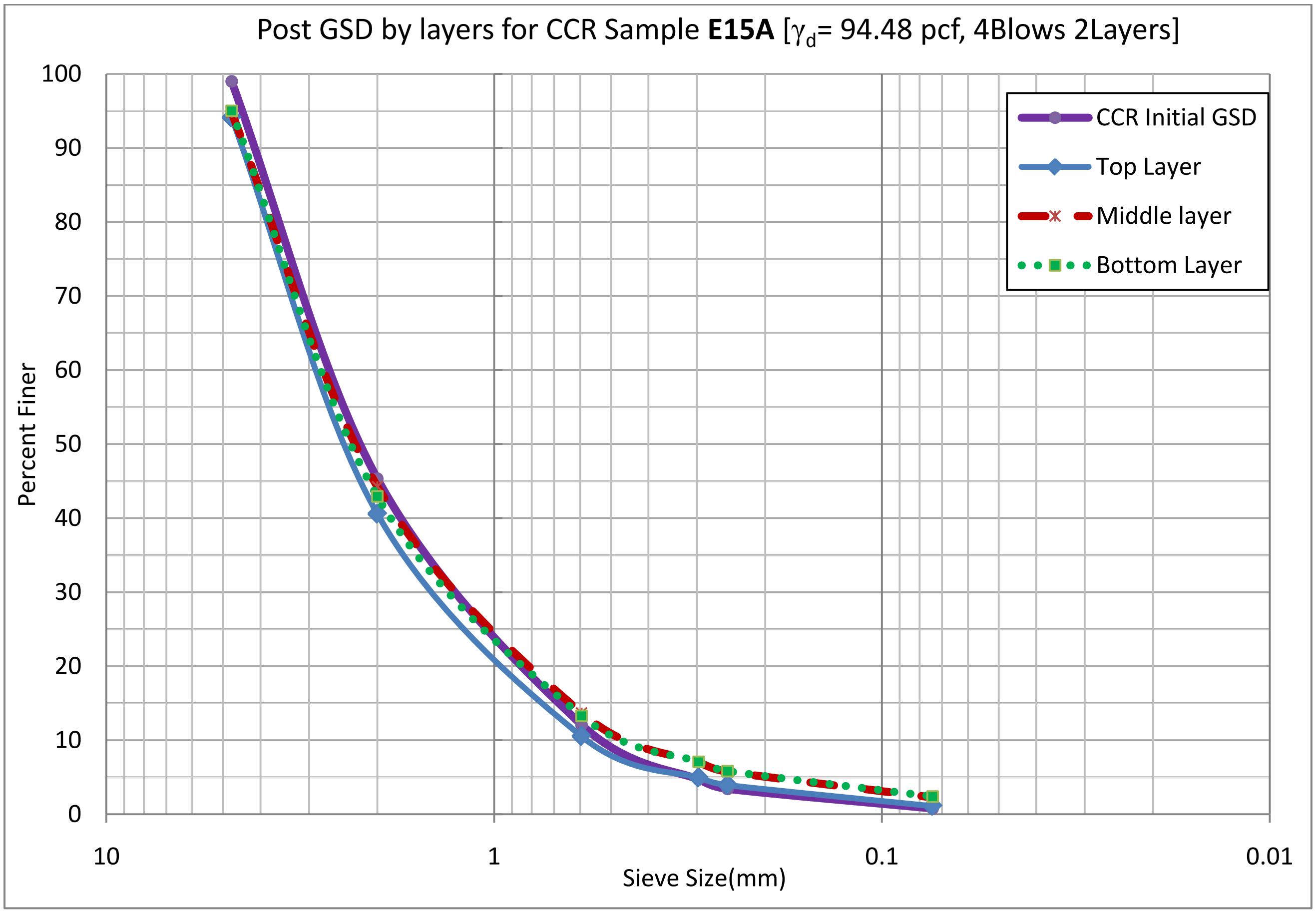
Analysis of Post GSD graphs of blended refuse (80/20 mix) samples lead to following observations:

- The post grain-size distribution of blended refuse (80/20 mix) samples indicate that, aggregation of fines occurring and due to that the GSD curve shift to a more larger particle size arrangement occurring because of binding of particles with fines.
- The aggregation of crushed fine particle <D_{60} to D_{10} as compared to the coarse coal refuse (CCR) is that the post GSD of blended refuse samples resemble the original GSD of coarse coal refuse.
- The aggregation of the fine particles is consistent with previous observations on the slaking effects of the refuse. The slaking produces the fine materials and causes the increase in packing density leading to hydrological impacts such as reduced porosity.

The analysis of blended refuse 60/40 mix sample was not performed because the sample was analyzed by the chemistry department for the particle movement tracking experiments.

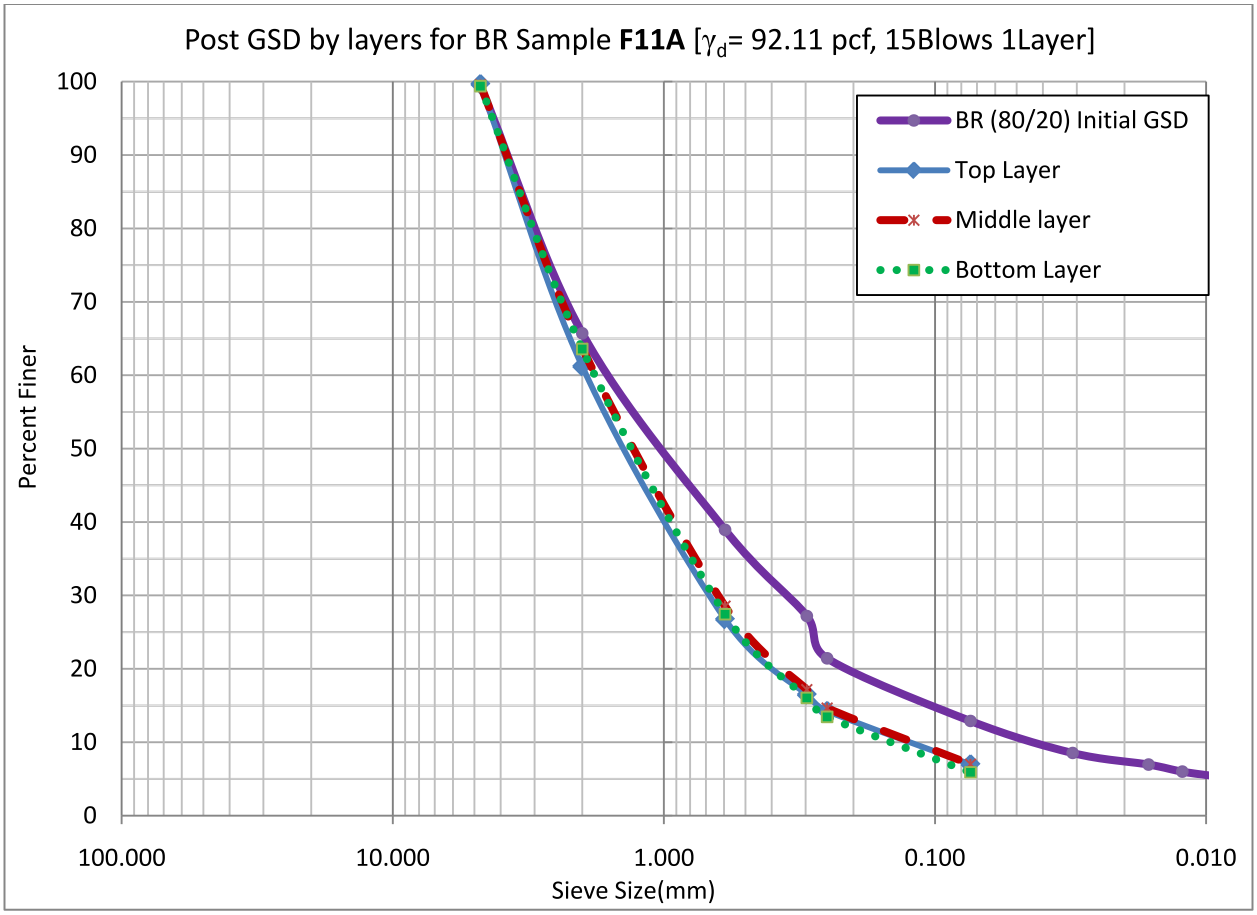
Post GSD of Acid permeant Samples

The post grain-size distribution was performed on the coarse coal refuse (CCR) samples, blended refuse 80/20 mix samples, and blended refuse 60/40 mix samples.



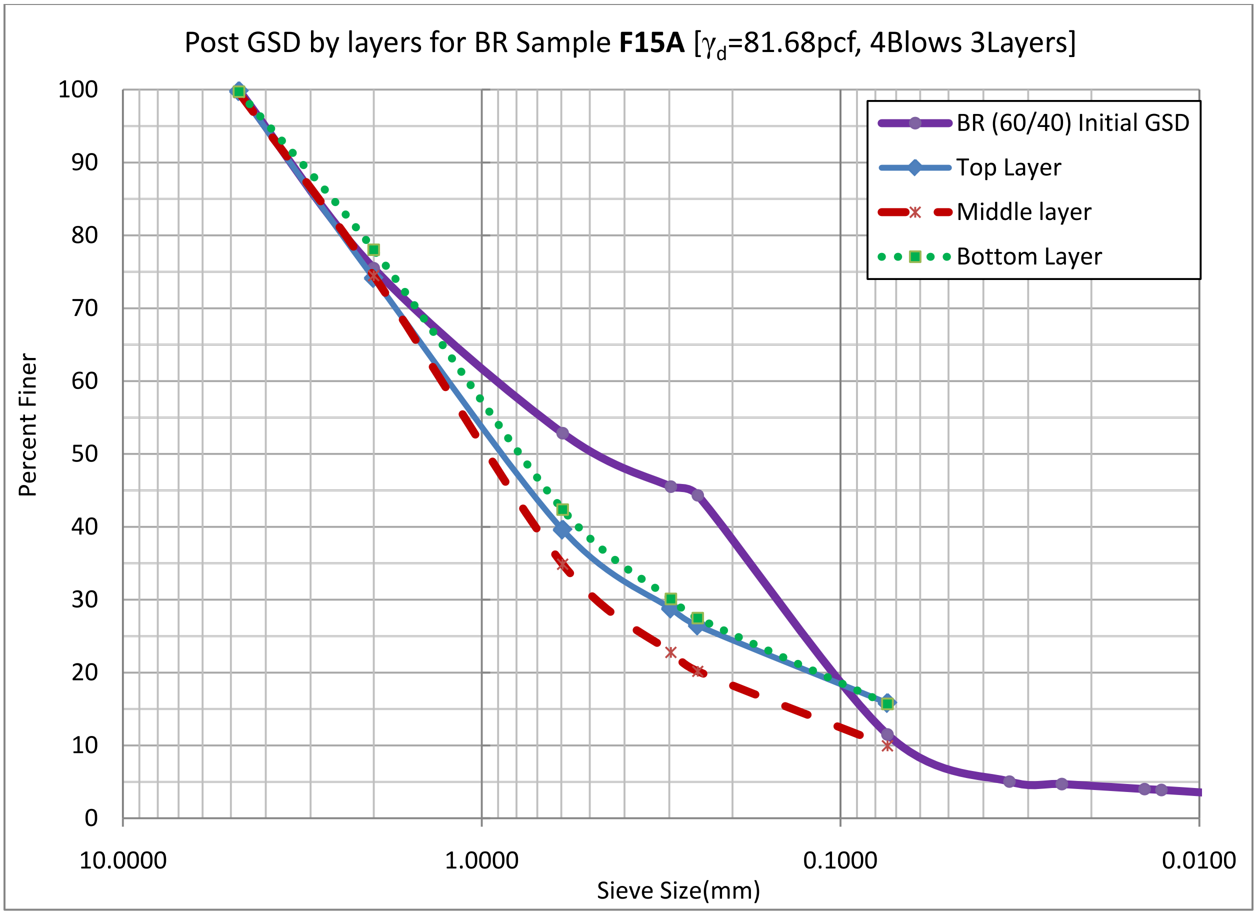
	CCR Initial GSD	CCR Post GSD (E15A)		
		Top	Middle	Bottom
D_{85}	3.9	4	4	4
D_{60}	2.7	2.9	2.8	2.8
D_{50}	2.2	2.5	2.3	2.4
D_{30}	1.3	1.55	1.3	1.4
D_{25}	1.1	1.3	1.1	1.1
D_{15}	0.68	0.76	0.65	0.65
D_{10}	0.53	0.59	0.46	0.46
C_u	5.09	4.92	6.09	6.09
C_c	1.18	1.40	1.31	1.52

Figure 6.23: Post GSD Data and graphs of E15 Acid Sample



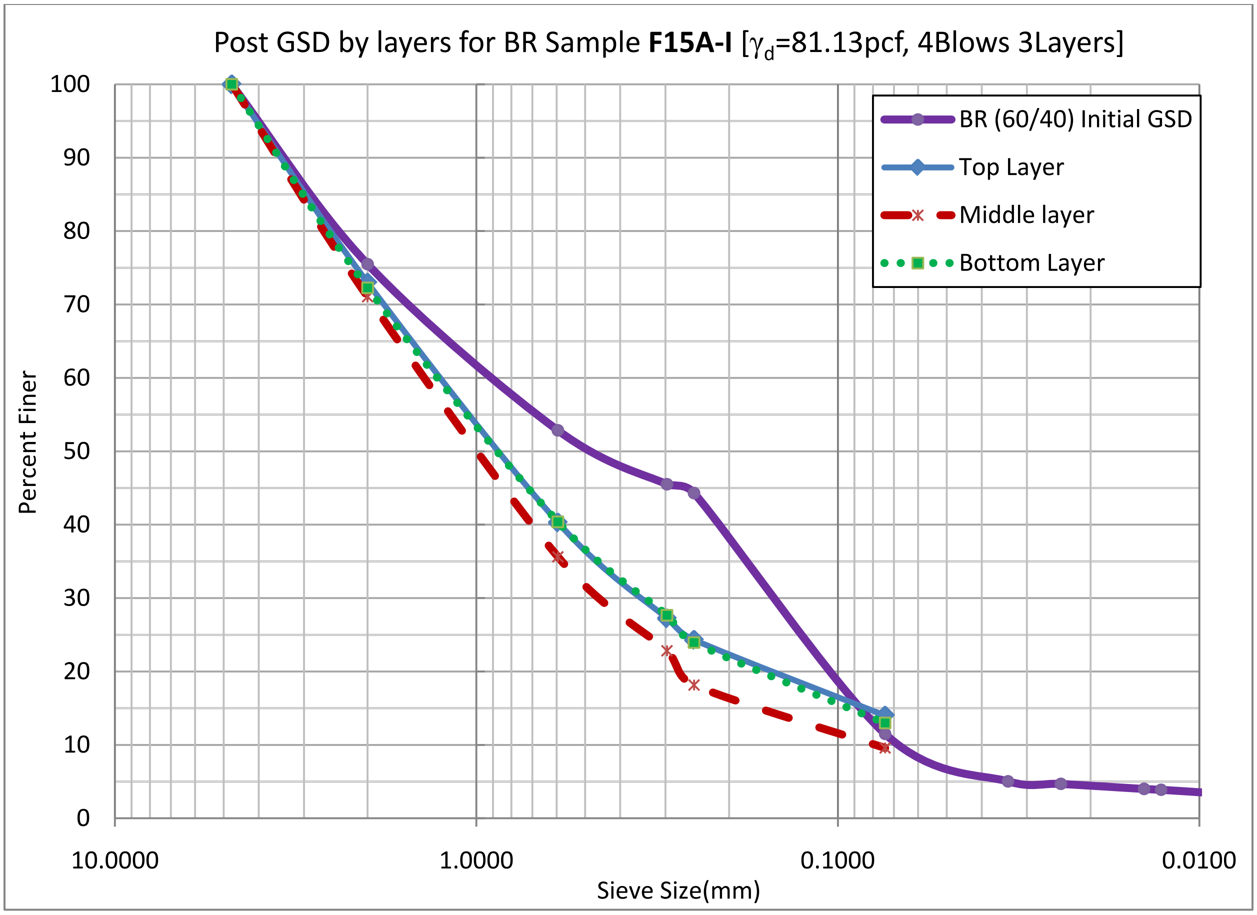
	BR Initial GSD	BR Post GSD (F11A)		
		Top	Middle	Bottom
D_{85}	3.5	3.5	3.5	3.5
D_{60}	1.6	1.9	1.8	1.8
D_{50}	1.1	1.5	1.4	1.4
D_{30}	0.35	0.69	0.64	0.66
D_{25}	0.28	0.65	0.6	0.65
D_{15}	0.12	0.27	0.26	0.28
D_{10}	0.045	0.13	0.13	0.15
C_u	35.56	14.62	13.85	12.00
C_c	1.70	1.93	1.75	1.61

Figure 6.24: Post GSD Data and graphs of F11 Acid Sample



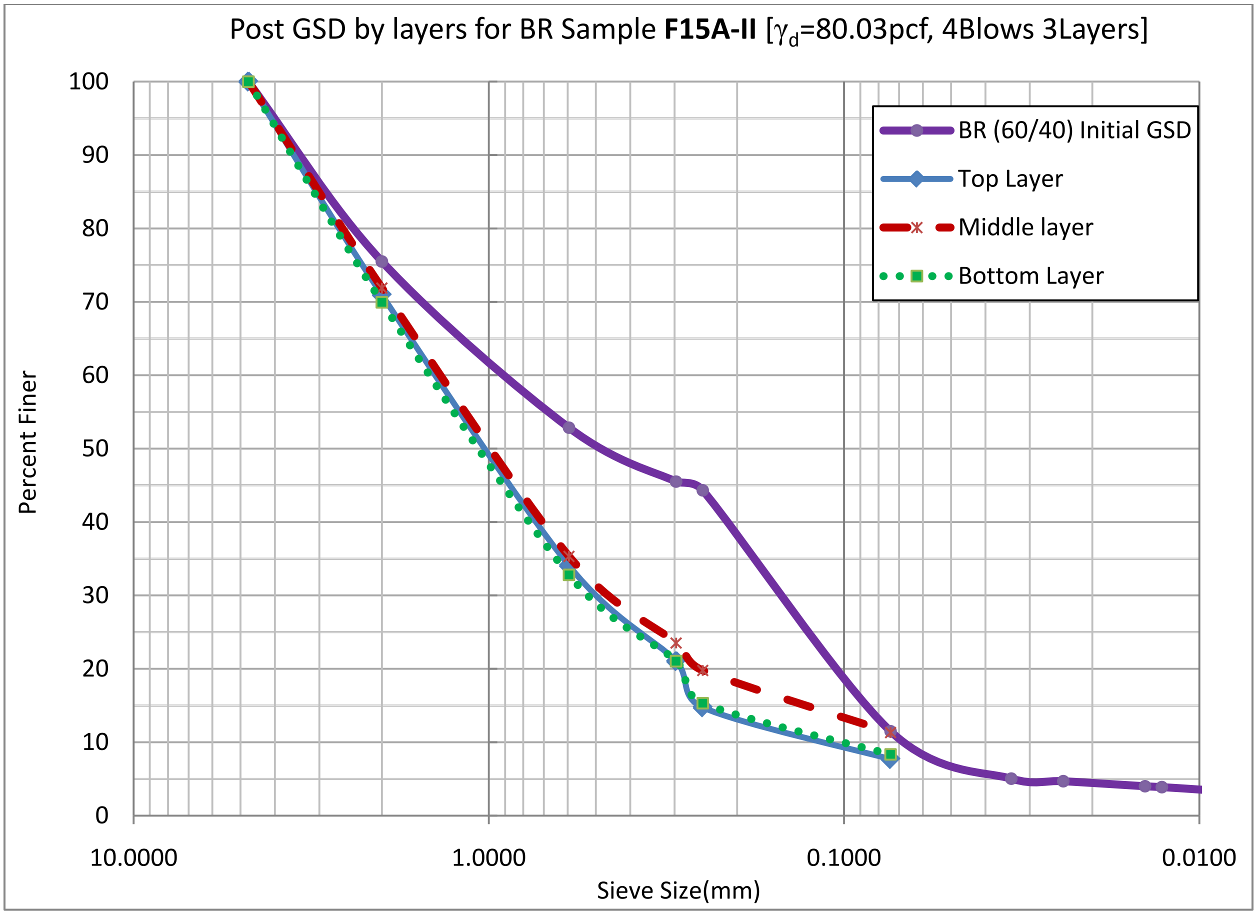
	BR Initial GSD	BR Post GSD (F15A)		
		Top	Middle	Bottom
D_{85}	2.9	2.9	2.9	2.7
D_{60}	0.9	1.3	1.4	1.1
D_{50}	0.5	0.89	0.95	0.8
D_{30}	0.16	0.33	0.49	0.3
D_{25}	0.14	0.21	0.35	0.2
D_{15}	0.086	0.70	0.14	0.70
D_{10}	0.069		0.075	
C_u	13.04		18.67	
C_c	0.41		2.29	

Figure 6.25: Post GSD Data and graphs of F15 Acid Sample



	BR Initial GSD	BR Post GSD (F15A-I)		
		Top	Middle	Bottom
D_{85}	2.9	3	3	3
D_{60}	0.9	1.35	1.5	1.35
D_{50}	0.5	0.88	1	0.88
D_{30}	0.16	0.35	0.46	0.35
D_{25}	0.14	0.27	0.35	0.27
D_{15}	0.086	0.085	0.17	0.09
D_{10}	0.069		0.08	
C_u	13.04		18.75	
C_c	0.41		1.76	

Figure 6.26: Post GSD Data and graphs of F15 Acid Sample-I



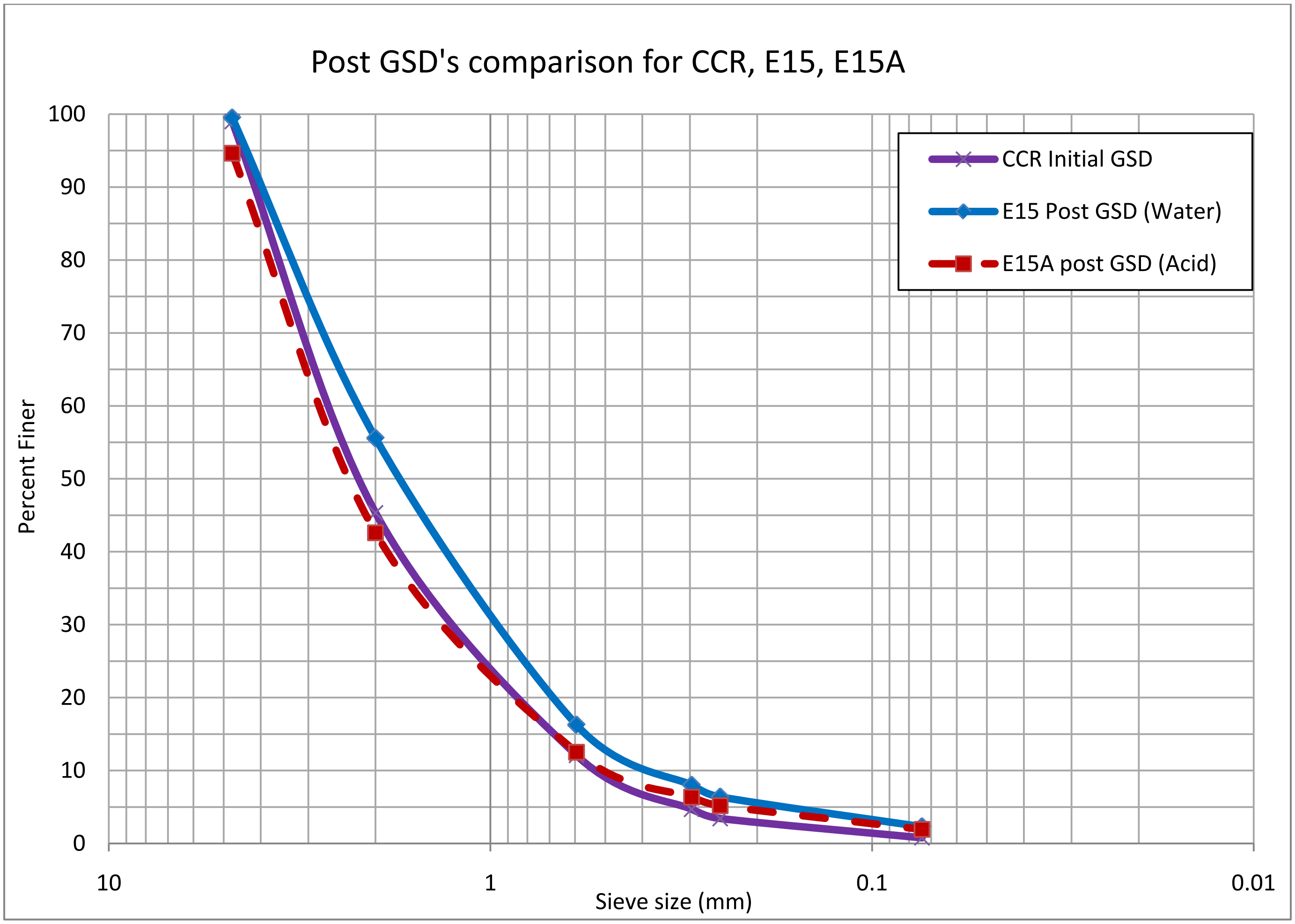
	BR Initial GSD	BR Post GSD (F15A-II)		
		Top	Middle	Bottom
D_{85}	2.9	3	3	3
D_{60}	0.9	1.5	1.45	1.5
D_{50}	0.5	1.05	1	1.05
D_{30}	0.16	0.5	0.46	0.53
D_{25}	0.14	0.38	0.33	0.38
D_{15}	0.086	0.26	0.13	0.26
D_{10}	0.069	0.13		0.11
C_u	13.04	11.54		13.64
C_c	0.41	1.28		1.70

Figure 6.27: Post GSD Data and graphs of F15 Acid Sample-II

Overall GSD comparisons with Water and Acid Permeants

The post GSD of CCR samples, BR 80/20 mix samples, BR 60/40 mix samples which are permeated with water and acid are compared for the analysis of acid effects.

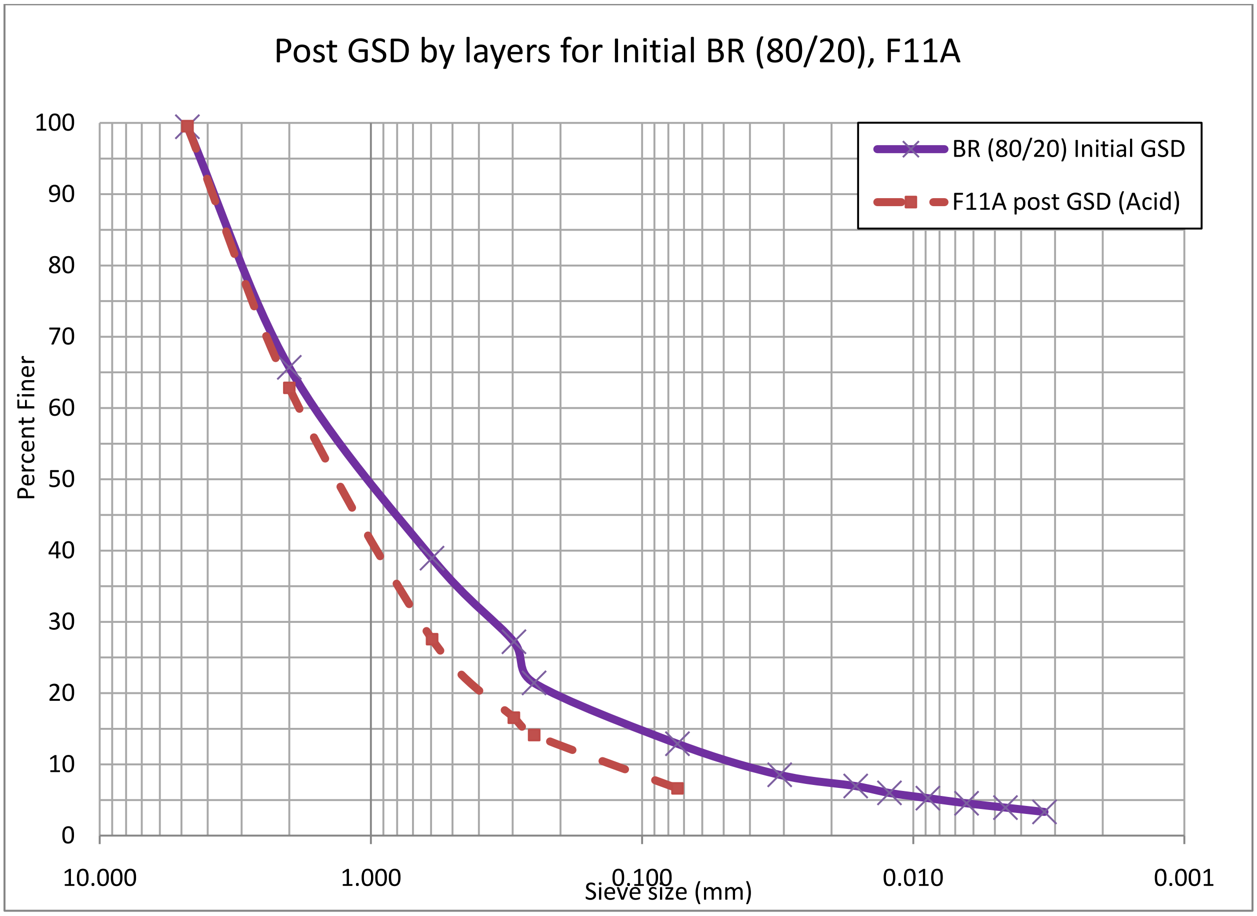
E15



	CCR Initial GSD	E15 (Water)	E15A (Acid)
D_{85}	3.9	3.7	4.1
D_{60}	2.7	2.3	2.8
D_{50}	2.2	1.8	2.3
D_{30}	1.3	0.97	1.4
D_{25}	1.1	0.8	1.2
D_{15}	0.68	0.57	0.68
D_{10}	0.53	0.40	0.50
C_u	5.09	5.75	5.60
C_c	1.18	1.02	1.40

Figure 6.28: Post GSD Comparisons of E15 sample with water and Acid permeants

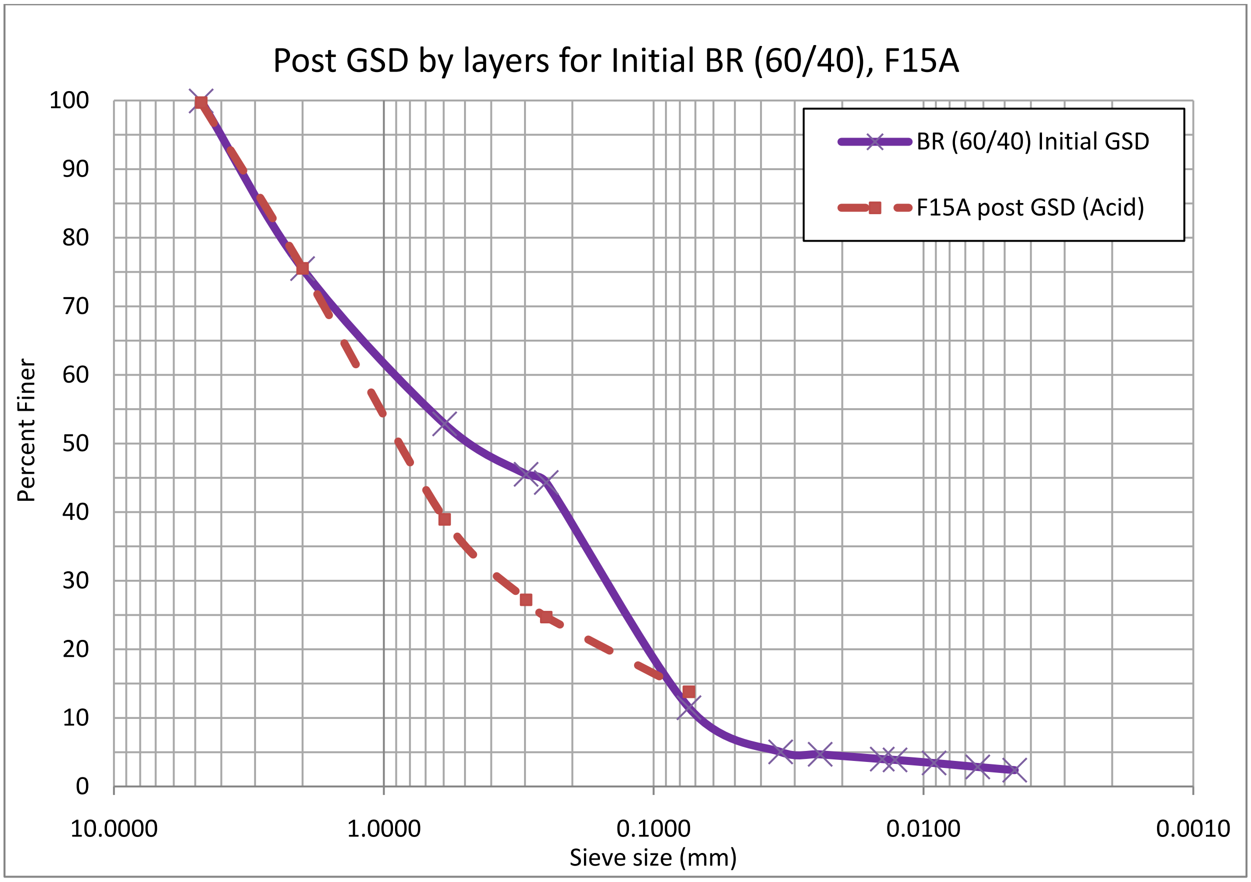
F11



	BR(80/20) Initial GSD	F11A (Acid)
D_{85}	3.5	3.5
D_{60}	1.6	1.8
D_{50}	1.1	1.4
D_{30}	0.35	0.65
D_{25}	0.28	0.53
D_{15}	0.12	0.27
D_{10}	0.045	0.14
C_u	35.56	12.86
C_c	1.70	1.68

Figure 6.29: Post GSD Comparisons of F11 sample with water and Acid permeants

F15



	BR (60/40)Initial GSD	F15A (Acid)
D_{85}	2.9	2.85
D_{60}	0.9	1.3
D_{50}	0.5	0.89
D_{30}	0.16	0.37
D_{25}	0.14	0.26
D_{15}	0.086	0.86
D_{10}	0.069	
C_u	13.04	
C_c	0.41	

Figure 6.30: Post GSD Comparisons of F15 sample with Acid permeants

The post GSD comparison of CCR, BR samples with acid and water permeants which are shown from Figure 6.23 to Figure 6.30 lead to following observations:

- For the CCR samples which are tested using the Acid permeant, the shift of GSD curve of compacted sample merges with the original GSD of CCR indicating the acid is flocculating the samples which cause the aggregation of materials. This trend is consistent with flocculation effects of fine grained soils in the presence of a low pH (acid) environment (Bowders et.al,1989)
- For blended refuse sample both 80/20 mix and 60/40 mix, the post GSD of acid samples indicate that acid is flocculating the samples leading to an increase in the hydraulic conductivity.

6.1.9. Geotextile Filtration & Clogging Design Analysis

The properties of geotextiles and the properties of coal refuse tested were used for the evaluation of geotextile design. Three types of design criteria were compared. They are Retention criteria, Permeability/Permittivity criteria, and Clogging criteria. Two types of samples were used for the comparison. They are coarse coal refuse (CCR) and blended refuse (BR). In the blended refuse two different mix proportions were used for the blending 80% coarse to 20% fine; and 60% coarse to 40% fine.

The soil parameters required for the design criteria are grain-size distribution, hydraulic conductivity and other geotextile parameters. The samples were compacted and then hydraulic conductivity test was performed. After hydraulic conductivity test, the sample was divided into three layers and then grain-size distribution was performed to assess the fine particle movement. The geotextile design will also be evaluated with the post grain size of the soil samples. The soil samples were compacted at different compaction energies as referenced inFigure 3.3.

<u>1. Coarse coal refuse (Initial GSD)</u>

The following are the parameters of cal refuse and geotextiles required for evaluation of geotextile design.

Table 6.4: Geotextile Filtration Design Parameters

Parameters of Coal Refuse		Parameters of Geotextile	
D_{85}	3.9	AOS (mm)	0.212
D_{60}	2.7	k (cm/s)	0.3
D_{50}	2.2	Ψ (s^{-1})	1.5
D_{15}	0.68		
D_{10}	0.53		
C_u	5.09		

<u>a) Retention criteria:</u>

MSHA (2009): $\boldsymbol{AOS\ (O_{95}) \leq B * D_{85}}$

Where B= 8/Cu= 8/5.09= 1.57, D_{85}= 3.9, AOS= 0.212

⇨ $0.212 \leq 1.57 * 3.9$

$0.212 \leq 6.123$ PASS

J.P. Giroud (1988): $\boldsymbol{O_{95} < \lambda_R D_{85}}$

Where $\lambda_R = 18{*}C_u^{-1.7} = 18{*}(5.09)^{-1.7} = 1.132$,

⇨ 0.212 < 1.132*3.9

0.212 < 4.14 PASS

b) Permeability (k) and Permittivity (Ψ) criteria:

MSHA (2009): $\boldsymbol{k_{geotextile} \geq k_{soil}}$

Where $k_{geo} = 0.30$ cm/s, $k_{soil} \approx (D_{10})^2 = (0.53)^2 = 0.28$ cm/s

⇨ 0.30 ≥ 0.28 PASS

J.P. Giroud (1988): $\boldsymbol{k_{geotextile} \geq k_{soil}/10}$

Where $k_{soil} = 0.28$ cm/s

⇨ 0.30 ≥ 0. 28/10

0.30 ≥ 0.028 PASS

MSHA (2009): $\boldsymbol{\Psi_{geo} \geq 0.5\ sec^{-1}}$

$\Psi_{geo} = 1.5\ sec^{-1}$

⇨ 1.5 ≥ 0.5 PASS

C) Clogging Criteria: $\boldsymbol{AOS\ (O_{95}) \geq 3 * D_{15}}$

0.212 ≥ 3* 0.68,

0.212 ≥ 2.07 FAIL

2. Coarse coal refuse (Post GSD) for compacted sample (E7)

The following are the parameters of cal refuse and geotextiles required for evaluation of geotextile design.

Table 6.5: Geotextile Filtration Design Parameters

Parameters of Coal Refuse		Parameters of Geotextile	
D_{85}	3.7	AOS (mm)	0.212
D_{60}	2.2	k (cm/s)	----
D_{50}	1.75	Ψ (s^{-1})	1.3
D_{15}	0.54		
D_{10}	0.32		
C_u	6.87		

a) <u>Retention criteria:</u>

MSHA (2009): $$\boldsymbol{AOS\ (O_{95}) \leq\ B * D_{85}}$$

Where B= 8/Cu= 8/6.875= 1.16, D_{85}= 3.7, AOS= 0.212

⇨ 0.212 ≤ 1.16 * 3.7

0.212 ≤ 4.29 PASS

J.P. Giroud (1988): $$\boldsymbol{O_{\ 95} <\ \lambda_R\ D_{85}}$$

Where λ_R= 18*$C_u^{-1.7}$= 18*$(6.87)^{-1.7}$= 0.6786,

⇨ 0.212 < 0.6786*3.7

0.212 < 2.51 PASS

b) <u>Permeability (k) and Permittivity (Ψ) criteria</u>:

MSHA (2009): $$\boldsymbol{k_{geotextile}\ \geq\ k_{soil}}$$

⇨ PASS

J.P. Giroud (1988): $$\boldsymbol{k_{geotextile}\ \geq\ k_{soil}/10}$$

Where k_{soil}= 5.82 *10^{-4} cm/s

⇨ $0.30 \geq 5.82 * 10^{-4} / 10$

$0.30 \geq 5.82 * 10^{-5}$ PASS

MSHA (2009): $\boldsymbol{\Psi_{geo} \geq 0.5\ sec^{-1}}$

$\Psi_{geo} = 1.3\ sec^{-1}$

⇨ $1.3 \geq 0.5$ PASS

C) <u>Clogging Criteria</u>: $\boldsymbol{AOS\ (O_{95}) \geq 3 * D_{15}}$

$0.212 \geq 3 * 0.54$,

$0.212 \geq 1.62$ FAIL

3. Blended coal refuse 80/20 mix (Initial GSD)

The following are the parameters of cal refuse and geotextiles required for evaluation of geotextile design.

Table 6.6: Geotextile Filtration Design Parameters

Parameters of Blended Refuse (80/20 mix)		Parameters of Geotextile	
D_{85}	3.5	AOS (mm)	0.212
D_{60}	1.6	k (cm/s)	0.3
D_{50}	1.1	Ψ (s^{-1})	1.5
D_{15}	0.12		
D_{10}	0.045		
C_u	35.56		

a) Retention criteria:

MSHA (2009): $\boldsymbol{AOS\ (O_{95}) \leq\ B * D_{85}}$

Where B= 1, D_{85}= 3.9, AOS= 0.212

⇨ $0.212 \leq 1 * 3.5$

$0.212 \leq 3.5$ PASS

J.P. Giroud (1988): $\boldsymbol{O_{\ 95} <\ \lambda_R\, D_{85}}$

Where λ_R= $18*C_u^{-1.7}$= $18*(35.56)^{-1.7}$= 0.041, D^{85}= $Cu^{0.7}*D^{50}$

⇨ $0.212 < 0.041*13.39$

$0.212 < 0.54$ PASS

b) Permeability (k) and Permittivity (Ψ) criteria:

MSHA (2009): $\boldsymbol{k_{geotextile}\ \geq\ k_{soil}}$

Where $k_{soil} \approx (D_{10})^2$= $(0.045)^2$= $2*10^{-3}$ cm/s

⇨ $0.3 \geq 2*\ 10^{-3}$ PASS

J.P. Giroud (1988): $\boldsymbol{k_{geotextile}\ \geq\ k_{soil}/10}$

Where k_{soil}= 2*10^{-3} cm/s

⇨ 0.30 ≥ 2*10^{-3}/10

0.30 ≥ 2*10^{-4} PASS

MSHA (2009): $\Psi_{geo} \geq 0.5\ sec^{-1}$

Ψ_{geo}= 1.5 sec^{-1}

⇨ 1.5 ≥ 0.5 PASS

C) Clogging Criteria: $AOS\ (O_{95}) \geq\ 3 * D_{15}$

0.212 ≥ 3* 0.12,

0.212 ≥ 0.36 FAIL

4. Blended coal refuse 80/20 mix (Post GSD) for compacted sample (F4)

The following are the parameters of cal refuse and geotextiles required for evaluation of geotextile design.

Table 6.7: Geotextile Filtration Design Parameters

Parameters of Blended Refuse (80/20 mix)		Parameters of Geotextile	
D_{85}	3.5	AOS (mm)	0.212
D_{60}	1.9	k (cm/s)	0.3
D_{50}	1.1	Ψ (s^{-1})	1.5
D_{15}	0.32		
D_{10}	0.23		
C_u	8.26		

a) Retention criteria:

MSHA (2009): $\boldsymbol{AOS\ (O_{95}) \leq B * D_{85}}$

Where B= 1, D_{85}= 3.5, AOS= 0.212

⇨ $0.212 \leq 1 * 3.5$

$0.212 \leq 3.5$ PASS

J.P. Giroud (1988): $\boldsymbol{O_{95} < \lambda_R D_{85}}$

Where $\lambda_R = 18*C_u^{-1.7} = 18*(8.26)^{-1.7} = 0.497$, $D^{85} = Cu^{0.7}*D^{50}$

⇨ $0.212 < 0.497*4.82$

$0.212 < 2.39$ PASS

b) Permeability (k) and Permittivity (Ψ) criteria:

MSHA (2009): $\boldsymbol{k_{geotextile} \geq k_{soil}}$

⇨ PASS

J.P. Giroud (1988): $\boldsymbol{k_{geotextile} \geq k_{soil}/10}$

PASS

MSHA (2009): $\boldsymbol{\Psi_{geo} \geq 0.5\ sec^{-1}}$

Ψ_{geo}= 1.3 sec^{-1}

⇨ 1.3 ≥ 0.5 PASS

C) <u>Clogging Criteria</u>: $\boldsymbol{AOS\ (O_{95}) \geq\ 3 * D_{15}}$

0.212 ≥ 3* 0.32

0.212 ≥ 0.96 FAIL

5. Blended coal refuse 60/40 mix (Initial GSD)

The following are the parameters of cal refuse and geotextiles required for evaluation of geotextile design.

Table 6.8: Geotextile Filtration Design Parameters

Parameters of Blended Refuse (60/40 mix)		Parameters of Geotextile	
D_{85}	2.9	AOS (mm)	0.212
D_{60}	0.9	k (cm/s)	0.3
D_{50}	0.5	Ψ (s^{-1})	1.5
D_{15}	0.086		
D_{10}	0.069		
C_u	13.04		

a) Retention criteria:

MSHA (2009): $$AOS\ (O_{95}) \leq B * D_{85}$$

Where B= 1, D_{85}= 2.9, AOS= 0.212

⇨ $0.212 \leq 1 * 2.9$

$0.212 \leq 2.9$ PASS

J.P. Giroud (1988): $$O_{95} < \lambda_R D_{85}$$

Where $\lambda_R = 18*C_u^{-1.7} = 0.229$, $D^{85} = Cu^{0.7}*D^{50}$

⇨ $0.212 < 0.229*3.017$

$0.212 < 0.69$ PASS

b) Permeability (k) and Permittivity (Ψ) criteria:

MSHA (2009): $$k_{geotextile} \geq k_{soil}$$

Where $k_{soil} \approx (D_{10})^2 = (0.069)^2 = 4.7*10^{-3}$ cm/s

⇨ $0.3 \geq 4.7*10^{-3}$ PASS

J.P. Giroud (1988): $$k_{geotextile} \geq k_{soil}/10$$

Where k_{soil}= 2*10^{-3} cm/s

⇨ $0.30 \geq 4.7*10^{-5}/10$
$0.30 \geq 4.7*10^{-5}$ PASS

MSHA (2009): $\mathbf{\Psi_{geo} \geq 0.5\ sec^{-1}}$

Ψ_{geo}= 1.5 sec^{-1}

⇨ $1.5 \geq 0.5$ PASS

C) <u>Clogging Criteria</u>: $\boldsymbol{AOS\ (O_{95}) \geq\ 3 * D_{15}}$

$0.212 \geq 3 * 0.086$,

$0.212 \geq 0.25$ FAIL

6. Blended coal refuse (Post GSD) for compacted sample (F15A-I)

The following are the parameters of cal refuse and geotextiles required for evaluation of geotextile design.

Table 6.9: Geotextile Filtration Design Parameters

Parameters of Blended Refuse (60/40 mix)		Parameters of Geotextile	
D_{85}	3	AOS (mm)	0.212
D_{60}	1.35	k (cm/s)	0.3
D_{50}	0.88	Ψ (s^{-1})	1.5
D_{15}	0.09		
D_{10}	0.04		
C_u	33.75		

a) Retention criteria:

MSHA (2009): $\boldsymbol{AOS\ (O_{95}) \leq\ B * D_{85}}$

Where B= 1, D_{85}= 3, AOS= 0.212

⇨ 0.212 ≤ 1 * 3

0.212 ≤ 3 PASS

J.P. Giroud (1988): $\boldsymbol{O_{\ 95} <\ \lambda_R\ D_{85}}$

Where λ_R= $18*C_u^{-1.7}$= $18*(33.75)^{-1.7}$= 0.497, D^{85}= $Cu^{0.7}*D^{50}$

⇨ 0.212 < 0.045*10.33

0.212 < 0.46 PASS

b) Permeability (k) and Permittivity (Ψ) criteria:

MSHA (2009): $\boldsymbol{k_{geotextile}\ \geq\ k_{soil}}$

⇨ PASS

J.P. Giroud (1988): $\boldsymbol{k_{geotextile}\ \geq\ k_{soil}/10}$

PASS

MSHA (2009): $\boldsymbol{\Psi_{geo} \geq 0.5\ sec^{-1}}$

Ψ_{geo}= 1.3 sec^{-1}

⇨ $1.3 \geq 0.5$ PASS

C) Clogging Criteria: $\boldsymbol{AOS\ (O_{95}) \geq\ 3 * D_{15}}$

$0.212 \geq 3 * 0.07$

$0.212 \geq 0.21$ PASS

The above analysis shows the geotextile design comparison for the selected samples of coarse coal refuse and blended refuse. The complete analysis of geotextile design comparison of all the coarse coal refuse and blended refuse samples is shown in the following pages:

Overall design comparison for Coal Refuse

The following analysis was based on evaluation of the coal refuse properties including: grain-size distribution, hydraulic conductivity and the geotextile properties. The geotextile filtration analysis was performed mostly using the geotextile NW6 which has an apparent opening size (O_{95}) of 0.212 mm. It was reasoned that the geotextile NW6 has the highest apparent opening size when compared to the other geotextile which would promote clogging.

1. Initial non-compacted CCR Analysis:

Table 6.10: Initial CCR non-compacted samples Filtration Design Analysis

Comparison Criteria for CCR Initial GSD [Non-critical Conditions]						
Sample	**Compaction effort**	**Geotextile**	**Retention Criteria**		**k, Ψ Cirteria**	**Clogging Criteria**
	kJ/m^3 (ft-lb/ft^3)		**MSHA**: $O_{95} \le B*D_{85}$	**J.P.Giroud**: O95 < λ_R*D85	**MSHA:** $k_{geo} \ge k_{soil}$ (cm/s)	**MSHA**: $O_{95} \ge 3*D_{15}$
E7	636.21 (13288)	Geotex 601 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E8	636.21 (13288)	Geotex 401 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E9	636.21 (13288)	Geotex 801 (0.180)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E10	636.21 (13288)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E11	636.21 (13288)	GSE NW 16 (0.150)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E12	203.58 (4252)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E13	203.58 (4252)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E14	203.58 (4252)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E15	67.84 (1417)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E16	67.84 (1417)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E17	67.84 (1417)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E18	135.73(2835)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E19	135.73(2835)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**
E20	135.73(2835)	GSE NW 6 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**

Where, P-passes the test, F-fails the test.

For the initial non-compacted coarse coal refuse, the Retention criteria lead to the following observations:

- The CCR which had No.4 sieve passing requirement, the material passed the retention criteria established by MSHA and J.P.Giroud which specifies the range of $0.212 \leq 6.12$ (MSHA) and $0.212 \leq 4.14$ (J.P.Giroud).

For the initial non-compacted CCR the Permeability/Permittivity criteria (k/Ψ) indicated the following observations:

- The CCR material passing No.4 sieve passed the permittivity criteria specified by MSHA.
- The permeability of the coal refuse was calculated using the formula $k \approx (D_{10})^2$
- For the permeability criterion which is specified by MSHA, the initial CCR just passes the test. For examples, the CCR had k_{soil} of 0.28 compared with k_{geo} of 0.30 with a percentage difference of 6.67%.

For the initial non-compacted CCR the Clogging criteria lead to following observations:

- All of the coarse coal refuse passing the No.4 sieve material failed the clogging criteria required by MSHA.
- For example, the geotextile AOS $0.212 \geq 2.07$ ($3*D_{15}$). The D_{15} criterion is based on the increase in fines tending more towards slurry (FCR) particle grain sizes.

2. <u>CCR Compacted samples Analysis:</u>

Table 6.11: CCR Compacted samples Filtration Design Analysis

Comparison Criteria for CCR Post GSD [Non-critical Condititons]						
Sample	**Compaction effort**	**Geotextile**	**Retention Criteria**		**k, Ψ Cirteria**	**Clogging Criteria**
	kJ/m³ (ft-lb/ft³)		**MSHA**: $O_{95} \leq B*D_{85}$	**J.P.Giroud**: $O95 \leq \lambda_R*D85$	$k_{geo} \geq k_{soil}$ (cm/s)	**MSHA**: $O_{95} \geq 3*D_{15}$
E7	636.21 (13288)	Geotex 601 (0.212)	P (0.212 ≤ 4.29)	P (0.212 < 2.51)	P ($0.30 \geq 5.06*10^{-4}$), (Ψ>0.5)	**F (0.212 ≥ 1.62)**
E8	636.21 (13288)	Geotex 401 (0.212)	*****	*****	*****	*****
E9	636.21 (13288)	Geotex 801 (0.180)	*****	*****	*****	*****
E10	636.21 (13288)	GSE NW 6 (0.212)	*****	*****	*****	*****
E11	636.21 (13288)	GSE NW 16 (0.150)	*****	*****	*****	*****
E12	203.58 (4252)	GSE NW 6 (0.212)	P (0.212 ≤ 4.66)	P (0.212 < 4.80)	P ($0.30 \geq 5.82*10^{-4}$), (Ψ>0.5)	**F (0.212 ≥ 1.62)**
E13	203.58 (4252)	GSE NW 6 (0.212)	P (0.212 ≤ 7.99)	P (0.212 < 5.52)	P ($0.30 \geq 5.82*10^{-4}$), (Ψ>0.5)	**F (0.212 ≥ 1.74)**
E14	203.58 (4252)	GSE NW 6 (0.212)	P (0.212 ≤ 5.56)	P (0.212 < 4.88)	P ($0.30 \geq 5.82*10^{-4}$), (Ψ>0.5)	**F (0.212 ≥ 1.86)**
E15	67.84 (1417)	GSE NW 6 (0.212)	P (0.212 ≤ 4.17)	P (0.212 < 2.42)	P ($0.30 \geq 1.43*10^{-3}$), (Ψ>0.5)	**F (0.212 ≥ 1.38)**
E16	67.84 (1417)	GSE NW 6 (0.212)	P (0.212 ≤ 4.80)	P (0.212 < 4.76)	P ($0.30 \geq 1.43*10^{-3}$), (Ψ>0.5)	**F (0.212 ≥ 1.50)**
E17	67.84 (1417)	GSE NW 6 (0.212)	P (0.212 ≤ 4.26)	P (0.212 < 4.76)	P ($0.30 \geq 1.43*10^{-3}$), (Ψ>0.5)	**F (0.212 ≥ 0.90)**
E18	135.73(2835)	GSE NW 6 (0.212)	P (0.212 ≤ 4.26)	P (0.212 < 3.94)	P ($0.30 \geq 1.05*10^{-3}$), (Ψ>0.5)	**F (0.212 ≥ 1.26)**
E19	135.73(2835)	GSE NW 6 (0.212)	P (0.212 ≤ 5.96)	P (0.212 < 4.28)	P ($0.30 \geq 1.05*10^{-3}$), (Ψ>0.5)	**F (0.212 ≥ 1.41)**
E20	135.73(2835)	GSE NW 6 (0.212)	P (0.212 ≤ 4.62)	P (0.212 < 2.94)	P ($0.30 \geq 1.05*10^{-3}$), (Ψ>0.5)	**F (0.212 ≥ 1.50)**

Where,

P-passes the test,

F-fails the test, and

*****- Did not perform GSD on samples

For the compacted CCR the Retention criteria lead to following observations:

- For the compacted CCR samples at varying compaction energies from 1, 417 ft-lb/ft^3 to 13,288 ft-lb/ft^3, all of the specimens passed both the MSHA and J.P.Giroud Retention criteria.
- For example the MSHA retention criteria was ranging as 0 .212 $\leq$ 4.17mm (low) to 7.99mm (high), and J.P.Giroud retention criteria was ranging as 0.212 $\leq$ 2.42mm (low) to 5.22 mm (high).
- The data of the compacted CCR showed an increase from 6. 12mm (non-compacted sample) to 7.99mm (compacted sample) and decrease from 6.12 to lowest value 4.17mm.
- The percentage change for the low and high values would be 31.8% decrease and 23.4% increase change. This reflects a wide performance range change.

For the compacted CCR the Permeability/Permittivity Criteria lead to the following observations:

- The post grain-size distributions of the compacted CCR samples are shown in figures 6.12 to 6.21. The previous observations of shifting in the graphs have its performance effects realized in the permeability criteria.
- All of the compacted CCR specimens passed the permittivity criteria specified by MSHA.
- All of the compacted CCR specimens (low to high compaction) passed the MSHA permeability criteria effectively. This is due to the increase compaction effort lowers the hydraulic conductivity of samples which makes the permeability criteria to pass easily.
- For example the various compaction energies produce the hydraulic conductivity ranging from $1.43*10^{-3}$ cm/s to $5.82*10^{-4}$ cm/s and these values are lower than k_{geo} (0.30cm/s).

For the compacted CCR the Clogging criteria lead to following observations:

- All of the compacted CCR specimens failed the clogging criteria as per MSHA clogging criteria.
- For the different compaction energies, the criteria ($3*D_{15}$) values varies from a high value 1.86 to a low value of 0.90.
- The percentage change for clogging criteria values for non-compacted and compacted specimens varied from 2.07 to 0.90 with a percentage change of 56.5%. The clogging criteria value was as close as from 2.07 to 1.86 with a percentage change of 10.1%.

3. Initial non-compacted BR (80/20) mix Analysis

The design analysis of BR (80/20) mix non-compacted samples was based on the Table 6.12 which lead to following observations:

Table 6.12: Initial non-compacted BR (80/20 mix) samples Filtration Design Analysis

Comparison Criteria for BR (80/20) Initial GSD [Non-critical Conditions]						
Sample	**Compaction effort**	**Geotextile**	**Retention Criteria**		**k, Ψ Cirteria**	**Clogging Criteria**
	kJ/m^3 (ft-lb/ft^3)		**MSHA**: $O_{95} \leq B*D_{85}$	**J.P.Giroud**: O95 < λ_R*D85	$k_{geo} \geq k_{soil}$ (cm/s)	**MSHA**: $O_{95} \geq 3*D_{15}$
F4	381.73 (7973)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F5	381.73 (7973)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F6	381.73 (7973)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F7	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F8	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F9	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F10	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F11	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**
F12	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**

Where, P-passes the test,

F-fails the test, and

******* - did not perform post GSD on the samples.

.

For the initial blended refuse (80/20) non-compacted samples, evaluation of the Retention criteria leads to the following observations:

- All Blended refuse (80/20 mix) non-compacted samples pass the retention criteria specified by MSHA and J.P.Giroud. The specific range of values for retention criteria being 0.212 ≤ 3.5mm (MSHA) and 0.212 ≤ 0.54mm (J.P.Giroud).
- The BR (80/20 mix) samples have less values of 3.5mm when compared to value of 6.12mm for CCR samples as per MSHA and have 0.54mm when compared to 4.14mm as per J.P.Giroud. so the geotextile may fail retention criteria when they have soil sample with more percentage of fines

For the initial blended refuse (80/20) non-compacted samples, the Permeability/Permittivity criteria lead to following observations:

- All the BR material passed the permittivity criteria specified by MSHA.
- The value of permeability of BR non-compacted sample was $2*10^{-3}$ cm/s, which is less than k_{geo} and passes the permeability criteria. The permeability of the initial CCR was 0.28 cm/sec and the initial BR (80/20 mix) was $2*10^{-3}$ cm/s which tend to indicate that the compaction effort resulting in the crushing of the fines results in a benefit by reducing the D_{15} particle size and enables the permeability criteria to be met.

For the initial blended refuse (80/20) non-compacted samples, the Clogging criteria lead to following observations:

- All Blended refuse non-compacted sample failed the clogging criteria mentioned by MSHA.
- For example, geotextile AOS 0.212 ≥ 0.36mm ($3*D_{15}$). The CCR value being 2.07mm which indicates that for the steady refuse material there were insufficient fine particles to satisfy the clogging criteria.

4. Compacted BR (80/20 mix) Samples Analysis

The design analysis of BR (80/20) mix compacted samples was based on the Table 6.13 which lead to following observations:

Table 6.13: BR (80/20 mix) Compacted samples Filtration Design Analysis

Comparison Criteria for BR (80/20) Post GSD [Non critical Conditions]					
Sample	**Compaction effort**	**Retention Criteria**		**k, Ψ Cirteria**	**Clogging Criteria**
	kJ/m³ (ft-lb/ft³)	**MSHA**: $O_{95} \leq B*D_{85}$	**J.P.Giroud**: $O95 \leq \lambda_R*D85$	$k_{geo} \geq k_{soil}$ (cm/s)	**MSHA**: $O_{95} \geq 3*D_{15}$
F4	381.73 (7973)	P (0.212 ≤ 3.5)	P (0.212 < 2.39)	P	**F (0.212 ≥ 0.96)**
F5	381.73 (7973)	P (0.212 ≤ 3.5)	P (0.212 < 2.63)	P	**F (0.212 ≥ 0.99)**
F6	381.73 (7973)	P (0.212 ≤ 3.5)	P (0.212 < 1.98)	P	**F (0.212 ≥ 0.87)**
F7	127.26 (2658)	*****	*****	*****	*****
F8	127.26 (2658)	*****	*****	*****	*****
F9	127.26 (2658)	*****	*****	*****	*****
F10	127.26 (2658)	*****	*****	*****	*****
F11	127.26 (2658)	*****	*****	*****	*****
F12	127.26 (2658)	*****	*****	*****	*****

Where, P-passes the test,

F-fails the test, and

******* - did not perform post GSD on the samples

The post grain-size distribution of compacted samples of blended refuse (80/20 mix) was performed on three samples only.

For compacted blended refuse samples, the Retention criteria lead to following observations:

- The D_{85} of the compacted samples did not change significantly which lead to the same observations as for non-compacted samples, that the material had a larger coarse fraction.
- The values being 0.212 ≥ 3.5mm as per MSHA and low of 1.98mm to a high of 2.63mm as per J.P.Giroud.

For the compacted blended refuse compacted samples, the Permeability/Permittivity criteria lead to following observations:

- All the blended refuse compacted samples passed both permeability and permittivity criteria.
- The increase in fines percentage of the samples decreases the hydraulic conductivity which rate as a pass.

For the compacted blended refuse samples, the Clogging criteria lead to following observations:

- All the blended refuse (80/20 mix) compacted samples failed the clogging criteria given by MSHA.
- Due to the particle binding and aggregation, the D_{15} value of BR compacted sample came close to the CCR non-compacted sample. The lowest value being 0.87mm and highest value being 0.99mm.
- The clogging criteria values for compacted BR samples increases when compared to non-compacted BR samples because of particle crushing and between the initial and final particle size aggregation of the materials increase.

5. BR (60%CCR, 40% passing No.100 sieve) samples analysis

The design analysis of BR (60/40) mix samples was based on the Table 6.14 which lead to following observations:

Table 6.14: Initial non-compacted BR (60/40 mix) samples Filtration Design Analysis

Comparison Criteria for BR (60/40) Initial GSD [Non-critical Conditions]						
Sample	**Compaction effort**	**Geotextile**	**Retention Criteria**		**k, Ψ Cirteria**	**Clogging Criteria**
			MSHA:	**J.P.Giroud**:		**MSHA**:
	kJ/m³ (ft-lb/ft³)		$O_{95} \leq B*D_{85}$	$O95 < \lambda_R*D85$	$k_{geo} \geq k_{soil}$ (cm/s)	$O_{95} \geq 3*D_{15}$
F15	381.73 (7973)	Gse NW 6 (0.212)	P (0.212 ≤ 2.9)	P (0.212 ≤ 0.69)	P (0.30 ≥ 4.7*10⁻³)	F (0.212 ≥ 0. 25)

Where, P-passes the test, F-fails the test, and ******* - did not perform post GSD on the samples.

For the initial blended refuse (60/40 mix) samples, the Retention criteria lead to following observations:

- All Blended refuse (60/40 mix) non-compacted samples pass the retention criteria specified by MSHA and J.P.Giroud. The specific range of values for retention criteria being 0.212 ≤ 2.9mm (MSHA) and 0.212 ≤ 0.69mm (J.P.Giroud).
- The retention criteria values of 60/40 mix being less then compared to the 80/20 mix and CCR material. This indicates an increase of fines may cause failure of the retention criteria of the geotextiles.
- For example, the value for 60/40 mix is 2.9mm, for 80/20 mix is 3.5mm and for CCR is 6.12mm as per MSHA. According to J.P.Giroud, the value for 60/40 mix is 0.69mm whereas for 80/20 mix is 0.54mm and for CCR is 4.14mm. J.P.Giroud criteria was based on C_u values.

For the BR (60/40 mix) non-compacted samples, the Permeability/Permittivity criteria lead to following observations:

- For all 60/40 mix BR non-compacted samples permeability and permittivity criteria passed.
- The fines percentage makes the permeability value of 60/40 mix decrease when compared to 80/20 mix and CCR samples which make the samples easily pass the test.

For the BR (60/40 mix) non-compacted samples, the Clogging criteria lead to following observations:

- All the BR (60/40 mix) non-compacted samples failed the clogging criteria as mentioned by MSHA.
- The clogging criteria value for BR 60/40 mix non-compacted samples is 0.25. While for BR 80/20 mix samples being 0.36 and for CCR being 2.07.

6. Acid Samples Analysis

The design analysis of Acid Permeant samples was based on the Table 6.15 which lead to following observations:

Table 6.15: Design Criteria Comparison of all Acid Permeant samples

Acid Permeant Samples [Non-Critical Conditions]											
Comparison Criteria Initial GSD							Comparison Criteria Post GSD				
Sample	Compaction effort	Geotextile	Retention Criteria		k, Ψ Cirteria	Clogging Criteria	Retention Criteria		k, Ψ Cirteria	Clogging Criteria
	kJ/m^3 (ft-lb/ft^3)		MSHA: $O_{95} \le B^*D_{85}$	J.P.Giroud: $O95 < \lambda_R^*D85$	$k_{geo} \ge k_{soil}$ (cm/s)	MSHA: $O_{95} \ge 3^*D_{15}$	MSHA: $O_{95} \le B^*D_{85}$	J.P.Giroud: $O95 \le \lambda_R^*D85$	$k_{geo} \ge k_{soil}$ (cm/s)	MSHA: $O_{95} \ge 3^*D_{15}$
E15A (CCR)	67.84 (1417)	Geotex 601 (0.212)	P (0.212 ≤ 6.12)	P (0.212 < 4.14)	P (0.30 ≥ 0.28), (Ψ>0.5)	**F (0.212 ≥ 2.07)**	P (0.212 ≤ 5.25)	P (0.212 < 7.089)	P	F (0.212 ≥ 1.95)
F11A (BR-80/20)	127.26 (2658)	GSE NW 6 (0.212)	P (0.212 ≤ 3.5)	P (0.212 < 0.54)	P (0.30 ≥ 2*10^{-3}), (Ψ>0.5)	**F (0.212 ≥ 0.36)**	P (0.212 ≤ 3.5)	P (0.212 < 2.09)	P	F (0.212 ≥ 0.84)
F15A-I (BR-60/40)	381.73 (7973)	Gse NW 6 (0.212)	P (0.212 ≤ 2.9)	P (0.212 ≤ 0.69)	P (0.30 ≥ 4.7*10^{-3})	F (0.212 ≥ 0. 25)	P (0.212 ≤ 0.9)	P (0.212 ≤ 0.65)	P	P (0.212 ≥ 0. 21)
F15A-II (BR-60/40)	381.73 (7973)	Gse NW 6 (0.212)	P (0.212 ≤ 2.9)	P (0.212 ≤ 0.69)	P (0.30 ≥ 4.7*10^{-3})	F (0.212 ≥ 0. 25)	P (0.212 ≤ 0.95)	P (0.212 ≤ 0.46)	P	F (0.212 ≥ 0. 25)
F15A-III (BR-60/40)	381.73 (7973)	Gse NW 6 (0.212)	P (0.212 ≤ 2.9)	P (0.212 ≤ 0.69)	P (0.30 ≥ 4.7*10^{-3})	F (0.212 ≥ 0. 25)	P	P	P	F (0.212 ≥ 0. 42)

CCR

For the compacted coarse coal refuse sample tested with the Acid permeant, the Retention criteria lead to following observations:

- Passes the retention criteria as per MSHA and J.P.Giroud.
- The Acid permeant sample retention criteria value is 5.25 whereas the water permeant sample retention criterion is 4.17. This is due to the change in the D_{85} value of the sample and is a result of the particle aggregate flocculation.

For the Compacted coarse coal refuse sample the permeability/Permittivity criteria lead to following observations:

- Passes both permeability and permittivity criteria as per MSHA and J.P.Giroud.

For the Compacted Coarse coal refuse sample that tested with Acid permeant, Clogging criteria lead to following observations:

- Clogging criteria fails for the acid permeant sample.
- Even with the Acid permeant and at different compaction energy condition the clogging criteria fails for the CCR as per design.

BR (80/20 mix)

For the Compacted blended refuse sample that tested with the Acid permeant, the Retention criteria lead to following observations:

- Passes the retention criteria as per MSHA and J.P.Giroud.
- The Acid permeant sample retention criteria value is 3.5 as per MSHA and 2.09 as per J.P.Giroud.

For the Compacted blended refuse sample the permeability/Permittivity criteria lead to following observations:

- Passes both permeability and permittivity criteria as per MSHA and J.P.Giroud.

For the Compacted blended refuse sample that tested with Acid permeant, Clogging criteria lead to following observations:

- Clogging criteria fails for the acid permeant sample.
- Even with the Acid permeant and at different compaction energy condition the clogging criteria fails for the BR (80/20 mix) samples as per design.

<u>BR (60/40 mix)-I</u>

For the Compacted blended refuse sample that tested with the Acid permeant, the Retention criteria lead to following observations:

- Passes the retention criteria as per MSHA and J.P.Giroud.
- The Acid permeant sample retention criteria value is 2.7 as per MSHA and 0.65 as per J.P.Giroud.

For the Compacted blended refuse sample the permeability/Permittivity criteria lead to following observations:

- Passes both permeability and permittivity criteria as per MSHA and J.P.Giroud.

For the Compacted blended refuse sample that tested with Acid permeant, Clogging criteria lead to following observations:

- Clogging criteria passes for the acid permeant sample.

6.1.10. Chemistry Data Results

Analysis of the graphs shown from Figure 6.31to Figure 6.36 leads to several observations:

1. An unknown problem arose with the level 9 samples. These were extracted at a different time using a slightly different procedure as part of the method development and the results do not appear to follow the trends seen. Although this could be genuine, there are several reasons to doubt this; all samples extracted at the same time and with the same methods did follow the trend. Therefore, results for this level were not considered in delineation of apparent trends.
2. Elements intrinsic to the coal refuse and found at lower concentrations showed relatively stable quantitative values across all of the excavated levels indicating minimal mobility under these experimental conditions
3. Intrinsic elements found at higher concentrations did show evidence of mobility, with relative concentration peaks seen around Levels 7 and 8. This corresponds to a depth in the cell of approximate 7-8 cm or about 75% of the way down.
4. It is reasonable to hypothesize that these trends correlate to solubility of the mineral forms of these metals under the treatment conditions used rather than being an artifact of the analytical procedure.
5. The added metal molybdenum showed maximum concentrations in the upper portion of the cell, indicating less mobility than the other added metals.
6. With the exception of Mo, the added metals, like the intrinsic metals, appeared to reach a maximum concentration in the lower portions of the cell. The behavior of added nickel and iron mimicked the pattern see in the intrinsic metals.
7. The added tungsten and chromium showed more distinctive concentration peaks in the lower region of the cell
8. It is reasonable to hypothesize that the mobility of the metals in the cell depends on the size of the metal beads added, their relative density, and intrinsic solubility in the water used to treat the cells.
9. The use of metal beads appears to have excellent potential as a particulate tracking method that could be applied to evaluation of clogging of geotextile fabrics.
10. Of the metal beads added, the tungsten (W), molybdenum (Mo), and chromium (Cr) showed the most promise based on where the concentrations were maximized.

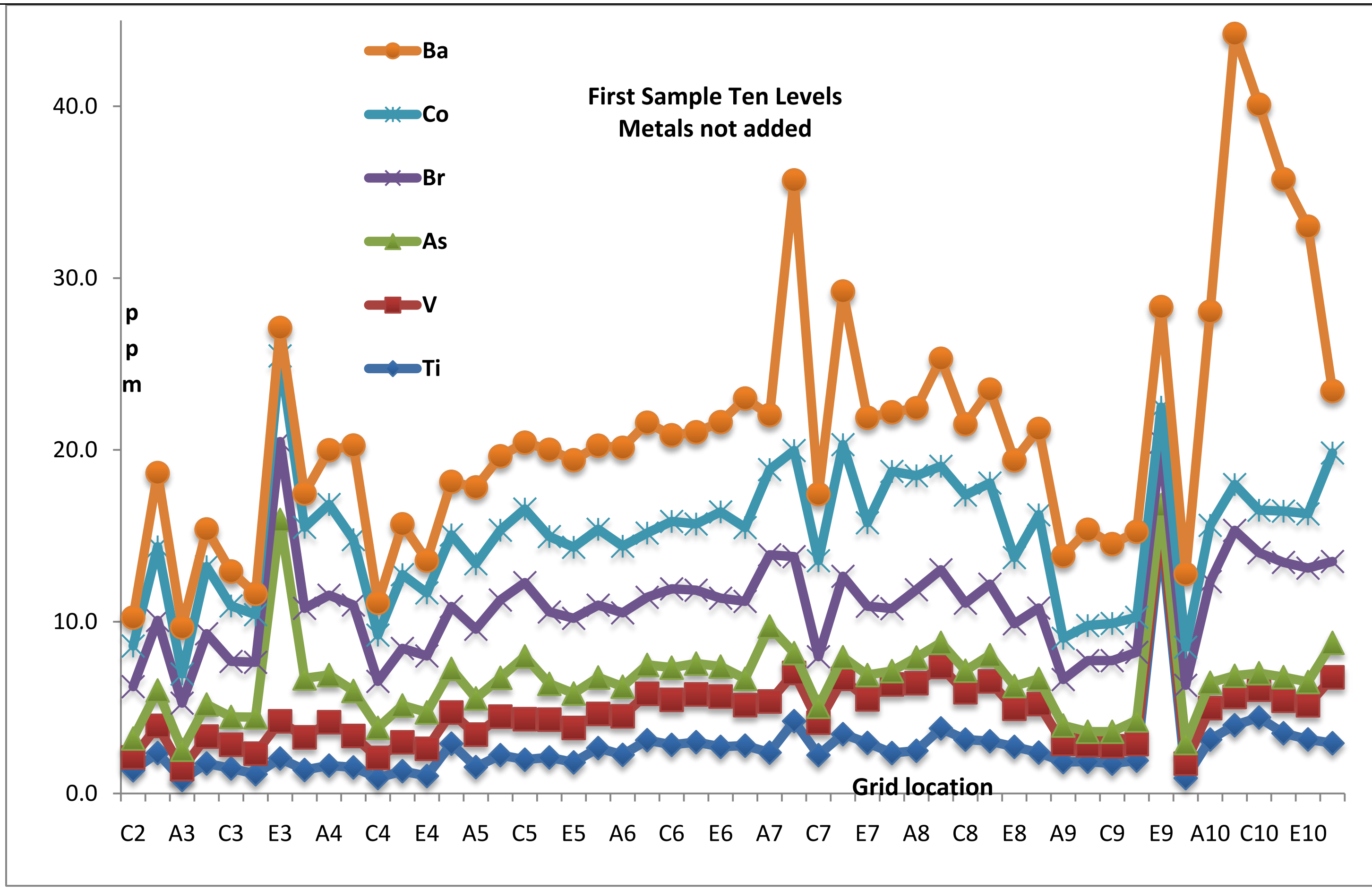


Figure 6.31: Concentration (lower) of elements in coal refuse without metals

Metals that were not constituents of the beads, lower concentration range

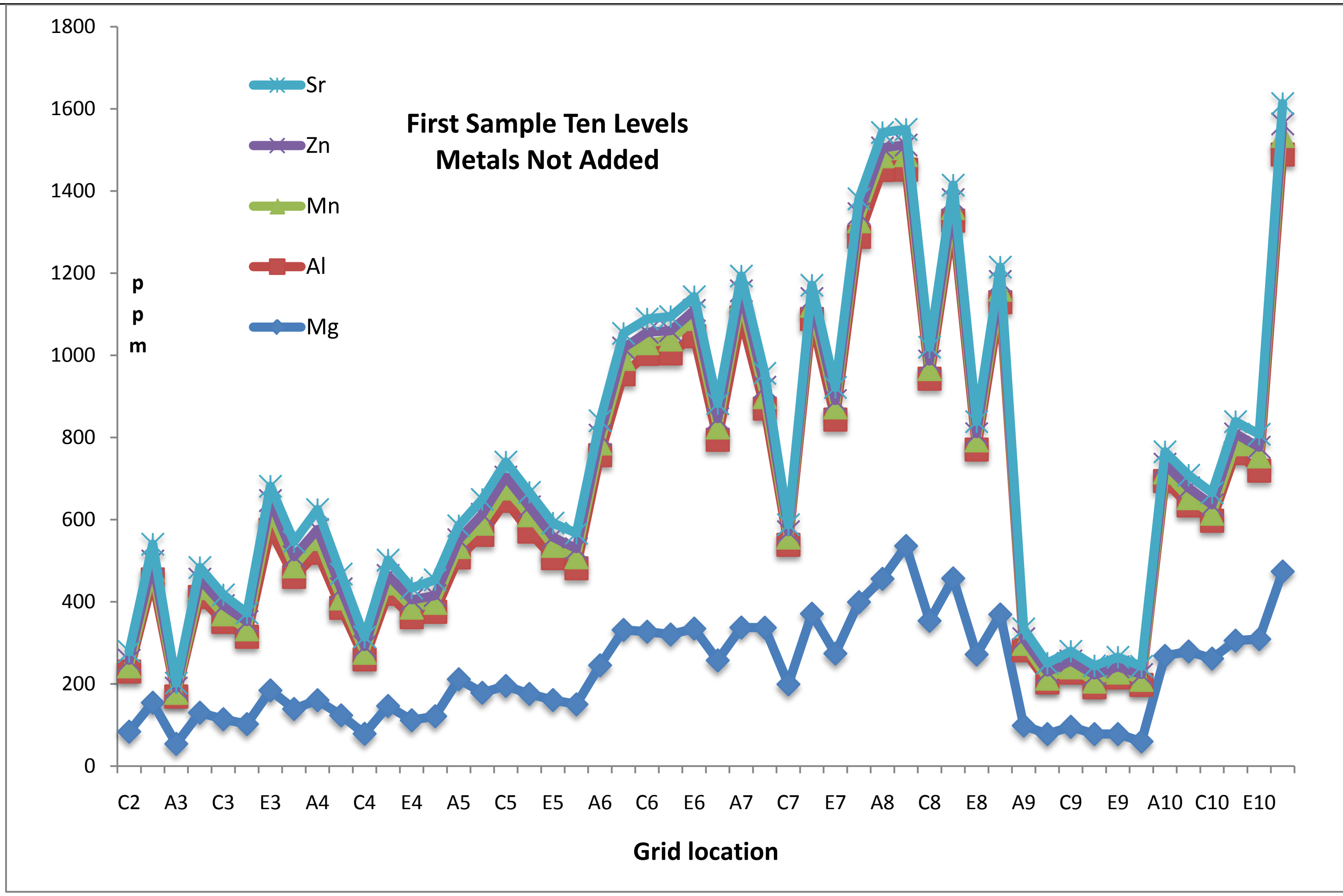


Figure 6.32: Concentration (higher) of elements in coal refuse without metals

Metals that were not constituents of the beads, higher concentration range

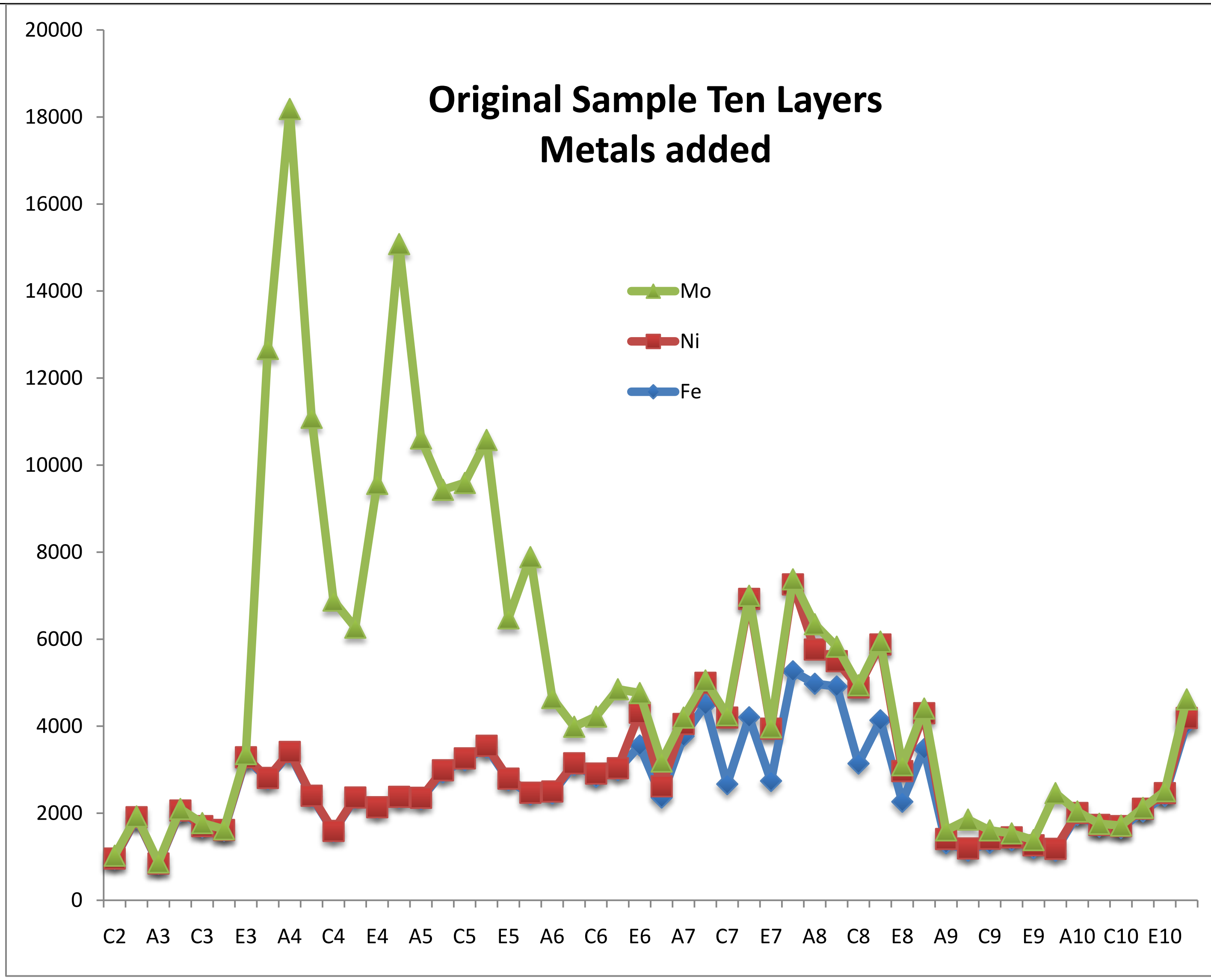


Figure 6.33: Concentration (higher) of elements in coal refuse with addition of metal beads

Added metals, higher concentration range

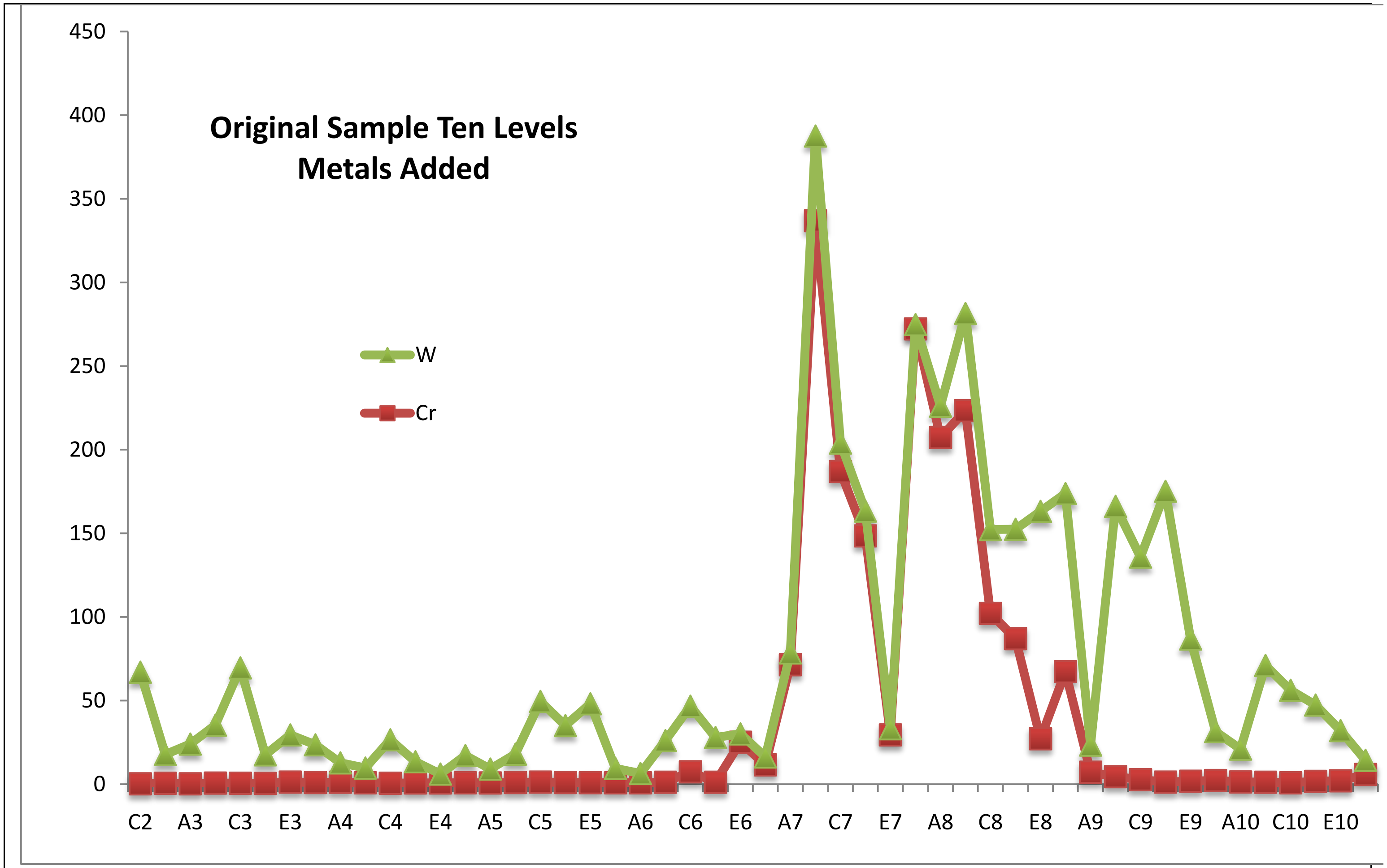


Figure 6.34: Concentration (higher) of elements in coal refuse with metal beads

Added metals, lower concentration range

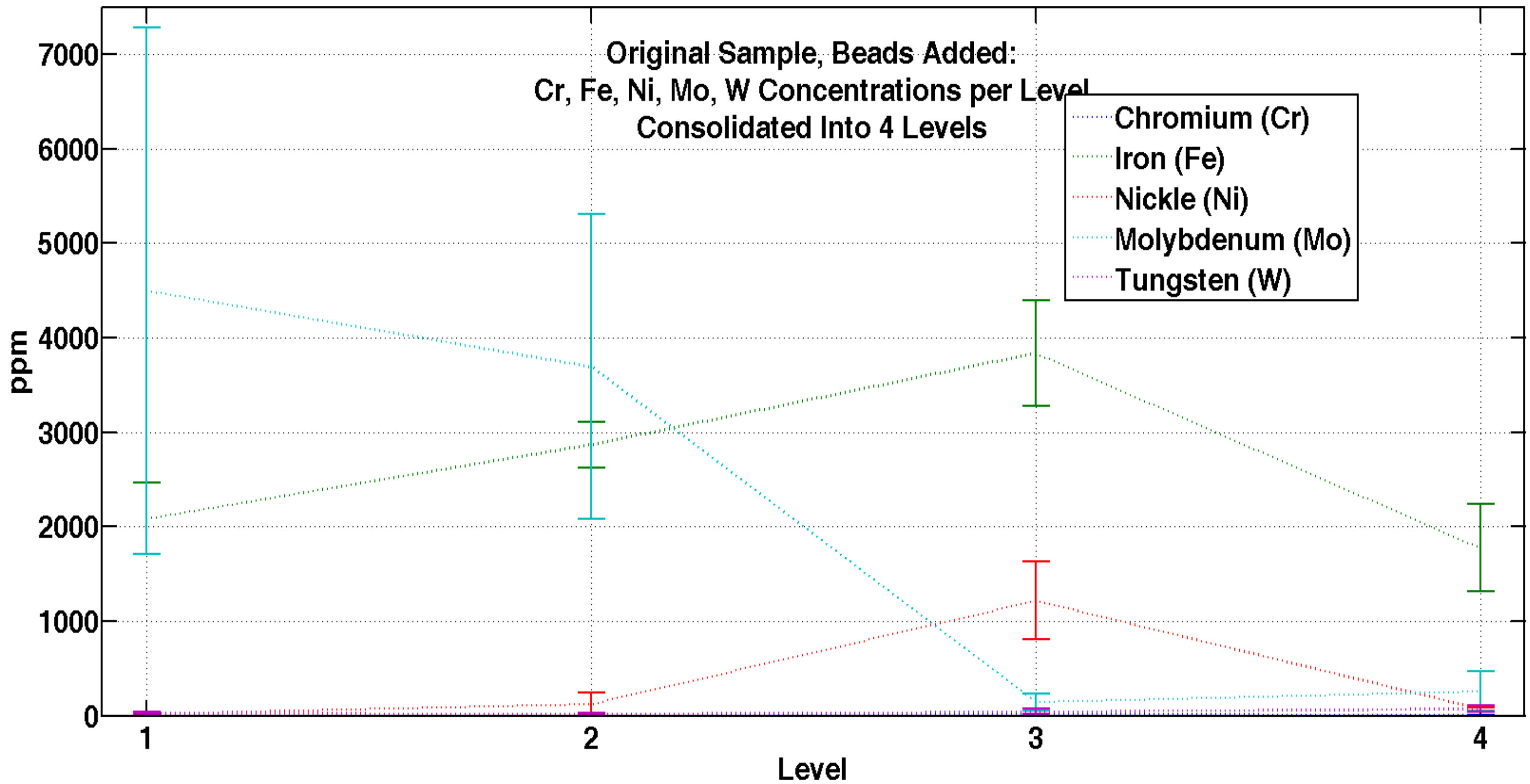


Figure 6.35: Concentration of Cr, Fe, Ni, Mo, W per level

Original sample, all added metals with associated range based on 95% confidence interval

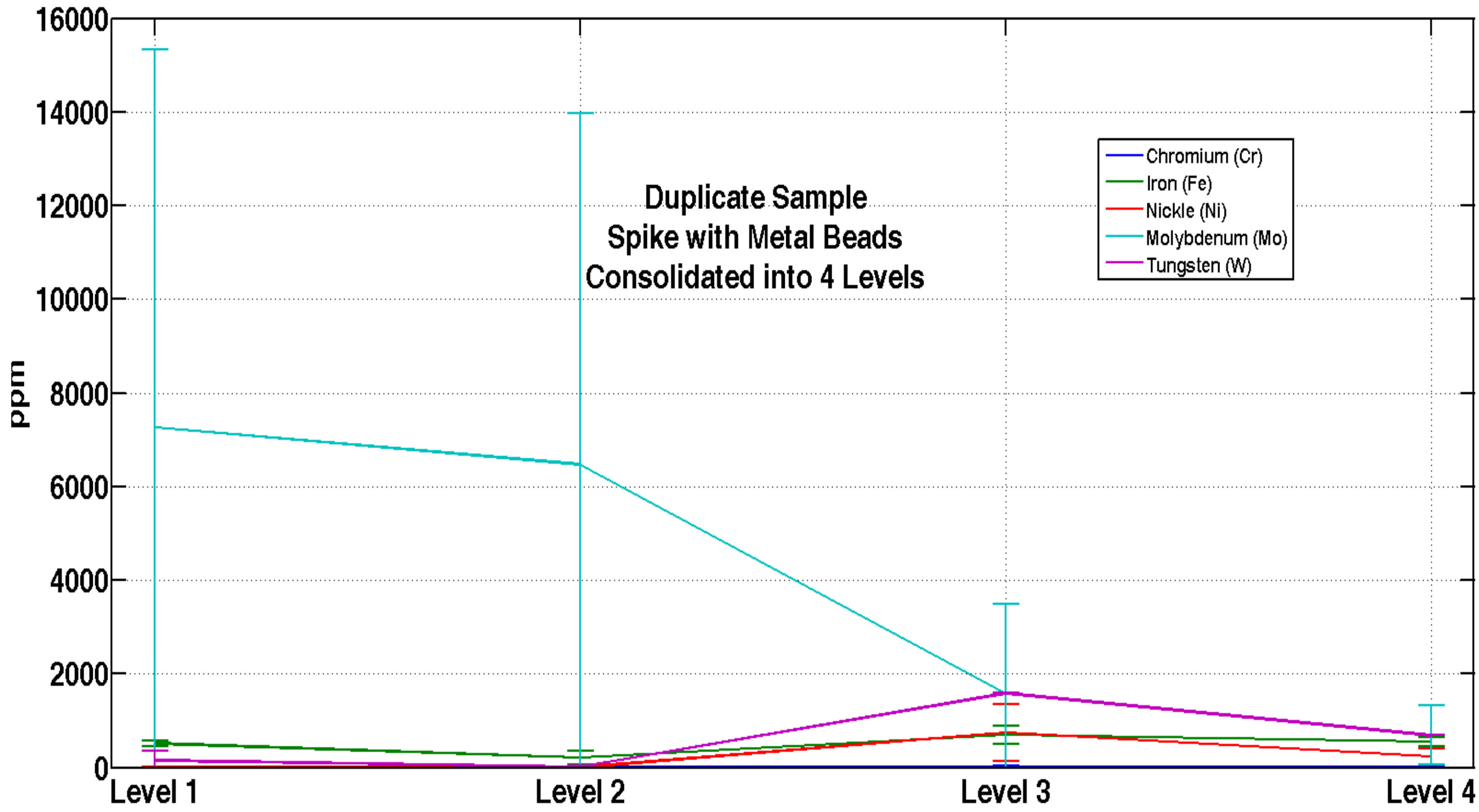


Figure 6.36: Concentration of Cr, Fe, Ni, Mo, W per level in Duplicate sample

Duplicate sample, all added metals with associated range based on 95% confidence interval

pH and Specific Conductance Results

pH and Specific Conductance tests were conducted on the acid permeants prior to the start of the test and after the test for sample E15A and F11A.

The Initial pH and Specific Conductance of Acid permeant used for test are 2.0 and 3.38 respectively. The results are shown below:

Table 6.16: pH and Specific Conductance of permeants for test E15A, F11A, and F11A-II

	Batch F-F11A	Batch F11A-II	Batch E15A	Batch F-F11A	Batch F11A-II	Batch E15A
Sample	**pH**			**Specific conductivity mS/cm**		
Raw	1.67	1.83	***NA***	6.39	6.00	***NA***
1	1.82	2.00	1.94	4.48	6.18	4.46
2	1.94	2.20	1.83	4.76	3.36	4.76
3	1.87	2.17	1.86	4.88	2.59	4.85
4	1.94	1.80	1.86	5.36	4.79	4.65
5	1.85	1.81	1.88	5.60	5.13	4.83
6	1.82	1.88	1.87	5.49	5.18	4.89
7	1.91	1.75	1.91	5.19	5.64	4.78
8	1.95	1.83	1.98	4.82	5.13	4.88
9	1.95	1.76	1.93	5.17	4.92	4.69
10	1.91	1.71	1.84	5.22	5.25	5.02
11	1.90	1.80	1.92	5.20	5.40	5.02
12	1.85	***NA***	***NA***	5.24	***NA***	***NA***

The statistical Analysis for the above tests is performed and the results are shown below:

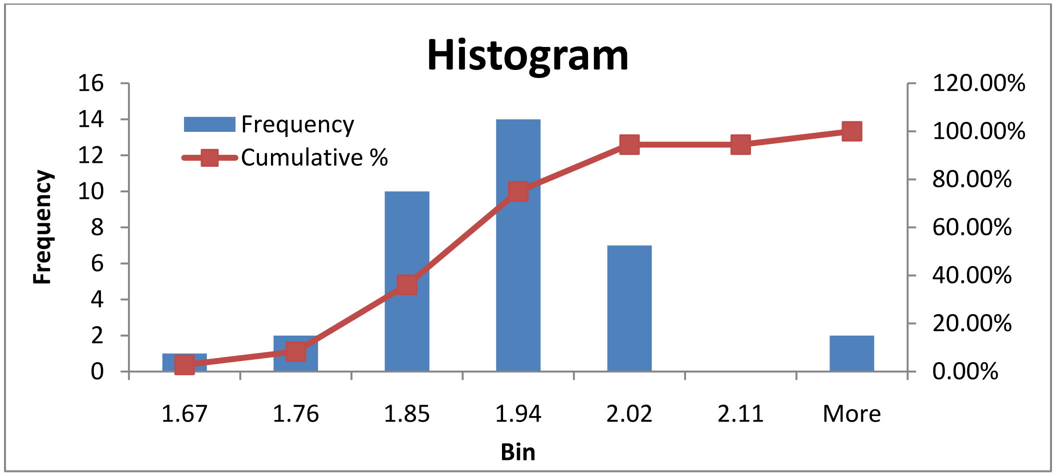


Figure 6.37: Statistical test results for pH of Acid Permeants

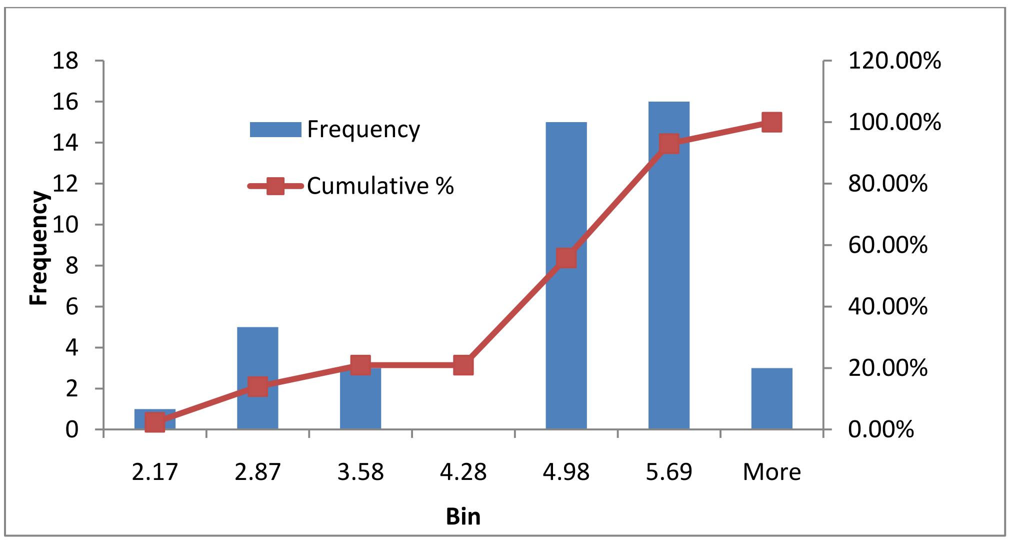


Figure 6.38: Statistical test results for Specific Conductance of Acid Permeants

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The main objectives of this research involved investigating the effects of coarse and fine coal refuse blends as they impact the field application of nonwoven geotextiles used in non-critical applications at coal waste impoundments under standard and reduced compaction energies. The significant conclusions of this research are as follows:

7.1.1. Coarse Coal Refuse

Grain Size Distribution Changes

1. During the compaction of the rigid wall permeameter samples the refuse experiences crushing and slaking effects which for a coarse grained refuse will produce an increase in the percentage of fines. This effect occurs at compaction energies ranging from optimum to reduced (13,288 to 1,417 ft-lb/ft^3). The percentage of fines produced appeared to be a consistent percentage increase of approximately 32%.
2. The post grain size distribution curves for the coarse coal refuse samples identified this trend as does MSHA (MSHA, 2009). The characteristics of the grain size shift can result in filtration concerns when evaluating the D_{15} criteria used in the clogging evaluations.

Hydraulic Conductivity

3. Graphs of the hydraulic conductivity versus time indicated that there was no stable filter developed within the coarse coal refuse specimens. The absence of this filter development may be due to the following reasons: i) limited percentage of fine particles occurring within the testing material, ii) low hydraulic gradients (5 to 7), iii) limited test durations and pore volumes of fluid, and iv) the use of the rigid wall permeameters may have permitted side wall leakage.

Geotextile Filtration Design Criteria

4. The GSE Lining Corporation's NW 6 nonwoven geotextile was selected as the "worst case" filter for comparison of the soil-geotextile system because it has the largest Apparent Opening Size (AOS) of 0.212 mm.
5. Results indicated that for both the initial (non-compacted) and the compacted refuse at all compaction density ranges that the Retention and Permeability Criteria were met (passed) both the MSHA and Giroud design criteria.

6. The corresponding results of the Clogging criteria indicated that the refuse failed under non-critical conditions. Evaluation of the refuse particle sizes and the MSHA and Giroud clogging criteria indicate that the refuse gradation passing the D_{15} size is insufficient to establish a stable filter.

7.1.2. Fine Coal Refuse (Blended Refuse)

Grain Size Distribution Changes (80/20)

7. Blends of fine and coarse coal refuse were developed in the laboratory which provided for a uniformly graded grain size distribution. This distribution was at 80% coarse to 20% fines (80/20) and at 60% coarse to 40% fines (60/40) which passed the No. 100 sieve. These mix proportions were selected as it would provide the most adverse grain size to evaluate potential refuse hydraulic conductivity reductions alone or reductions due to fine particles clogging the geotextile.
8. Results of the post compaction grain size distributions identified that the crushed particles formed aggregates and produced a shift in the shape of the curve which resembled more of a coarse refuse material.
9. The aggregation of the fine particles was consistent across all tested samples and exhibited similar ranges of increases to the D_{85}, D_{60}, D_{15} and D_{10} particle sizes.

Hydraulic Conductivity (80/20)

10. Considering the FCR 80/20 mix, no apparent reduction in the hydraulic conductivity or development of a stable filter media was observed under the ranges of the test parameters. The reasons for this effect may be similar to the coarse coal refuse test results.
11. The FCR 80/20 mix evaluation of the refuse particle sizes and the MSHA and Giroud clogging criteria indicate that the refuse gradation passing the D_{15} size, while it increased in particle diameter due to aggregating, showed insufficient capability to establish a stable filter.

Hydraulic Conductivity (60/40)

12. For 60/40 FCR material passing No.100 sieve, a stable filter was formed after 75 hours of testing and the stable filter was continued throughout the end of the test.

Geotextile Filtration Design Criteria (80/20)

13. Results indicated that for both the initial (non-compacted) and the compacted 80/20 refuse blend at all compaction density ranges that the Retention and Permeability Criteria were met (passed) both the MSHA and Giroud design criteria. For the compacted 80/20 refuse blend the formation of the aggregated particles changes the D_{85} particle diameter to a coarser particle size whereby minimizing the retention criteria range for acceptance.
14. The corresponding results of the Clogging criteria indicated that the 80/20 refuse failed under non-critical conditions.

Geotextile Filtration Design Criteria (60/40)

15. The 60/40 FCR material passing No.100 sieve passes the retention criteria, permeability criteria, however it fails the clogging criteria as per the MSHA design under non-critical conditions. The samples show a reduction in the hydraulic conductivity along with the formation of a stable filter. This indicates that clogging potential is more influenced by the increase in fines percentage.
16. The Retention Criteria value for the 60/40 blended mix showed that decreases in the particle diameters narrow the difference between the passage or failure of this criteria.

7.1.3. Acid Permeability

17. For the Coarse Coal Refuse the acid permeant resulted in the geotextile passing the retention and permeability criteria and failing the clogging criteria. This was the same effect as the water permeability tests on the CCR.
18. The post GSD of Acid samples indicates that low pH H_2SO_4 acid resulted in flocculating the fine grained particles contributing to increasing the voids which increased the permeability rates by one order of magnitude overall. The flocculation was apparent for both CCR and BR samples.
19. For the 80/20 Blended Refuse mix the acid permeant resulted in the geotextile passing the retention and permeability criteria and failing the clogging criteria. This was the same effect as the water permeability tests.
20. For the 60/40 Blended Refuse, the acid permeant resulted in the geotextile passing all criteria: retention, permeability, and clogging.

7.1.4. Chemical Analysis and Particle Tracking

The objectives of this research were to investigate the chemical composition of the coal refuse and to attempt to track the fine particle movements of refuse amended with fine particle metal beads. This research attempted to develop a particle tracking method for coal refuse and determine geosynthetic filter clogging characteristics. Photo microscopy was used to obtain visual images of sample nonwoven geotextile filters impacted with coal refuse material.

The conclusions of this research are as follows.

21. Based on the use of ICPMS analysis, elements intrinsic to the coal refuse and found at lower concentrations showed relatively stable quantitative values across all of the excavated levels indicating minimal mobility under these experimental conditions
22. Results of the particle tracking identified that the added metal molybdenum showed maximum concentrations in the upper portion of the cell, indicating less mobility than the other added metals. With the exception of Mo, the added metals, like the intrinsic metals, appeared to reach a maximum concentration in the lower portions of the cell. The behavior of added nickel and iron mimicked the pattern see in the intrinsic metals.
23. The results further indicate that the mobility of the metals in the cell depends on the size of the metal beads added, their relative density, and intrinsic solubility in the water used to treat the cells.
24. The use of metal beads appears to have excellent potential as a particulate tracking method that could be applied to evaluation of clogging of geotextile fabrics.
25. Of the metal beads added, the tungsten (W), molybdenum (Mo), and chromium (Cr) showed the most promise based on where the concentrations were maximized.

7.2. Recommendations & Comments

Based on the evaluation of the research presented here, the following recommendations are presented to support the use of non-woven geotextile application in the field.

Recommendation #1: Retention Criteria

i. Post grain size distribution tests should be performed on specimens at the optimum compaction level to observe changes in D_{85} for meeting the Retention Criteria requirements. This will take the particle crushing and slaking effects into consideration. It should be noted that the continued or repetitive compaction of the CCR material may reduce the particle diameter to less than the geotextile's Apparent Opening Size (AOS) which then renders potential failure in achieving the Retention Criteria.

ii. Review of the fine particle percentages should be performed to identify potential changes in the retention criteria because the values may decrease in D_{85} which affects the retention criteria.

Recommendation #2: Permeability Criteria

i. Installation of the geotextile in a field application having only Coarse Coal Refuse should be performed at the optimum compaction (energy value 13,288 ft-lb/ft^3) level. This is preferred over a reduced compaction (end dump) condition in order to increase the potential to satisfy the permeability criteria due to the increase in fines.

ii. If the permeability criteria is a critical parameter for the geotextile installation then percentage of fines may be increased in order to decrease the refuse hydraulic conductivity to pass the permeability criteria ($k_{geotextile} \geq k_{soil}$).

iii. It is suggested to use a geotextile having a permittivity value greater than 0.5 s^{-1} in order to pass the Permittivity Criteria.

Recommendation #3: Clogging Criteria

i. Post grain size distribution tests should be performed on specimens at the optimum compaction level to observe changes in D_{15} for meeting the Clogging Criteria requirements. This will take the soil particle size into consideration when comparing to the fabric AOS, (AOS $\geq$ 3*D_{15}) (Non-critical Conditions). The increase in refuse fines percentage tends to develop a stable internal filter thereby tending to reduce potential geotextile clogging.

Comment #1: Acidic Groundwater Conditions

i. If an acidic groundwater condition exists within a coarse coal refuse site, such as an acid mine drainage environment, the geotextile could be expected to pass the retention and permeability criteria; and fail the clogging criteria.
ii. The combination of an acidic groundwater and a high fine particle refuse grain size distribution placed at optimum compaction increases the likely hood of passing the clogging criteria. This can result in Retention Criteria failure due to the increase in fines at the D_{85} particle size (Non-Critical Condition).

Comment #2: Particle Tracking

i. The results indicate that the mobility of the metals in the cell depends on the size of the metal beads added, their relative density, and intrinsic solubility in the water used to treat the cells.
ii. The use of metal beads appears to have excellent potential as a particulate tracking method that could be applied to evaluation of clogging of geotextile fabrics. Of the metal beads added, the tungsten (W), molybdenum (Mo), and chromium (Cr) showed the most promise based on where the concentrations were maximized.

8. REFERENCES

Ahmet, H. A., Seyfullah, H. O., and Tuncer, B. E. (2005). "Constriction Size of Geotextile Filters." *Journal of Geotechnical and Geoenvironmental Engineering*.

Ahmet, H. A., Seyfullah, H. O., and Tuncer, B. E. (2002). "Digital Image Analysis to Determine Pore opening Size Distribution of Nonwoven Geotextiles." *Journal of Computing in Civil Engineering*.

ASTM Designation D-5101. (1999). "Standard Test Method for Measurement of Soil-Geotextile System Clogging Potential by the Gradient Ratio." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D-422. (2007). "Standard Test Method for Particle-Size Analysis of Soils." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D-698. (2007). "Standard Test Method for laboratory Compaction Characteristics of Soils Using Standard Effort (12400 ft-lbf/ft^3 (600 KN-m/m^3))." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D-2216. (2007). "Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D-854. (2007). "Standard Test Method for Specific Gravity of Soil Solids by Water Pycnometer." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D-4318. (2007). "Standard Test Method for Liquid Limit, Plastic Limit and Plasticity Index of Soils." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D-5856. (2005). "Standard test Method for Measurement of Hydraulic Conductivity of Porous Material using a Rigid-Wall, Compaction-Mold Permeameter." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

ASTM Designation D 2487. (2010). "Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)." *Annual Book of ASTM Standards, American Society of Testing Materials*, Easton, MD.

Bowders, J., and Daniel, D. (1987). "Hydraulic Conductivity of Compacted Clay to Dilute Organic Chemicals." *Journal of Geotechnical and Geoenvironmental Engineering.*, 113(12). 1432-1448.

Busch, R.A., R.R. Backer and L.A. Atkins, (1974), "Physical Property Data on Coal Waste Embankment Materials," Report of Investigations 7964, U.S. Department of the Interior, Bureau of Mines, Pittsburgh, PA.

Busch, R.A., R.R. Backer and L.A. Atkins, (1975), "Physical Property Data on Fine Coal Refuse," Report of Investigations 8062, U.S. Department of the Interior, Bureau of Mines, Pittsburgh, PA.

Backer, R.R., R.A. Busch and L.A. Atkins, (1977), *Physical Properties of Western Coal Waste Materials*, Report of Investigations 8216, U.S. Department of the Interior, Bureau of Mines, Spokane, WA.

Chapuis, R. P. (2001). "Permeability Tests in Rigid-Wall Permeameters: Determining the Degree of Saturation, its Evolution, and its Influence on Test Results." *Geotechnical Testing Journal, GTJ10905*, Vol. 27, No. 3, 227-231.

Cheng, S. C., and Usmen. (1987). "Variability of Coal Refuse and its Significance in Geotechnical Engineering Design." *Reclamation, treatment and Utilization of Coal Mining Wastes, edited by A.K.M. Rainbow Elsevier Science publishers B.V.,* Amsterdam, Netherlands.

D'Appolonia Consulting Engineers Inc., "Environmental Effects of Slaking of Surface Mine Spoils Eastern & Central United States," *US Department of the Interior Bureau of Mines*, Final Report Contract No. J0285024, September 1980.

Federal Highway Administration National Highway institute (FHWA). "Filter Experiments and Design Criteria." *Geotextile Engineering Manual*, Washington, D.C.

Fell, R., and Foster, M. (2000). "Seepage through Dams and their Foundations." *ASDSO - FEMA Workshop*.

Fisher, G. R., Holtz, R. D., and Christopher, B. R. (1990). "Filter Criteria based on Pore Opening Size Distribution." *Proc., 4th Int. Conf. on geotextiles*, Vol. 1, the Hague, the Netherlands, 289-294.

Gabler, R. C. (1984). "Properties of Filter Cloths for Seepage Control in Coal Mine Waste Embankments." *Bureau of Mines Report of Investigations*.

Giroud, J. P. (1988). "Review of Geotextile Filter Criteria." *First Indian Geotextiles conference on Reinforced Soil and Geotextiles*, Florida.

Gonzalez Canibano, J., Fernandez Valcarce, J. A., Falcon, A., Ibarzabel, J. L., Rodriguez Ortiz, J. M., and Hinojosa, J. A. (1990). "Static leaching of coal mining wastes." *In: Reclamation, Treatment and Utilization of Coal Mining Wastes, A.K.M. Rainbow (ed.),* Balkema, Rotterdam, 165–175.

Gonzalez Canibano, J., Leininger, D., Direccion (1987). "The Characteristics and use of coal wastes." *In: Reclamation, Treatment and Utilization of Coal Mining Wastes, A.K.M. Rainbow Elsevier Science publishers* B.V., Amsterdam, Netherlands.

Hegazy, Y. A., Cushing, A. G., and Lewis, C. J (2004). "Physical, mechanical and hydraulic properties of coal refuse for slurry impoundment design." *D'Appolonia Engineering*, Monroeville, PA.

Holtz, R. D., Christopher, B. R., and Berg, R. R. (1997). Geosynthetic Engineering, 1st Edition, Richmond, British Columbia, Canada.

Jacek, L., Stephen, R. W., and Ronald, D. H. (1983). "Impact of Coal Refuse Disposal on Groundwater." *United States Environmental Protection Agency (EPA).*

Kutay, M. E., and Ahmet, H. A. (2005). "Filtration Performance of Two-Layer Geotextile Systems." *ASTM International*, West Conshohocken, PA.

Lawson, C. R. (1982). "Filter Criteria for Geotextiles: Relevance and Use." *Journal of Geotechnical Engineering, ASCE*, Vol. 108, No. GT 10, 1300-1317.

Maheshwari, B. K., and Gunjagi, D. A. (2008). "Filtration and Clogging Behavior of Geotextiles with Roorkee Soils." *Geotech GeolEng*.

MSHA. (2009). Engineering and Design Manual: Coal Refuse Disposal Facilities, Second Edition. U.S. Department of Labor, 937p.

NRC (National Research Council). (2002). "Coal Waste Impoundments: Risks, Responses, and Alternatives." Washington, DC: National Academy Press, 230.

Quaranta, J. D., Tolikonda, R., and Bell, S. (2009). "Geotextile Filtration Performance with Coal Refuse under Standard and Reduced Compaction Energies." *Tailing and Mine Waste*, West Virginia University, Morgantown, West Virginia, USA.

Quaranta, J. D., Gutta, B., Stout, B., McAteer, D., Ziemkiewicz, P. (2004). "Improving the Safety of Coal Slurry Impoundments in West Virginia." Tailings, Vail CO.

Palmeira, E. M., and Gardoni, M. G. (2000). "The Influence of Partial Clogging and Pressure on the Behaviour of Geotextiles in Drainage Systems." *Geosynthetics International*, Vol. 7, 4-6.

Rao, G. V., Gupta, K. K., and Pradhan, M. P. S. (1991). "Long-term Filtration Behaviour of Soil-Geotextile System." *American Society for Testing and Materials*.

Slaughter, S., Turner, R., Capsanis, J., and Grey, D. (1992). "Investigation of Coal Fines at Coal and Allied Hunter Valley Mine." *Third Large Open Pit Mining Conference*.

West Virginia Department of Environmental Protection (WVDEP), Permit file # 0-1011-93, Application volume #2.

West Virginia Department of Environmental Protection (WVDEP), Permit file # 0-1011-93, Drainage certification, MR-13.

West Virginia Department of Environmental Protection (WVDEP), Permit file # 0-1011-93, I.BR.No.03, Volume II.

West Virginia Department of Environmental Protection (WVDEP), Permit file # 0-1011-93, I.BR.No.03, Volume I of II, Section V.

West Virginia Department of Environmental Protection (WVDEP), Permit file # 0-1011-93, Drainage certification 2009.

Windisch, E. J. (1996). "Grain-Size Distribution of Mixed Aggregates." *Geotechnical Testing Journal, GTJODJ*, Vol. 19, No. 2, 227-231.

9. APPENDICES

Appendix I Hydraulic Conductivity Tables

Hydraulic Conductivity tables

Coarse Coal refuse without geotextile

Standard compaction density sample

Hydraulic Conductivity without Fabric (25B, 3 L)												
Sample- CCR : Test Started on 3/7/10												
Time	**Vol(ml)**	**time**	**Δt (sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		
										ΔpV	Cumulative	t(Hours)
2.24 P.M.	0	0	0	-	5	81.03	-	-	-			
2.29 P.M.	50	300	300	50	5	81.03	0.17	4.11E-04	4.11E-06	0.24	0.24	0.08
2.48 P.M.	200	1440	1140	150	5	81.03	0.13	3.25E-04	3.25E-06	0.72	0.95	0.40
3.00 P.M.	320	2160	720	120	5	81.03	0.17	4.11E-04	4.11E-06	0.57	1.53	0.60
3.10 P.M.	420	2760	600	100	5	81.03	0.17	4.11E-04	4.11E-06	0.48	2.00	0.77
3.18 P.M.	530	3240	480	110	5	81.03	0.23	5.66E-04	5.66E-06	0.52	2.53	0.90
3.24 P.M.	600	3600	360	70	5	81.03	0.19	4.80E-04	4.80E-06	0.33	2.86	1.00
3.37 P.M.	780	4380	780	180	5	81.03	0.23	5.70E-04	5.70E-06	0.86	3.72	1.22
3.43 P.M.	840	4740	360	60	5	81.03	0.17	4.11E-04	4.11E-06	0.29	4.01	1.32
3.56 P.M.	1000	5520	780	160	5	81.03	0.21	5.06E-04	5.06E-06	0.76	4.77	1.53
4.05 P.M.	1120	6060	540	120	5	81.03	0.22	5.48E-04	5.48E-06	0.57	5.34	1.68
4.15 P.M.	1250	6660	600	130	5	81.03	0.22	5.35E-04	5.35E-06	0.62	5.96	1.85
4.30 P.M.	1460	7560	900	210	5	81.03	0.23	5.76E-04	5.76E-06	1.00	6.96	2.10
4.36 P.M.	1520	7920	360	60	5	81.03	0.17	4.11E-04	4.11E-06	0.29	7.25	2.20
4.53 P.M.	1720	8940	1020	200	5	81.03	0.20	4.84E-04	4.84E-06	0.95	8.20	2.48
5.00 P.M.	1800	9360	420	80	5	81.03	0.19	4.70E-04	4.70E-06	0.38	8.59	2.60
5.13 P.M.	1960	10140	780	160	5	81.03	0.21	5.06E-04	5.06E-06	0.76	9.35	2.82
5.18 P.M.	2000	10440	300	40	5	81.03	0.13	3.29E-04	3.29E-06	0.19	9.54	2.90
5.29 P.M.	2160	10980	540	160	5	81.03	0.30	7.31E-04	7.31E-06	0.76	10.30	3.05
5.37 P.M.	2280	11460	480	120	5	81.03	0.25	6.17E-04	6.17E-06	0.57	10.87	3.18
5.42 P.M.	2350	11760	300	70	5	81.03	0.23	5.76E-04	5.76E-06	0.33	11.21	3.27
5.50 P.M.	2470	12240	480	120	5	81.03	0.25	6.17E-04	6.17E-06	0.57	11.78	3.40
6.01 P.M.	2640	12900	660	170	5	81.03	0.26	6.36E-04	6.36E-06	0.81	12.59	3.58
6.07 P.M.	2740	13260	360	100	5	81.03	0.28	6.86E-04	6.86E-06	0.48	13.07	3.68
6.32 P.M.	3090	14760	1500	350	5	81.03	0.23	5.76E-04	5.76E-06	1.67	14.74	4.10
6.40 P.M.	3190	15840	1080	100	5	81.03	0.09	2.29E-04	2.29E-06	0.48	15.21	4.40
6.55 P.M.	3380	16740	900	190	5	81.03	0.21	5.21E-04	5.21E-06	0.91	16.12	4.65
7.16 P.M.	3640	18000	1260	260	5	81.03	0.21	5.09E-04	5.09E-06	1.24	17.36	5.00
							AVG	5.06E-04	5.06E-06			

Reduced compaction (12blows 2layers) sample

Hydraulic Conductivity without Fabric (12B, 2L)												
Sample- CCR : Test Started on 3/9/10												
Time	**Vol(ml)**	**time**	**Δt (sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		
										ΔpV	Cumulative	t(Hours)
1.17 P.M.	0	0	0	-	5	81.03	-	-	-			
1.20 P.M.	50	180	180	50	5	81.03	0.28	6.86E-04	6.86E-06	0.17	0.17	0.05
1.29 P.M.	200	720	540	150	5	81.03	0.28	6.86E-04	6.86E-06	0.51	0.68	0.20
1.36 P.M.	300	1140	420	100	5	81.03	0.24	5.88E-04	5.88E-06	0.34	1.03	0.32
1.39 P.M.	360	1320	180	60	5	81.03	0.33	8.23E-04	8.23E-06	0.21	1.23	0.37
1.45 P.M.	460	1680	360	100	5	81.03	0.28	6.86E-04	6.86E-06	0.34	1.57	0.47
2.00 P.M.	680	2580	900	220	5	81.03	0.24	6.03E-04	6.03E-06	0.75	2.33	0.72
2.06 P.M.	770	2940	360	90	5	81.03	0.25	6.17E-04	6.17E-06	0.31	2.63	0.82
2.14 P.M.	890	3420	480	120	5	81.03	0.25	6.17E-04	6.17E-06	0.41	3.04	0.95
3.23 P.M.	1695	7560	4140	805	5	81.03	0.19	4.80E-04	4.80E-06	2.75	5.80	2.10
4.08 P.M.	2295	10260	2700	600	5	81.03	0.22	5.48E-04	5.48E-06	2.05	7.85	2.85
4.48 P.M.	2695	12660	2400	400	5	81.03	0.17	4.11E-04	4.11E-06	1.37	9.22	3.52
5.29 P.M.	3375	15120	2460	680	5	81.03	0.28	6.82E-04	6.82E-06	2.33	11.55	4.20
6.52 P.M.	3665	20100	4980	290	5	81.03	0.06	1.44E-04	1.44E-06	0.99	12.54	5.58
							AVG	5.82E-04	5.82E-06			

Reduced compaction (4blows 2layers) sample

Sample- CCR : Test Started on 3/11/10												
Time	**Vol(ml)**	**time**	**Δt (sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		
										ΔpV	Cumulative	t(Hours)
3.02 P.M.	0	0	0	-	5	81.03	-	-	-			
3.06 P.M.	110	240	240	110	5	81.03	0.46	1.13E-03	1.13E-05	0.31	0.31	0.07
3.13 P.M.	240	660	420	130	5	81.03	0.31	7.64E-04	7.64E-06	0.37	0.68	0.18
3.20 P.M.	360	1080	420	120	5	81.03	0.29	7.05E-04	7.05E-06	0.34	1.02	0.30
3.27 P.M.	490	1500	420	130	5	81.03	0.31	7.64E-04	7.64E-06	0.37	1.39	0.42
3.30 P.M.	560	1680	180	70	5	81.03	0.39	9.60E-04	9.60E-06	0.20	1.58	0.47
3.39 P.M.	700	2220	540	140	5	81.03	0.26	6.40E-04	6.40E-06	0.40	1.98	0.62
3.47 P.M.	810	2700	480	110	5	81.03	0.23	5.66E-04	5.66E-06	0.31	2.29	0.75
3.52 P.M.	930	3000	300	120	5	81.03	0.40	9.87E-04	9.87E-06	0.34	2.63	0.83
3.57 P.M.	1020	3300	300	90	5	81.03	0.30	7.40E-04	7.40E-06	0.25	2.89	0.92
4.04 P.M.	1130	3720	420	110	5	81.03	0.26	6.46E-04	6.46E-06	0.31	3.20	1.03
4.14 P.M.	1310	4320	600	180	5	81.03	0.30	7.40E-04	7.40E-06	0.51	3.71	1.20
4.27 P.M.	1510	5100	780	200	5	81.03	0.26	6.33E-04	6.33E-06	0.57	4.27	1.42
4.35 P.M.	1620	5580	480	110	5	81.03	0.23	5.66E-04	5.66E-06	0.31	4.58	1.55
4.48 P.M.	1815	6360	780	195	5	81.03	0.25	6.17E-04	6.17E-06	0.55	5.14	1.77
4.56 P.M.	1930	6840	480	115	5	81.03	0.24	5.91E-04	5.91E-06	0.33	5.46	1.90
5.00 P.M.	1970	7080	240	840	5	81.03	3.50	8.64E-03	8.64E-05	2.38	5.57	1.97
5.13 P.M.	2180	7860	780	210	5	81.03	0.27	6.65E-04	6.65E-06	0.59	6.17	2.18
5.19 P.M.	2260	8220	360	750	5	81.03	2.08	5.14E-03	5.14E-05	2.12	6.39	2.28
5.25 P.M.	2360	8580	360	390	5	81.03	1.08	2.67E-03	2.67E-05	1.10	6.68	2.38
5.25 P.M.	2460	9000	420	100	5	81.03	0.24	5.88E-04	5.88E-06	0.28	6.96	2.50
5.57 P.M.	3250	10500	1500	790	5	81.03	0.53	1.30E-03	1.30E-05	2.24	9.20	2.92
							AVG	1.43E-03	1.43E-05			

Reduced compaction (8blows 2layers) sample

Hydraulic Conductivity without Fabric (8B, 2L)												
Sample- CCR : Test Started on 3/14/10												
Time	**Vol(ml)**	**time**	**Δt (sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		
										ΔpV	Cumulative	t(Hours)
8.05 P.M.	0	0	0	-	7.14	81.03	-	-	-			
8.10 P.M.	120	300	300	120	7.14	81.03	0.40	6.91E-04	6.91E-06	0.38	0.38	0.08
8.16 P.M.	240	660	360	120	7.14	81.03	0.33	5.76E-04	5.76E-06	0.38	0.77	0.18
8.22 P.M.	380	1020	360	140	7.14	81.03	0.39	6.72E-04	6.72E-06	0.45	1.21	0.28
8.34 P.M.	620	1740	720	240	7.14	81.03	0.33	5.76E-04	5.76E-06	0.77	1.98	0.48
8.40 P.M.	760	2100	360	140	7.14	81.03	0.39	6.72E-04	6.72E-06	0.45	2.43	0.58
8.47 P.M.	900	2520	420	140	7.14	81.03	0.33	5.76E-04	5.76E-06	0.45	2.87	0.70
8.54 P.M.	1050	2940	420	150	7.14	81.03	0.36	6.17E-04	6.17E-06	0.48	3.35	0.82
9.01 P.M.	1230	3360	420	180	7.14	81.03	0.43	7.41E-04	7.41E-06	0.57	3.93	0.93
9.13 P.M.	1480	4080	720	250	7.14	81.03	0.35	6.00E-04	6.00E-06	0.80	4.73	1.13
9.26 P.M.	1780	4860	780	300	7.14	81.03	0.38	6.65E-04	6.65E-06	0.96	5.68	1.35
9.36 P.M.	1960	5460	600	180	7.14	81.03	0.30	5.19E-04	5.19E-06	0.57	6.26	1.52
9.38 P.M.	2000	5580	120	40	7.14	81.03	0.33	5.76E-04	5.76E-06	0.13	6.39	1.55
9.49 P.M.	2280	6120	540	280	7.14	81.03	0.52	8.96E-04	8.96E-06	0.89	7.28	1.70
10.02 P.M.	2570	6900	780	290	7.14	81.03	0.37	6.43E-04	6.43E-06	0.93	8.21	1.92
10.14 P.M.	2850	7620	720	280	7.14	81.03	0.39	6.72E-04	6.72E-06	0.89	9.10	2.12
10.19 P.M.	2950	7920	300	1170	7.14	81.03	3.90	6.74E-03	6.74E-05	3.74	9.42	2.20
10.26 P.M.	3130	8340	420	180	7.14	81.03	0.43	7.41E-04	7.41E-06	0.57	10.00	2.32
10.40 P.M.	3400	9180	840	1400	7.14	81.03	1.67	2.88E-03	2.88E-05	4.47	10.86	2.55
10.58 P.M.	3780	10260	1080	830	7.14	81.03	0.77	1.33E-03	1.33E-05	2.65	12.07	2.85
11.14 P.M.	4050	11220	960	270	7.14	81.03	0.28	4.86E-04	4.86E-06	0.86	12.93	3.12
11.28 P.M.	4350	12060	840	300	7.14	81.03	0.36	6.17E-04	6.17E-06	0.96	13.89	3.35
11.41 P.M.	4620	12840	780	270	7.14	81.03	0.35	5.98E-04	5.98E-06	0.86	14.75	3.57
							AVG	1.05E-03	1.05E-05			

Coarse Coal Refuse with geotextile

Coarse Coal Refuse (E7-E9)

Hydraulic Conductivity with Fabric													
Sample- E7 : Test Started on 5/5/09 at 10:45A.M.													
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:45 A.M.	0	0	0	-	5	81.03	-	-	-				
11:45 A.M.	60	3600	3600	60	5	81.03	0.02	4.11E-05	4.11E-07	0.33	0.33	1.00	1.00
12:45 P.M.	125	7200	3600	65	5	81.03	0.02	4.46E-05	4.46E-07	0.36	0.69	2.00	3.00
1:45 P.M.	190	10800	3600	65	5	81.03	0.02	4.46E-05	4.46E-07	0.36	1.05	3.00	6.00
3:45 P.M.	295	18000	7200	105	5	81.03	0.01	3.60E-05	3.60E-07	0.58	1.64	5.00	11.00
4:20 P.M.	330	20100	2100	35	5	81.03	0.02	4.11E-05	4.11E-07	0.19	1.83	5.58	16.58
5:20 P.M.	360	23700	3600	30	5	81.03	0.01	2.06E-05	2.06E-07	0.17	2.00	6.58	23.17
5:45 P.M.	380	25200	1500	20	5	81.03	0.01	3.29E-05	3.29E-07	0.11	2.11	7.00	30.17
6:45 P.M.	430	28800	3600	50	5	81.03	0.01	3.43E-05	3.43E-07	0.28	2.38	8.00	38.17

Hydraulic Conductivity with Fabric													
Sample- E8 : Test Started on 5/5/09 at 10:46A.M.													
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:46 A.M.	0	0	0	-	5	81.03	-	-	-				
11:46 A.M.	350	3600	3600	350	5	81.03	0.10	2.40E-04	2.40E-06	1.71	1.71	1.00	1.00
12:46 P.M.	668	7200	3600	318	5	81.03	0.09	2.18E-04	2.18E-06	1.55	3.26	2.00	3.00
1:46 P.M.	796	10800	3600	128	5	81.03	0.04	8.78E-05	8.78E-07	0.63	3.89	3.00	6.00
3:46 P.M.	1370	18000	7200	574	5	81.03	0.08	1.97E-04	1.97E-06	2.80	6.69	5.00	11.00
4:21 P.M.	1770	20100	2100	400	5	81.03	0.19	4.70E-04	4.70E-06	1.95	8.65	5.58	16.58
5:21 P.M.	1920	23700	3600	150	5	81.03	0.04	1.03E-04	1.03E-06	0.73	9.38	6.58	23.17
5:46 P.M.	1990	25200	1500	70	5	81.03	0.05	1.15E-04	1.15E-06	0.34	9.72	7.00	30.17
6:46 P.M.	2150	28800	3600	160	5	81.03	0.04	1.10E-04	1.10E-06	0.78	10.50	8.00	38.17
8:20 P.M.	2420	34440	5640	270	5	81.03	0.05	1.18E-04	1.18E-06	1.32	11.82	9.57	47.73
9:05 P.M.	2690	37140	2700	270	5	81.03	0.10	2.47E-04	2.47E-06	1.32	13.14	10.32	58.05
9:35 P.M.	2750	38940	1800	60	5	81.03	0.03	8.23E-05	8.23E-07	0.29	13.43	10.82	68.87

Hydraulic Conductivity with Fabric													
Sample- E9 : Test Started on 5/5/09 at 10:47A.M.													
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:47 A.M.	0	0	0	-	5	81.03	-	-	-				
11:47 A.M.	440	3600	3600	440	5	81.03	0.12	3.02E-04	3.02E-06	2.10	2.10	1.00	1.00
12:47 P.M.	865	7200	3600	425	5	81.03	0.12	2.91E-04	2.91E-06	2.02	4.12	2.00	3.00
1:47 P.M.	1230	10800	3600	365	5	81.03	0.10	2.50E-04	2.50E-06	1.74	5.86	3.00	6.00
3:47 P.M.	1835	18000	7200	605	5	81.03	0.08	2.07E-04	2.07E-06	2.88	8.74	5.00	11.00
4:22 P.M.	2010	20100	2100	175	5	81.03	0.08	2.06E-04	2.06E-06	0.83	9.57	5.58	16.58
5:22 P.M.	2090	23700	3600	80	5	81.03	0.02	5.48E-05	5.48E-07	0.38	9.95	6.58	23.17
5:47 P.M.	2210	25200	1500	120	5	81.03	0.08	1.97E-04	1.97E-06	0.57	10.52	7.00	30.17
6:47 P.M.	2610	28800	3600	400	5	81.03	0.11	2.74E-04	2.74E-06	1.90	12.43	8.00	38.17
8:20 P.M.	3270	34380	5580	660	5	81.03	0.12	2.92E-04	2.92E-06	3.14	15.57	9.55	47.72
9:05 P.M.	3605	37080	2700	335	5	81.03	0.12	3.06E-04	3.06E-06	1.60	17.17	10.30	58.02
9:35 P.M.	3755	38880	1800	150	5	81.03	0.08	2.06E-04	2.06E-06	0.71	17.88	10.80	68.82

Coarse Coal Refuse (E7-E9) Duplicate

Hydraulic Conductivity with Fabric													
Sample- E7-II : Test Started on 5/10/09 at 2:50 P.M.													
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
2:50	0	0	0	-	5	81.03	-	-	-				
3:50	485	3600	3600	485	5	81.03	0.13	3.33E-04	3.33E-06	2.68	2.68	1.00	1.00
4:42	1000	6720	3120	515	5	81.03	0.17	4.07E-04	4.07E-06	2.85	5.53	1.87	2.87
5:50	1910	10800	4080	910	5	81.03	0.22	5.51E-04	5.51E-06	5.04	10.57	3.00	5.87
6:35	2460	13500	2700	550	5	81.03	0.20	5.03E-04	5.03E-06	3.04	13.61	3.75	9.62
7:02	2810	15120	1620	350	5	81.03	0.22	5.33E-04	5.33E-06	1.94	15.55	4.20	13.82
7:35	3190	17100	1980	380	5	81.03	0.19	4.74E-04	4.74E-06	2.10	17.65	4.75	18.57
8:08	3575	19080	1980	385	5	81.03	0.19	4.80E-04	4.80E-06	2.13	19.78	5.30	23.87
8:39	3920	20940	1860	345	5	81.03	0.19	4.58E-04	4.58E-06	1.91	21.69	5.82	29.68
8:56	4110	21960	1020	190	5	81.03	0.19	4.60E-04	4.60E-06	1.05	22.74	6.10	35.78

Hydraulic Conductivity with Fabric													
Sample- E8-II : Test Started on 5/10/09 at 2:50 P.M.													
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
2:50	0	0	0	-	5	81.03	-	-	-				
3:50	450	3600	3600	450	5	81.03	0.13	3.09E-04	3.09E-06	2.20	2.20	1.00	1.00
4:34	1034	6240	2640	584	5	81.03	0.22	5.46E-04	5.46E-06	2.86	5.06	1.73	2.73
5:34	1884	9840	3600	850	5	81.03	0.24	5.83E-04	5.83E-06	4.16	9.22	2.73	5.47
6:22	2609	12720	2880	725	5	81.03	0.25	6.21E-04	6.21E-06	3.55	12.77	3.53	9.00
7:02	3259	15120	2400	650	5	81.03	0.27	6.68E-04	6.68E-06	3.18	15.95	4.20	13.20
7:34	3734	17040	1920	475	5	81.03	0.25	6.11E-04	6.11E-06	2.32	18.27	4.73	17.93
8:08	4224	19080	2040	490	5	81.03	0.24	5.93E-04	5.93E-06	2.40	20.67	5.30	23.23

Hydraulic Conductivity with Fabric													
Sample- E9-II : Test Started on 5/10/09 at 2:50 P.M.													
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulat	t(Hours)	t,Cumulative
2:50	0	0	0	-	5	81.03	-	-	-				
3:13	500	1380	1380	500	5	81.03	0.36	8.94E-04	8.94E-06	2.36	2.36	0.38	0.38
3:25	794	2100	720	294	5	81.03	0.41	1.01E-03	1.01E-05	1.39	3.76	0.58	0.97
3:48	1316	3480	1380	522	5	81.03	0.38	9.34E-04	9.34E-06	2.47	6.22	0.97	1.93
3:57	1578	4020	540	262	5	81.03	0.49	1.20E-03	1.20E-05	1.24	7.46	1.12	3.05
4:13	2160	4980	960	582	5	81.03	0.61	1.50E-03	1.50E-05	2.75	10.22	1.38	4.43
4:20	2410	5400	420	250	5	81.03	0.60	1.47E-03	1.47E-05	1.18	11.40	1.50	5.93
4:36	2910	6360	960	500	5	81.03	0.52	1.29E-03	1.29E-05	2.36	13.76	1.77	7.70
4:54	3458	7440	1080	548	5	81.03	0.51	1.25E-03	1.25E-05	2.59	16.36	2.07	9.77
5:11	3988	8460	1020	530	5	81.03	0.52	1.28E-03	1.28E-05	2.51	18.86	2.35	12.12
5:20	4293	9000	540	305	5	81.03	0.56	1.39E-03	1.39E-05	1.44	20.30	2.50	14.62

Coarse Coal Refuse (E7-E9) Triplicate

Hydraulic Conductivity with Fabric													
Sample- E7-III : Test Started on 5/13/09 at 10:00AM													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:00	0	0	0	-	5	81.03	-	-	-				
10:20	205	1200	1200	205	5	81.03	0.17	4.22E-04	4.22E-06	1.13	1.13	0.33	0.33
11:00	860	3600	2400	655	5	81.03	0.27	6.74E-04	6.74E-06	3.60	4.72	1.00	1.33
11:08	1000	4080	480	140	5	81.03	0.29	7.20E-04	7.20E-06	0.77	5.49	1.13	2.47
11:30	1470	5400	1320	470	5	81.03	0.36	8.79E-04	8.79E-06	2.58	8.07	1.50	3.97
11:42	1725	6120	720	255	5	81.03	0.35	8.74E-04	8.74E-06	1.40	9.47	1.70	5.67
12:00	2125	7200	1080	400	5	81.03	0.37	9.14E-04	9.14E-06	2.20	11.67	2.00	7.67
12:31	2725	9060	1860	600	5	81.03	0.32	7.96E-04	7.96E-06	3.29	14.96	2.52	10.18
1:01	3385	10860	1800	660	5	81.03	0.37	9.05E-04	9.05E-06	3.62	18.59	3.02	13.20
1:18	3750	11880	1020	365	5	81.03	0.36	8.83E-04	8.83E-06	2.00	20.59	3.30	16.50

Hydraulic Conductivity with Fabric													
Sample- E8-III : Test Started on 5/13/09 at 10.00 A.M													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:00	0	0	0	-	5	81.03	-	-	-				
10:20	290	1200	1200	290	5	81.03	0.24	5.96E-04	5.96E-06	1.41	1.41	0.33	0.33
10:34	500	2040	840	210	5	81.03	0.25	6.17E-04	6.17E-06	1.02	2.43	0.57	0.90
11:00	895	3600	1560	395	5	81.03	0.25	6.25E-04	6.25E-06	1.92	4.36	1.00	1.90
11:30	1415	5400	1800	520	5	81.03	0.29	7.13E-04	7.13E-06	2.53	6.89	1.50	3.40
12:00	2050	7200	1800	635	5	81.03	0.35	8.71E-04	8.71E-06	3.09	9.98	2.00	5.40
12:27	2488	8820	1620	438	5	81.03	0.27	6.67E-04	6.67E-06	2.13	12.11	2.45	7.85
1:02	3158	10920	2100	670	5	81.03	0.32	7.87E-04	7.87E-06	3.26	15.37	3.03	10.88
1:19	3508	11940	1020	350	5	81.03	0.34	8.47E-04	8.47E-06	1.70	17.08	3.32	14.20

Hydraulic Conductivity with Fabric													
Sample- E9-III : Test Started on 5/13/09 at 10:00 A.M													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:00	0	0	0	-	5	81.03	-	-	-				
10:17	390	1020	1020	390	5	81.03	0.38	9.44E-04	9.44E-06	1.87	1.87	0.28	0.28
10:35	900	2100	1080	510	5	81.03	0.47	1.17E-03	1.17E-05	2.45	4.32	0.58	0.87
10:50	1325	3000	900	425	5	81.03	0.47	1.17E-03	1.17E-05	2.04	6.36	0.83	1.70
11:00	1500	3600	600	175	5	81.03	0.29	7.20E-04	7.20E-06	0.84	7.20	1.00	2.70
11:13	1900	4380	780	400	5	81.03	0.51	1.27E-03	1.27E-05	1.92	9.12	1.22	3.92
11:27	2400	5220	840	500	5	81.03	0.60	1.47E-03	1.47E-05	2.40	11.52	1.45	5.37
11:41	2900	6060	840	500	5	81.03	0.60	1.47E-03	1.47E-05	2.40	13.93	1.68	7.05
12:03	3540	7380	1320	640	5	81.03	0.48	1.20E-03	1.20E-05	3.07	17.00	2.05	9.10
12:16	3900	8160	780	360	5	81.03	0.46	1.14E-03	1.14E-05	1.73	18.73	2.27	11.37
12:30	4325	9000	840	425	5	81.03	0.51	1.25E-03	1.25E-05	2.04	20.77	2.50	13.87

Coarse Coal Refuse (E10-E11)

E10												
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time
										ΔpV	Cumulative	t(Hours)
3:15:00 AM	0	0	0	-	5	81.03	-	-	-			
3:45:00 AM	445	1800	1800	445	5	81.03	0.247	6.10E-04	6.10E-06	2.19	2.19	0.50
4:15	905	3600	1800	460	5	81.03	0.256	6.31E-04	6.31E-06	2.27	4.46	1.00
5:00	1779	6300	2700	874	5	81.03	0.324	7.99E-04	7.99E-06	4.31	8.77	1.75
5:13	2054	7080	780	275	5	81.03	0.353	8.70E-04	8.70E-06	1.35	10.12	1.97
6:10	2899	10500	3420	845	5	81.03	0.247	6.10E-04	6.10E-06	4.16	14.28	2.92
6:48	3454	12780	2280	555	5	81.03	0.243	6.01E-04	6.01E-06	2.73	17.02	3.55
7:31	4054	15360	2580	600	5	81.03	0.233	5.74E-04	5.74E-06	2.96	19.97	4.27
7:57	4404	16920	1560	350	5	81.03	0.224	5.54E-04	5.54E-06	1.72	21.70	4.70

E11												
Time	Vol(ml)	time	Δt (sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time
										ΔpV	Cumulative	t(Hours)
3:15:00 AM	0	0	0	-	5	81.03	-	-	-			
3:45:00 AM	95	1800	1800	95	5	81.03	0.053	1.30E-04	1.30E-06	0.46	0.46	0.50
4:15	190	3600	1800	95	5	81.03	0.053	1.30E-04	1.30E-06	0.46	0.92	1.00
5:02	350	6420	2820	160	5	81.03	0.057	1.40E-04	1.40E-06	0.78	1.70	1.78
6:11	600	10560	4140	250	5	81.03	0.060	1.49E-04	1.49E-06	1.22	2.92	2.93
6:50	760	12900	2340	160	5	81.03	0.068	1.69E-04	1.69E-06	0.78	3.70	3.58
7:33	955	15480	2580	195	5	81.03	0.076	1.87E-04	1.87E-06	0.95	4.65	4.30
7:40	1000	15900	420	45	5	81.03	0.107	2.64E-04	2.64E-06	0.22	4.87	4.42
8:11	1160	17760	1860	160	5	81.03	0.086	2.12E-04	2.12E-06	0.78	5.65	4.93
9:37	1835	22920	5160	675	5	81.03	0.131	3.23E-04	3.23E-06	3.29	8.93	6.37

Coarse Coal Refuse (E10-E11) Duplicate

E10-II													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:00:00 AM	0	0	0	-	5	81.03	-	-	-				
10:30:00 AM	100	1800	1800	100	5	81.03	0.056	1.37E-04	1.37E-06	0.55	0.55	0.50	0.50
11:01	190	3660	1860	90	5	81.03	0.048	1.19E-04	1.19E-06	0.50	1.05	1.02	1.52
11:31	280	5460	1800	90	5	81.03	0.050	1.23E-04	1.23E-06	0.50	1.55	1.52	3.03
12:00	360	7200	1740	80	5	81.03	0.046	1.13E-04	1.13E-06	0.44	2.00	2.00	5.03
12:29	430	8940	1740	70	5	81.03	0.040	9.93E-05	9.93E-07	0.39	2.38	2.48	7.52
1:01	490	10860	1920	60	5	81.03	0.031	7.71E-05	7.71E-07	0.33	2.72	3.02	10.53
1:31	550	12660	1800	60	5	81.03	0.033	8.23E-05	8.23E-07	0.33	3.05	3.52	14.05
2:01	605	14460	1800	55	5	81.03	0.031	7.54E-05	7.54E-07	0.30	3.35	4.02	18.07
2:31	660	16260	1800	55	5	81.03	0.031	7.54E-05	7.54E-07	0.30	3.66	4.52	22.58
3:01	705	18060	1800	45	5	81.03	0.025	6.17E-05	6.17E-07	0.25	3.91	5.02	27.60
3:30	760	19800	1740	55	5	81.03	0.032	7.80E-05	7.80E-07	0.30	4.21	5.50	33.10
4:00	805	21600	1800	45	5	81.03	0.025	6.17E-05	6.17E-07	0.25	4.46	6.00	39.10
4:31	840	23460	1860	35	5	81.03	0.019	4.64E-05	4.64E-07	0.19	4.66	6.52	45.62
5:02	875	25320	1860	35	5	81.03	0.019	4.64E-05	4.64E-07	0.19	4.85	7.03	52.65
5:31	910	27060	1740	35	5	81.03	0.020	4.96E-05	4.96E-07	0.19	5.05	7.52	60.17
6:00	940	28800	1740	30	5	81.03	0.017	4.26E-05	4.26E-07	0.17	5.21	8.00	68.17
8:29	1110	37740	8940	170	5	81.03	0.019	4.69E-05	4.69E-07	0.94	6.15	10.48	78.65

E11-II													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
10:00:00 AM	0	0	0	-	5	81.03	-	-	-				
10:30:00 AM	185	1800	1800	185	5	81.03	0.103	2.54E-04	2.54E-06	1.01	1.01	0.50	0.50
11:02	450	3720	1920	265	5	81.03	0.138	3.41E-04	3.41E-06	1.44	2.45	1.03	1.53
11:29	720	5340	1620	270	5	81.03	0.167	4.11E-04	4.11E-06	1.47	3.92	1.48	3.02
11:57	1000	7020	1680	280	5	81.03	0.167	4.11E-04	4.11E-06	1.52	5.44	1.95	4.97
12:30	1330	9000	1980	330	5	81.03	0.167	4.11E-04	4.11E-06	1.79	7.23	2.50	7.47
1:01	1610	10860	1860	280	5	81.03	0.151	3.72E-04	3.72E-06	1.52	8.76	3.02	10.48
1:31	1870	12660	1800	260	5	81.03	0.144	3.57E-04	3.57E-06	1.41	10.17	3.52	14.00
1:47	2000	13620	960	130	5	81.03	0.135	3.34E-04	3.34E-06	0.71	10.88	3.78	17.78
2:02	2120	14760	1140	120	5	81.03	0.105	2.60E-04	2.60E-06	0.65	11.53	4.10	21.88
2:30	2350	16440	1680	230	5	81.03	0.137	3.38E-04	3.38E-06	1.25	12.78	4.57	26.45
2:59	2600	18180	1740	250	5	81.03	0.144	3.55E-04	3.55E-06	1.36	14.14	5.05	31.50
3:29	2840	19980	1800	240	5	81.03	0.133	3.29E-04	3.29E-06	1.31	15.44	5.55	37.05
3:50	3000	21240	1260	160	5	81.03	0.127	3.13E-04	3.13E-06	0.87	16.31	5.90	42.95
4:00	3070	21840	600	70	5	81.03	0.117	2.88E-04	2.88E-06	0.38	16.70	6.07	49.02
4:30	3300	23640	1800	230	5	81.03	0.128	3.15E-04	3.15E-06	1.25	17.95	6.57	55.58
5:00	3510	25440	1800	210	5	81.03	0.117	2.88E-04	2.88E-06	1.14	19.09	7.07	62.65
5:30	3720	27240	1800	210	5	81.03	0.117	2.88E-04	2.88E-06	1.14	20.23	7.57	70.22
6:02	3930	29160	1920	210	5	81.03	0.109	2.70E-04	2.70E-06	1.14	21.37	8.10	78.32

Coarse Coal Refuse (E10-E11) Triplicate

E10-III

Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
11:00:00 AM	0	0	0	-	5	81.03	-	-	-				
11:30:00 AM	145	1800	1800	145	5	81.03	0.081	1.99E-04	1.99E-06	0.80	0.80	0.50	0.50
12:00	255	3600	1800	110	5	81.03	0.061	1.51E-04	1.51E-06	0.61	1.41	1.00	1.50
12:30	340	5400	1800	85	5	81.03	0.047	1.17E-04	1.17E-06	0.47	1.87	1.50	3.00
1:00	420	7200	1800	80	5	81.03	0.044	1.10E-04	1.10E-06	0.44	2.32	2.00	5.00
1:30	495	9000	1800	75	5	81.03	0.042	1.03E-04	1.03E-06	0.41	2.73	2.50	7.50
2:00	539	10800	1800	44	5	81.03	0.024	6.03E-05	6.03E-07	0.24	2.97	3.00	10.50
2:30	569	12600	1800	30	5	81.03	0.017	4.11E-05	4.11E-07	0.17	3.14	3.50	14.00
3:00	590	14400	1800	21	5	81.03	0.012	2.88E-05	2.88E-07	0.12	3.25	4.00	18.00
3:30	605	16200	1800	15	5	81.03	0.008	2.06E-05	2.06E-07	0.08	3.34	4.50	22.50
4:00	625	18000	1800	20	5	81.03	0.011	2.74E-05	2.74E-07	0.11	3.45	5.00	27.50
4:30	640	19800	1800	15	5	81.03	0.008	2.06E-05	2.06E-07	0.08	3.53	5.50	33.00
10:00	810	39600	19800	170	5	81.03	0.009	2.12E-05	2.12E-07	0.94	4.47	11.00	44.00
7:13	1170	72780	33180	360	5	81.03	0.011	2.68E-05	2.68E-07	1.98	6.45	20.22	64.22
8:27	1215	77220	4440	45	5	81.03	0.010	2.50E-05	2.50E-07	0.25	6.70	21.45	85.67
9:59	1675	82680	5460	460	5	81.03	0.084	2.08E-04	2.08E-06	2.54	9.23	22.97	108.63
12:00	1745	93540	10860	70	5	81.03	0.006	1.59E-05	1.59E-07	0.39	9.62	25.98	134.62
2:44	1835	103380	9840	90	5	81.03	0.009	2.26E-05	2.26E-07	0.50	10.12	28.72	163.33
3:57	1865	107760	4380	30	5	81.03	0.007	1.69E-05	1.69E-07	0.17	10.28	29.93	193.27
4:20	1885	109140	1380	20	5	81.03	0.014	3.58E-05	3.58E-07	0.11	10.39	30.32	223.58
7:08	2240	119220	10080	355	5	81.03	0.035	8.69E-05	8.69E-07	1.96	12.35	33.12	256.70
9:56	2300	129300	10080	60	5	81.03	0.006	1.47E-05	1.47E-07	0.33	12.68	35.92	292.62
12:36	2357	138900	9600	57	5	81.03	0.006	1.47E-05	1.47E-07	0.31	12.99	38.58	331.20

E11-III

Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
11:00:00 AM	0	0	0	-	5	81.03	-	-	-				
11:30:00 AM	16	1800	1800	16	5	81.03	0.009	2.19E-05	2.19E-07	0.08	0.08	0.50	0.50
12:00	34	3600	1800	18	5	81.03	0.010	2.47E-05	2.47E-07	0.09	0.18	1.00	1.50
12:28	50	5280	1680	16	5	81.03	0.010	2.35E-05	2.35E-07	0.08	0.26	1.47	2.97
0:58	66	7080	1800	16	5	81.03	0.009	2.19E-05	2.19E-07	0.08	0.34	1.97	4.93
1:28	82	8880	1800	16	5	81.03	0.009	2.19E-05	2.19E-07	0.08	0.43	2.47	7.40
1:58	92	10680	1800	10	5	81.03	0.006	1.37E-05	1.37E-07	0.05	0.48	2.97	10.37
2:28	108	12480	1800	16	5	81.03	0.009	2.19E-05	2.19E-07	0.08	0.56	3.47	13.83
2:58	123	14280	1800	15	5	81.03	0.008	2.06E-05	2.06E-07	0.08	0.64	3.97	17.80
3:28	138	16080	1800	15	5	81.03	0.008	2.06E-05	2.06E-07	0.08	0.72	4.47	22.27
3:58	154	17880	1800	16	5	81.03	0.009	2.19E-05	2.19E-07	0.08	0.80	4.97	27.23
4:28	168	19680	1800	14	5	81.03	0.008	1.92E-05	1.92E-07	0.07	0.87	5.47	32.70
10:00	324	39600	19920	324	5	81.03	0.016	4.01E-05	4.01E-07	1.69	2.56	11.00	43.70
7:15	210	72900	33300	210	5	81.03	0.006	1.56E-05	1.56E-07	1.09	3.66	20.25	63.95
8:28	240	77280	4380	30	5	81.03	0.007	1.69E-05	1.69E-07	0.16	3.81	21.47	85.42
10:00	270	78420	5520	30	5	81.03	0.005	1.34E-05	1.34E-07	0.16	3.81	21.78	85.73
12:00	310	85620	7200	40	5	81.03	0.006	1.37E-05	1.37E-07	0.21	4.02	23.78	109.52
2:45	362	95520	9900	52	5	81.03	0.005	1.30E-05	1.30E-07	0.27	4.29	26.53	136.05
3:56	385	99780	4260	23	5	81.03	0.005	1.33E-05	1.33E-07	0.12	4.41	27.72	163.77
7:07	665	111240	11460	280	5	81.03	0.024	6.03E-05	6.03E-07	1.46	5.87	30.90	194.67
9:52	712	121140	9900	47	5	81.03	0.005	1.17E-05	1.17E-07	0.24	6.11	33.65	228.32
0:37	760	131040	9900	48	5	81.03	0.005	1.20E-05	1.20E-07	0.25	6.36	36.40	264.72
6:57	1050	153840	22800	290	5	81.03	0.013	3.14E-05	3.14E-07	1.51	7.87	42.73	307.45

Coarse Coal Refuse (E12-E14)

Sample- E12 : Test Started on 5/29/09 at 7:45 A.M.													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
7:45 A.M.	0	0	0	-	5	81.03	-	-	-				
8:09 A.M.	70	1440	1440	70	5	81.03	0.049	1.20E-04	1.20E-06	0.33	0.33	0.40	0.40
8:46 A.M.	210	3660	2220	140	5	81.03	0.063	1.56E-04	1.56E-06	0.66	0.99	1.02	1.42
9:23 A.M.	400	5880	2220	190	5	81.03	0.086	2.11E-04	2.11E-06	0.90	1.89	1.63	3.05
10:17 A.M.	730	9120	3240	330	5	81.03	0.102	2.51E-04	2.51E-06	1.56	3.45	2.53	5.58
11:02 A.M.	1000	11220	2100	270	5	81.03	0.129	3.17E-04	3.17E-06	1.27	4.72	3.12	8.70
11:39 A.M.	1210	13440	2220	210	5	81.03	0.095	2.33E-04	2.33E-06	0.99	5.71	3.73	12.43
12:21 P.M.	1430	15840	2400	220	5	81.03	0.092	2.26E-04	2.26E-06	1.04	6.75	4.40	16.83
1:36 P.M.	1800	20340	4500	370	5	81.03	0.082	2.03E-04	2.03E-06	1.75	8.50	5.65	22.48
2:29 P.M	2030	23520	3180	230	5	81.03	0.072	1.79E-04	1.79E-06	1.09	9.59	6.53	29.02
5:17 P.M.	2730	33600	10080	700	5	81.03	0.069	1.71E-04	1.71E-06	3.31	12.89	9.33	38.35
5:45 P.M.	2830	35220	1620	100	5	81.03	0.062	1.52E-04	1.52E-06	0.47	13.36	9.78	48.13
10:50 P.M.	3650	53520	18300	820	5	81.03	0.045	1.11E-04	1.11E-06	3.87	17.23	14.87	63.00

Sample- E13 : Test Started on 5/28/09 at 8:20 A.M.													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
8:20 A.M.	0	0	0	-	5	81.03	-	-	-				
8:54 A.M.	360	2040	2040	360	5	81.03	0.18	4.36E-04	4.36E-06	1.76	1.76	0.57	0.57
9:30 A.M.	750	4200	2160	390	5	81.03	0.18	4.46E-04	4.46E-06	1.91	3.68	1.17	1.73
9:55 A.M.	1000	5700	1500	250	5	81.03	0.17	4.11E-04	4.11E-06	1.23	4.90	1.58	3.32
11:25 A.M.	1770	11100	5400	770	5	81.03	0.14	3.52E-04	3.52E-06	3.77	8.68	3.08	6.40
12:04 p.M.	2050	13440	2340	280	5	81.03	0.12	2.95E-04	2.95E-06	1.37	10.05	3.73	10.13
1:12 P.M.	2530	16560	3120	480	5	81.03	0.15	3.80E-04	3.80E-06	2.35	12.40	4.60	14.73
2:00 P.M.	2818	19440	2880	288	5	81.03	0.10	2.47E-04	2.47E-06	1.41	13.81	5.40	20.13
2:35 P.M.	3000	21540	2100	182	5	81.03	0.09	2.14E-04	2.14E-06	0.89	14.70	5.98	26.12
4:20 P.M.	3480	24240	2700	480	5	81.03	0.18	4.39E-04	4.39E-06	2.35	17.06	6.73	32.85
5:20 P.M.	3680	27840	3600	200	5	81.03	0.06	1.37E-04	1.37E-06	0.98	18.04	7.73	40.58
7:10 P.M.	4250	34440	6600	570	5	81.03	0.09	2.13E-04	2.13E-06	2.79	20.83	9.57	50.15

Sample- E14 : Test Started on 5/28/09 at 8:20 A.M.													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
8:20 A.M.	0	0	0	-	5	81.03	-	-	-				
8:52 A.M.	650	1920	1920	650	5	81.03	0.34	8.36E-04	8.36E-06	2.99	2.99	0.53	0.53
9:19 A.M.	1000	3540	1620	350	5	81.03	0.22	5.33E-04	5.33E-06	1.61	4.61	0.98	1.52
9:57 A.M.	1790	5820	2280	790	5	81.03	0.35	8.55E-04	8.55E-06	3.64	8.25	1.62	3.13
10:11 A.M.	2000	6660	840	210	5	81.03	0.25	6.17E-04	6.17E-06	0.97	9.21	1.85	4.98
11:18 A.M.	3000	10680	4020	1000	5	81.03	0.25	6.14E-04	6.14E-06	4.61	13.82	2.97	7.95
12:07 P.M.	3610	13620	2940	610	5	81.03	0.21	5.12E-04	5.12E-06	2.81	16.63	3.78	11.73
12:39 P.M.	4000	15540	1920	390	5	81.03	0.20	5.01E-04	5.01E-06	1.80	18.43	4.32	16.05
1:10 P.M.	4515	17400	1860	515	5	81.03	0.28	6.83E-04	6.83E-06	2.37	20.80	4.83	20.88

Coarse Coal Refuse (E15-E17)

Hydraulic Conductivity with Fabric													
Sample- E15 : Test Started on 6/10/09 at 3:10 P.M.													
Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
3:10 PM	0	0	0	-	5	81.03	-	-	-				
3:42 PM	530	1920	1920	530	5	81.03	0.28	6.81E-04	6.81E-06	1.73	1.73	0.53	0.53
4:02 PM	890	3120	1200	360	5	81.03	0.30	7.40E-04	7.40E-06	1.17	2.90	0.87	1.40
4:36 PM	1410	5160	2040	520	5	81.03	0.25	6.29E-04	6.29E-06	1.69	4.60	1.43	2.83
5:02 PM	2000	6720	1560	590	5	81.03	0.38	9.33E-04	9.33E-06	1.92	6.52	1.87	4.70
6:00 PM	2920	10200	3480	920	5	81.03	0.26	6.53E-04	6.53E-06	3.00	9.52	2.83	7.53
6:07 PM	3000	10620	420	80	5	81.03	0.19	4.70E-04	4.70E-06	0.26	9.78	2.95	10.48
7:00 PM	3730	13800	3180	730	5	81.03	0.23	5.67E-04	5.67E-06	2.38	12.16	3.83	14.32
7:15 PM	4000	14700	900	270	5	81.03	0.30	7.40E-04	7.40E-06	0.88	13.04	4.08	18.40
8:00 PM	4560	17400	2700	560	5	81.03	0.21	5.12E-04	5.12E-06	1.83	14.86	4.83	23.23
8:10 PM	4660	18000	600	100	5	81.03	0.17	4.11E-04	4.11E-06	0.33	15.19	5.00	28.23
8:15 PM	4700	18300	300	40	5	81.03	-	-	-	-	-	-	-
8:33 PM	5000	19380	1080	300	5	81.03	0.28	6.86E-04	6.86E-06	0.98	16.17	5.38	33.62
9:18 PM	5860	22080	2700	860	5	81.03	0.32	7.86E-04	7.86E-06	2.80	18.97	6.13	39.75
9:27 PM	6000	22620	540	140	5	81.03	0.26	6.40E-04	6.40E-06	0.46	19.43	6.28	46.03
10:26 PM	7000	26160	3540	1000	5	81.03	0.28	6.97E-04	6.97E-06	3.26	22.69	7.27	53.30
11:28 PM	8000	29880	3720	1000	5	81.03	0.27	6.64E-04	6.64E-06	3.26	25.95	8.30	61.60
12:39 AM	9000	34140	4260	1000	5	81.03	0.23	5.79E-04	5.79E-06	3.26	29.21	9.48	71.08
12:46 AM	9100	34560	420	100	5	81.03	0.24	5.88E-04	5.88E-06	0.33	29.53	9.60	80.68
12:56 AM	9200	35160	600	100	5	81.03	-	-	-	-	-	-	-
1:18 AM	9850	36480	1320	650	5	81.03	0.49	1.22E-03	1.22E-05	2.12	31.65	10.13	90.82
2:13 AM	10850	39780	3300	1000	5	81.03	0.30	7.48E-04	7.48E-06	3.26	34.91	11.05	101.87
3:12 AM	11850	43320	3540	1000	5	81.03	0.28	6.97E-04	6.97E-06	3.26	38.17	12.03	113.90
3:57 AM	12510	46020	2700	660	5	81.03	0.24	6.03E-04	6.03E-06	2.15	40.32	12.78	126.68
4:56 AM	13310	49560	3540	800	5	81.03	0.23	5.58E-04	5.58E-06	2.61	42.93	13.77	140.45

Hydraulic Conductivity with Fabric

Sample- E16 : Test Started on 6/10/09 at 3:10 P.M.

Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
3:10 P.M.	0	0	0	-	5	81.03	-	-	-				
3:43 P.M.	510	1980	1980	510	5	81.03	0.26	6.36E-04	6.36E-06	1.93	1.93	0.55	0.55
4:02 P.M.	825	3120	1140	315	5	81.03	0.28	6.82E-04	6.82E-06	1.19	3.13	0.87	1.42
4:37 P.M.	1360	5220	2100	535	5	81.03	0.25	6.29E-04	6.29E-06	2.03	5.16	1.45	2.87
5:00 P.M.	1865	6600	1380	505	5	81.03	0.37	9.03E-04	9.03E-06	1.92	7.07	1.83	4.70
5:12 P.M.	2000	7320	720	135	5	81.03	0.19	4.63E-04	4.63E-06	0.51	7.58	2.03	6.73
6:00 P.M.	2670	10200	2880	670	5	81.03	0.23	5.74E-04	5.74E-06	2.54	10.12	2.83	9.57
6:25 P.M.	3000	11700	1500	330	5	81.03	0.22	5.43E-04	5.43E-06	1.25	11.38	3.25	12.82
7:00 P.M.	3410	13800	2100	410	5	81.03	0.20	4.82E-04	4.82E-06	1.55	12.93	3.83	16.65
7:50 P.M.	4000	16800	3000	590	5	81.03	0.20	4.85E-04	4.85E-06	2.24	15.17	4.67	21.32
8:00 P.M.	4130	17400	600	130	5	81.03	0.22	5.35E-04	5.35E-06	0.49	15.66	4.83	26.15
8:35 P.M.	4485	19500	2100	355	5	81.03	0.17	4.17E-04	4.17E-06	1.35	17.01	5.42	31.57
9:17 P.M.	4485	22020	2520	0	5	81.03	-	-	-	-	-	-	-
9:51 P.M.	5000	24060	2040	515	5	81.03	0.25	6.23E-04	6.23E-06	1.95	18.96	6.68	38.25
10:27 P.M.	5520	26220	2160	520	5	81.03	0.24	5.94E-04	5.94E-06	1.97	20.93	7.28	45.53
11:44 P.M.	6520	30840	4620	1000	5	81.03	0.22	5.34E-04	5.34E-06	3.79	24.72	8.57	54.10
1:11 A.M.	7520	36060	5220	1000	5	81.03	0.19	4.73E-04	4.73E-06	3.79	28.52	10.02	64.12
2:56 A.M.	8520	42360	6300	1000	5	81.03	0.16	3.92E-04	3.92E-06	3.79	32.31	11.77	75.88
3:36 A.M.	8880	44760	2400	360	5	81.03	0.15	3.70E-04	3.70E-06	1.37	33.67	12.43	88.32
3:43 A.M.	8920	45180	420	40	5	81.03	-	-	-	-	-	-	-
3:55 A.M.	9120	45900	720	200	5	81.03	0.28	6.86E-04	6.86E-06	0.76	34.43	12.75	101.07
4:58 A.M.	10120	49680	3780	1000	5	81.03	0.26	6.53E-04	6.53E-06	3.79	38.22	13.80	114.87
5:08 A.M.	10270	50280	600	150	5	81.03	0.25	6.17E-04	6.17E-06	0.57	38.79	13.97	128.83
7:05 A.M.	11370	57300	7020	1100	5	81.03	0.16	3.87E-04	3.87E-06	4.17	42.96	15.92	144.75
8:16 A.M.	12270	61440	4140	900	5	81.03	0.22	5.37E-04	5.37E-06	3.41	46.38	17.07	161.82
8:59 A.M.	12870	64020	2580	600	5	81.03	0.23	5.74E-04	5.74E-06	2.28	48.65	17.78	179.60
9:29 A.M.	13270	65820	1800	400	5	81.03	0.22	5.48E-04	5.48E-06	1.52	50.17	18.28	197.88

Hydraulic Conductivity with Fabric

Sample- E17 : Test Started on 6/10/09 at 3:10 P.M.

Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
										ΔpV	Cumulative	t(Hours)	t,Cumulative
3:10 P.M.	0	0	0	-	5	81.03	-	-	-				
3:46 P.M.	1000	2160	2160	1000	5	81.03	0.46	1.14E-03	1.14E-05	3.81	3.81	0.60	0.60
4:03 P.M.	1515	3180	1020	515	5	81.03	0.50	1.25E-03	1.25E-05	1.96	5.77	0.88	1.48
4:23 P.M.	2000	4380	1200	485	5	81.03	0.40	9.98E-04	9.98E-06	1.85	7.61	1.22	2.70
5:00 P.M.	3000	6600	2220	1000	5	81.03	0.45	1.11E-03	1.11E-05	3.81	11.42	1.83	4.53
5:40 P.M.	4000	9000	2400	1000	5	81.03	0.42	1.03E-03	1.03E-05	3.81	15.23	2.50	7.03
6:00 P.M.	4490	10200	1200	490	5	81.03	0.41	1.01E-03	1.01E-05	1.87	17.10	2.83	9.87
6:12 P.M.	4490	-	-	-	5	81.03	-	-	-	-	-	-	-
6:30 P.M.	5030	11280	1080	540	5	81.03	0.50	1.23E-03	1.23E-05	2.06	19.15	3.13	13.00
7:00 P.M.	5925	13080	1800	895	5	81.03	0.50	1.23E-03	1.23E-05	3.41	20.50	3.63	13.50
7:05 P.M.	6000	13380	300	75	5	81.03	0.25	6.17E-04	6.17E-06	0.29	20.79	3.72	17.22
7:40 P.M.	7000	15480	2100	1000	5	81.03	0.48	1.18E-03	1.18E-05	3.81	24.60	4.30	21.52
8:00 P.M.	7500	16680	1200	500	5	81.03	0.42	1.03E-03	1.03E-05	1.90	26.50	4.63	26.15
8:20 P.M.	8040	17880	1200	540	5	81.03	0.45	1.11E-03	1.11E-05	2.06	28.56	4.97	31.12
9:17 P.M.	9130	21300	3420	1090	5	81.03	0.32	7.87E-04	7.87E-06	4.15	32.71	5.92	37.03
9:25 P.M.	9150	21780	480	20	5	81.03	-	-	-	-	-	-	-
9:56 P.M.	10000	23640	1860	850	5	81.03	0.46	1.13E-03	1.13E-05	3.24	35.94	6.57	43.60
10:30 P.M.	11000	25680	2040	1000	5	81.03	0.49	1.21E-03	1.21E-05	3.81	39.75	7.13	50.73
11:12 P.M.	12000	28200	2520	1000	5	81.03	0.40	9.79E-04	9.79E-06	3.81	43.56	7.83	58.57
11:54 P.M.	13000	30720	2520	1000	5	81.03	0.40	9.79E-04	9.79E-06	3.81	47.36	8.53	67.10

Coarse Coal Refuse (E18-E20)

E18												
Time	**Vol(ml)**	**time**	**Δt (sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		Time
										ΔpV	Cumulative	t(Hours)
8:15:00 AM	0	0	0	-	7.14	81.03	-	-	-			
8:55:00 AM	610	2400	2400	610	7.14	81.03	0.254	4.39E-04	4.39E-06	2.06	2.06	0.67
9:19	1000	3840	1440	390	7.14	81.03	0.271	4.68E-04	4.68E-06	1.32	3.38	1.07
10:33	2000	8280	4440	1000	7.14	81.03	0.225	3.89E-04	3.89E-06	3.38	6.76	2.30
11:17	2710	10920	2640	710	7.14	81.03	0.269	4.65E-04	4.65E-06	2.40	9.16	3.03
11:34	3000	11940	1020	290	7.14	81.03	0.284	4.91E-04	4.91E-06	0.98	10.14	3.32
12:40	4030	15900	3960	1030	7.14	81.03	0.260	4.50E-04	4.50E-06	3.48	13.62	4.42
1:32	4685	19020	3120	655	7.14	81.03	0.210	3.63E-04	3.63E-06	2.21	15.84	5.28
1:59	5000	20640	1620	315	7.14	81.03	0.194	3.36E-04	3.36E-06	1.06	16.90	5.73
2:53	6000	23880	3240	1000	7.14	81.03	0.309	5.33E-04	5.33E-06	3.38	20.28	6.63
3:53	7000	27480	3600	1000	7.14	81.03	0.278	4.80E-04	4.80E-06	3.38	23.66	7.63
5:01	8000	31560	4080	1000	7.14	81.03	0.245	4.24E-04	4.24E-06	3.38	27.04	8.77
6:11	9000	35760	4200	1000	7.14	81.03	0.238	4.12E-04	4.12E-06	3.38	30.42	9.93
6:24	9200	36540	780	200	7.14	81.03	0.256	4.43E-04	4.43E-06	0.68	31.10	10.15
6:28	9500	37500	960	300	7.14	81.03	0.313	5.40E-04	5.40E-06	1.01	32.11	10.42
6:44	10400	40800	3300	900	7.14	81.03	0.273	4.71E-04	4.71E-06	3.04	35.15	11.33
7:39	11400	44760	3960	1000	7.14	81.03	0.253	4.36E-04	4.36E-06	3.38	38.53	12.43
8:45	12400	48780	4020	1000	7.14	81.03	0.249	4.30E-04	4.30E-06	3.38	41.91	13.55
9:52	13400	53100	4320	1000	7.14	81.03	0.231	4.00E-04	4.00E-06	3.38	45.29	14.75
11:04	13650	54300	1200	250	7.14	81.03	0.208	3.60E-04	3.60E-06	0.85	46.14	15.08

E19												
Time	**Vol(ml)**	**time**	**Δt (sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		Time
										ΔpV	Cumulative	t(Hours)
8:15:00 AM	0	0	0	-	7.14	81.03	-	-	-			
8:54:00 AM	880	2340	2340	880	7.14	81.03	0.376	6.50E-04	6.50E-06	3.60	3.60	0.65
9:00	1000	2700	360	120	7.14	81.03	0.333	5.76E-04	5.76E-06	0.49	4.09	0.75
9:48	2000	5580	2880	1000	7.14	81.03	0.347	6.00E-04	6.00E-06	4.09	8.19	1.55
10:34	2800	8340	2760	800	7.14	81.03	0.290	5.01E-04	5.01E-06	3.27	11.46	2.32
10:43	3000	8880	540	200	7.14	81.03	0.370	6.40E-04	6.40E-06	0.82	12.28	2.47
11:17	3740	10920	2040	740	7.14	81.03	0.363	6.27E-04	6.27E-06	3.03	15.31	3.03
11:29	4000	11640	720	260	7.14	81.03	0.361	6.24E-04	6.24E-06	1.06	16.37	3.23
11:53	4480	13080	1440	480	7.14	81.03	0.333	5.76E-04	5.76E-06	1.96	18.34	3.63
12:15	5120	14400	1320	640	7.14	81.03	0.485	8.38E-04	8.38E-06	2.62	20.96	4.00
12:55	6175	16800	2400	1055	7.14	81.03	0.440	7.60E-04	7.60E-06	4.32	25.28	4.67
1:35	7225	19200	2400	1050	7.14	81.03	0.438	7.56E-04	7.56E-06	4.30	29.58	5.33
2:20	8225	21900	2700	1000	7.14	81.03	0.370	6.40E-04	6.40E-06	4.09	33.67	6.08
2:55	9035	24000	2100	810	7.14	81.03	0.386	6.67E-04	6.67E-06	3.32	36.99	6.67
3:05	9225	24600	600	190	7.14	81.03	0.317	5.47E-04	5.47E-06	0.78	37.76	6.83
3:40	10225	26700	2100	1000	7.14	81.03	0.476	8.23E-04	8.23E-06	4.09	41.86	7.42
4:19	11225	29040	2340	1000	7.14	81.03	0.427	7.39E-04	7.39E-06	4.09	45.95	8.07
5:02	12225	31620	2580	1000	7.14	81.03	0.388	6.70E-04	6.70E-06	4.09	50.05	8.78
5:50	13225	34500	2880	1000	7.14	81.03	0.347	6.00E-04	6.00E-06	4.09	54.14	9.58
6:01	13425	35160	660	200	7.14	81.03	0.303	5.24E-04	5.24E-06	0.82	54.96	9.77

E20

Time	Vol(ml)	time	Δt (sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time
										ΔpV	Cumulative	t(Hours)
8:15:00 AM	0	0	0	-	7.14	81.03	-	-	-			
8:54:00 AM	620	2340	2340	620	7.14	81.03	0.265	4.58E-04	4.58E-06	2.62	2.62	0.65
9:16	1000	3660	1320	380	7.14	81.03	0.288	4.98E-04	4.98E-06	1.61	4.23	1.02
10:29	2000	8040	4380	1000	7.14	81.03	0.228	3.95E-04	3.95E-06	4.23	8.46	2.23
11:17	2760	10920	2880	760	7.14	81.03	0.264	4.56E-04	4.56E-06	3.21	11.67	3.03
11:33	3000	11880	960	240	7.14	81.03	0.250	4.32E-04	4.32E-06	1.01	12.68	3.30
12:44	4000	16140	4260	1000	7.14	81.03	0.235	4.06E-04	4.06E-06	4.23	16.91	4.48
1:32	4550	19020	2880	550	7.14	81.03	0.191	3.30E-04	3.30E-06	2.33	19.24	5.28
2:07	5000	21120	2100	450	7.14	81.03	0.214	3.70E-04	3.70E-06	1.90	21.14	5.87
3:05	6000	24600	3480	1000	7.14	81.03	0.287	4.97E-04	4.97E-06	4.23	25.37	6.83
4:18	7000	28980	4380	1000	7.14	81.03	0.228	3.95E-04	3.95E-06	4.23	29.60	8.05
5:40	8000	33900	4920	1000	7.14	81.03	0.203	3.51E-04	3.51E-06	4.23	33.83	9.42
6:45	8750	37800	3900	750	7.14	81.03	0.192	3.32E-04	3.32E-06	3.17	37.00	10.50
7:31	9250	41160	3360	500	7.14	81.03	0.149	2.57E-04	2.57E-06	2.11	39.11	11.43
8:38	10250	45180	4020	1000	7.14	81.03	0.249	4.30E-04	4.30E-06	4.23	43.34	12.55
9:48	11250	49380	4200	1000	7.14	81.03	0.238	4.12E-04	4.12E-06	4.23	47.57	13.72
11:09	12250	54240	4860	1000	7.14	81.03	0.206	3.56E-04	3.56E-06	4.23	51.80	15.07
11:27	12450	55320	1080	200	7.14	81.03	0.185	3.20E-04	3.20E-06	0.85	52.64	15.37
1:17	13450	58200	2880	1000	7.14	81.03	0.347	6.00E-04	6.00E-06	4.23	56.87	16.17

Blended Refuse (F13-F14) without geotextile

F13- Hydraulic Conductivity														
Time	**Vol(ml)**	**Δt (sec)**	**Δt (min)**	**Cum. t(sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/27/09 8:50	0				-	15	81.03	-	-	-				
7/27/09 9:48	280	3480	0:58:00	3480.00	280	15	81.03	0.08	6.62E-05	6.62E-07	1.06	1.06	0.96667	0.97
7/27/09 10:55	580	4020	1:07:00	7500.00	300	15	81.03	0.07	6.14E-05	6.14E-07	1.13	2.19	2.08333	3.05
7/27/09 11:28	720	1980	0:33:00	9480.00	140	15	81.03	0.07	5.82E-05	5.82E-07	0.53	2.72	2.63333	5.68
7/27/09 11:55	835	1620	0:27:00	11100.00	115	15	81.03	0.07	5.84E-05	5.84E-07	0.43	3.15	3.08333	8.77
7/27/09 12:48	1049	3180	0:53:00	14280.00	214	15	81.03	0.07	5.54E-05	5.54E-07	0.81	3.96	3.96667	12.73
7/27/09 13:06	1329	1080	0:18:00	15360.00	280	15	81.03	0.26	2.13E-04	2.13E-06	1.06	5.01	4.26667	17.00
7/27/09 14:35	1429	5340	1:29:00	20700.00	100	15	81.03	0.02	1.54E-05	1.54E-07	0.38	5.39	5.75000	22.75
7/27/09 15:00	1525	1500	0:25:00	22200.00	96	15	81.03	0.06	5.27E-05	5.27E-07	0.36	5.75	6.16667	28.92
7/27/09 15:38	1659	2280	0:38:00	22980.00	134	15	81.03	0.06	4.84E-05	4.84E-07	0.51	5.89	6.38333	35.30
7/27/09 17:19	2044	6060	1:41:00	29040.00	385	15	81.03	0.06	5.23E-05	5.23E-07	1.45	7.35	8.06667	43.37
7/27/09 17:44	2117	1500	0:25:00	30540.00	73	15	81.03	0.05	4.00E-05	4.00E-07	0.28	7.62	8.48333	51.85
7/27/09 21:11	2857	12420	3:27:00	42960.00	740	15	81.03	0.06	4.90E-05	4.90E-07	2.79	10.41	11.93333	63.78

F14- Hydraulic Conductivity

Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	$\Delta V(cm^3)$	i	$Area(cm^2)$	$q_{out}(cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/27/09 8:50	0				-	15	81.03	-	-	-				
7/27/09 9:48	150	3480	0:58:00	3480.00	150	15	81.03	0.04	3.55E-05	3.55E-07	0.57	0.57	0.96667	0.97
7/27/09 10:56	325	4080	1:08:00	7560.00	175	15	81.03	0.04	3.53E-05	3.53E-07	0.67	1.24	2.10000	3.07
7/27/09 11:28	410	1920	0:32:00	9480.00	85	15	81.03	0.04	3.64E-05	3.64E-07	0.32	1.57	2.63333	5.70
7/27/09 11:55	480	1620	0:27:00	11100.00	70	15	81.03	0.04	3.56E-05	3.56E-07	0.27	1.83	3.08333	8.78
7/27/09 12:53	630	3480	0:58:00	14580.00	150	15	81.03	0.04	3.55E-05	3.55E-07	0.57	2.41	4.05000	12.83
7/27/09 13:07	820	840	0:14:00	15420.00	190	15	81.03	0.23	1.86E-04	1.86E-06	0.73	3.13	4.28333	17.12
7/27/09 14:36	880	5340	1:29:00	20760.00	60	15	81.03	0.01	9.24E-06	9.24E-08	0.23	3.36	5.76667	22.88
7/27/09 15:00	950	1440	0:24:00	22200.00	70	15	81.03	0.05	4.00E-05	4.00E-07	0.27	3.63	6.16667	29.05
7/27/09 15:38	1042	2280	0:38:00	23040.00	92	15	81.03	0.04	3.32E-05	3.32E-07	0.35	3.71	6.40000	35.45
7/27/09 17:19	1320	6060	1:41:00	29100.00	278	15	81.03	0.05	3.77E-05	3.77E-07	1.06	4.78	8.08333	43.53
7/27/09 17:44	1374	1500	0:25:00	30600.00	54	15	81.03	0.04	2.96E-05	2.96E-07	0.21	4.98	8.50000	52.03
7/27/09 21:12	1986	12480	3:28:00	43080.00	612	15	81.03	0.05	4.03E-05	4.03E-07	2.34	7.32	11.96667	64.00
7/28/09 6:57	3921	35100	9:45:00	78180.00	1935	15	81.03	0.06	4.54E-05	4.54E-07	7.40	14.72	21.71667	85.72
7/28/09 8:36	4271	5940	1:39:00	84120.00	350	15	81.03	0.06	4.85E-05	4.85E-07	1.34	16.06	23.36667	109.08

Blended refuse with geotextile

Blended Refuse (F4-F6)

Hydraulic Conductivity with Fabric														
Sample- F4 : Test Started on 7/9/09 at 7:11 A.M.-7/17/09 10:51 P.M.														
Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/9/09 7:11	0				-	32.50	81.03	-	-	-				
7/9/09 11:00	81	13740	3:49:00	13740.00	81	32.50	81.03	0.0059	2.24E-06	2.24E-08	0.32	0.32	3.82	3.82
7/9/09 12:05	105	3900	1:05:00	17640.00	24	32.50	81.03	0.0062	2.34E-06	2.34E-08	0.10	0.42	4.90	8.72
7/9/09 13:00	125	3300	0:55:00	20940.00	20	32.50	81.03	0.0061	2.30E-06	2.30E-08	0.08	0.50	5.82	14.53
7/9/09 14:00	150	3600	1:00:00	24540.00	25	32.50	81.03	0.0069	2.64E-06	2.64E-08	0.10	0.60	6.82	21.35
7/9/09 15:45	180	6300	1:45:00	30840.00	30	32.50	81.03	0.0048	1.81E-06	1.81E-08	0.12	0.72	8.57	29.92
7/10/09 7:45	480	57600	16:00:00	88440.00	300	32.50	81.03	0.0052	1.98E-06	1.98E-08	1.20	1.92	24.57	54.48
7/10/09 11:00	532	11700	3:15:00	100140.00	52	32.50	81.03	0.0044	1.69E-06	1.69E-08	0.21	2.13	27.82	82.30
7/10/09 13:04	560	7440	2:04:00	107580.00	28	32.50	81.03	0.0038	1.43E-06	1.43E-08	0.11	2.24	29.88	112.18
7/10/09 16:29	625	12300	3:25:00	119880.00	65	32.50	81.03	0.0053	2.01E-06	2.01E-08	0.26	2.50	33.30	145.48
7/10/09 17:21	638	3120	0:52:00	123000.00	13	32.50	81.03	0.0042	1.58E-06	1.58E-08	0.05	2.55	34.17	179.65
7/11/09 20:30	1056	97740	27:09:00	220740.00	418	32.50	81.03	0.0043	1.62E-06	1.62E-08	1.67	4.22	61.32	240.97
7/12/09 16:01	1271	70260	19:31:00	291000.00	215	32.50	81.03	0.0031	1.16E-06	1.16E-08	0.86	5.08	80.83	321.80
7/12/09 23:12	1438	25860	7:11:00	316860.00	167	32.50	81.03	0.0065	2.45E-06	2.45E-08	0.67	5.75	88.02	409.82
7/13/09 7:40	1558	30480	8:28:00	347340.00	120	32.50	81.03	0.0039	1.49E-06	1.49E-08	0.48	6.23	96.48	506.30
7/13/09 12:36	1638	17760	4:56:00	365100.00	80	32.50	81.03	0.0045	1.71E-06	1.71E-08	0.32	6.55	101.42	607.72
7/13/09 15:06	1678	9000	2:30:00	374100.00	40	32.50	81.03	0.0044	1.69E-06	1.69E-08	0.16	6.71	103.92	711.63
7/13/09 17:15	1708	7740	2:09:00	381840.00	30	32.50	81.03	0.0039	1.47E-06	1.47E-08	0.12	6.83	106.07	817.70
7/14/09 7:27	1938	51120	14:12:00	432960.00	230	32.50	81.03	0.0045	1.71E-06	1.71E-08	0.92	7.75	120.27	937.97
7/14/09 11:15	1996	13680	3:48:00	446640.00	58	32.50	81.03	0.0042	1.61E-06	1.61E-08	0.23	7.98	124.07	1062.03
7/14/09 12:20	2008	3900	1:05:00	450540.00	12	32.50	81.03	0.0031	1.17E-06	1.17E-08	0.05	8.03	125.15	1187.18
7/14/09 16:01	2068	13260	3:41:00	463800.00	60	32.50	81.03	0.0045	1.72E-06	1.72E-08	0.24	8.27	128.83	1316.02
7/14/09 20:54	2147	17580	4:53:00	481380.00	79	32.50	81.03	0.0045	1.71E-06	1.71E-08	0.32	8.59	133.72	1449.73
7/15/09 7:41	2312	38820	10:47:00	520200.00	165	32.50	81.03	0.0043	1.61E-06	1.61E-08	0.66	9.25	144.50	1594.23
7/15/09 10:57	2365	11760	3:16:00	531960.00	53	32.50	81.03	0.0045	1.71E-06	1.71E-08	0.21	9.46	147.77	1742.00
7/15/09 14:06	2415	11340	3:09:00	543300.00	50	32.50	81.03	0.0044	1.67E-06	1.67E-08	0.20	9.66	150.92	1892.92
7/15/09 15:12	2428	3960	1:06:00	547260.00	13	32.50	81.03	0.0033	1.25E-06	1.25E-08	0.05	9.71	152.02	2044.93
7/15/09 16:44	2455	5520	1:32:00	552780.00	27	32.50	81.03	0.0049	1.86E-06	1.86E-08	0.11	9.82	153.55	2198.48
7/16/09 7:41	2737	53820	14:57:00	606600.00	282	32.50	81.03	0.0052	1.99E-06	1.99E-08	1.13	10.95	168.50	2366.98
7/16/09 11:23	2752	13320	3:42:00	619920.00	15	32.50	81.03	0.0011	4.28E-07	4.28E-09	0.06	11.01	172.20	2539.18
7/16/09 13:05	2782	6120	1:42:00	626040.00	30	32.50	81.03	0.0049	1.86E-06	1.86E-08	0.12	11.13	173.90	2713.08
7/16/09 16:51	2842	13560	3:46:00	639600.00	60	32.50	81.03	0.0044	1.68E-06	1.68E-08	0.24	11.37	177.67	2890.75
7/17/09 9:18	3117	59220	16:27:00	698820.00	275	32.50	81.03	0.0046	1.76E-06	1.76E-08	1.10	12.47	194.12	3084.87
7/17/09 10:51	3147	5580	1:33:00	704400.00	30	32.50	81.03	0.0054	2.04E-06	2.04E-08	0.12	12.59	195.67	3280.53

Hydraulic Conductivity with Fabric

Sample- F5 : Test Started on 7/09/09 at 7:11 A.M.

Time	Vol(ml)	Δt (sec)	Δt (min)	t(sec)	$\Delta V (cm^3)$	i	$Area (cm^2)$	$q_{out} (cm^3/sec)$	k (cm/sec)	k(m/sec)	Pore Volume		Time
											ΔpV	Cumulative	t(Hours)
7/9/09 7:11	0				-	32.5	81.03	-	-	-			
7/9/09 11:00	59	13740	3:49:00	13740	59	32.5	81.03	0.0043	1.63E-06	1.63E-08	0.26	0.26	3.82
7/9/09 12:05	80	3900	1:05:00	17640	21	32.5	81.03	0.0054	2.04E-06	2.04E-08	0.09	0.36	4.90
7/9/09 13:00	90	3300	0:55:00	20940	10	32.5	81.03	0.0030	1.15E-06	1.15E-08	0.04	0.40	5.82
7/9/09 14:00	105	3600	1:00:00	24540	15	32.5	81.03	0.0042	1.58E-06	1.58E-08	0.07	0.47	6.82
7/9/09 15:45	130	6300	1:45:00	30840	25	32.5	81.03	0.0040	1.51E-06	1.51E-08	0.11	0.58	8.57
7/10/09 7:45	340	57600	16:00:00	88440	210	32.5	81.03	0.0036	1.38E-06	1.38E-08	0.94	1.52	24.57
7/10/09 11:01	378	11760	3:16:00	100200	38	32.5	81.03	0.0032	1.23E-06	1.23E-08	0.17	1.69	27.83
7/10/09 13:04	400	7380	2:03:00	107580	22	32.5	81.03	0.0030	1.13E-06	1.13E-08	0.10	1.79	29.88
7/10/09 16:29	442	12300	3:25:00	119880	42	32.5	81.03	0.0034	1.30E-06	1.30E-08	0.19	1.98	33.30
7/10/09 17:29	452	3600	1:00:00	123480	10	32.5	81.03	0.0028	1.05E-06	1.05E-08	0.04	2.03	34.30
7/11/09 20:30	767	97260	27:01:00	220740	315	32.5	81.03	0.0032	1.23E-06	1.23E-08	1.41	3.44	61.32
7/12/09 16:02	997	70320	19:32:00	291060	230	32.5	81.03	0.0033	1.24E-06	1.24E-08	1.03	4.47	80.85
7/12/09 23:12	1082	25800	7:10:00	316860	85	32.5	81.03	0.0033	1.25E-06	1.25E-08	0.38	4.85	88.02
7/13/09 7:40	1187	30480	8:28:00	347340	105	32.5	81.03	0.0034	1.31E-06	1.31E-08	0.47	5.32	96.48
7/13/09 12:37	1242	17820	4:57:00	365160	55	32.5	81.03	0.0031	1.17E-06	1.17E-08	0.25	5.56	101.43
7/13/09 15:06	1272	8940	2:29:00	374100	30	32.5	81.03	0.0034	1.27E-06	1.27E-08	0.13	5.70	103.92
7/13/09 17:15	1300	7740	2:09:00	381840	28	32.5	81.03	0.0036	1.37E-06	1.37E-08	0.13	5.82	106.07
7/14/09 7:28	1462	51180	14:13:00	433020	162	32.5	81.03	0.0032	1.20E-06	1.20E-08	0.73	6.55	120.28
7/14/09 11:16	1502	13680	3:48:00	446700	40	32.5	81.03	0.0029	1.11E-06	1.11E-08	0.18	6.73	124.08
7/14/09 12:21	1512	3900	1:05:00	450600	10	32.5	81.03	0.0026	9.74E-07	9.74E-09	0.04	6.77	125.17
7/14/09 16:02	1552	13260	3:41:00	463860	40	32.5	81.03	0.0030	1.15E-06	1.15E-08	0.18	6.95	128.85
7/14/09 20:56	1607	17640	4:54:00	481500	55	32.5	81.03	0.0031	1.18E-06	1.18E-08	0.25	7.20	133.75
7/15/09 7:42	1727	38760	10:46:00	520260	120	32.5	81.03	0.0031	1.18E-06	1.18E-08	0.54	7.74	144.52
7/15/09 10:58	1772	11760	3:16:00	532020	45	32.5	81.03	0.0038	1.45E-06	1.45E-08	0.20	7.94	147.78
7/15/09 14:07	1802	11340	3:09:00	543360	30	32.5	81.03	0.0026	1.00E-06	1.00E-08	0.13	8.07	150.93
7/15/09 15:12	1812	3900	1:05:00	547260	10	32.5	81.03	0.0026	9.74E-07	9.74E-09	0.04	8.12	152.02
7/15/09 16:44	1832	5520	1:32:00	552780	20	32.5	81.03	0.0036	1.38E-06	1.38E-08	0.09	8.21	153.55
7/16/09 7:41	2002	53820	14:57:00	606600	170	32.5	81.03	0.0032	1.20E-06	1.20E-08	0.76	8.97	168.50
7/16/09 11:24	2042	13380	3:43:00	619980	40	32.5	81.03	0.0030	1.14E-06	1.14E-08	0.18	9.15	172.22
7/16/09 13:05	2062	6060	1:41:00	626040	20	32.5	81.03	0.0033	1.25E-06	1.25E-08	0.09	9.24	173.90
7/16/09 16:51	2112	13560	3:46:00	639600	50	32.5	81.03	0.0037	1.40E-06	1.40E-08	0.22	9.46	177.67
7/17/09 10:58	2324	65220	18:07:00	704820	212	32.5	81.03	0.0033	1.23E-06	1.23E-08	0.95	10.41	195.78

Hydraulic Conductivity with Fabric													
Sample- F6 : Test Started on 7/9/09 at 7:11 A.M.													
Time	**Vol(ml)**	**Δt (sec)**	**Δt (min)**	**t(sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		Time
											ΔpV	Cumulative	t(Hours)
7/9/09 7:11	0				-	32.5	81.03	-	-	-	-	-	-
7/9/09 11:00	38	13740	3:49:00	13740.00	38	32.5	81.03	0.0028	1.05E-06	1.05E-08	0.17	0.17	3.82
7/9/09 12:07	50	4020	1:07:00	17760.00	12	32.5	81.03	0.0030	1.13E-06	1.13E-08	0.05	0.22	4.93
7/9/09 13:00	53	3180	0:53:00	20940.00	3	32.5	81.03	0.0009	3.58E-07	3.58E-09	0.01	0.23	5.82
7/9/09 14:00	63	3600	1:00:00	24540.00	10	32.5	81.03	0.0028	1.05E-06	1.05E-08	0.04	0.28	6.82
7/9/09 15:45	83	6300	1:45:00	30840.00	20	32.5	81.03	0.0032	1.21E-06	1.21E-08	0.09	0.36	8.57
7/10/09 7:45	230	57600	16:00:00	88440.00	147	32.5	81.03	0.0026	9.69E-07	9.69E-09	0.64	1.01	24.57
7/10/09 11:01	262	11760	3:16:00	100200.00	32	32.5	81.03	0.0027	1.03E-06	1.03E-08	0.14	1.15	27.83
7/10/09 13:04	280	7380	2:03:00	107580.00	18	32.5	81.03	0.0024	9.26E-07	9.26E-09	0.08	1.23	29.88
7/10/09 16:29	310	12300	3:25:00	119880.00	30	32.5	81.03	0.0024	9.26E-07	9.26E-09	0.13	1.36	33.30
7/10/09 17:22	320	3180	0:53:00	123060.00	10	32.5	81.03	0.0031	1.19E-06	1.19E-08	0.04	1.40	34.18
7/11/09 20:30	560	97680	27:08:00	220740.00	240	32.5	81.03	0.0025	9.33E-07	9.33E-09	1.05	2.45	61.32
7/12/09 16:03	730	70380	19:33:00	291120.00	170	32.5	81.03	0.0024	9.17E-07	9.17E-09	0.74	3.20	80.87
7/12/09 23:17	798	26040	7:14:00	317160.00	68	32.5	81.03	0.0026	9.92E-07	9.92E-09	0.30	3.50	88.10
7/13/09 7:41	870	30240	8:24:00	347400.00	72	32.5	81.03	0.0024	9.04E-07	9.04E-09	0.32	3.81	96.50
7/13/09 12:38	912	17820	4:57:00	365220.00	42	32.5	81.03	0.0024	8.95E-07	8.95E-09	0.18	4.00	101.45
7/13/09 15:07	935	8940	2:29:00	374160.00	23	32.5	81.03	0.0026	9.77E-07	9.77E-09	0.10	4.10	103.93
7/13/09 17:16	955	7740	2:09:00	381900.00	20	32.5	81.03	0.0026	9.81E-07	9.81E-09	0.09	4.18	106.08
7/14/09 7:29	1075	51180	14:13:00	433080.00	120	32.5	81.03	0.0023	8.90E-07	8.90E-09	0.53	4.71	120.30
7/14/09 11:16	1107	13620	3:47:00	446700.00	32	32.5	81.03	0.0023	8.92E-07	8.92E-09	0.14	4.85	124.08
7/14/09 12:32	1115	4560	1:16:00	451260.00	8	32.5	81.03	0.0018	6.66E-07	6.66E-09	0.04	4.89	125.35
7/14/09 16:05	1145	12780	3:33:00	464040.00	30	32.5	81.03	0.0023	8.91E-07	8.91E-09	0.13	5.02	128.90
7/14/09 20:56	1185	17460	4:51:00	481500.00	40	32.5	81.03	0.0023	8.70E-07	8.70E-09	0.18	5.19	133.75
7/15/09 7:42	1274	38760	10:46:00	520260.00	89	32.5	81.03	0.0023	8.72E-07	8.72E-09	0.39	5.58	144.52
7/15/09 10:58	1300	11760	3:16:00	532020.00	26	32.5	81.03	0.0022	8.40E-07	8.40E-09	0.11	5.70	147.78
7/15/09 14:07	1323	11340	3:09:00	543360.00	23	32.5	81.03	0.0020	7.70E-07	7.70E-09	0.10	5.80	150.93
7/15/09 16:13	1330	7560	2:06:00	550920.00	7	32.5	81.03	0.0009	3.52E-07	3.52E-09	0.03	5.83	153.03
7/15/09 16:44	1344	1860	0:31:00	552780.00	14	32.5	81.03	0.0075	2.86E-06	2.86E-08	0.06	5.89	153.55
7/16/09 7:41	1465	53820	14:57:00	606600.00	121	32.5	81.03	0.0022	8.54E-07	8.54E-09	0.53	6.42	168.50
7/16/09 11:24	1493	13380	3:43:00	619980.00	28	32.5	81.03	0.0021	7.95E-07	7.95E-09	0.12	6.54	172.22
7/16/09 13:06	1505	6120	1:42:00	626100.00	12	32.5	81.03	0.0020	7.45E-07	7.45E-09	0.05	6.59	173.92
7/16/09 16:51	1535	13500	3:45:00	639600.00	30	32.5	81.03	0.0022	8.44E-07	8.44E-09	0.13	6.73	177.67
7/17/09 10:57	1675	65160	18:06:00	704760.00	140	32.5	81.03	0.0021	8.16E-07	8.16E-09	0.61	7.34	195.77

Blended Refuse (F7-F9)

Hydraulic Conductivity with Fabric														
Sample- F7 : Test Started on 7/20/09 at 11:40 A.M.														
Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/20/09 11:40	0				-	15	81.03	-	-	-				
7/20/09 11:50	245	600.00	0:10:00	600.00	245	15	81.03	0.41	3.36E-04	3.36E-06	0.89	0.89	0.17	0.17
7/20/09 12:10	755	1200	0:20:00	1800.00	510	15	81.03	0.43	3.50E-04	3.50E-06	1.85	2.74	0.50	0.67
7/20/09 12:40	1470	1800	0:30:00	3600.00	715	15	81.03	0.40	3.27E-04	3.27E-06	2.59	5.33	1.00	1.67
7/20/09 13:00	2470	1200	0:20:00	4800.00	1000	15	81.03	0.83	6.86E-04	6.86E-06	3.62	8.95	1.33	3.00
7/20/09 13:45	3495	2700	0:45:00	7500.00	1025	15	81.03	0.38	3.12E-04	3.12E-06	3.71	12.66	2.08	5.08
7/20/09 14:10	3995	1500	0:25:00	9000.00	500	15	81.03	0.33	2.74E-04	2.74E-06	1.81	14.47	2.50	7.58
7/20/09 14:36	4495	1560	0:26:00	10560.00	500	15	81.03	0.32	2.64E-04	2.64E-06	1.81	16.28	2.93	10.52
7/20/09 14:40	4495				-	15	81.03	-	-	-				
7/20/09 15:15	5265	2100	0:35:00	12660.00	770	15	81.03	0.37	3.02E-04	3.02E-06	2.79	19.07	3.52	3.52
7/20/09 15:25	5495	600	0:10:00	13260.00	230	15	81.03	0.38	3.15E-04	3.15E-06	0.83	19.91	3.68	7.20
7/20/09 16:11	6495	2760	0:46:00	16020.00	1000	15	81.03	0.36	2.98E-04	2.98E-06	3.62	23.53	4.45	11.65
7/20/09 16:58	7495	2820	0:47:00	18840.00	1000	15	81.03	0.35	2.92E-04	2.92E-06	3.62	27.15	5.23	16.88
7/20/09 17:45	8495	2820	0:47:00	21660.00	1000	15	81.03	0.35	2.92E-04	2.92E-06	3.62	30.78	6.02	22.90
7/20/09 18:01	8887	960.00	0:16:00	22620.00	392	15	81.03	0.41	3.36E-04	3.36E-06	1.42	32.20	6.28	29.18

Hydraulic Conductivity with Fabric													
Sample- F8 : Test Started on 7/20/09 at 11:40 A.M.													
Time	Vol(ml)	Δt (sec)	Δt (min)	t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time
											ΔpV	Cumulative	t(Hours)
7/20/09 11:40	0				-	15	81.03	-	-	-			
7/20/09 11:50	450	600.00	0:10:00	600.00	450	15	81.03	0.75	6.17E-04	6.17E-06	1.36	1.36	0.17
7/20/09 12:00	890	1200	0:10:00	1800.00	440	15	81.03	0.37	3.02E-04	3.02E-06	1.33	2.69	0.50
7/20/09 12:15	1530	1800	0:15:00	3600.00	640	15	81.03	0.36	2.93E-04	2.93E-06	1.94	4.63	1.00
7/20/09 12:40	3090	1200	0:25:00	4800.00	1560	15	81.03	1.30	1.07E-03	1.07E-05	4.72	9.35	1.33
7/20/09 12:53	3560	2700	0:13:00	7500.00	470	15	81.03	0.17	1.43E-04	1.43E-06	1.42	10.77	2.08
7/20/09 13:10	4250	1500	0:17:00	9000.00	690	15	81.03	0.46	3.78E-04	3.78E-06	2.09	12.86	2.50
7/20/09 13:35	4950	1560	0:25:00	10560.00	700	15	81.03	0.45	3.69E-04	3.69E-06	2.12	14.97	2.93
7/20/09 13:45	4950	-	-	-	-	15	81.03	-	-	-	-	-	-
7/20/09 13:50	5130	300	0:05:00	10860.00	180	15	81.03	0.60	4.94E-04	4.94E-06	0.54	15.52	3.02
7/20/09 14:10	5810	1200	0:20:00	12060.00	680	15	81.03	0.57	4.66E-04	4.66E-06	2.06	17.58	3.35
7/20/09 14:42	6980	2760	0:32:00	14820.00	1170	15	81.03	0.42	3.49E-04	3.49E-06	3.54	21.12	4.12
7/20/09 15:12	7980	2820	0:30:00	17640.00	1000	15	81.03	0.35	2.92E-04	2.92E-06	3.03	24.14	4.90
7/20/09 15:44	8980	2820	0:47:00	20460.00	1000	15	81.03	0.35	2.92E-04	2.92E-06	3.03	27.17	5.68
7/20/09 15:50	9180	360	0:06:00	20820.00	200	15	81.03	0.56	4.57E-04	4.57E-06	0.61	27.77	5.78
7/20/09 15:55	9180	-	-	-	-	15	81.03	-	-	-	-	-	-
7/20/09 16:11	10180	960	0:16:00	21780.00	1000	15	81.03	1.04	8.57E-04	8.57E-06	3.03	30.80	6.05
7/20/09 16:40	11265	1740	0:29:00	23520.00	1085	15	81.03	0.62	5.13E-04	5.13E-06	3.28	34.08	6.53
7/20/09 17:35	13265	3300	0:55:00	26820.00	2000	15	81.03	0.61	4.99E-04	4.99E-06	6.05	40.13	7.45
7/20/09 17:46	13685	660	0:11:00	27480.00	420	15	81.03	0.64	5.24E-04	5.24E-06	1.27	41.40	7.63

Hydraulic Conductivity with Fabric

Sample- F9 : Test Started on 7/20/09 at 11:40 A.M.

Time	Vol(ml)	Δt (sec)	Δt (min)	t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/20/09 11:40	0				-	15	81.03	-	-	-	-	-	-	-
7/20/09 11:51	218	660.00	0:11:00	660.00	218	15	81.03	0.33	2.72E-04	2.72E-06	0.69	0.69	0.18	0.18
7/20/09 12:11	700	1200	0:20:00	1860.00	482	15	81.03	0.40	3.30E-04	3.30E-06	1.52	2.20	0.52	0.70
7/20/09 12:40	1390	1740	0:29:00	3600.00	690	15	81.03	0.40	3.26E-04	3.26E-06	2.17	4.37	1.00	1.70
7/20/09 13:07	2390	1620	0:27:00	5220.00	1000	15	81.03	0.62	5.08E-04	5.08E-06	3.15	7.52	1.45	3.15
7/20/09 13:55	3390	2880	0:48:00	8100.00	1000	15	81.03	0.35	2.86E-04	2.86E-06	3.15	10.67	2.25	5.40
7/20/09 14:10	3690	900	0:15:00	9000.00	300	15	81.03	0.33	2.74E-04	2.74E-06	0.94	11.61	2.50	7.90
7/20/09 14:49	4390	2340	0:39:00	11340.00	700	15	81.03	0.30	2.46E-04	2.46E-06	2.20	13.81	3.15	11.05
7/20/09 15:00	4570	660	0:11:00	12000.00	180	15	81.03	0.27	2.24E-04	2.24E-06	0.57	14.38	3.33	14.38
7/20/09 15:02	4570	-	-	-	-	15	81.03	-	-	-	-	-	-	-
7/20/09 15:14	4745	720	0:12:00	12720.00	175	15	81.03	0.24	2.00E-04	2.00E-06	0.55	14.93	3.53	17.92
7/20/09 16:02	5765	2880	0:48:00	15600.00	1020	15	81.03	0.35	2.91E-04	2.91E-06	3.21	18.14	4.33	22.25
7/20/09 16:54	6765	3120	0:52:00	18720.00	1000	15	81.03	0.32	2.64E-04	2.64E-06	3.15	21.29	5.20	27.45
7/20/09 17:54	7765	3600	1:00:00	22320.00	1000	15	81.03	0.28	2.29E-04	2.29E-06	3.15	24.43	6.20	33.65
7/20/09 18:01	8005	420.00	0:07:00	22740.00	240	15	81.03	0.57	4.70E-04	4.70E-06	0.76	25.19	6.32	39.97
7/20/09 18:16	8255	900	0:15:00	23640.00	250	15	81.03	0.28	2.29E-04	2.29E-06	0.79	25.98	6.57	46.53
7/20/09 18:39	8670	1380	0:23:00	25020.00	415	15	81.03	0.30	2.47E-04	2.47E-06	1.31	27.28	6.95	53.48
7/20/09 19:01	9050	1320	0:22:00	26340.00	380	15	81.03	0.29	2.37E-04	2.37E-06	1.20	28.48	7.32	60.80

Blended Refuse (F10-F12)

F10														
Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/23/09 12:28	0				-	15	81.03	-	-	-				
7/23/09 12:58	230	1800	0:30:00	1800.00	230	15	81.03	0.13	1.05E-04	1.05E-06	0.76	0.76	0.50	0.50
7/23/09 13:28	460	1800	0:30:00	3600.00	230	15	81.03	0.13	1.05E-04	1.05E-06	0.76	1.52	1.00	1.00
7/23/09 13:43	595	900	0:15:00	4500.00	135	15	81.03	0.15	1.23E-04	1.23E-06	0.45	1.97	1.25	1.25
7/23/09 13:58	720	900	0:15:00	5400.00	125	15	81.03	0.14	1.14E-04	1.14E-06	0.41	2.39	1.50	1.50
7/23/09 14:13	850	900	0:15:00	6300.00	130	15	81.03	0.14	1.19E-04	1.19E-06	0.43	2.82	1.75	1.75
7/23/09 14:28	960	900	0:15:00	7200.00	110	15	81.03	0.12	1.01E-04	1.01E-06	0.36	3.18	2.00	2.00
7/23/09 15:00	1182	1920	0:32:00	9120.00	222	15	81.03	0.12	9.51E-05	9.51E-07	0.74	3.92	2.53	2.53
7/23/09 15:17	1320	1020	0:17:00	10140.00	138	15	81.03	0.14	1.11E-04	1.11E-06	0.46	4.38	2.82	2.82
7/23/09 15:44	1490	1620	0:27:00	11760.00	170	15	81.03	0.10	8.63E-05	8.63E-07	0.56	4.48	3.27	3.27
7/23/09 16:55	1898	4260	1:11:00	16020.00	408	15	81.03	0.10	7.88E-05	7.88E-07	1.35	5.83	4.45	4.45
7/23/09 17:20	2040	1500	0:25:00	17520.00	142	15	81.03	0.09	7.79E-05	7.79E-07	0.47	6.30	4.87	4.87
7/23/09 17:50	2170	1800	0:30:00	19320.00	130	15	81.03	0.07	5.94E-05	5.94E-07	0.43	6.74	5.37	5.37
7/23/09 18:12	2275	1320	0:22:00	20640.00	105	15	81.03	0.08	6.54E-05	6.54E-07	0.35	7.08	5.73	5.73
7/23/09 19:13	2585	3660.00	1:01:00	24300.00	310	15	81.03	0.08	6.97E-05	6.97E-07	1.03	8.11	6.75	6.75
7/23/09 19:30	2665	1020	0:17:00	25320.00	80	15	81.03	0.08	6.45E-05	6.45E-07	0.27	8.38	7.03	7.03
7/23/09 19:53	2755	1380.00	0:23:00	26700.00	90	15	81.03	0.07	5.37E-05	5.37E-07	0.30	8.67	7.42	7.42
7/23/09 20:31	2940	2280	0:38:00	28980.00	185	15	81.03	0.08	6.68E-05	6.68E-07	0.61	9.29	8.05	8.05
7/23/09 20:43	2990	720.00	0:12:00	29700.00	50	15	81.03	0.07	5.71E-05	5.71E-07	0.17	9.45	8.25	8.25

F11

Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/23/09 12:28	0				-	15	81.03	-	-	-				
7/23/09 12:58	130	1800	0:30:00	1800.00	130	15	81.03	0.07	5.94E-05	5.94E-07	0.44	0.44	0.50	0.50
7/23/09 13:28	260	1800	0:30:00	3600.00	130	15	81.03	0.07	5.94E-05	5.94E-07	0.44	0.87	1.00	1.00
7/23/09 13:43	328	900	0:15:00	4500.00	68	15	81.03	0.08	6.22E-05	6.22E-07	0.23	1.10	1.25	1.25
7/23/09 13:58	400	900	0:15:00	5400.00	72	15	81.03	0.08	6.58E-05	6.58E-07	0.24	1.34	1.50	1.50
7/23/09 14:13	470	900	0:15:00	6300.00	70	15	81.03	0.08	6.40E-05	6.40E-07	0.23	1.58	1.75	1.75
7/23/09 14:28	535	900	0:15:00	7200.00	65	15	81.03	0.07	5.94E-05	5.94E-07	0.22	1.79	2.00	2.00
7/23/09 15:00	665	1920	0:32:00	9120.00	130	15	81.03	0.07	5.57E-05	5.57E-07	0.44	2.23	2.53	2.53
7/23/09 15:17	740	1020	0:17:00	10140.00	75	15	81.03	0.07	6.05E-05	6.05E-07	0.25	2.48	2.82	2.82
7/23/09 15:46	840	1620	0:29:00	11760.00	100	15	81.03	0.06	5.08E-05	5.08E-07	0.34	2.57	3.27	3.27
7/23/09 16:56	1059	4260	1:10:00	16020.00	219	15	81.03	0.05	4.23E-05	4.23E-07	0.73	3.30	4.45	4.45
7/23/09 17:20	1140	1500	0:24:00	17520.00	81	15	81.03	0.05	4.44E-05	4.44E-07	0.27	3.57	4.87	4.87
7/23/09 17:50	1222	1800	0:30:00	19320.00	82	15	81.03	0.05	3.75E-05	3.75E-07	0.28	3.85	5.37	5.37
7/23/09 18:12	1320	1320	0:22:00	20640.00	98	15	81.03	0.07	6.11E-05	6.11E-07	0.33	4.18	5.73	5.73
7/23/09 19:14	1650	3660.00	1:02:00	24300.00	330	15	81.03	0.09	7.42E-05	7.42E-07	1.11	5.28	6.75	6.75
7/23/09 19:30	1735	1020	0:16:00	25320.00	85	15	81.03	0.08	6.86E-05	6.86E-07	0.29	5.57	7.03	7.03
7/23/09 19:49	1838	1380.00	0:19:00	26700.00	103	15	81.03	0.07	6.14E-05	6.14E-07	0.35	5.91	7.42	7.42
7/23/09 20:31	2053	2280	0:42:00	28980.00	215	15	81.03	0.09	7.76E-05	7.76E-07	0.72	6.63	8.05	8.05
7/23/09 20:44	2113	720.00	0:13:00	29700.00	60	15	81.03	0.08	6.86E-05	6.86E-07	0.20	6.83	8.25	8.25

F12														
Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	q_{out}(cm^3/sec)	k (cm/sec)	k(m/sec)	Pore Volume		Time	
											ΔpV	Cumulative	t(Hours)	t,Cumulative
7/23/09 12:28	0				-	15	81.03	-	-	-				
7/23/09 12:58	185	1800	0:30:00	1800.00	185	15	81.03	0.10	8.46E-05	8.46E-07	0.62	0.62	0.50	0.50
7/23/09 13:28	358	1800	0:30:00	3600.00	173	15	81.03	0.10	7.91E-05	7.91E-07	0.58	1.20	1.00	1.50
7/23/09 13:43	460	900	0:15:00	4500.00	102	15	81.03	0.11	9.32E-05	9.32E-07	0.34	1.55	1.25	2.75
7/23/09 13:58	550	900	0:15:00	5400.00	90	15	81.03	0.10	8.23E-05	8.23E-07	0.30	1.85	1.50	4.25
7/23/09 14:13	650	900	0:15:00	6300.00	100	15	81.03	0.11	9.14E-05	9.14E-07	0.34	2.19	1.75	6.00
7/23/09 14:28	755	900	0:15:00	7200.00	105	15	81.03	0.12	9.60E-05	9.60E-07	0.35	2.54	2.00	8.00
7/23/09 15:00	950	1920	0:32:00	9120.00	195	15	81.03	0.10	8.36E-05	8.36E-07	0.66	3.19	2.53	10.53
7/23/09 15:17	1070	1020	0:17:00	10140.00	120	15	81.03	0.12	9.68E-05	9.68E-07	0.40	3.60	2.82	13.35
7/23/09 15:47	1280	1800	0:30:00	11940.00	210	15	81.03	0.12	9.60E-05	9.60E-07	0.71	4.30	3.32	16.67
7/23/09 16:57	1815	4200	1:10:00	16140.00	535	15	81.03	0.13	1.05E-04	1.05E-06	1.80	6.10	4.48	21.15
7/23/09 17:21	1998	1440	0:24:00	17580.00	183	15	81.03	0.13	1.05E-04	1.05E-06	0.62	6.72	4.88	26.03
7/23/09 17:51	2160	1800	0:30:00	19380.00	162	15	81.03	0.09	7.40E-05	7.40E-07	0.54	7.26	5.38	31.42
7/23/09 18:11	2280	1200	0:20:00	20580.00	120	15	81.03	0.10	8.23E-05	8.23E-07	0.40	7.67	5.72	37.13
7/23/09 19:15	2670	3840.00	1:04:00	24420.00	390	15	81.03	0.10	8.36E-05	8.36E-07	1.31	8.98	6.78	43.92
7/23/09 19:30	2770	900	0:15:00	25320.00	100	15	81.03	0.11	9.14E-05	9.14E-07	0.34	9.31	7.03	50.95
7/23/09 19:50	3360	1200.00	0:20:00	26520.00	590	15	81.03	0.49	4.05E-04	4.05E-06	1.98	11.30	7.37	58.32
7/23/09 20:31	3598	2460	0:41:00	28980.00	238	15	81.03	0.10	7.96E-05	7.96E-07	0.80	12.10	8.05	66.37
7/23/09 20:44	3660	780.00	0:13:00	29760.00	62	15	81.03	0.08	6.54E-05	6.54E-07	0.21	12.31	8.27	74.63

Blended Refuse F15

Hydraulic Conductivity with Fabric															
Sample- F15: Test Started on 8/10/09 at 9:00 A.M.															
Time	**Vol(ml)**	**Δt (sec)**	**Δt (min)**	**Cum. t(sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		Time		
											ΔpV	Cumulative	t(Hours)	t,Cumulative	
8/10/09 9:00	0														
8/10/09 9:19	380	1140	0:19:00	1140.00	380	31	81.03	0.3333	1.33E-04	1.33E-06	1.19	1.19	0.32	0.32	Cell 1
8/10/09 9:30	580	660	0:11:00	1800.00	200	31	81.03	0.3030	1.21E-04	1.21E-06	0.63	1.82	0.50	0.82	
8/10/09 9:45	880	900	0:15:00	2700.00	300	31	81.03	0.3333	1.33E-04	1.33E-06	0.94	2.76	0.75	1.57	
8/10/09 10:00	1150	900	0:15:00	3600.00	270	31	81.03	0.3000	1.19E-04	1.19E-06	0.85	3.61	1.00	2.57	
8/10/09 10:15	1438	900	0:15:00	4500.00	288	31	81.03	0.3200	1.27E-04	1.27E-06	0.90	4.51	1.25	3.82	
8/10/09 10:31	1740	960	0:16:00	5460.00	302	31	81.03	0.3146	1.25E-04	1.25E-06	0.95	5.46	1.52	5.33	
8/10/09 10:45	1880	840	0:14:00	6300.00	140	31	81.03	0.1667	6.64E-05	6.64E-07	0.44	5.90	1.75	7.08	
8/10/09 11:05	2260	1200	0:20:00	7500.00	380	31	81.03	0.3167	1.26E-04	1.26E-06	1.19	7.09	2.08	9.17	
8/10/09 11:25	2620	1200	0:20:00	8700.00	360	31	81.03	0.3000	1.19E-04	1.19E-06	1.13	8.22	2.42	11.58	
8/10/09 11:38	2880	780	0:13:00	9480.00	260	31	81.03	0.3333	1.33E-04	1.33E-06	0.82	9.03	2.63	14.22	
8/10/09 12:00	3250	1320	0:22:00	10800.00	370	31	81.03	0.2803	1.12E-04	1.12E-06	1.16	10.19	3.00	17.22	
8/10/09 12:37	3880	2220	0:37:00	13020.00	630	31	81.03	0.2838	1.13E-04	1.13E-06	1.98	12.17	3.62	20.83	
8/10/09 12:39	3880														Cell 2
8/10/09 13:20	4100	2460	0:41:00	15480.00	220	31	81.03	0.0894	3.56E-05	3.56E-07	0.69	12.86	4.30	4.30	
8/10/09 13:58	4300	2280	0:38:00	17760.00	200	31	81.03	0.0877	3.49E-05	3.49E-07	0.63	13.48	4.93	9.23	
8/10/09 14:49	4560	3060	0:51:00	20820.00	260	31	81.03	0.0850	3.38E-05	3.38E-07	0.82	14.30	5.78	15.02	
8/10/09 15:26	4750	2220	0:37:00	23040.00	190	31	81.03	0.0856	3.41E-05	3.41E-07	0.60	14.89	6.40	21.42	
8/10/09 15:40	4820	840	0:14:00	23880.00	70	31	81.03	0.0833	3.32E-05	3.32E-07	0.22	15.11	6.63	28.05	
8/10/09 15:55	4880	900	0:15:00	24780.00	60	31	81.03	0.0667	2.65E-05	2.65E-07	0.19	15.30	6.88	34.93	
8/10/09 17:16	5310	4860	1:21:00	29640.00	430	31	81.03	0.0885	3.52E-05	3.52E-07	1.35	16.65	8.23	43.17	
8/10/09 17:44	5440	1680	0:28:00	31320.00	130	31	81.03	0.0774	3.08E-05	3.08E-07	0.41	17.06	8.70	51.87	
8/10/09 19:03	5840	4740	1:19:00	36060.00	400	31	81.03	0.0844	3.36E-05	3.36E-07	1.25	18.31	10.02	61.88	
8/10/09 22:20	6800	11820	3:17:00	47880.00	960	31	81.03	0.0812	3.23E-05	3.23E-07	3.01	21.32	13.30	75.18	
8/10/09 23:26	7120	3960	1:06:00	51840.00	320	31	81.03	0.0808	3.22E-05	3.22E-07	1.00	22.33	14.40	89.58	
8/10/09 23:53	7240	1620	0:27:00	53460.00	120	31	81.03	0.0741	2.95E-05	2.95E-07	0.38	22.70	14.85	104.43	
8/11/09 0:28	7400	2100	0:35:00	55560.00	160	31	81.03	0.0762	3.03E-05	3.03E-07	0.50	23.20	15.43	119.87	
8/11/09 1:00	7550	1920	0:32:00	57480.00	150	31	81.03	0.0781	3.11E-05	3.11E-07	0.47	23.67	15.97	135.83	
8/11/09 1:39	7675	2340	0:39:00	59820.00	125	31	81.03	0.0534	2.13E-05	2.13E-07	0.39	24.07	16.62	152.45	
8/11/09 2:05	7840	1560	0:26:00	61380.00	165	31	81.03	0.1058	4.21E-05	4.21E-07	0.52	24.58	17.05	169.50	
8/11/09 2:34	7990	1740	0:29:00	63120.00	150	31	81.03	0.0862	3.43E-05	3.43E-07	0.47	25.05	17.53	187.03	
8/11/09 2:39	7990														Cell 3
8/11/09 7:13	8690	16440	4:34:00	79560.00	700	31	81.03	0.0426	1.70E-05	1.70E-07	2.19	27.25	22.10	209.13	
8/11/09 8:25	8870	4320	1:12:00	83880.00	180	31	81.03	0.0417	1.66E-05	1.66E-07	0.56	27.81	23.30	232.43	
8/11/09 9:00	8970	2100	0:35:00	85980.00	100	31	81.03	0.0476	1.90E-05	1.90E-07	0.31	28.13	23.88	256.32	
8/11/09 10:00	9110	3600	1:00:00	89580.00	140	31	81.03	0.0389	1.55E-05	1.55E-07	0.44	28.57	24.88	281.20	
8/11/09 11:54	9410	6840	1:54:00	96420.00	300	31	81.03	0.0439	1.75E-05	1.75E-07	0.94	29.51	26.78	307.98	
8/11/09 15:27	9830	12780	3:33:00	109200.00	420	31	81.03	0.0329	1.31E-05	1.31E-07	1.32	30.82	30.33	338.32	
8/11/09 19:19	10400	13920	3:52:00	123120.00	570	31	81.03	0.0409	1.63E-05	1.63E-07	1.79	32.61	34.20	372.52	
8/11/09 20:24	10550	3900	1:05:00	127020.00	150	31	81.03	0.0385	1.53E-05	1.53E-07	0.47	33.08	35.28	407.80	
8/11/09 21:18	10670	3240	0:54:00	130260.00	120	31	81.03	0.0370	1.47E-05	1.47E-07	0.38	33.46	36.18	443.98	
8/11/09 21:20	10670														Cell 4
8/11/09 22:05	10710	2700	0:45:00	132960.00	40	31	81.03	0.0148	5.90E-06	5.90E-08	0.13	33.58	36.93	480.92	
8/12/09 6:50	11350	31500	8:45:00	164460.00	640	31	81.03	0.0203	8.09E-06	8.09E-08	2.01	35.59	45.68	526.60	
8/12/09 8:30	11470	6000	1:40:00	170460.00	120	31	81.03	0.0200	7.96E-06	7.96E-08	0.38	35.97	47.35	573.95	
8/12/09 9:39	11550	4140	1:09:00	174600.00	80	31	81.03	0.0193	7.69E-06	7.69E-08	0.25	36.22	48.50	622.45	
8/12/09 10:37	11628	3480	0:58:00	178080.00	78	31	81.03	0.0224	8.92E-06	8.92E-08	0.24	36.46	49.47	671.92	
8/12/09 12:47	11770	7800	2:10:00	185880.00	142	31	81.03	0.0182	7.25E-06	7.25E-08	0.45	36.91	51.63	723.55	
8/12/09 14:17	11885	5400	1:30:00	191280.00	115	31	81.03	0.0213	8.48E-06	8.48E-08	0.36	37.27	53.13	776.68	
8/12/09 14:57	11930	2400	0:40:00	193680.00	45	31	81.03	0.0188	7.46E-06	7.46E-08	0.14	37.41	53.80	830.48	
8/12/09 16:00	12008	3780	1:03:00	197460.00	78	31	81.03	0.0206	8.21E-06	8.21E-08	0.24	37.65	54.85	885.33	
8/13/09 6:59	13028	53940	14:59:00	251400.00	1020	31	81.03	0.0189	7.53E-06	7.53E-08	3.20	40.85	69.83	955.17	
8/13/09 8:30	13148	5460	1:31:00	256860.00	120	31	81.03	0.0220	8.75E-06	8.75E-08	0.38	41.23	71.35	1026.52	
8/13/09 9:40	13228	4200	1:10:00	261060.00	80	31	81.03	0.0190	7.58E-06	7.58E-08	0.25	41.48	72.52	1099.03	
8/13/09 10:31	13288	3060	0:51:00	264120.00	60	31	81.03	0.0196	7.81E-06	7.81E-08	0.19	41.67	73.37	1172.40	
8/13/09 11:36	13358	3900	1:05:00	268020.00	70	31	81.03	0.0179	7.15E-06	7.15E-08	0.22	41.89	74.45	1246.85	
8/13/09 12:49	13443	4380	1:13:00	272400.00	85	31	81.03	0.0194	7.73E-06	7.73E-08	0.27	42.15	75.67	1322.52	
8/13/09 14:38	13558	6540	1:49:00	278940.00	115	31	81.03	0.0176	7.00E-06	7.00E-08	0.36	42.51	77.48	1400.00	
8/13/09 15:48	13638	4200	1:10:00	283140.00	80	31	81.03	0.0190	7.58E-06	7.58E-08	0.25	42.76	78.65	1478.65	
8/13/09 16:36	13706	2880	0:48:00	286020.00	68	31	81.03	0.0236	9.40E-06	9.40E-08	0.21	42.98	79.45	1558.10	
8/14/09 7:38	14678	54120	15:02:00	340140.00	972	31	81.03	0.0180	7.15E-06	7.15E-08	3.05	46.03	94.48	1652.58	

Sample- F15: Continuation on 8/14/09 at 7:41 A.M.															
Time	**Vol(ml)**	**Δt (sec)**	**Δt (min)**	**Cum. t(sec)**	**ΔV(cm^3)**	**i**	**Area(cm^2)**	**q_{out}(cm^3/sec)**	**k (cm/sec)**	**k(m/sec)**	**Pore Volume**		Time		
8/14/09 7:41	14678														Cell 5
8/14/09 9:15	14778	5640	1:34:00	345780.00	100	31	81.03	0.0177	7.06E-06	7.06E-08	0.31	46.34	96.05	1748.63	
8/14/09 10:15	14848	3600	1:00:00	349380.00	70	31	81.03	0.0194	7.74E-06	7.74E-08	0.22	46.56	97.05	1845.68	
8/14/09 11:49	14958	5640	1:34:00	355020.00	110	31	81.03	0.0195	7.76E-06	7.76E-08	0.34	46.90	98.62	1944.30	
8/14/09 13:45	15088	6960	1:56:00	361980.00	130	31	81.03	0.0187	7.44E-06	7.44E-08	0.41	47.31	100.55	1849.18	
8/14/09 14:45	15156	3600	1:00:00	365580.00	68	31	81.03	0.0189	7.52E-06	7.52E-08	0.21	47.52	101.55	1947.23	
8/15/09 6:05	16174	55200	15:20:00	420780.00	1018	31	81.03	0.0184	7.34E-06	7.34E-08	3.19	50.72	116.88	2061.18	
8/15/09 13:52	16666	28020	7:47:00	448800.00	492	31	81.03	0.0176	6.99E-06	6.99E-08	1.54	52.26	124.67	1973.85	
8/15/09 19:32	17044	20400	5:40:00	469200.00	378	31	81.03	0.0185	7.38E-06	7.38E-08	1.19	53.44	130.33	2077.57	
8/16/09 16:21	18316	74940	20:49:00	544140.00	1272	31	81.03	0.0170	6.76E-06	6.76E-08	3.99	57.43	151.15	2212.33	
8/16/09 17:34	18386	4380	1:13:00	548520.00	70	31	81.03	0.0160	6.36E-06	6.36E-08	0.22	57.65	152.37	2126.22	
8/16/09 17:36	18386														Cell 6
8/17/09 7:16	19266	49200	13:40:00	597720.00	880	31	81.03	0.0179	7.12E-06	7.12E-08	2.76	60.41	166.03	2292.25	
8/17/09 8:45	19346	5340	1:29:00	603060.00	80	31	81.03	0.0150	5.96E-06	5.96E-08	0.25	60.66	167.52	2459.77	
8/17/09 9:00	19366	900	0:15:00	603960.00	20	31	81.03	0.0222	8.85E-06	8.85E-08	0.06	60.73	167.77	2627.53	
8/17/09 10:00	19424	3600	1:00:00	607560.00	58	31	81.03	0.0161	6.41E-06	6.41E-08	0.18	60.91	168.77	2796.30	
8/17/09 12:23	19566	8580	2:23:00	616140.00	142	31	81.03	0.0166	6.59E-06	6.59E-08	0.45	61.35	171.15	2967.45	
8/17/09 15:25	19756	10920	3:02:00	627060.00	190	31	81.03	0.0174	6.93E-06	6.93E-08	0.60	61.95	174.18	3141.63	
8/18/09 7:11	20685	56760	15:46:00	683820.00	929	31	81.03	0.0164	6.52E-06	6.52E-08	2.91	64.86	189.95	3331.58	
8/18/09 10:06	20846	10500	2:55:00	694320.00	161	31	81.03	0.0153	6.10E-06	6.10E-08	0.50	65.37	192.87	3524.45	
8/18/09 11:06	20886	3600	1:00:00	697920.00	40	31	81.03	0.0111	4.42E-06	4.42E-08	0.13	65.49	193.87	3718.32	
8/18/09 12:00	20954	3240	0:54:00	701160.00	68	31	81.03	0.0210	8.36E-06	8.36E-08	0.21	65.71	194.77	3913.08	
8/18/09 15:08	21126	11280	3:08:00	712440.00	172	31	81.03	0.0152	6.07E-06	6.07E-08	0.54	66.24	197.90	4110.98	
8/19/09 9:40	22156	66720	18:32:00	779160.00	1030	31	81.03	0.0154	6.15E-06	6.15E-08	3.23	69.47	216.43	4327.42	
8/19/09 11:26	22251	6360	1:46:00	785520.00	95	31	81.03	0.0149	5.95E-06	5.95E-08	0.30	69.77	218.20	4545.62	
8/19/09 13:03	22341	5820	1:37:00	791340.00	90	31	81.03	0.0155	6.16E-06	6.16E-08	0.28	70.05	219.82	4765.43	
8/19/09 15:24	22466	8460	2:21:00	799800.00	125	31	81.03	0.0148	5.88E-06	5.88E-08	0.39	70.45	222.17	4987.60	
8/19/09 15:30	22466														Cell 7
8/19/09 17:29	22606	7140	1:59:00	806940.00	140	31	81.03	0.0196	7.81E-06	7.81E-08	0.44	70.89	224.15	5211.75	
8/20/09 12:09	23746	67200	18:40:00	874140.00	1140	31	81.03	0.0170	6.75E-06	6.75E-08	3.57	74.46	242.82	5454.57	
8/20/09 13:16	23816	4020	1:07:00	878160.00	70	31	81.03	0.0174	6.93E-06	6.93E-08	0.22	74.68	243.93	5698.50	
8/20/09 14:47	23906	5460	1:31:00	883620.00	90	31	81.03	0.0165	6.56E-06	6.56E-08	0.28	74.96	245.45	5943.95	
8/20/09 15:12	23928	1500	0:25:00	885120.00	22	31	81.03	0.0147	5.84E-06	5.84E-08	0.07	75.03	245.87	6189.82	
8/20/09 16:10	23986	3480	0:58:00	888600.00	58	31	81.03	0.0167	6.64E-06	6.64E-08	0.18	75.21	246.83	6436.65	
8/21/09 13:00	25204	75000	20:50:00	963600.00	1218	31	81.03	0.0162	6.47E-06	6.47E-08	3.82	79.03	267.67	6704.32	
8/21/09 13:53	25246	3180	0:53:00	966780.00	42	31	81.03	0.0132	5.26E-06	5.26E-08	0.13	79.16	268.55	6972.87	
8/21/09 14:35	25286	2520	0:42:00	969300.00	40	31	81.03	0.0159	6.32E-06	6.32E-08	0.13	79.29	269.25	7242.12	
8/21/09 15:21	25326	2760	0:46:00	972060.00	40	31	81.03	0.0145	5.77E-06	5.77E-08	0.13	79.41	270.02	7512.13	
8/21/09 16:53	25421	5520	1:32:00	977580.00	95	31	81.03	0.0172	6.85E-06	6.85E-08	0.30	79.71	271.55	7783.68	
8/22/09 1:19	25899	30360	8:26:00	1007940.00	478	31	81.03	0.0157	6.27E-06	6.27E-08	1.50	81.21	279.98	8063.67	
8/22/09 1:24	25899														Cell 8
8/22/09 16:01	26777	52620	14:37:00	1060560.00	878	31	81.03	0.0167	6.64E-06	6.64E-08	2.75	83.96	294.60	8358.27	
8/22/09 16:55	26829	3240	0:54:00	1063800.00	52	31	81.03	0.0160	6.39E-06	6.39E-08	0.16	84.13	295.50	8653.77	
8/23/09 15:43	28097	82080	22:48:00	1145880.00	1268	31	81.03	0.0154	6.15E-06	6.15E-08	3.98	88.10	318.30	8972.07	
8/23/09 16:04	28119	1260	0:21:00	1147140.00	22	31	81.03	0.0175	6.95E-06	6.95E-08	0.07	88.17	318.65	9290.72	
8/23/09 21:35	28429	19860	5:31:00	1167000.00	310	31	81.03	0.0156	6.21E-06	6.21E-08	0.97	89.14	324.17	9614.88	
8/24/09 7:25	28939	35400	9:50:00	1202400.00	510	31	81.03	0.0144	5.74E-06	5.74E-08	1.60	90.74	334.00	9948.88	
8/24/09 8:46	29019	4860	1:21:00	1207260.00	80	31	81.03	0.0165	6.55E-06	6.55E-08	0.25	91.00	335.35	10284.23	
8/24/09 10:55	29119	7740	2:09:00	1215000.00	100	31	81.03	0.0129	5.14E-06	5.14E-08	0.31	91.31	337.50	10621.73	
8/24/09 12:23	29199	5280	1:28:00	1220280.00	80	31	81.03	0.0152	6.03E-06	6.03E-08	0.25	91.56	338.97	10960.70	
8/24/09 13:45	29259	4920	1:22:00	1225200.00	60	31	81.03	0.0122	4.85E-06	4.85E-08	0.19	91.75	340.33	11301.03	
8/24/09 14:18	29297	1980	0:33:00	1227180.00	38	31	81.03	0.0192	7.64E-06	7.64E-08	0.12	91.87	340.88	11641.92	
8/24/09 15:45	29359	5220	1:27:00	1232400.00	62	31	81.03	0.0119	4.73E-06	4.73E-08	0.19	92.06	342.33	11984.25	

Acid samples

E15A-I

E15A-I													
Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	**k (cm/sec)**	**k(m/sec)**	Time		**ΔpV**	**pV CUM.**
										t(Hours)	t,Cumulative		
9/3/09 12:00	0												
9/3/09 12:13	350	780	0:13:00	780.00	350	5	81.03	1.11E-03	1.11E-05	0.22	0.22	0.99	0.99
9/3/09 12:31	1000	1080	0:18:00	1860.00	650	5	81.03	1.49E-03	1.49E-05	0.52	0.73	1.84	2.83
9/3/09 13:29	2820	3480	0:58:00	5340.00	1820	5	81.03	1.29E-03	1.29E-05	1.48	2.22	5.15	7.98
9/3/09 13:52	3520	1380	0:23:00	6720.00	700	5	81.03	1.25E-03	1.25E-05	1.87	4.08	1.98	9.96
9/3/09 13:56	3520											0.00	9.96
9/3/09 14:28	4720	1920	0:32:00	8640.00	1200	5	81.03	1.54E-03	1.54E-05	2.40	2.40	3.40	13.36
9/3/09 15:19	6528	3060	0:51:00	11700.00	1808	5	81.03	1.46E-03	1.46E-05	3.25	5.65	5.12	18.48
9/3/09 15:33	7008	840	0:14:00	12540.00	480	5	81.03	1.41E-03	1.41E-05	3.48	9.13	1.36	19.84
9/3/09 15:40	7258	420	0:07:00	12960.00	250	5	81.03	1.47E-03	1.47E-05	3.60	12.73	0.71	20.54

E15A-II

E15A-II												
Time	Vol(ml)	Δt (sec)	Δt (min)	Cum. t(sec)	ΔV(cm^3)	i	Area(cm^2)	**k (cm/sec)**	**k(m/sec)**	Time	**ΔpV**	**pV CUM**
										t(Hours)		
9/11/09 7:17	0											
9/11/09 7:39	420	1320	0:22:00	1320.00	420	5	81.03	7.85E-04	7.85E-06	0.37	1.17	1.17
9/11/09 8:01	800	1320	0:22:00	2640.00	380	5	81.03	7.11E-04	7.11E-06	0.73	1.06	2.22
9/11/09 8:40	1400	2340	0:39:00	4980.00	600	5	81.03	6.33E-04	6.33E-06	1.38	1.67	3.89
9/11/09 8:59	1650	1140	0:19:00	6120.00	250	5	81.03	5.41E-04	5.41E-06	1.70	0.69	4.59
9/11/09 9:59	2650	3600	1:00:00	9720.00	1000	5	81.03	6.86E-04	6.86E-06	2.70	2.78	7.37
9/11/09 10:15	2900	960	0:16:00	10680.00	250	5	81.03	6.43E-04	6.43E-06	2.97	0.69	8.06
											0.00	8.06
9/11/09 11:05	2900										0.00	8.06
9/11/09 11:30	3680	1500	0:25:00	16800.00	780	5	81.03	1.28E-03	1.28E-05	4.67	2.17	10.23
9/11/09 11:45	4170	900	0:15:00	17700.00	490	5	81.03	1.34E-03	1.34E-05	4.92	1.36	11.59
9/11/09 12:06	4730	1260	0:21:00	18960.00	560	5	81.03	1.10E-03	1.10E-05	5.27	1.56	13.15
9/11/09 12:12	4900	360	0:06:00	19320.00	170	5	81.03	1.17E-03	1.17E-05	5.37	0.47	13.62
9/11/09 12:42	5740	1800	0:30:00	21120.00	840	5	81.03	1.15E-03	1.15E-05	5.87	2.33	15.96
9/11/09 12:46	5850	240	0:04:00	21360.00	110	5	81.03	1.13E-03	1.13E-05	5.93	0.31	16.26
9/11/09 13:05	6380	1140	0:19:00	22500.00	530	5	81.03	1.15E-03	1.15E-05	6.25	1.47	17.73
9/11/09 13:24	6850	1140	0:19:00	23640.00	470	5	81.03	1.02E-03	1.02E-05	6.57	1.31	19.04
9/11/09 13:29											0.00	19.04
9/11/09 13:45	7230										0.00	19.04
9/11/09 14:29	8260	1200	0:44:00	26040.00	1030	5	81.03	2.12E-03	2.12E-05	7.23	2.86	21.90
9/11/09 14:50	8790	2640	0:21:00	28680.00	530	5	81.03	4.96E-04	4.96E-06	7.97	1.47	23.38
9/11/09 16:06	10060	1260	1:16:00	29940.00	1270	5	81.03	2.49E-03	2.49E-05	8.32	3.53	26.91
9/11/09 16:49	10690	420	0:43:00	30360.00	630	5	81.03	3.70E-03	3.70E-05	8.43	1.75	28.66
9/11/09 17:08	10690										0.00	28.66
9/11/09 18:00	12390	420	0:52:00	30780.00	1700	5	81.03	9.99E-03	9.99E-05	8.55	4.73	33.38

F11A

F11A-I												
Time	Δt (min)	Δt (sec)	ΔV	V	i	A (cm^2)	**k (cm/s)**	**k (m/sec)**	**t (min)**	**t (hour)**	**pV**	**ΔpV**
9/18/09 10:19			0	0.00								
9/18/09 10:49	0:30	1800.00	1120	1120.00	13.68	81.03	5.613E-04	5.613E-06	0:30	0.50	3.42	3.42
9/18/09 11:08	0:19	1140.00	880	2000.00	13.68	81.03	6.964E-04	6.964E-06	0:49	0.82	2.69	6.11
9/18/09 11:30	0:22	1320.00	1000	3000.00	13.68	81.03	6.834E-04	6.834E-06	1:11	1.18	3.06	9.17
9/18/09 11:50	0:20	1200.00	915	3915.00	13.68	81.03	6.879E-04	6.879E-06	1:31	1.52	2.80	11.97
9/18/09 11:55	0:05				13.68						0.00	11.97
9/18/09 12:22	0:27	1620.00	1290	5205.00	13.68	81.03	7.184E-04	7.184E-06	1:58	1.97	3.94	15.91
9/18/09 12:39	0:17	1020.00	1290	6495.00	13.68	81.03	1.141E-03	1.141E-05	2:15	2.25	3.94	19.85
9/18/09 13:00	0:21	1260.00	1000	7495.00	13.68	81.03	7.160E-04	7.160E-06	2:36	2.60	3.06	22.91
9/18/09 13:11	0:11	660.00	540	8035.00	13.68	81.03	7.381E-04	7.381E-06	2:47	2.78	1.65	24.56
9/18/09 13:21	0:10				13.68						0.00	24.56
9/18/09 13:47	0:26	1560.00	1280	9315.00	13.68	81.03	7.402E-04	7.402E-06	3:13	3.22	3.91	28.47
9/18/09 14:34	0:47	2820.00	2000	11315.00	13.68	81.03	6.398E-04	6.398E-06	4:00	4.00	6.11	34.58
9/18/09 14:46	0:12	720.00	890	12205.00	13.68	81.03	1.115E-03	1.115E-05	4:12	4.20	2.72	37.30
9/18/09 14:56	0:10				13.68						0.00	37.30
9/18/09 15:21	0:25	1500.00	1175	13380.00	13.68	81.03	7.067E-04	7.067E-06	4:37	4.62	3.59	40.90
9/18/09 15:41	0:20	1200.00	2080	15460.00	13.68	81.03	1.564E-03	1.564E-05	4:57	4.95	6.36	47.25
9/18/09 16:07	0:26	1560.00	1140	16600.00	13.68	81.03	6.592E-04	6.592E-06	5:23	5.38	3.48	50.74
9/18/09 16:29	0:22	1320.00	865	17465.00	13.68	81.03	5.912E-04	5.912E-06	5:45	5.75	2.64	53.38

F11A-II

F11A-II												
Time	Δt (min)	Δt (sec)	ΔV	V	i	A (cm^2)	**k (cm/s)**	**k (m/sec)**	**t (min)**	**t (hour)**	**ΔpV**	**pV**
9/25/09 10:14			0	0.00								
9/25/09 10:29	0:15	600.00	560	560.00	13.68	81.03	8.420E-04	8.420E-06	0.17	0.17	1.79	1.79
9/25/09 10:45	0:16	960.00	720	1280.00	13.68	81.03	6.766E-04	6.766E-06	0.27	0.43	2.30	4.09
9/25/09 10:56	0:11	660.00	470	1750.00	13.68	81.03	6.424E-04	6.424E-06	0.18	0.62	1.50	5.59
9/25/09 11:11	0:15	900.00	650	2400.00	13.68	81.03	6.515E-04	6.515E-06	0.25	0.87	2.07	7.66
9/25/09 11:20	0:09	540.00	350	2750.00	13.68	81.03	5.847E-04	5.847E-06	0.15	1.02	1.12	8.78
9/25/09 11:31	0:11	660.00	480	3230.00	13.68	81.03	6.561E-04	6.561E-06	0.18	1.20	1.53	10.31
9/25/09 11:55	0:24	1440.00	960	4190.00	13.68	81.03	6.014E-04	6.014E-06	0.40	1.60	3.06	13.37
9/25/09 12:04	0:09	540.00	0	4190.00	13.68				0.15		0.00	13.37
9/25/09 12:24	0:20	1200.00	480	4670.00	13.68	81.03	3.609E-04	3.609E-06	0.33	1.93	1.53	14.90
9/25/09 12:57	0:33	1980.00	1570	6240.00	13.68	81.03	7.153E-04	7.153E-06	0.55	2.48	5.01	19.91

F15A-I (with beads)

Time	Δt (min)	Δt (sec)	ΔV	V	i	A (cm^2)	**k (cm/s)**	**k (m/sec)**	**t (min)**	**t (hour)**
10/26/09 11:39			0	0.00						
10/26/09 12:15	0:36	2160.00	1430	1430.00	32.57	81.03	2.509E-04	2.509E-06	0.60	0.60
10/26/09 12:35	0:20	1200.00	610	2040.00	32.57	81.03	1.926E-04	1.926E-06	0.33	0.93
10/26/09 12:55	0:20	1200.00	630	2670.00	32.57	81.03	1.989E-04	1.989E-06	0.33	1.27
10/26/09 13:13	0:18	1080.00	370	3040.00	32.57	81.03	1.298E-04	1.298E-06	0.30	1.57
10/26/09 13:36	0:23	1380.00	810	3850.00	32.57	81.03	2.224E-04	2.224E-06	0.38	1.95
10/26/09 13:46	0:10	600.00	0	3850.00	32.57	81.03	0.000E+00	0.000E+00	0.17	
10/26/09 14:12	0:26	1560.00	375	4225.00	32.57	81.03	9.108E-05	9.108E-07	0.43	2.38
10/26/09 14:56	0:44	2640.00	555	4780.00	32.57	81.03	7.966E-05	7.966E-07	0.73	3.12
10/26/09 15:17	0:21	1260.00	265	5045.00	32.57	81.03	7.969E-05	7.969E-07	0.35	3.47
10/26/09 15:36	0:19	1140.00	240	5285.00	32.57	81.03	7.977E-05	7.977E-07	0.32	3.78
10/26/09 16:50	1:14	4440.00	960	6245.00	32.57	81.03	8.193E-05	8.193E-07	1.23	5.02
10/26/09 17:50	1:00	3600.00	665	6910.00	32.57	81.03	6.999E-05	6.999E-07	1.00	6.02
10/26/09 18:33	0:43	2580.00	525	7435.00	32.57	81.03	7.710E-05	7.710E-07	0.72	6.73
10/26/09 18:43	0:10	600.00	0	7435.00	32.57	81.03	0.000E+00	0.000E+00	0.17	
10/26/09 20:53	2:10	7800.00	915	8350.00	32.57	81.03	4.445E-05	4.445E-07	2.17	8.90
10/26/09 22:55	2:02	7320.00	820	9170.00	32.57	81.03	4.245E-05	4.245E-07	2.03	10.93
10/26/09 23:04	0:09	540.00	0	9170.00	32.57	81.03	0.000E+00	0.000E+00	0.15	
10/27/09 9:25	10:21	37260.00	2950	12120.00	32.57	81.03	3.000E-05	3.000E-07	10.35	21.28
10/27/09 11:15	1:50	6600.00	520	12640.00	32.57	81.03	2.985E-05	2.985E-07	1.83	23.12
10/27/09 12:11	0:56	3360.00	250	12890.00	32.57	81.03	2.819E-05	2.819E-07	0.93	24.05
10/27/09 13:46	1:35	5700.00	425	13315.00	32.57	81.03	2.825E-05	2.825E-07	1.58	25.63
10/27/09 14:00	0:14	840.00	0	13315.00	32.57	81.03	0.000E+00	0.000E+00	0.23	
10/27/09 15:19	1:19	4740.00	285	13600.00	32.57	81.03	2.278E-05	2.278E-07	1.32	26.95
10/27/09 16:33	1:14	4440.00	257	13857.00	32.57	81.03	2.193E-05	2.193E-07	1.23	28.18
10/27/09 17:49	1:16	4560.00	258	14115.00	32.57	81.03	2.144E-05	2.144E-07	1.27	29.45
10/27/09 18:53	1:04	3840.00	230	14345.00	32.57	81.03	2.270E-05	2.270E-07	1.07	30.52
10/27/09 23:08	4:15	15300.00	890	15235.00	32.57	81.03	2.204E-05	2.204E-07	4.25	34.77
10/28/09 10:24	11:16	40560.00	2170	17405.00	32.57	81.03	2.027E-05	2.027E-07	11.27	46.03
10/28/09 12:49	2:25	8700.00	378	17783.00	32.57	81.03	1.646E-05	1.646E-07	2.42	48.45
10/28/09 12:51	0:02	120.00	0	17783.00	32.57	81.03	0.000E+00	0.000E+00	0.03	
10/28/09 14:34	1:43	6180.00	280	18063.00	32.57	81.03	1.717E-05	1.717E-07	1.72	50.17
10/28/09 15:56	1:22	4920.00	288	18351.00	32.57	81.03	2.218E-05	2.218E-07	1.37	51.53
10/28/09 16:50	0:54	3240.00	192	18543.00	32.57	81.03	2.245E-05	2.245E-07	0.90	52.43
10/28/09 19:11	2:21	8460.00	560	19103.00	32.57	81.03	2.508E-05	2.508E-07	2.35	54.78
10/29/09 10:25	15:14	54840.00	2495	21598.00	32.57	81.03	1.724E-05	1.724E-07	15.23	70.02
10/29/09 13:31	3:06	11160.00	470	22068.00	32.57	81.03	1.596E-05	1.596E-07	3.10	73.12
10/29/09 13:43	0:12	720.00	0	22068.00	32.57	81.03	0.000E+00	0.000E+00	0.20	
10/29/09 15:34	1:51	6060.00	290	22358.00	32.57	81.03	1.813E-05	1.813E-07	1.68	74.80
10/29/09 16:50	1:16	4560.00	240	22598.00	32.57	81.03	1.994E-05	1.994E-07	1.27	76.07
10/30/09 10:53	18:03	64980.00	3015	25613.00	32.57	81.03	1.758E-05	1.758E-07	18.05	94.12
10/30/09 11:41	0:48	2880.00	110	25723.00	32.57	81.03	1.447E-05	1.447E-07	0.80	94.92
10/30/09 13:53	2:12	7920.00	310	26033.00	32.57	81.03	1.483E-05	1.483E-07	2.20	97.12
10/30/09 14:06	0:13	780.00	0	26033.00	32.57	81.03	0.000E+00	0.000E+00	0.22	
10/31/09 13:21	23:15	83700.00	2525	28558.00	32.57	81.03	1.143E-05	1.143E-07	23.25	120.37
11/1/09 15:08	25:47:00	92820.00	1510	30068.00	32.57	81.03	6.164E-06	6.164E-08	25.78	146.15
11/1/09 15:15	0:07	420.00	0	30068.00	32.57	81.03	0.000E+00	0.000E+00	0.12	
11/2/09 15:49	24:34:00	88440.00	1340	31408.00	32.57	81.03	5.741E-06	5.741E-08	24.57	170.72

F15A-II

F15A-II										
Time	Δt (min)	Δt (sec)	ΔV	V	i	A (cm^2)	**k (cm/s)**	**k (m/sec)**	**t (min)**	**t (hour)**
10/6/09 9:55			0	0.00						
10/6/09 11:14	1:19	4740.00	190	190.00	32.5	81.03	1.522E-05	1.522E-07	1.32	1.32
10/6/09 11:44	0:30	1800.00	70	260.00	32.5	81.03	1.477E-05	1.477E-07	0.50	1.82
10/6/09 12:14	0:30	1800.00	60	320.00	32.5	81.03	1.266E-05	1.266E-07	0.50	2.32
10/6/09 13:39	1:25	5100.00	335	655.00	32.5	81.03	2.494E-05	2.494E-07	1.42	3.73
10/6/09 15:25	1:46	6360.00	415	1070.00	32.5	81.03	2.478E-05	2.478E-07	1.77	5.50
10/6/09 16:07	0:42	2520.00	130	1200.00	32.5	81.03	1.959E-05	1.959E-07	0.70	6.20
10/6/09 16:56	0:49	2940.00	120	1320.00	32.5	81.03	1.550E-05	1.550E-07	0.82	7.02
10/6/09 18:35	1:39	5940.00	180	1500.00	32.5	81.03	1.151E-05	1.151E-07	1.65	8.67
10/6/09 21:01	2:26	8760.00	200	1700.00	32.5	81.03	8.670E-06	8.670E-08	2.43	11.10
10/7/09 10:00	12:59	46740.00	700	2400.00	32.5	81.03	5.687E-06	5.687E-08	12.98	24.08
10/7/09 12:14	2:14	8040.00	95	2495.00	32.5	81.03	4.487E-06	4.487E-08	2.23	26.32
10/7/09 14:48	2:34	9240.00	115	2610.00	32.5	81.03	4.726E-06	4.726E-08	2.57	28.88
10/7/09 17:50	3:02	10920.00	135	2745.00	32.5	81.03	4.694E-06	4.694E-08	3.03	31.92
10/8/09 6:30	12:40	45600.00	485	3230.00	32.5	81.03	4.039E-06	4.039E-08	12.67	44.58
10/8/09 8:35	2:05	7500.00	100	3330.00	32.5	81.03	5.063E-06	5.063E-08	2.08	46.67
10/8/09 10:28	1:53	6780.00	50	3380.00	32.5	81.03	2.800E-06	2.800E-08	1.88	48.55
10/8/09 11:39	1:11	4260.00	30	3410.00	32.5	81.03	2.674E-06	2.674E-08	1.18	49.73
10/8/09 13:48	2:09	7740.00	70	3480.00	32.5	81.03	3.434E-06	3.434E-08	2.15	51.88
10/8/09 15:55	2:07	7620.00	70	3550.00	32.5	81.03	3.488E-06	3.488E-08	2.12	54.00
10/8/09 18:54	2:59	10740.00	98	3648.00	32.5	81.03	3.465E-06	3.465E-08	2.98	56.98
10/8/09 18:58	0:04	240.00	0	3648.00	32.5	81.03	0.000E+00	0.000E+00	0.07	
10/9/09 10:19	15:21	55260.00	570	4218.00	32.5	81.03	3.917E-06	3.917E-08	15.35	72.33
10/9/09 11:54	1:35	5700.00	35	4253.00	32.5	81.03	2.332E-06	2.332E-08	1.58	73.92
10/9/09 12:08	0:14	840.00	15	4268.00	32.5	81.03	6.781E-06	6.781E-08	0.23	74.15
10/9/09 16:26	4:18	15480.00	110	4378.00	32.5	81.03	2.698E-06	2.698E-08	4.30	78.45
10/10/09 11:04	18:38	67080.00	530	4908.00	32.5	81.03	3.000E-06	3.000E-08	18.63	97.08
10/10/09 18:45	7:41	27660.00	200	5108.00	32.5	81.03	2.746E-06	2.746E-08	7.68	104.77
10/11/09 12:00	17:15	62100.00	420	5528.00	32.5	81.03	2.568E-06	2.568E-08	17.25	122.02
10/11/09 14:50	2:50	10200.00	70	5598.00	32.5	81.03	2.606E-06	2.606E-08	2.83	124.85
10/12/09 10:59	20:09	72540.00	500	6098.00	32.5	81.03	2.617E-06	2.617E-08	20.15	145.00
10/12/09 14:11	3:12	11520.00	75	6173.00	32.5	81.03	2.472E-06	2.472E-08	3.20	148.20
10/12/09 14:39	0:28	1680.00	15	6188.00	32.5	81.03	3.390E-06	3.390E-08	0.47	148.67
10/12/09 17:06	2:27	8820.00	55	6243.00	32.5	81.03	2.368E-06	2.368E-08	2.45	151.12
10/13/09 9:10	16:04	57840.00	385	6628.00	32.5	81.03	2.528E-06	2.528E-08	16.07	167.18
10/13/09 11:44	2:34	9240.00	60	6688.00	32.5	81.03	2.466E-06	2.466E-08	2.57	169.75
10/14/09 11:39	23:55	86100.00	585	7273.00	32.5	81.03	2.580E-06	2.580E-08	23.92	193.67
10/14/09 14:29	2:50	10200.00	72	7345.00	32.5	81.03	2.680E-06	2.680E-08	2.83	196.50
10/14/09 16:24	0:12	720.00	0	8675.00	32.5	81.03	0.000E+00	0.000E+00	0.20	
10/15/09 10:59	18:35	66900.00	980	9655.00	32.5	81.03	5.563E-06	5.563E-08	18.58	215.08
10/15/09 15:35	4:36	16560.00	130	9785.00	32.5	81.03	2.981E-06	2.981E-08	4.60	219.68
10/16/09 11:57	20:22	73320.00	550	10335.00	32.5	81.03	2.848E-06	2.848E-08	20.37	240.05
10/16/09 15:15	3:18	11880.00	75	10410.00	32.5	81.03	2.397E-06	2.397E-08	3.30	243.35
10/16/09 18:13	2:58	10680.00	65	10475.00	32.5	81.03	2.311E-06	2.311E-08	2.97	246.32
10/17/09 13:59	19:46	71160.00	475	10950.00	32.5	81.03	2.535E-06	2.535E-08	19.77	266.08
10/19/09 10:30	44:31:00	160260.00	1055	12005.00	32.5	81.03	2.500E-06	2.500E-08	44.52	310.60
10/19/09 14:10	3:40	13200.00	90	12095.00	32.5	81.03	2.589E-06	2.589E-08	3.67	314.27
10/19/09 16:38	2:28	8880.00	50	12145.00	32.5	81.03	2.138E-06	2.138E-08	2.47	316.73
10/19/09 17:40	1:02	3720.00	30	12175.00	32.5	81.03	3.062E-06	3.062E-08	1.03	317.77
10/20/09 13:51	20:11	72660.00	502	12677.00	32.5	81.03	2.623E-06	2.623E-08	20.18	337.95
10/20/09 18:04	4:13	15180.00	103	12780.00	32.5	81.03	2.577E-06	2.577E-08	4.22	342.17

John H. Hagen
Digitally signed by John H. Hagen
DN: cn=John H. Hagen, o=West Virginia University Libraries, ou=Acquisitions Department, email=John.Hagen@mail.wvu.edu, c=US
Date: 2010.12.14 13:38:56 -05'00'