Roller Compacted Base Course Construction Using Lime Stabilized Fly Ash and Flue Gas Desulfurization Sludge By-Product

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Keywords: lime, stabilization, flue gas desulfurization

ABSTRACT

Dewatered calcium sulfite and calcium sulfate sludges from unoxidized flue gas desulfurization (FGD) processes at coal fired power plants can be mixed with coal fly ash and lime to cause a cementitious chemical reaction used to construct a roller compacted base course (RCFGD) or an impermeable pond liner. The chemical reaction is described as lime reacting with alumina from the fly ash which in turn reacts with the calcium sulfite and sulfate FGD waste to form calcium sulfo-aluminate compounds. Leachate data is similar to primary drinking water quality standards. Two field demonstrations of RCFGD and a proposed mix design procedure are described. Factors that affect strength gain and freeze-thaw durability such as optimum moisture content, fly ash to FGD ratio, and age of FGD are discussed. Better understanding is needed on how to predict long term strength performance and expansive potential given the nature of long term hydration forming ettringite compounds and the vulnerability to destructive freeze-thaw cycles.

INTRODUCTION

Lime is commonly used as a reagent to remove SO_2 from power plant emission burning medium and high sulfur bituminous coal. A leading supplier of lime products for flue gas treatment applications, the Dravo Lime Company is also extensively involved in the development of lime-based environmental technologies, including ways to better manage the large volume of waste product resulting from these efforts to clean the stack gases from large coal-fired publicly owned utilities. In the United States alone, over 68 million tons of coal ash materials and 20 million tons of flue gas desulfurization (FGD) materials must be handled. Most of the ash and nearly all of the FGD by-products must be disposed in landfills.[1] This huge volume of waste material disposal applies to unoxidized FGD systems that use either lime or limestone as the alkaline sorbent.

A common practice for landfill disposal with twenty years experience is a sludge fixation process whereby the FGD sludge is dewatered by vacuum filtration or centrifuges, and the cake solids are mixed with the plant's fly ash that was collected separately and some pulverized quicklime. This mixture is referred to as fixated scrubber sludge solids (FSSS). As it is being placed and compacted in a landfill disposal cell, chemical reactions begin causing the material to harden.

The Dravo Lime Company (DLC) serves 14 power stations in the Ohio River Valley generating about 13,500 MW of power. Twelve of these stations practice the above lime-fly ash stabilization process, often called by the original process tradename, POZ-O-TEC. The strength of FSSS for landfill disposal is not high enough at 200 psi @ 28 days curing or durable enough for heavy traffic and freeze-thaw conditions. However, when compared to natural soils, fixated FGD scrubber sludge solids have been shown to have high natural strength and low permeability.[2] Although important, permeability testing and results will not be covered in this paper.

This paper will discuss the progress of on-going research at Dravo Lime Company on how this fixated scrubber sludge solids (FSSS) mixture can be upgraded in terms of strength gain and durability and be used as a roadbase pavement or structural fill material that would be applied by placing it using construction techniques similar to those for roller compacted concrete (RCC).

ROLLER COMPACTED CONCRETE OR STABILIZED BASE COURSE

Conventional RCC is a dry and stable mix of aggregate, portland cement or lime, and water. It is also similar to lime stabilization of soil or aggregate base course which is widely used to improve the strength and durability of soils by ion exchange and cementitious reactions, enabling their use as engineering materials in the construction of pavements and structural fills. RCC is typically laid by modified asphalt pavers or a road grader and compacted by rollers that follow close behind. The material should show tremendous stability in the fresh state. As the FGD-fly ash-lime mixture hydrates, the material acquires strength but not likely as much strength as conventional portland cement concrete. Adequate strength for stabilized base course is about 400 psi in 28 days curing for most applications. It is believed the FSSS mixture using additional lime and coal ash material can be designed to attain 400 psi. It will be called roller compacted FGD stabilized base material (RCFGD).

However, the RCC made from FSSS is not suited to perform as a highway wearing cause pavement because of low abrasion resistance. Some experience suggests it can exhibit suitable durability in terms of freeze-thaw resistance but more proof is needed to define the durability limitations which is discussed further.

CHARACTERIZATION OF FSSS COMPONENTS

Fixated scrubber sludge solids (FSSS) is the term to apply to the mixture of sludge cake, fly ash, and lime to allow stabilization of the sludge cake for landfill disposal. The term for upgraded FSSS for use as roller compacted base course will be labeled roller compacted FGD (RCFGD). The FGD scrubber solids mineralogical composition from a lime scrubber, most of which are based on the Dravo Lime magnesium enhanced lime Thiosorbic process and some inhibited oxidation limestone scrubbers, is mostly calcium sulfite hemi-hydrate ($CaSO_3 \cdot \frac{1}{2}H_2O$) ranging 75-85% and some calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$) ranging 10-20% with minor amount of calcium carbonate ($CaCO_3$) ranging 5-15% and minor amounts fly ash minerals. Coal fly ash is mostly clay like minerals composed of alumina, silica, and iron oxide. A geochemical oxide or elemental form analysis is listed in Table 1. Also listed in the composition of the quicklime component which is closer to a unhydrated calcitic quicklime than a dolomitic lime.

One method to evaluate pavement performance is the unconfined compression test (ASTM D2166). In this procedure strengths of specimens compacted to a known density and water content according to ASTM D698 (Standard Procter Test) are evaluated after different curing periods and conditions.[3]

MIX PROPORTION FOR LANDFILL DISPOSAL

The proportion of the components as they are mixed to stabilize the FGD sludge for landfill disposal varies somewhat from plant to plant and from day to day depending on the percent solids of the dewatered sludge cake and the availability of the fly ash. The objective is do make a mixture that can be compacted to a density required by the solid waste regulatory authority. Generally, the ratio of fly ash to scrubber solids is 0.75 or less for every 1.0 on a dry weight basis. The predominately calcium sulfite sludge comes from large diameter thickeners and then is dewatered by drum vacuum filters or centrifuges to about 40% solids based on the total wet weight. The cake is mixed with the fly ash and 2-3% pulverized quicklime (CaO) in a pug mill. Only enough lime is added to cause enough hardening to stabilize the sludge and prevent leachate by adequate strength development and resultant clay-like impermeability. The approximately 35-42% FGD sludge solids is increased to about 60-65% solids in the FSSS. Smith presents a good description of the FSSS process.[4] The mixture is conveyed to a stockpile area to cure for a few days and stiffen to facilitate placement and compaction in the landfill. The state EPA regulatory operating permit will specify for landfill disposal the density and permeability of the compacted solids, thereby governing the amount of compaction effort.

ENVIRONMENTAL WATER QUALITY IMPACT

From combustion of bituminous coal, the FGD solids and fly ash are classified by the USEPA as non-hazardous. Presented in August, 1993, their final regulatory decision on wet FGD emission control waste stated that these materials are not regulated as hazardous wastes under CERCLA Subtitle C and officially placed them under Subtitle D as solid wastes under the jurisdiction of individual states. Classified as a residual solid waste, the State of Ohio EPA program encourages beneficial reuse of FSSS as long as water quality of the surrounding area is not affected. They require each specific project submit a proposal and description for beneficial use status. However, the process of mixing a FSSS with additional fly ash and lime makes the roller compacted mix a product and thus exempt from requiring Ohio EPA approval. However, correspondence with local and state regulatory officials is prudent to foster understanding of the technology and minimal environmental impact of beneficial uses of RCFGD.

The Ohio EPA judges from leachate water quality testing any potential risk. As shown in Table 2 the leachate from one FSSS and fly ash source being utilized are one example showing concentrations of heavy metal elements very much below concentrations considered hazardous (RCRA limits)and actually similar to primary drinking water standards. As permitted by Ohio EPA, the ASTM leachate procedure 3987-85 using distilled water was used instead of the TCLP method that uses acid. The levels are well below Ohio EPA residual waste Class III limits. Leachate concentration for elements other than the TCLP metals are shown.

CEMENTITIOUS POZZOLANIC AND SULFO-POZZOLANIC REACTIONS

There are two basic but related types of chemical reactions that are responsible for the hardening process. Both are a type of pozzolanic reactivity commonly used in stabilization and solidification of waste materials. The first hardening reaction is the more understood pozzolanic reaction where the high pH lime (CaO) solubilizes the silica (SiO_2), glassy amorphous alumina (Al_2O_3), and aluminosiliceous glass from the fly ash component in the presence of high pH and water. These reactions are similar to the hydration of portland cement. This relatively slow reaction solidification is noticeable in about four hours by the stiffening to a mortar or stiff paste like consistency. If compacted, this consumption of free moisture in the FSSS cake material will cause the sludge cake to harden and gain bearing strength. Calcium silicate hydrates (xCaO - $ySiO_2$ - zH_2O), calcium aluminate hydrates (xCaO - yAl_2O_3 - zH_2O), calcium silica-alumina hydrates (wCaO - xAl_2O_3 - $ySiO_2$ - zH_2O) and calcium alumina-ferro hydrates (wCaO - xAl_2O_3 - yFe_2O_3 - zH_2O) are the reaction products.

A secondary reaction begins once the calcium aluminate hydrates are formed. Often called sulfo-pozzolanic, calcium aluminate at high pH reacts with calcium sulfite and calcium sulfate react to form a class of compounds called calcium sulfo-aluminate or calcium aluminosulfate minerals. This type of chemical compound, called ettringite, is represented by the following reaction.

$$2Ca(OH)_2 + 3CaSO_4 \cdot 2H_2O + CaO \cdot Al_2O_3 + 3OH_2O \rightarrow (CaO)_6\,Al_2(SO_4)_3 \cdot 32H_2O$$

Another molecular formula for ettringite is written as $3CaO \cdot Al_2O_3$ - $CaSO_4 \cdot 32H_2O$. This reaction continues to occur for more than one year. It utilizes 32 moles of water for every 3 moles of available CaO and 3 moles of $CaSO_4$ consumed, and thus ettringite is a big contributor to long term development of compressive strength. However, as noted later, its long term stability is questioned. McCarthy and Tishmack express the reaction differently as follows:

$$6\,Ca^{2+} + 2\,Al(OH)_4^- + 3\,SO_4^{2-} + 4(OH)^- + 26\,H_2O \rightarrow Ca_6\,Al_2(SO_4)_3\,(OH)_{12} \cdot 26H_2O$$

They state the actual phase is more complex, with some carbonate substitution for sulfate and variable H_2O content. Also, Si can substitute for Al, forming solid solutions with thaumasite, $Ca_6\,Si_2\,(SO_4)_2\,(CO_3)_2\,(OH)_{12} \cdot 24H_2O$. [5]

PRODUCTION OF RCFGD: TWO CASE HISTORIES

FSSS that is produced for landfill disposal on any given day may not be suitable for beneficial uses such as structural fill, road base, or pond liner. A more controlled and batch type mixing process is preferable where quality and productivity are more assured. A quality control / quality assurance program can be more effective if there is a smaller or secondary pug mill to mix the FSSS containing extra fly ash with additional lime or lime related materials, i.e., lime kiln dust, and additional ash by-products i.e. bottom ash. The addition of both can offer a good means to help the FSSS achieve both more pozzolanic reactivity and a higher percent solids and therefore be closer to its optimum dry density necessary for facilitate the compaction effort. Otherwise, excessive levels of moisture or variations in the amount of fly ash in the FSSS component would prevent a uniform mix and hinder product quality control.

A process for developing RC base course mixes that will satisfy mix design criteria, i.e. 400 psi at 28 days, is being researched by DLC in cooperation with other organizations namely American Electric Power Service Corporation (AEP), VFL Technology Corporation (VFL), and The Ohio State University (OSU).

1993 OSU Cattle Feedlot Pavement: In 1993 DLC and OSU, Department of Civil Engineering performed laboratory studies that showed adequate RCFGD strengths could be made for a base course pavement at a cattle feedlot. In cooperation with the American Electric Power Service Corporation, FSSS from their Conesville plant was converted into RCFGD for a pavement to keep cattle out of the mud during the winter at the feedlot and a storage area for large round hay bales. As shown in Table 3, the ratio of fly ash to FGD was doubled from 0.8:1.0 for the FSSS control (landfill product) to 1.6:1.0 for the RCFGD product. Also, the lime content was increased from 2.0% in the FSSS to 6.5% for two test sections and 11.5% in a third section. Samples of each material were taken to lab and allowed to cure. The 28 day strength increased from 45 psi for the FSSS mix to 190-260 psi for the RCFGD mixes at 6.5% CaO. The 90 day strengths increased likewise from 100 psi to 480-580 psi. A third test at 11.5% lime did not increase strengths at the higher amount. A block of pavement was cut out and removed after the first winter at 9 months age. A strength of 400 psi was found. More detail on this first RCFGD project has been previously reported.[2]

1995 Bob Evans Farm Cattle Feedlot Pavement: In the summer of 1995, an opportunity arose to use a portable pug mill to make lime activated RCFGD, operated by VFL Technology and in cooperation with American Electric Power Gavin Plant personnel. This means of secondary mixing provides a way to add extra ash, i.e., bottom ash or boiler slag, and extra lime bearing material into the FSSS in order to maintain better quality of the RCFGD mix by controlling the percent solids and cementitious reagent. The FSSS was specified to have minimum 1:1 FA to FGD. The pug mill has two variable speed feed hoppers. One is for the FSSS and one for additional bottom ash. A silo will store and feed the cementitious reagent. It produces continuous quantities upon demand much like an asphalt hot mix or ready mix concrete plant at a rate of about 120-150 tons per hour.

One of project objectives was to compare the extra lime fines to the use of lime kiln dust, which is generally 20% ± 5% quicklime and 75% pulverized limestone. Therefore, more is required. The dosages compared in the plant mixes described in Table 4 are 8% lime fines and 20% lime kiln dust (LKD). More research will determine the optimum dosage of each. Table 4 also shows a lab mix of 8% LKD. Unconfined compressive strengths with 8 and 20% LKD tests surpassed the 400 psi at 28 days age criteria. These strength and densities agreed closely with similar lab mixes performed earlier by American Electric Power's Civil Engineering Laboratory.[6] Details of results including costs and durability tests i.e. freeze-thaw resistance, will be the subject of a future report.

MIX DESIGN PROCEDURE TO MAKE RCFGD FROM FSSS

A proposed procedure is outlined for designing and confirming a mix design to meet the design strength for RCFGD and can be summarized in four steps:

Step 1 - Specification for FSSS: The first stage is to develop a specification or criteria for the fixated scrubber sludge solids (FSSS) that is to be the main component in the RCFGD mix. When placing an order for RCFGD, a separate stockpile of "high grade" FSSS can be segregated on the concrete storage pad. To start with, the filter cake solids should be maximized or have a minimum of 40% solids (wet weight basis). The amount of fly ash and lime added to make FSSS should be mixed to increase the percent solids to about 66% or more (a 66% solids wet weight basis equals to 51.5% on a dry weight basis). The ratio of fly ash to filter cake solids on a dry weight basis should approximate 1:1. More fly ash if available up to 1.6:1.0 may be better for more moisture control. At least 2-3% pulverized quicklime should be added to initiate the chemical reaction. Experience has shown the FSSS should cure at least one day in a stockpile before using it to make RCFGD but not more than 3 days. Over four days, the strength gain in the FSSS mix alone would be destroyed when re-mixing for RCFGD.

Step 2 - Develop procedure to design RCFGD: The second stage is to determine the optimum moisture content (OMC) so as to determine the amount of additional extra dry pozzolanic and cementitious material to increase the strength of RCFGD. Excessive water contents would prevent optimum compaction or maximum dry density. However, 2-5% of extra moisture is desirable to hydrate the extra lime required (~5% CaO as free, available and pulverized quicklime or equivalent).

a) The amount of free moisture that achieves a compacted base course of maximum dry density is determined by constructing / generating a OMC curve according to ASTM D-698[3]. It is reported on a dry weight basis i.e. weight of moisture divided by the weight of dry solids. An example is shown in Table 5.

b) The optimum moisture content is apt to be much lower than the moisture content of the FSSS. Additional ash and/or lime based cementitious fines, i.e. pulverize quicklime or lime kiln dust, needs to be added in a second mixing operation like that described at the VFL pugmill to closely approach the OMC. The amount of additional ash material needed can be represented by the following formula:

$$\text{OMC} = \frac{\text{water content present in FSSS}}{\text{solids in FSSS + additional solids needed}} \times 100$$

Example: Assume an OMC is found to be about 35% on a dry weight basis. Assume the FSSS is 66% solids on the wet basis. It contains 34% water. The amount of additional ash required calculates to 0.31 lb for every 1.0 lb of FSSS. The added ash is assumed here to be dry. Variable speed settings of each hopper feeder can be set accordingly.

$$35\%\ \text{OMC} = \frac{0.34\ \text{water}}{0.66\ \text{FSSS} + 0.31\ \text{added ash}} \times 100$$

c) Strength gain should be confirmed. In this phase of Step 2, one is to mold specimens to determine unconfined compression strength (UCS) of the OMC mix. This should be done in conjunction with checking levels of extra cementitious reagent in order to confirm strength gain from at least 7 to 28 days but as early as 4 days curing. UCS should be determined according to ASTM D-2166-85. Dry and wet density would be calculated. The water content of the broken procter cylinders for strength should be determined and recorded.

Step 3 - Field Demonstration Mix and Conformation, Field Sampling for UCS, Water Content, and Density: Once placed and compacted in the field in place densities and water content should be determined and compared to that designed. Molded samples for UCS should be made to cure and break for strength gain confirmation.

FIELD SAMPLING FOR UNCONFINED COMPRESSIVE STRENGTH, MOISTURE, AND DENSITY

The specimens would be extruded on site, kept moist, and transported safely to a laboratory curing chamber. Unconfined compressive strength is determined at 7, 14, 28, and 60 days. Two specimens are broken on at least two of the days to check for repetition/consistency. Each molded sample should be weighed and checked for wet density. After compaction and extrusion of the specimen, only a small amount of water should be observed on the base of the mold. Surfaces of the specimens should appear damp. The dry density can be determined after determining the free moisture of the uncompacted material assuming very little if any water was compacted out of the specimen during the molding process. Extra specimens for durability testing such as wet-dry or freeze-thaw resistance would also have to be made.

In place density measurements using the sand cone volumetric displacement procedure (ASTM D4914) or a Troxler nuclear densionmeter should be taken for comparison to the procter mold densities. The free moisture should be a few percentage points in excess of the OMC content to account for quicklime hydration.

RCFGD BENEFICIAL USE - NEED FOR CAUTION, PROOF OF DURABILITY

Road base construction using RCFGD in the thousands of tons have been applied in Florida and Texas.[7,8,9] Both lime and portland cement has been used as the stabilizing agent, and other sources than coal FGD wet sludge have been used. In the Ohio River Valley, power plants that scrub are more interested in learning how to design and construct beneficial use applications such as roller compacted pavement or structural fill. One of the major concerns for successful long term applications of this cementitious reaction in the more northern climate is the long term durability, most specifically resistance to degradation from freeze-thaw cycles.

The first record of attempting FSSS for roadbase construction in the Ohio Valley region was near Pittsburgh, PA, in 1977.[10] Cores of the road base were taken after 3 and 7 years for freeze-thaw testing by the vacuum saturation method as stipulated in ASTM C-593.[11] Strengths were not decreased as one might expect by this severe test.

The only recent work has been reported by researchers at OSU, AEP and VFL. They all used ASTM D 560 method titled "Freezing and Thawing Compacted Soil-Cement Mixtures."[3] However, Wolfe, Chen, and Hargroves at OSU [12,13] modified the procedure to gauge results by testing UCS rather than measuring weight loss after each freeze-thaw cycle. VFL and AEP are researching a pass-fail criteria based on volume change and strength as opposed to the conventional practice of measuring weight loss per ASTM D560.[6] More research needs to confirm if this criteria can be met for RCFGD using extra lime and fly ash at the respective OMC.

Chen and Wolfe of OSU found good strengths under freeze-thaw conditions provided 5% extra lime was added to the FSSS before compaction and the time from compaction to first freeze was at least 60 days. Also, they showed that water contents above 40% (dry weight) exhibited low strength after 12 cycles of freeze-thaw.[12] Hargroves of OSU showed that after 60 days curing the 12 cycles of freeze-thaw lowered compressive stengths from about 600 psi to 300-

500 psi..[13] More research must confirm if this loss in strength is acceptable. In general, more experience by various researchers is needed before a consensus can be found on how to perform freeze-thaw testing and what criteria and parameters to judge user acceptance.

Another major need for answers to questions from highway construction design engineers is the potential for swelling reactions like those reportedly caused by other types of compacted FGD by-product materials. Specifically, dry FGD by-products from fluid bed combustion and duct injection systems have similar chemical and mineralogical composition and cementitious strength gaining reactions when conditioned with water and then compacted. Studies have reported dry FGD by-products have swelling characteristics due to the slow hydration and formation of ettringite.[14] Swelling has been known to occur after clay soils high in sulfate content were stabilized with lime in order to construct a road.[15] Graham et.al. reported that under a confining pressure, ettringite formed preferentially inside available pore space, indicating that the formation mechanism may be regulated by a surcharge.[16] Others fear the subsequent formation of thaumosite ($Ca_6Si_{12}(CO_3)_2(SO_4)_2(OH)_{12}\cdot24H_2O$) may further degrade performance.[5,17] Still others have reported studies where the addition of extra pulverized fly ash improved durability of the dry FGD mixtures for structural fill or pelletized for use as construction aggregates.[18] Papers on FSSS by the noted author Charles Smith of Conversion Systems, Inc. have never mentioned potential swelling or descriptive tests to predict same.[4,5,8] Saylak et.al. states ettringite is stable if there is ample supply of sulfate available.[6] They recommend using low alumina content portland cement as the cementitious stabilizing agent. Long term swelling tests need to be conducted using ASTM method D4546.[2]

ASTM SUB-COMMITTEE 50.03

The ASTM E50.03 coal ash task group recently published a standard ASTM P5 23-95 "Guide for the Use of Coal Combustion Fly Ash Structural Fills".[19] This provisional guide covers the design and construction procedures for consideration of engineering, economics, and environmental factors in the development of fly ash structural fills. Committee E-50 covers environmental risk assessment. The sub-committee E50.03 is responsible for pollution prevention, reuse, recycling, and environmental efficiency. Utilization of coal combustion fly ash conserves land, natural resources, and energy. A similar effort in creating guidelines should be considered for RCFGD for use as a stabilized base and structural fill.

SUMMARY AND CONCLUSIONS

Roller compacted stabilized base course for construction projects required to withstand heavy weight traffic is a potential high volume beneficial use for fixated FGD scrubber sludge solids (FSSS) that are enhanced by the addition of extra fly ash/bottom ash and quicklime in order to efficiently compact to maximum density and thereby attain higher compressive strength and long-term durability.

The chemical composition of the mix components and cementitious chemical reactions that cause increases in bearing strength are discussed. The common practice of producing FSSS for landfill disposal is compared to the advanced mixing process to obtain higher strengths for beneficial use applications in land construction. Leachate water quality of FSSS is non-toxic and similar to primary drinking water standards. State of Ohio regulatory policy encourages large scale demonstrations of beneficial use. Processing to enhance the FGD by-products for beneficial use eliminates the requirement for regulatory approval, but the EPA authorities still need information for better understanding and public support.

Two case histories and a procedure for designing a mix to have optimum moisture content (OMC) were discussed. One recent case used a portable pug mill to obtain OMC and increased strength by addition of extra coal ash and lime. Twenty percent lime kiln dust was successfully used as a substitute for 8% pulverized quicklime. Adequate strength of 400 psi can be achieved.

Concerns about long term durability are discussed. There is not enough field demonstration evidence that satisfactory long term durability can be attained under freeze-thaw conditions. Better consensus is needed on how to test for durability. The risk of potential swelling from expansive long term hydration reactions of ettringite formation must be clarified. ASTM E-50 committee on environmental risk assessment using recycled products offers a means to write a specification for designing roller compacted base course using FGD and coal ash by-products. Efforts to develop beneficial uses of these materials should be enhanced by the growing public interest in concepts and the example of environmental sustainability.

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Table 1

Chemical Composition of RCFGD Components

	Range, % by weight		
	Conesville FGD Solids	**Fly Ash**	**Quick Lime**
CaO	29 - 35	1 - 3	87 - 95
MgO	1.3 - 1.5	0.5 - 1.0	3 - 6
SiO_2	10 - 17	33 - 45	1.8 - 2.9
Al_2O_3	5 - 10	17 - 22	0.5 - 0.7
Fe_2O_3	5 - 10	20 - 34	0.2 - 0.3
Na_2O	<0.2	0.2 - 0.6	trace
K_2O	0.2 - 0.8	1.3 - 2.2	trace
SO_3	26 - 33	1.0 - 2.4	<0.20
LOI	10 - 13	1 - 6	0.4 - 1.5

Table 2

Leachate Tests of Conesville FSSS and Fly Ash
ASTM Distilled Water Extraction (18 hr., 20:1 water : solid)

units: mg/l	FSSS Conesville	Fly Ash Conesville	Class III Residual Waste	RCRA Limits	Primary Drinking Water Standards
Parameters - toxic metals:					
As	0.008	0.15	1	5	0.05
Ba	0.22	0.13	30	100	1
Cd	<0.005	0.01	0.2	1	0.01
Cr	<0.002	0.02	1	5	0.05
Pb	<0.002	<0.002	1	5	0.05
Hg	<0.0002	<0.0002	0.04	0.2	0.002
Se	0.007	<0.005	0.2	1	0.01
Ag	<0.005	<0.003	1	5	0.05
Other Trace Elements :					
B	0.36	–	–		
Cu	0.001	0.27	–		
Cl	61	2	7,500		
F	0.8	0	120		
Fe	<0.01	5	9		
Mn	<0.01	0	9		
SO_4	36	650	7,500		
Na	7.4	10.5	7,500		
TDS	560	940	10,000		
pH	10.5	4.1			
alkalinity	260	<1			
acidity	<1	202			

Table 3

RCFGD at OSU Feedlot made from Conesville Plant FGD Solids (FSSS) plus extra Fly Ash and Lime, September, 1993

	Control Mix (FSSS)	Extra Lime Added at OSU Feedlot	Extra Lime Added at Conesville	Extra Lime, Conesville and OSU
FA:FGD (dry)	1.0 : 1.0	1.6 : 1.0	1.6 : 1.0	1.6 : 1.0
Total Lime Added, %	2	6.5	6.5	11.5
Per Cent Solids	52.6	61.7	63.1	62.8
Wet Density, lbs./cu.ft.	101.5	97.2	99.8	99.1
Dry Density, lbs./cu.ft.	68.8	70.3	72.9	72.2
Unconfined Compressive Strength, psi :				
28 day	45	190	260	220
90 day	100	580	480	310

Table 4

Roller Compacted FGD Base Course made at Bob Evans Feedlot and mixed at Gavin AEP - VFL Pug Mill, August, 1995

	Plant Mix	Plant Mix	Lab Mix
Extra Lime:	8% Lime Fines	20% Lime Kiln Dust	8% Lime Kiln Dust
Mix Design:			
FA:FGD (1)	1.0:1.0	1.0:1.0	
FSSS (2)	80%	80%	100%
BA (3)	20%	20%	0%
Results:			
Moisture	29%	32%	34%
Wet Density: lbs./cu.ft.	107.2	110.1	103.8
Dry Density: lbs./cu.ft.	83.2	83.6	85.0
Unconfined Compressive Strength: psi			
7 day	90	100	114
14 day	190	220	270
28 day	350	470	400
60 day	520	790	510 (87 day)

Notes: 1) FA = Gavin flyash; FA:FGD ratio is on dry weight basis to make FSSS.
2) FSSS is the FA:FGD mixture plus 2% quicklime mixed at Gavin pugmill.
3) BA is the bottom ash mixed along with extra lime at VFL pug mill.

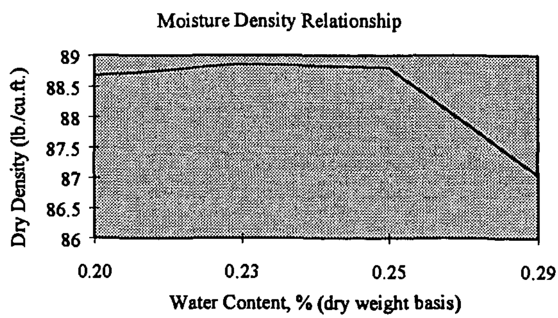
Table 5

Moisture-Density Relationship for Gavin FSSS + 20% Lime Kiln Dust

Proportions adjusted to meet the criteria for the 4 different WC ratios.

SAMPLE	WC2	WC3	WC4	WC5
WT MOLD + WS (lb.)	13.96	14.06	14.12	14.16
WT MOLD (lb.)	10.42	10.42	10.42	10.42
VOL MOLD (cu. ft.)	0.0333	0.0333	0.0333	0.0333
WET DENSITY (lb./cu.ft.)	106.3	109.3	111	112.3
WT TARE + WS (g)	232.9	234.7	242.2	224.3
WT TARE + DS (g)	197.9	194.8	198.2	178.6
WT TARE (g)	21.9	21.9	21.9	21.9
WT DS (g)	176	172.9	176.3	156.7
WT WATER (g)	35	39.9	44	45.7
WATER CONTENT %	0.20	0.23	0.25	0.29
DRY DENSITY (lb./cu.ft.)	88.67	88.86	88.8	87.05

(legend: WT = weight, WS = wet solids, DS = dry solids)



ACKNOWLEDGMENTS

The author wishes to thank Professor Wm. Wolfe of The Ohio State University, Department of Civil Engineering, and Mr. Pedro Amanya and Mr. Greg Keenan of the American Electric Power Service Corporation for their advice and information in preparing this paper.