Chapter 3

Properties of We Energies Coal Combustion Products

Fly ash and bottom ash produced at the six coal-fired power plants that are owned and operated by We Energies have been subjected to extensive tests for physical and chemical properties. The type of coal, percentage of incombustible matter in the coal, the pulverization process, furnace types and the efficiency of the combustion process determine the chemical composition of the coal ash.

Another factor affecting the quality of coal ash is whether the power plant is base loaded or frequently being brought in and out of service. A base loaded plant operates at consistent temperatures and combustion rate. Plants that are frequently changing load or coming in and out of service tend to produce more variability in coal ash characteristics. The use of low NO_x burners at power plants has generally resulted in an increase in loss on ignition and carbon content in the fly ash. Likewise, many SO_x reduction processes result in higher sulfur compounds in the coal ash.

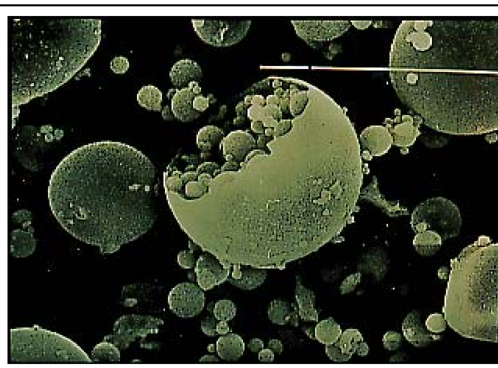

Figure 3-1: Fly ash particles are spherical and average about 10 microns in diameter

We Energies purchases coal from several mines. Several factors affect the selection of coal source, but the quality and cost of coal are two very important considerations. The consistency of fly ash does not change significantly if the coal used in the plant is from a single geological formation or from a consistent blend of coals. But when coal sources change, the chemical and physical properties of the fly ash may change significantly if the type or chemistry of coal is switched. At times, coal from different sources may be blended to improve air emissions, to reduce generation costs, to increase the efficiency of combustion and/or to improve the quality of fly ash generated.

Physical, Chemical and Mechanical Properties of Fly Ash

Table 3-1 gives the chemical composition of fly ash from various We Energies power plants. The results tabulated are based on tests performed at We Energies' own state-certified lab and various other outside certified testing facilities. We Energies fly ash marketers have on-site labs that test the fly ash generated from the power plant daily and more often if warranted. The quality and chemical composition of fly ash do not change very often because coal is usually purchased on long-term contracts. Fly ash from Pleasant Prairie Power Plant has actually been more consistent than many Portland cements.

Figures 3-2 and 3-3 show the loss on ignition and fineness consistency for Pleasant Prairie's fly ash. A customer may request samples for independent testing on a particular fly ash to independently determine its properties. As can be seen from Table 3-1, the chemical composition of fly ash differs from plant to plant and sometimes from unit to unit within a power plant.

Table 3-1: Chemical Composition of We Energies Fly Ash

Source	ASTM C618 Class F Class C	OCPP Units 5-6	OCPP Units 7-8	PIPP Units 1-4	PIPP Units 5-6	PIPP Units 7-9	PPPP	VAPP
SiO_2, %	- -	36.1	34.3	40.4	36.9	37.0	41.4	39.27
Al_2O_2, %	- -	19.5	19.4	18.5	18.1	18.6	21.8	15.93
Fe_2O_3, %	- -	6.0	5.7	4.2	3.6	5.5	5.6	4.57
SiO_2+Al_2O_3+Fe_2O_3, %	70.0 Min 50.0 Min	61.6	59.4	63.1	58.6	61.1	68.8	59.77
SO_3, %	5.0 Max 5.0 Max	1.6	1.4	0.6	0.7	2.4	1.4	1.11
CaO, %	- -	24.3	25.8	3.0	2.9	19.5	19.3	3.31
Moisture Content, %	3.0 Max 3.0 Max	0	0	0	0.1	0	0.0	0.00
LOI, %	6.0 Max * 6.0 Max	0.1	0.3	28.0	33.2	0.9	0.8	31.31
Available Alkali as Na_2O, %	AASHTO M 295-00 1.5 Max	1.3	1.4	0.7	0.7	1.8	1.3	- 0.6

*The use of Class F Pozzolan containing up to 12.0% loss on ignition may be approved by the user if either acceptable performance records or laboratory test results are made available.

Fly ash is classified as Class F or Class C by ASTM C618 based on its chemical and physical composition. We Energies contracts with marketers that distribute and test fly ash to ensure that customer supply, quality and consistency requirements are met.

The chemical composition of We Energies' fly ash generated by burning sub-bituminous coal is different from that generated by burning bituminous coal. For example, burning 100% Wyoming Powder River Basin (PRB) sub-bituminous coal produces fly ash with a calcium oxide content, typically in the range of 16 to 28%. However, burning 100% bituminous coal generates a fly ash with a CaO content in the range of 2 to 4%.

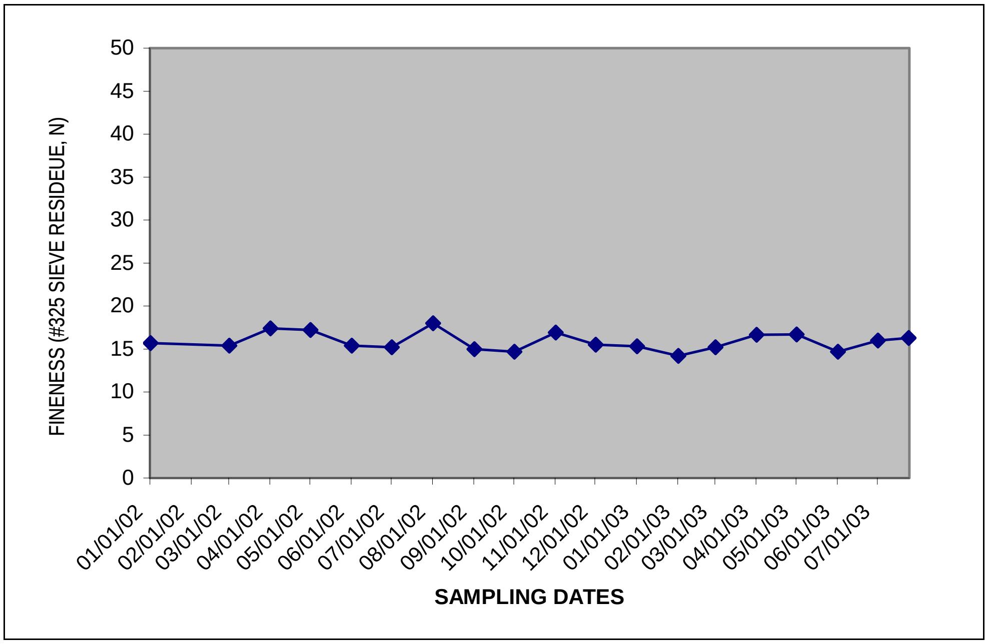

Figure 3-2: Fineness Consistency of PPPP Fly Ash

According to ASTM C618, when the sum of SiO_2, Al_2O_3 and Fe_2O_3 is greater than 70%, the fly ash can be classified as Class F and when the sum is greater than 50% it can be classified as Class C fly ash. The fly ash must also meet the ASTM C618 limits for SO_3, loss on ignition, fineness and other requirements.

Presque Isle Power Plant generates both Class C and Class F fly ash and has separate silos for each variety (see Table 3-1). By reviewing the chemical composition of fly ash from each plant, it is easy to determine if the fly ash is Class C or Class F and to select an ash that best meets end use requirements.

By graphing individual parameter test results, it is possible to identify any significant changes. This is helpful in order to determine if a specific fly ash is suitable for a particular application or whether a blend of one or more materials is needed.

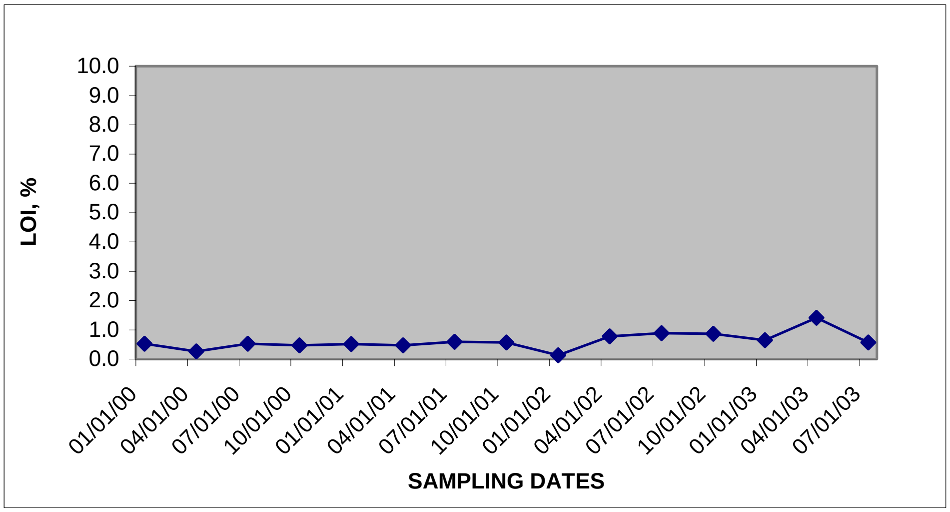

Figure 3-3: Loss on Ignition Consistency for PPPP Fly Ash

Table 3-2 shows the physical properties of fly ash at various We Energies power plants, along with the ASTM standard requirements.

Table 3-2: Fly Ash Physical Properties

SOURCE	ASTM C618 Class F	ASTM C618 Class C	OCPP Units 5-6	OCPP Units 7-8	PIPP Units 1-4	PIPP Units 5-6	PIPP Units 7-9	PPPP	VAPP
Fineness:									
Retained on #325 Sieve, (%)	34 Max	34 Max	7.2	14.0	33.7	31.2	15.7	14.4	64.9
Strength Activity Index with Portland Cement, (%) :									
% of Control @ 7 days	75 Min	75 Min	99.8	100.9	60.9	45.4	92.8	97.3	29.3
% of Control @ 28 days	75 Min	75 Min	104.6	104.6	63.8	52.0	95.6	98.4	34.0
Water Requirement:									
% of Control	105 Max	105 Max	92.6	93.4	109.5	116.5	92.6	92.6	121.9
Soundness:									
Autoclave Expansion (%)	0.8 Max	0.8 max	0.07	0.07	0.01	0.02	0.06	0.03	0.02
Specific Gravity	-	-	2.68	2.68	1.94	1.96	2.61	2.34	1.94

Physical, Chemical and Mechanical Properties of Bottom Ash

The coal combustion process also generates bottom ash, which is second in volume to the fly ash. Bottom ash is a dark gray black or brown granular, porous, predominantly sand size material. The characteristics of the bottom ash depend on the type of furnace used to burn the coal, the variety of coal, the transport system (wet or dry), and whether the bottom ash is ground prior to transport and storage. We Energies generates over 107,000 tons of bottom ash each year at its six coal-fired power plants.

It is important that the physical, chemical and mechanical properties of bottom ash be studied before it can be beneficially utilized. The primary chemical constituents of We Energies bottom ash are shown in Table 3-3. These chemical characteristics of bottom ash are generally not as critical as for fly ash, which is often used in concrete, where cementitious properties and pozzolanic properties are important.

Table 3-3: Chemical Composition of We Energies Bottom Ash

Constituent	PPPP	MCPP	OCPP Units 7	VAPP	PIPP Unit 1-6	PIPP Unit 7-9
SiO_2	47.50	54.15	46.29	57.32	56.84	48.64
Al_2O_3	19.27	30.22	18.55	23.14	24.17	19.00
Fe_2O_3	5.60	6.21	5.16	6.23	7.51	6.46
CaO	17.78	2.53	18.75	4.64	4.79	14.99
MgO	3.31	0.89	4.60	1.69	1.71	3.58
SO_3	0.33	0.37	0.52	0.85	0.65	0.82
Na_2O	0.90	0.39	1.02	1.22	1.06	2.54
K_2O	0.57	2.50	0.25	1.44	1.32	0.67

In the case of bottom ash, physical and mechanical properties are critical. We Energies has been studying the properties of bottom ash that are important in construction applications for comparison to virgin materials currently dominating the market.

An additional consideration for bottom ash is its staining potential if used as an aggregate in concrete masonry products. Staining can occur if certain iron compounds such as pyrite are present. Pyrites can also present corrosion potential for buried metals. For these applications, it is important to identify if pyrites exist in sufficient quantity to present a problem ($\geq$ 3.0 %).

Moisture-Density Relationship (ASTM D1557)

Bottom ash samples were tested to determine maximum dry density and optimum moisture content per the ASTM D1557 test method. The test results are shown in Table 3-4.

Table 3-4: Physical Properties of Bottom Ash

Bottom Ash Source	Max Dry Density, pcf	Optimum Moisture Content, %	Hydraulic Conductivity K(cm/sec)
OCPP	87.2	23.7	1.0×10^{-3}
MCPP	74.9	13.4	2.2×10^{-4}
PWPP	81.1	15.5	4.6×10^{-3}
PPPP	89.2	19.2	4.9×10^{-3}
Unit 1-6 PIPP	54.4	21.9	4.8×10^{-3}
Unit 7-9 PIPP	91.3	14.3	1.4×10^{-3}
VAPP	49.3	33.0	5.4×10^{-3}
SAND	110 – 115	7 – 17	10^{-2} to 10^{-3}

We Energies bottom ashes are generally angular particles with a rough surface texture. The dry density of bottom ash is lower than sand or other granular materials typically used in backfilling.

The grain size distribution is shown in Table 3-5. Figures 3-4 through 3-9 show the grain size distribution curves for the various We Energies bottom ashes.

Engineering Properties of We Energies Bottom Ash

Unlike fly ash, the primary application of bottom ash is as an alternative for aggregates in applications such as subbase and base courses under rigid and flexible pavements. It has also been used as a coarse aggregate for hot mix asphalt (HMA) and as an aggregate in masonry products. In these applications, the chemical properties are generally not a critical factor in utilizing bottom ash.

However, some engineering properties of the material are important and may need to be evaluated. These properties influence the performance of the material when exposed to freezing and thawing conditions and their associated stress cycles.

Table 3-5: Bottom Ash - Grain Size Distribution (ASTM D422)

Sieve Size	PPPP	MCPP	OCPP Units 5-6	OCPP Units 7&8	VAPP	PIPP Units 1-6	PIPP Units 7-9
3/4”	99.3	91.9	96.3	98.2	100	99.9	97.7
1/2”	98.7	76.1	91.8	91.8	100	99.7	93.7
3/8”	97.8	59.1	84.8	86.8	100	99.5	89.9
#4	90.6	28.2	77.3	73.2	99.9	96.8	76.6
#8	79.2	14.7	65.9	60.9	99.7	88.8	62.7
#16	60.9	6.3	56.9	48.8	99.2	75.8	49.4
#30	44.9	2.9	48.9	39.6	98.3	61.6	39.4
#40	37.1	2.0	43.5	34.7	96.1	53.5	34.8
#50	28.2	1.1	35.6	29.1	66.2	33.0	30.2
#100	15.7	0.3	23.0	19.9	48.0	16.8	23.0
#200	8.4	0.1	14.1	12.8	41.8	11.3	17.8

The major test procedures and standards established by AASHTO and followed by many Transportation and highway departments, including the Wisconsin Department of Transportation (WisDOT) and Michigan Department of Transportation (MODOT), are listed in Table 3-6.

Table 3-6: AASHTO Test Procedures

Test Procedure	AASHTO Designation
Soundness (Magnesium Sulfate/Sodium Sulfate)	AASHTO T-104
Los Angeles Abrasion	AASHTO T-96
Grain Size	AASHTO T-27
Modified Proctor	AASHTO T-180
Atterberg Limits	AASHTO T-89 and T-90
Resistance to Freeze/Thaw (50 Cycles)	AASHTO T-103

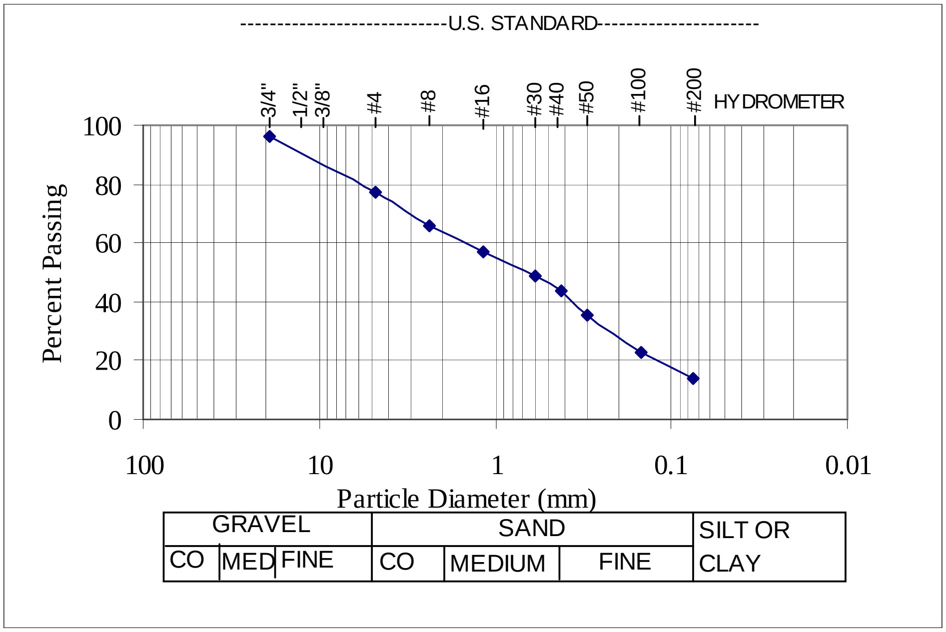

Figure 3-4: OCPP Bottom Ash Grain Size Distribution Curve

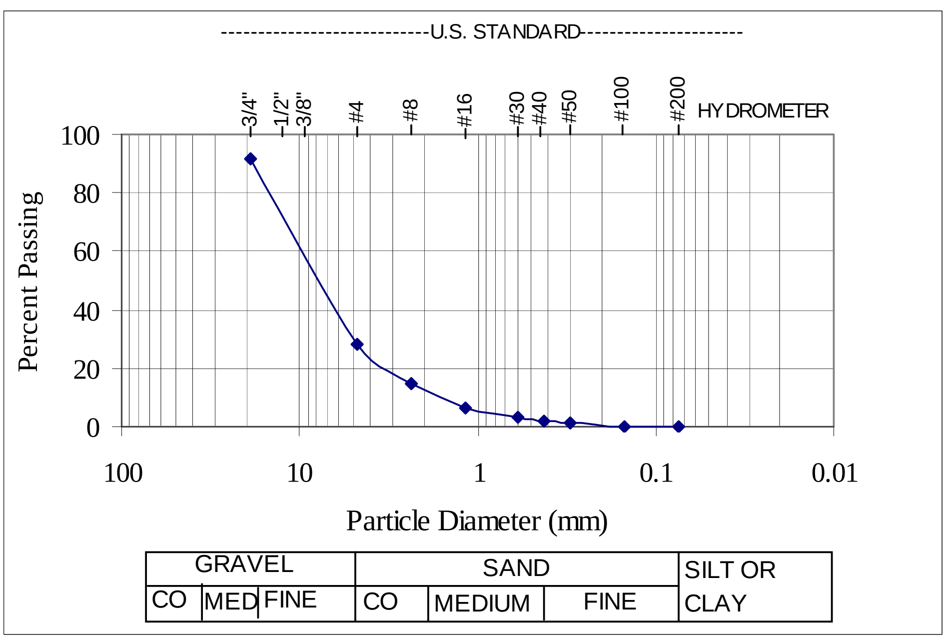

Figure 3-5: MCPP Bottom Ash Grain Size Distribution Curve

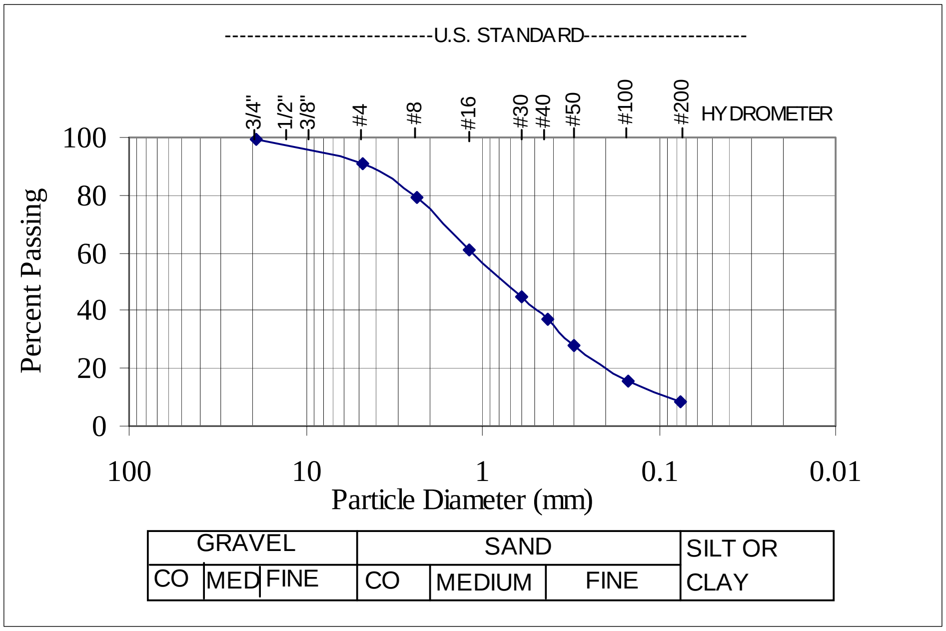

Figure 3-6: PPPP Bottom Ash Grain Size Distribution Curve

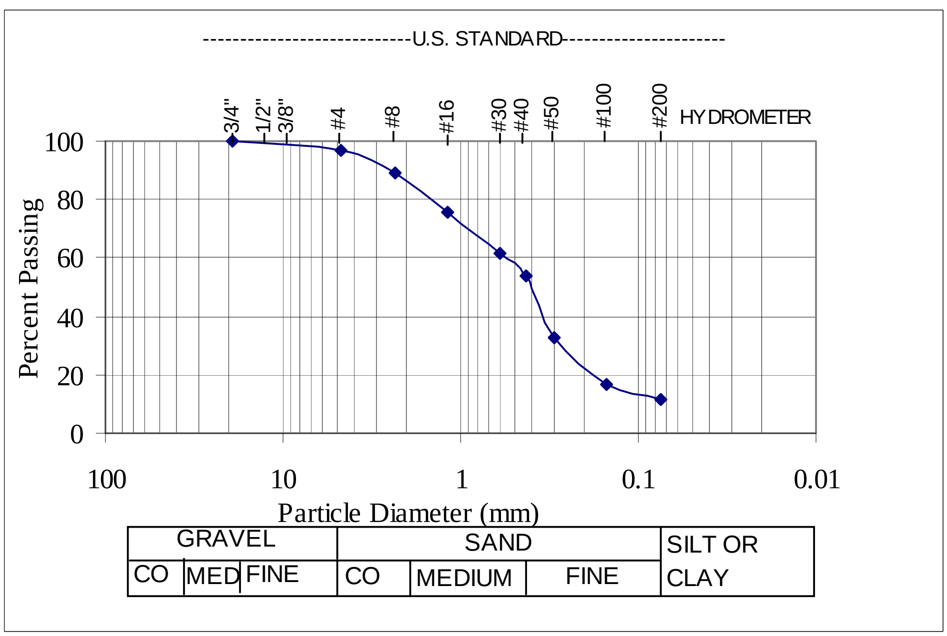

Figure 3-7: PIPP Units 1–6 Bottom Ash Grain Size Distribution Curve

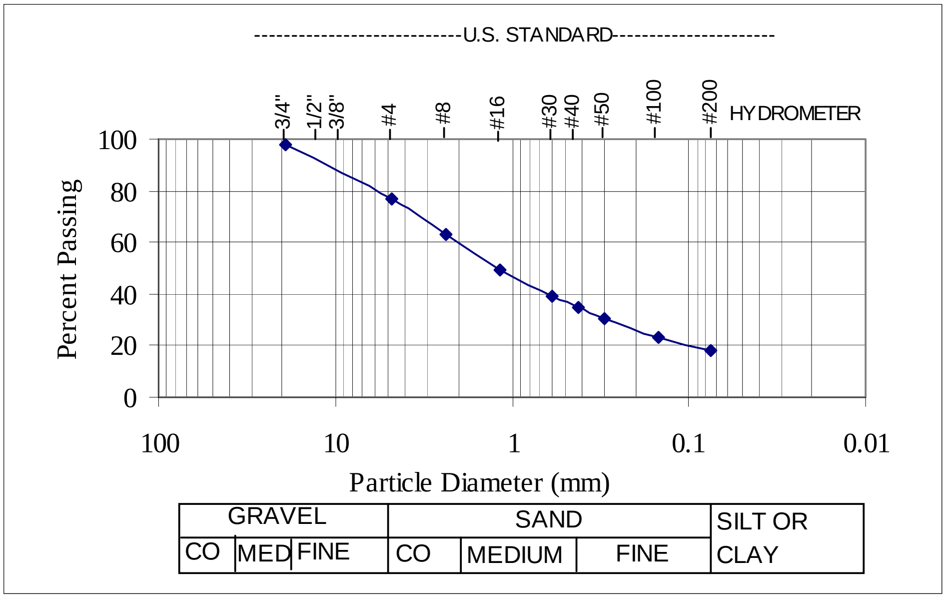

Figure 3-8: PIPP Units 7–9 Bottom Ash Grain Size Distribution Curve

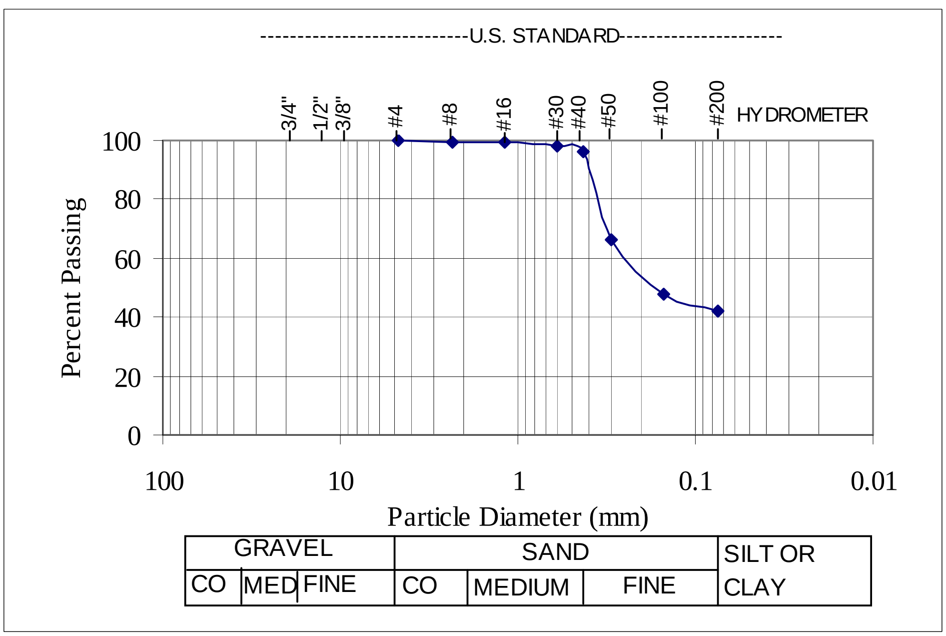

Figure 3-9: VAPP Bottom Ash Grain Size Distribution Curve

Results of Testing to AASHTO Standards

In early 1994 and 2004, testing was performed on We Energies bottom ash to evaluate its use as a base course material, as granular fill for subbase and as a coarse aggregate for hot mix asphalt (HMA), following the procedures in the AASHTO Standards. The test results were then compared with the requirements in the WisDOT's standard specifications (16) and the MDOT's standard specifications for construction (17). The test results are tabulated in Tables 3-7 and 3-8.

Atterberg Limit tests were performed on Pleasant Prairie and Presque Isle bottom ashes. The results show that all three materials tested are non-liquid and non-plastic. Section 301.2.3.5 of WisDOT Standard Specifications require that the base course aggregate not have a liquid limit of more than 25 and not have a plastic index of more than 6. WisDOT standard specifications do not identify a maximum liquid limit for hot mix asphalt coarse aggregate. Therefore, the bottom ash materials meet the WisDOT standard specification requirements for Atterberg Limits.

The Los Angeles Abrasion test results showed that the bottom ash samples tested were not as sound or durable as natural aggregate. However, the test results fall within the WisDOT limits of maximum 50% loss by abrasion for Mixtures E-0.3 and E-1.

WisDOT standard specifications require a minimum 58% fracture face for dense base course aggregate. The bottom ash meets the specifications, because of the angular texture in nature.

MDOT specifications limit a maximum loss of 50% for dense graded aggregates. Other grades of aggregates have a lower limit on abrasion loss. Hence, the samples tested meet only MDOT specifications for dense graded aggregates.

Pleasant Prairie bottom ash and Presque Isle bottom ash did not meet the gradation requirements of WisDOT section 305.2.2.1 of the Standard Specifications for base course aggregate, and section 401.2.5 for hot mixed asphalt coarse aggregate. The material requires blending with other aggregates and/or screening to meet requirements of WisDOT sections 305.2.2.1 and 401.2.5.

Pleasant Prairie bottom ash and Presque Isle units bottom ash met the gradation requirements for Grade 2 granular fill specified by WisDOT although both of these materials need to be blended, washed or screened to meet the WisDOT specification for Grade 1 granular fill. Presque Isle 5-6 bottom ash fails to meet the WisDOT requirements for granular fill.

Table 3-7: Summary Of We Energies Bottom Ash Test Data and Comparison to WisDOT Specifications (16)

Analysis	Pleasant Prairie Bottom Ash	Presque Isle Unit 1-6 Bottom Ash	Presque Isle Unit 7-9 Bottom Ash	Reference Specifications
Soundness				
Result				
Coarse Fraction	1.12	N/A	1.91	
Fine Fraction	2.45	3.91	3.18	
Compliance				
Coarse Fraction	Pass	N/A	Pass	WisDOT 301.2.3.5 & 460.2.7
Fine Fraction	Pass	Pass	Pass	WisDOT 301.2.3.5 & 460.2.7
Atterberg Limits				
Result	Non-Liquid/ Non-Plastic	Non-Liquid/ Non-Plastic	Non-Liquid/ Non-Plastic	
Compliance	Pass	Pass	Pass	WisDOT 301.2.3.5
Los Angeles Abrasion				
Result	46.8	N/A	47.7	
Compliance	Pass E-0.3 and E-1	N/A	Pass E-0.3 and E-1	WisDOT 301.2.3.5 & 460.2.7
Gradation				
Result	See this chapter	See this chapter	See this chapter	
Compliance				
As HMA Coarse Agg.	Fail (1)	Fail	Fail	WisDOT 460.2.2.3
As Base Coarse Agg.	Fail (1)	Fail (1)	Fail	WisDOT 305.2.2.1
As Granular Backfill	Pass Grade 2	Pass Grade 2	Fail (2)	WisDOT 209.2.2.
Freeze-Thaw Durability				
Result	N/A	N/A	N/A	
Compliance	N/A	N/A	N/A	AASHTO T-103 (50 Cycles)
Aggregate Angularity	(3)	(3)	(3)	CMM13.9

N/A- Not Available

(1) - Requires blending with other aggregate to meet specifications.

(2) - Requires blending, washing or screening to reduce the amount of fines to meet specifications.

(3) - Bottom ash is angular in nature.

Table 3-8: Summary of We Energies Bottom Ash Test Data and Comparison to Michigan DOT Specifications (17)

Analysis	Pleasant Prairie Bottom Ash	Presque Isle Unit 1-6 Bottom Ash	Presque Isle Unit 7-9 Bottom Ash	Reference Specifications
Soundness				
Result				
Coarse Fraction	1.12	N/A	1.91	
Fine Fraction	2.45	3.91	3.18	
Compliance				
Coarse Fraction	N/A (1)	N/A (1)	N/A(1)	AASHTO T-104
Fine Fraction	N/A (1)	N/A (1)	N/A (1)	AASHTO T-104
Atterberg Limits				
Result	Non-Liquid/ Non-Plastic	Non-Liquid/ Non-Plastic	Non-Liquid/ Non-Plastic	
Compliance	N/A (2)	N/A (2)	N/A (2)	AASHTO T-89 & T-90
Los Angeles Abrasion				
Result	46.8	N/A	47.7	
Compliance	(3)	N/A	(3)	MDOT 8.02.05
Gradation				
Result	See Attached	See Attached	See Attached	
Compliance				
As HMA Coarse Agg.	Fail (4)	Fail (4)	Fail (4)	MDOT 902
As Base Coarse Agg.	Fail (4)	Fail (4)	Fail (4)	MDOT 902
As Granular Backfill	Fail (4)	Fail (4)	Fail (4)	MDOT 902
Freeze-Thaw Durability				
Result				
Compliance				AASHTO T-103 (50 Cycles)

N/A = Not Available

(1) - MDOT does not have a specific requirement for soundness. Instead, MDOT relies on results of freeze-thaw durability.

(2) - MDOT does not have a specific requirement for Atterberg Limits.

(3) - Does not meet specifications for coarse aggregates or any of the open-graded aggregates. The materials meet the requirements for dense graded aggregates.

(4) - Material could be blended with another aggregate to help meet specifications.

Soundness test results for all three samples are well within the allowable limits per section 301.2.3.5 and section 460.2.7 of the WisDOT standard specifications. MDOT specifies a maximum percent material loss by washing through the No. 200 sieve in lieu of the soundness test. Both Pleasant Prairie bottom ash and Presque Isle bottom ash did not met the MDOT specification for a dense graded aggregate, a coarse graded aggregate nor an open graded aggregate.

In addition, Milwaukee County bottom ash met the gradation requirements of open graded aggregate and both Grade #1 and Grade #2 granular fill specified by WisDOT. Oak Creek bottom ash met the gradation requirements of Grade #2 granular fill specified by WisDOT.