

# THE CHARACTERIZATION OF INCINERATOR RESIDUE IN THE CITY OF NEW YORK

**WARREN H. CHESNER AND  
ROBERT J. COLLINS**  
Chesner Engineering, P.C.  
Commack, New York

**TOM FIESINGER**  
New York State Energy Research  
and Development Authority  
Albany, New York

## ABSTRACT

This paper reviews currently available ash management options and presents the results of one year of sampling and characterization of incinerator residue at a mass burn incinerator in New York City. The data presented include summaries of the physical properties of combined ash, bottom ash and fly ash collected from the New York City facility. The paper also provides guidance to assist in developing plans for potential residue processing and recycling activities.

## INTRODUCTION

The management of residue from solid waste combustion facilities is an issue facing many communities. Land disposal of residue is currently the primary means of ash management in this country. With the exception of ferrous metal which has been recovered at several major mass burn installations, the remaining residue is almost exclusively landfilled. Some use of residue has been reported, including the utilization of mass burn incinerator residue as landfill cover and landfill road base [1, 2], and the use of residue from refuse-derived fuel boilers as aggregate in cement applications [3]. The use of incinerator residue as an aggregate in road-building applications has been reported at numerous European installations [4].

During the mid-1960's and 1970's, a number of residue recycling investigations were conducted in this country. These studies demonstrated the potential for recycling all or part of incinerator residue. During the 1960's, the U.S. Bureau of Mines performed one of the first comprehensive, documented analyses of the physical and chemical components of incinerator residue [5]. The Federal Highway Administration (FHWA) sponsored several investigations that evaluated the use of fused and unfused residue in bituminous paving mixtures, and stabilized road base [6-16]. Several other investigations undertaken at universities [17, 18] and for the State of Massachusetts are also documented [19]. Studies by FHWA and Massachusetts included demonstration programs, where test roadways were paved with residue/asphalt mixes. These studies indicated that incinerator residue has the potential for use as an aggregate substitute in paving materials.

It is unfortunate that during the 70's, when the results of these studies were being published, most incinerator facilities were shutting down. This was due to the expense associated with meeting new Clean Air Act requirements, and to the availability of cheaper landfill alternatives. As a result of this trend toward closing incinerators, little work was initiated to follow-up on the ash utilization studies of the 60's and 70's.

Recent data have raised environmental concerns as-

sociated with incinerator residue, particularly the fly ash component of the residue. These concerns have resulted from test data showing the presence of heavy metals [20] and trace organic compounds [21, 22]. Concentrations of metals and organics in the fly ash can be attributed to the condensation of metals, and condensation or formation of organic compounds on the fly ash particles. It is estimated that fly ash represents approximately 10% by weight of the total residue generated in a mass burn facility equipped with an electrostatic precipitator.

As new incinerators come on-line, increasing quantities of ash will be generated. To effectively provide for the management of these increasing quantities, a review and evaluation of ash management strategies are needed. This review along with additional ash characterization data would better define safe and cost-effective means for residue utilization and/or disposal.

## ASH MANAGEMENT OPTIONS

Residue or ash management options can be conveniently subdivided into three general categories: high technology, medium technology and low technology options. This type of classification is similar, in concept, to that proposed by the Electric Power Research Institute (EPRI) for use in categorizing options for utility-fly ash management and utilization [23]. This subdivision is arranged in order of increasing ash processing requirements as follows:

- (a) Low Technology
  - (1) Landfill Disposal
  - (2) Ocean Disposal
- (b) Medium Technology
  - (1) Size Separation
  - (2) Ferrous Recovery
  - (3) Stabilization
  - (4) Solidification
- (c) High Technology
  - (1) Fusion

While the aforementioned subdivisions are somewhat arbitrary and not rigidly defined, they can be conveniently used to discuss available approaches.

The low technology options, the landfill or ocean disposal options, require little or no processing, other than perhaps quenching of the ash for dust suppression, and transport of the ash to an approved landfill or ocean disposal site. In the past, the landfill option was the cheapest alternative. However, new regulations concerning landfill requirements, coupled with new concerns relative to components in the fly ash, will

increase the cost of this option. Ocean disposal is not practiced in this country. It is generally considered an option of last resort, and is not readily favored by regulatory agencies. However, with increasing difficulties in siting landfills, some coastal regions may find the ocean disposal option worthy of further consideration. Additional studies concerning the environmental impact of ocean disposal are needed.

The medium technology option is designed to reduce the quantity of residue requiring ultimate disposal (i.e., land or ocean) through recycling of portions of the ash. It is also designed to address through processing, some of the potential environmental concerns associated with ash components.

Examples of the medium technology option include ferrous recovery (i.e., in mass-burn facilities), screening of the residue to produce aggregate for construction uses, the addition of alkaline substances (e.g., lime) to the fly ash for the purpose of minimizing metal leaching properties, and solidification or encapsulation of the residue, or specific components, by means of cementitious reactions or incorporation into asphaltic mixtures. A typical medium technology strategy could include separate collection of fly ash and bottom ash; stabilization of the fly ash via lime addition; removal of ferrous from the bottom ash; trommeling of the ferrous-free component to recover appropriate particle sizes for use as an aggregate; and disposing of the oversized material and stabilized fly ash in a landfill.

Some incinerator installations currently practice medium technology strategies. These include magnetic separation and trommeling to separate ferrous metals and various fractions of the residue. However, with the exception of ferrous metal, little of the ash material has been utilized.

The major high technology option being considered is ash fusion. This approach is intended to stabilize and recycle most of the residue. It requires ferrous metal separation and oversize material separation or shredding, and the melting of ash in a separate ash furnace to produce a glassy end-product. The advantages of this approach include provision of the combustion of the remaining combustibles and trace organics in the ash and the potential to effectively encapsulate the metals which are retained in the ash. The final product is a nonabrasive, glazed, black, lightweight aggregate, which could easily be substituted for construction aggregate.

Ash fusion is not a new idea. Fusion of combined incinerator ash and sewage sludge is currently being practiced in Japan [24], and has been tested at a pilot facility in the City of Philadelphia [9, 11]. Ash similar to that produced at the Philadelphia facility was used

in an asphalt paving demonstration with excellent results [12].

## MARKETING CONSIDERATIONS

The potential for using ash materials is dependent upon the availability of markets for its utilization. Such markets are dependent upon the availability and price of alternate materials and the acceptance of the processed ash for use by local regulatory agencies.

It is this latter requirement which must be overcome if the possibility of residue recycling is to become a reality. To meet this requirement it will be necessary to demonstrate that the engineering and environmental properties of the ash components to be used are acceptable. Prior to reaching this stage of development, substantial basic research and data need to be developed with respect to the nature and properties of incinerator residue, to ensure that any residue utilized will meet all engineering and environmentally-related requirements.

## CITY OF NEW YORK PROGRAM

Recognizing the need to generate new information and data concerning the nature of incinerator residue, the City of New York Department of Sanitation, in conjunction with the New York State Energy Research and Development Authority, embarked upon a one-year residue sampling and characterization program.

The primary objective of the program was to initiate the development of a data base which could be used to evaluate:

- (a) the primary physical components and engineering properties of New York City residue
- (b) the variability of these properties from season to season
- (c) selected properties of the residue relative to aggregate specifications for road paving applications

### Sampling and Laboratory Program

Sampling was undertaken at the Southwest Brooklyn Incinerator in New York City. This facility contains four 250 ton (227 t)/day refractory-walled furnaces with reciprocating grate stokers. Each furnace contains a primary and secondary combustion chamber. Air pollution control is provided with individual gas-conditioning towers (i.e., spray towers) and electrostatic precipitators for each furnace.

Residue generated in the facility consists of bottom ash, secondary ash and fly ash. The bottom ash, which is quenched after leaving the primary furnace chamber, and the fly ash, which is collected from the electrostatic precipitators and gas-conditioning towers, are both conveyed to one of two barge conveyors. These conveyors bring the ash to a barge for transport to a City landfill.

Secondary ash is deposited in the secondary furnace chamber prior to the air pollution control train. This ash is periodically collected for landfill disposal. It makes up a very small percentage of the residue generated at the plant.

The conveyor arrangement at the incinerator made it possible to divert fly ash or bottom ash to either one of two barge conveyors. As a result, it was possible to combine or segregate the fly ash from the bottom ash within the facility. The sampling and laboratory program included the collection of 170 bottom ash and combined ash samples, 30 fly ash samples and 12 secondary ash samples from January 1984 to January 1985.

A specific sampling and analytical protocol was developed to provide for the collection of representative samples that could be handled and analyzed in a safe manner. The details associated with this protocol are presented elsewhere [25].

In general, the sampling program was designed to:

- (a) sample bottom and combined ash directly from the barge conveyor

- (b) sample fly ash from a fly ash conveyor

- (c) filter combined and bottom ash samples with a 2 in. (50.8 mm) screen to generate a plus 2 in. (50.8 mm) or P2 component, and a minus 2 in. (50.8 mm) or M2 component

A minimum of three sample extractions were collected from the barge conveyor over a 4 hr period, and were composited to form "one sample" that would represent the character of the residue during the collection period. Each individual extraction from the conveyor weighed approximately 30–40 lb (13.6–18.2 kg).

The three extractions were screened to separate the plus 2 in. (50.8 mm) or P2 component from the minus 2 in. (50.8 mm) or M2 component. The M2 component from each of the three extractions was composited, and mixed to prepare the final M2 sample. The resultant M2 sample was a 30–40 lb (13.6–18.2 kg) sample that was subsequently transported to the laboratory for analysis. The P2 component of each individual extraction was characterized and the average value of the three extractions was calculated to represent one sample value.

A number of analyses were performed to characterize the P2, M2, fly ash and secondary ash samples. A list of these analyses are shown in Table 1.

## ANALYTICAL RESULTS

Data presented for most of the samples analyzed include mean values, standard deviation, maximum and minimum values and number of samples analyzed.

### P2 Characterization

A total of 170 P2 samples were collected and analyzed. A tabular summary of the annual average values and quarterly values of visually classified P2 components is presented in percent wet weight in Table 2.

The data presented in Table 2 highlight the following:

(a) The P2 fraction of the total residue sample (i.e., P2 plus M2 components) averaged 19.3% by weight over the course of the year.

(b) This P2 fraction (i.e., approximately 20%) varied little from season to season, as indicated by the minor quarterly variations, and the low standard deviations listed in Table 2.

(c) The P2 sample of the residue was found to consist predominantly of metal; the annual average metal fraction was 84.0% by wet weight of the P2 sample.

(d) The combustible fraction of the P2 sample was found to have a relatively high annual average value of 9.7% by weight.

(e) The remaining category of "others" was found to consist primarily of concrete blocks, bricks, and ceramics, and had an annual average value of 6.4% by weight of the P2 sample.

(f) The metal fraction of the P2 component showed the least variability from sample to sample, demonstrated by a relatively low coefficient of variation (i.e., standard deviation divided by the mean) of approximately 13%.

(g) The combustible and other fractions showed high degrees of variability, demonstrated by their relatively high coefficients of variation of 107% and 103%, respectively.

(h) Seasonal variations, as indicated by the average quarterly results listed in Table 2, were relatively minor; average quarterly metal fractions ranged from 76.6 to 89.1%; average quarterly combustible fractions ranged from 6.3 to 13.3%; average quarterly other fractions ranged from 4.7 to 10.1%.

(i) The wide range of maximum and minimum values of individual samples collected indicates that significant error can result if too few samples are used to characterize the P2 component of the residue.

TABLE 1 ANALYTICAL TEST OUTLINE

<b>A. PLUS 2 (P2) INCH (50.8 MM) COMPONENT</b>	
*1.	fraction of total sample weight
*2.	visual classification of metals, combustibles, and others category
<b>B. MINUS 2 (M2) INCH (50.8 MM) COMPONENT</b>	
1.	Natural Moisture Content (ASTM D2216)
*2.	Sieve Analysis (ASTM D422)
3.	Friable Particles (ASTM C142)
4.	Percent Organics (ASTM C114)
5.	Organic Impurities (ASTM C40)
*6.	visual classification of ferrous metals, nonferrous metals, glass, ceramics, minerals and ash, and combustibles (undertaken on plus 1/4 in. fraction)
7.	Dry Rodded Weight (ASTM C29)
<b>C. FLY ASH</b>	
1.	Sieve Analysis (ASTM D422)
*2.	Percent Organics (ASTM C114)
<b>D. SECONDARY ASH</b>	
1.	Sieve Analysis (ASTM D422)

\* Results are presented in this paper.

### M2 Characterization

A total of 170 M2 samples were collected and analyzed. Visual classification of the M2 sample was possible on all particle sizes greater than 1/4 in. (6.35 mm). The M2 sample which was visually classified represented approximately 50% of the total M2 sample by dry weight. The visually classified fraction, consisting of minus 2 in. (50.8 mm) to plus 1/4 in. (6.35 mm) residue, is referred to as the M2\* component of the M2 sample. Ferrous metal content was determined by passing a magnet over the sample component analyzed. A listing of the results on both a quarterly and an annual basis is presented in Table 3.

The data presented in Table 3 illustrate the following:

(a) The predominant components of the M2\* sample was found to be glass (32.4%), minerals and ash (28.5%), and ferrous metal (22.7%).

(b) The average combustible content of the M2\* sample (2.7%) was found to be significantly lower than that of the P2 component (9.7%).

(c) A relatively small quantity (3.4%) of nonferrous metal was found in the M2\* samples.

TABLE 2 PLUS 2 in. ANNUAL AND QUARTERLY SUMMARY (1984)\*

INTERVAL	IDENT.	% OF TOTAL**	% METAL	% COMB.	% OTHERS	TOTALS
<b>ANNUAL SUMMARY</b>						
	MEAN	19.3	84.0	9.7	6.4	100.0
	STD. DEV.	2.8	10.9	10.4	6.6	
	MAX.	29.5	100.0	63.0	26.6	
	MIN.	12.1	36.7	0.0	0.0	
	N	170	170	170	170	
<b>FIRST QTR.</b>						
	MEAN	20.1	85.4	9.3	5.3	100.0
	STD. DEV.	3.3	8.7	9.2	5.5	
	MAX.	29.5	100.0	38.4	17.7	
	MIN.	12.1	61.6	0.0	0.0	
	N	67	67	67	67	
<b>SECOND QTR.</b>						
	MEAN	20.0	76.6	13.3	10.1	100.0
	STD. DEV.	2.7	14.3	14.8	8.6	
	MAX.	28.7	97.1	63.0	26.6	
	MIN.	14.9	36.7	0.0	0.0	
	N	40	40	40	40	
<b>THIRD QTR.</b>						
	MEAN	18.0	83.8	10.4	5.8	100.0
	STD. DEV.	1.6	10.6	10.1	5.8	
	MAX.	21.3	100.0	40.0	21.0	
	MIN.	15.4	60.0	0.0	0.0	
	N	23	23	23	23	
<b>FOURTH QTR.</b>						
	MEAN	17.8	89.1	6.3	4.7	100.0
	STD. DEV.	1.3	5.1	4.1	4.5	
	MAX.	20.7	100.0	18.1	13.9	
	MIN.	15.4	75.5	0.0	0.0	
	N	40	40	40	40	

\*Data reported as percent wet weight.

\*\*Represents the plus 2 in. fraction of the total sample.

TABLE 3 MINUS 2 in. ANNUAL AND QUARTERLY SUMMARY (1984)\*  
(Percent Residue Fraction)

ANNUAL SUMMARY								
	IDENT.	FERR. METAL	NONFERR. METAL	GLASS	CERAMICS	MINERALS & ASH	COMBUST.	TOTALS
	MEAN	22.7	3.4	32.4	10.3	28.5	2.7	100.0
	STD. DEV	8.9	2.7	12.0	7.6	11.5	2.8	
	MAX.	47.6	18.1	63.9	38.5	67.1	19.7	
	MIN.	3.1	0.2	10.5	0.0	3.5	0.1	
	N	170	170	170	170	170	170	
QUARTERLY SUMMARY								
QTR.	IDENT.	FERR. METAL	NONFERR. METAL	GLASS	CERAMICS	MINERALS & ASH	COMBUST.	TOTALS
1	MEAN	27.0	3.3	31.4	10.2	25.3	2.8	100.0
	STD. DEV	8.2	3.2	10.9	8.0	10.1	2.8	
	MAX.	45.4	18.1	63.9	37.0	49.0	19.7	
	MIN.	7.9	0.2	12.0	0.2	7.8	0.1	
	N	67	67	67	67	67	67	
2	MEAN	18.7	3.6	31.4	14.8	28.6	2.9	100.0
	STD. DEV	8.6	2.3	12.1	8.1	12.7	3.3	
	MAX.	47.6	9.2	62.1	38.5	52.1	19.5	
	MIN.	4.6	0.5	11.4	4.1	3.5	0.1	
	N	40	40	40	40	40	40	
3	MEAN	22.0	3.4	24.8	9.2	37.1	3.5	100.0
	STD. DEV	9.5	2.4	11.4	6.3	11.9	3.2	
	MAX.	37.3	9.7	51.4	28.3	67.1	11.2	
	MIN.	3.1	0.7	10.5	0.0	15.0	0.1	
	N	23	23	23	23	23	23	
4	MEAN	19.7	3.5	39.3	6.7	29.2	1.6	100.0
	STD. DEV	6.6	2.4	10.4	3.9	9.6	0.9	
	MAX.	37.9	11.0	60.8	15.2	63.0	3.5	
	MIN.	5.7	0.3	15.5	0.3	13.7	0.1	
	N	40	40	40	40	40	40	

\* Data reported as percent dry weight.

(d) The ceramic content of the M2\* sample was found to be 10.3%.

(e) The mean quarter values of the M2\* components varied little during the course of the year.

(f) Standard deviations reported for each component indicate that the greatest variability in sampling results can be expected for those components with the minimum concentrations (i.e., nonferrous metals, ceramics, and combustibles).

(g) The wide range of maximum and minimum values of individual samples collected illustrate that significant error can result if too few samples are used to characterize the M2\* component of the residue.

#### Fly Ash Characteristics

The results of the analysis of 30 fly ash samples collected, with respect to their moisture, organic, and ash content are presented in Table 4.

The results indicated that fly ash is primarily ash, but nonetheless contains a significant percentage of organic matter (i.e., mean value of 6.2% by weight).

#### Particle Size Distribution of Combined Ash and Bottom Ash Fractions

Particle size distribution summaries are presented in this subsection for the M2 sample. The results are divided into combined ash (CA) and bottom ash (BA) samples. CA samples were collected from the barge conveyor during periods when both bottom ash and fly ash were combined in the same barge conveyor for transport to the barge. BA samples were collected from the barge conveyor during periods when fly ash was directed to a second barge conveyor (i.e., segregated from the bottom ash).

Since fly ash does not completely mix with bottom ash during its transport on the conveyor, it was assumed that completely mixed combined ash samples were not being collected. The M2 sample collection procedures previously outlined were used for the collection of BA and CA samples. A total of 108 CA samples and 62 BA samples were collected for analysis.

Annual and quarterly gradation summaries for CA and BA samples are tabulated in Tables 5 and 6, respectively. Figures 1 and 2 illustrate the range (i.e., extreme maximum and minimum values) and mean gradations for both the CA and BA samples, respectively.

The data presented illustrate the following:

(a) The mean bottom ash (BA) gradation is somewhat coarser than the combined ash (CA) gradation, which has a slightly higher fines fraction.

TABLE 4 ANNUAL AVERAGE SUMMARY OF MOISTURE, ORGANIC AND ASH CONTENT OF FLY ASH\*

	% MOISTURE	% ORGANICS	% ASH
MEAN	4.3	6.2	89.5
STD. DEVIATION	3.1	2.2	4.1
MAXIMUM VALUE	12.4	11.0	94.7
MINIMUM VALUE	1.7	2.2	80.0
NUMBER OF SAMPLES	30	30	30

\* Data reported as percent wet weight.

(b) Average seasonal gradations listed in Tables 5 and 6 are generally consistent from quarter-to-quarter. In nearly all instances average seasonal gradation values fall within one standard deviation of the annual mean.

## ANALYSIS AND DISCUSSION

### P2 Characterization

The data generated indicate that the plus 2 in. (P2) component of the total sample constitutes approximately 20% of the sample fraction. The data also illustrate that the major component of this fraction is metal (84%). The predominant metal type was observed to be ferrous metal. The data also indicate that the combustible content (9.2%) of the P2 fraction is higher than that of the M2\* fraction.

Due to limitations of the sampling program, in which large pieces of residue, greater than 10 in. (254 mm), could not be extracted from the barge conveyor, the 20% value was judged to be an underestimate of the true value of the P2 fraction of the total sample. It is projected that the actual value is probably closer to 25%.

The high metal content of 84% in the P2 fraction indicates that sieving a sample through a 2 in. (50.8 mm) screen or trommel would segregate primarily metals from the residue stream, along with oversized combustibles, bricks and ceramics. The ferrous metal could be recovered from this stream with a magnetic separator and the remaining oversized materials discarded, or shredded into finer aggregate.

TABLE 5 MINUS 2 in. COMBINED ASH (CA) PARTICLE SIZE DISTRIBUTION\* ANNUAL AND QUARTERLY DATA SUMMARY (1984)

	( PERCENT PASSING SIEVE SIZE (IN.))									
	1.50	1.00	0.625	0.25	No 6	No 20	No 40	No 80	No 200	
<b>ANNUAL SUMMARY</b>										
MEAN	97.3	90.8	79.6	50.2	35.5	16.3	10.2	4.6	2.1	
STD. DEV.	3.6	6.0	8.1	10.6	9.1	5.1	3.7	2.1	1.1	
MAX.	100.0	100.0	93.9	75.9	59.2	30.1	20.4	12.3	6.0	
MIN.	77.0	66.0	54.4	27.8	17.0	7.5	4.3	1.6	0.0	
N	108	108	108	108	108	108	108	108	108	
<b>QUARTERLY SUMMARY</b>										
<b>FIRST QUARTER</b>										
MEAN	97.6	92.2	82.3	59.2	42.7	19.7	12.1	5.3	2.6	
STD. DEV.	3.3	4.3	6.4	9.9	8.3	3.8	2.4	1.4	1.1	
MAX.	100.0	100.0	93.9	75.9	59.2	28.5	18.2	10.1	5.8	
MIN.	88.3	84.2	72.3	40.3	27.0	12.4	6.9	2.7	1.1	
N	32	32	32	32	32	32	32	32	32	
<b>SECOND QUARTER</b>										
MEAN	97.7	89.3	76.6	48.3	36.6	19.9	14.2	6.7	3.0	
STD. DEV.	2.6	7.2	8.8	9.0	7.9	4.8	3.3	2.5	1.3	
MAX.	100.0	97.8	92.3	66.7	54.0	30.1	20.4	12.3	6.0	
MIN.	89.7	66.0	54.4	29.6	21.2	12.3	9.2	2.9	0.9	
N	23	23	23	23	23	23	23	23	23	
<b>THIRD QUARTER</b>										
MEAN	99.0	94.0	80.5	52.4	39.7	20.8	14.0	5.7	2.8	
STD. DEV.	1.1	4.3	9.2	10.0	8.5	4.7	3.2	1.4	0.9	
MAX.	100.0	98.6	92.3	66.7	54.0	30.1	20.4	8.0	4.2	
MIN.	96.5	84.2	62.0	34.8	27.0	15.3	8.8	3.0	1.0	
N	15	15	15	15	15	15	15	15	15	
<b>FOURTH QUARTER</b>										
MEAN	97.7	92.0	80.3	45.9	30.5	12.5	7.3	3.2	1.5	
STD. DEV.	2.8	4.2	6.4	6.3	5.1	2.2	1.3	0.7	0.5	
MAX.	100.0	98.5	90.9	56.2	41.9	18.3	10.4	4.7	2.8	
MIN.	86.0	81.2	63.3	31.4	18.2	8.9	4.6	1.9	0.0	
N	40	40	40	40	40	40	40	40	40	

\* Data reported as percent dry weight.



TABLE 6

TABLE 6 MINUS 2 in. BOTTOM ASH [BA] PARTICLE SIZE DISTRIBUTION\* ANNUAL AND QUARTERLY DATA SUMMARY (1984)

	{ PERCENT PASSING SIEVE SIZE [IN.] }									
	1.50	1.00	0.625	0.25	No 6	No 20	No 40	No 80	No 200	
ANNUAL SUMMARY										
MEAN	97.0	88.4	76.7	47.6	33.0	14.3	8.8	3.9	1.9	
STD. DEV.	3.5	5.6	8.1	9.1	6.8	3.3	2.4	1.6	1.0	
MAX.	100.0	98.9	94.0	67.2	47.0	22.7	14.1	8.4	5.4	
MIN.	87.2	73.2	54.7	25.5	16.2	7.2	3.9	1.1	0.1	
N	62	62	62	62	62	62	62	62	62	
QUARTERLY SUMMARY										
FIRST QTR.										
MEAN	97.0	88.1	76.8	47.4	32.0	13.0	7.8	3.6	1.9	
STD. DEV.	2.9	4.9	7.2	9.6	7.3	3.1	2.1	1.4	1.1	
MAX.	100.0	96.8	88.2	67.2	47.0	19.1	13.6	8.4	5.4	
MIN.	91.0	77.2	58.7	25.5	16.2	7.2	3.9	1.1	0.1	
N	35	35	35	35	35	35	35	35	35	
SECOND QTR.										
MEAN	96.1	87.2	73.9	44.8	32.9	15.6	9.9	4.3	1.8	
STD. DEV.	4.0	6.6	9.1	7.2	5.6	2.4	2.0	1.9	0.7	
MAX.	100.0	98.9	94.0	59.6	45.5	20.5	13.3	8.0	3.0	
MIN.	90.2	73.2	54.7	32.6	24.6	10.8	5.8	2.0	0.7	
N	17	17	17	17	17	17	17	17	17	
THIRD QTR.										
MEAN	98.5	91.3	81.3	53.2	36.8	16.5	10.3	4.2	2.1	
STD. DEV.	3.8	4.9	6.8	7.3	5.5	3.1	2.2	1.6	1.3	
MAX.	100.0	97.1	90.3	62.3	46.5	22.7	14.1	8.1	5.1	
MIN.	87.2	80.6	69.7	43.6	29.4	11.3	7.0	2.7	0.8	
N	10	10	10	10	10	10	10	10	10	

\* Data reported as percent dry weight.

NOTE: BA SAMPLES WERE COLLECTED FROM JAN.-JULY 1984

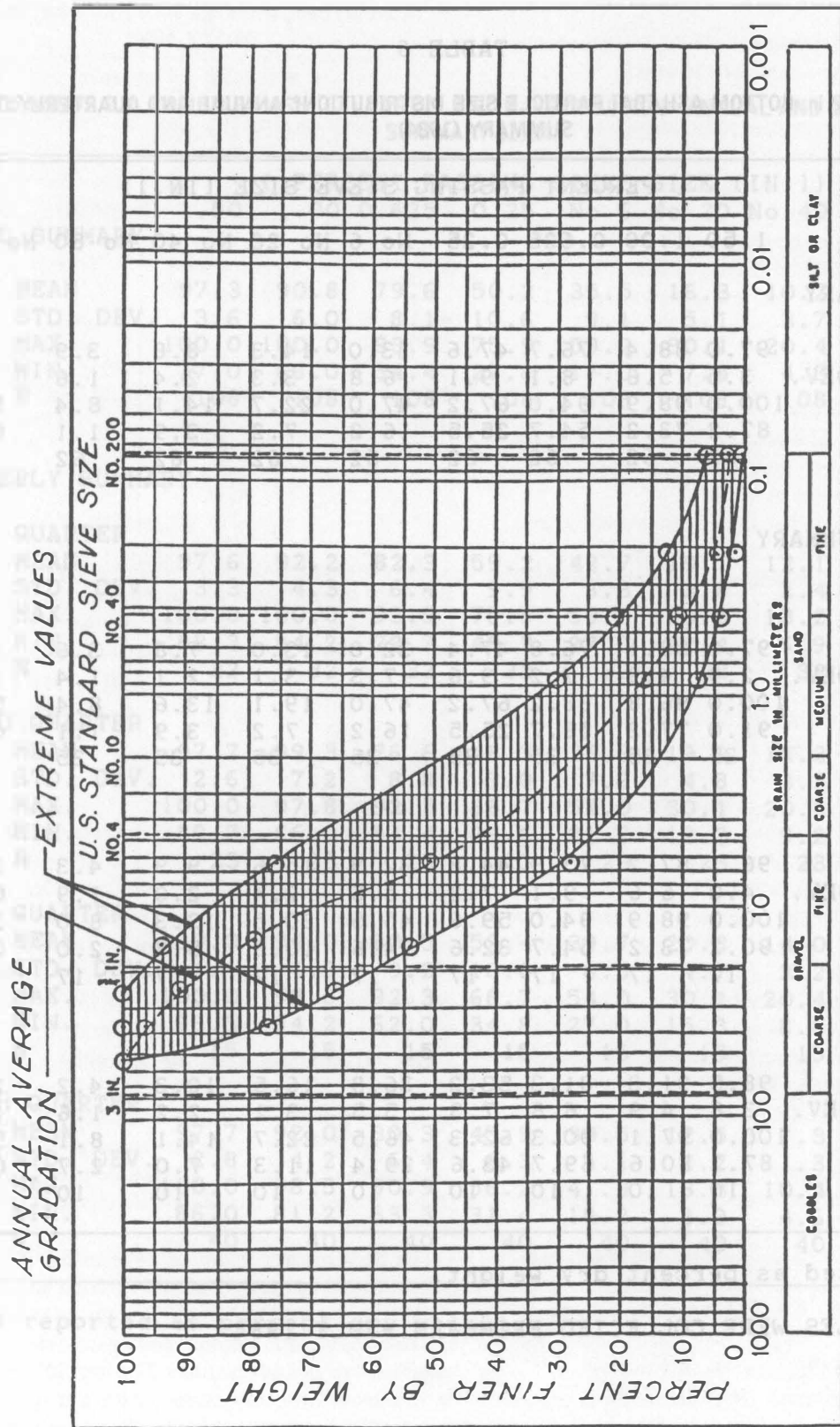


FIG. 1 PARTICLE SIZE DISTRIBUTION  
 [Combined Ash (CA) Samples (M2 Component) Annual Average and Extreme Values (108 Samples)]



## M2 Characterization

The M2\* component visually characterized in the sampling program represented approximately 50% of the total minus 2 in. (50.8 mm) fraction. A complete projection of the minus 2 in. (50.8 mm) sample would require estimates of the components which make up the minus 1/4 in. (6.35 mm) portion of the sample.

Previously reported data [8] on well-burnt incinerator residue indicate that the minus 1/4 in. (6.35 mm) portion of incinerator residue has a higher percentage of combustible matter, glass, and nonferrous metal than that of a minus 3 in. (76.2 mm) to plus 1/4 in. (6.35 mm) fraction of residue. The reported data [8] also indicate that the minus 1/4 in. (6.35 mm) has lower percentages of ferrous, and minerals and ash. No data was provided for the ceramics component [8]. Using relative quantities of each component found in the fractions of the reported samples [8], it was possible to provide an approximation of the total quantities of each component in the Southwest Brooklyn M2 samples.

The average combustible content of the minus 1/4 in. (6.35 mm) samples reported in these studies [8] was approximately five to six times higher than that of the plus 1/4 in. (6.35 mm) samples. The average nonferrous metal content of the minus 1/4 in. (6.35 mm) samples in the reported data [8], was found to be approximately two to three times higher than that of the plus 1/4 in. samples; and the average glass content was found to be approximately one to two times higher. The ferrous metal and minerals and ash content of the minus 1/4 in. (6.35 mm) fraction was found to be approximately 90% and 50%, respectively, of that of the plus 1/4 in. (6.35 mm) fraction [8].

Assuming that the reported relative proportions of the various components of the minus and plus 1/4 in. (6.35 mm) fractions [8] apply to the M2 sample; a negligible change in the relative proportions of ceramics; and also assuming a 50% minus 1/4 in. (6.35 mm) fraction of the M2 sample, it is possible to approximate the physical composition of the total M2 sample at Southwest Brooklyn. The results of these calculations yield the following physical composition:

<u>Component</u>	<u>Percentage</u>
Glass	37
Minerals and Ash	21
Ferrous Metals	19
Ceramics	9
Combustibles	8
Nonferrous Metals	6

### Total Characterization of Incinerator Residue

A combined P2 and M2 characterization can also

be estimated, assuming a 25% P2 fraction, a negligible moisture content in the P2 component, combining the other category of the P2 component with the ceramics category of the M2 component, and assuming the P2 metal to be ferrous metal. The result of this approximated characterization is as follows:

<u>Component</u>	<u>Percentage</u>
Ferrous metal	35
Glass	28
Minerals and Ash	16
Ceramics	8
Combustibles	9
Nonferrous Metal	4

### Gradation Characterization

Since gradation is a physical property which helps to define the utility of natural aggregate in various engineering applications, residue gradation is an important characteristic to be considered in assessing the potential for the utilization of residue as a substitute aggregate material.

A comparison of a residue gradation with that of a New York State Department of Transportation Specification for a Type 3 asphalt binder mix was undertaken to determine the potential for utilizing incinerator residue as an aggregate substitute in this mix. This mix has a top size requirement of 1.50 in. (38.1 mm). Type 3 asphalt binder is typically used as an intermediate asphalt layer between the road base and wearing surface.

A comparison of an adjusted residue gradation with that of the Type 3 specification is presented in Table 7 for minus 1.50 in. (38.1 mm) bottom ash and combined ash. This minus 1.50 in. (38.1 mm) fraction represents approximately 97% of the M2 component and 70–75% of the total residue generated at the facility.

The results, presented in Table 7, indicate that minus 1.50 inch (38.1 mm) bottom ash (BA) or combined ash (CA) do not comply with all the gradation limits of the Type 3 asphalt binder mix gradation specification. However, the average BA gradation is out of specification in only three size ranges, and the CA gradation is out of specification in only one size range. By mixing specified percentages of bottom ash or combined ash with appropriately graded aggregate, a mix of ash and aggregate can easily be prepared that will meet the required gradation specification.

Table 8 presents the results of a projected mix of 10% combined ash with 90% of a natural aggregate gradation currently being used at a private asphalt plant in New York City. The data depict extreme upper and lower values of the gradation, which represent extreme values of individual samples, as well as mean

TABLE 7 COMPARISON OF ADJUSTED RESIDUE GRADATION TO SELECTED ASPHALT PAVING MIX SPECIFICATION

SIEVE IN.	SIZE [MM]	SPECIFICATION GRADATION LIMITS* (percent passing sieve)	ADJUSTED GRADATION**	
			BA	CA
1.5	38.1	100	100.0	100.0
1	25.4	95 - 100	<u>91.1</u>	<u>93.3</u>
0.5	12.7	70 - 90	74.7	77.1
0.25	6.35	48 - 74	49.1	51.6
0.125	3.175	32 - 62	<u>31.3</u>	37.0
No. 20	0.84	15 - 39	<u>14.7</u>	16.8
No. 40	0.42	8 - 27	9.1	10.5
No. 80	0.21	4 - 16	4.0	4.7
No. 200	0.074	2 - 8	2.0	2.2

\* New York State Department of Transportation Type 3 Binder Coarse for asphalt paving specification.

\*\* Adjusted average gradation for 1.50 in. (38.1 mm) top size; underlined fractions denote particle size ranges which do not comply with specification gradation limits.

values. The results indicate that mixing 10% combined ash with 90% natural aggregate has little impact on gradation specifications and will meet gradation limit requirements 100% of the time.

**CONCLUSIONS**

The results of the data presented indicate that the physical properties of incinerator residue can be expected to exhibit sufficiently consistent and predictable results for utilization as a partial aggregate substitute. The variable properties of incoming refuse appear to be attenuated in the combustion process.

It is concluded that the physical properties of screened residue are consistent and that design mixes can be established for the use of residue in aggregate-type applications.

Additional studies, however, are recommended to address the physical properties of residue from various incinerator types and service areas. These studies are needed to assess whether data collected at given facilities can be extrapolated to other facilities with similar service areas and/or stoker-types.

In addition, as previously discussed, environmental characteristics of ash materials and alternative ash management options should be rigorously pursued to address potential environmental questions and to foster the development of improved ash management systems.

TABLE 8 TYPE 3 BINDER COURSE MIX WITH 10% COMBINED ASH (CA)

SIEVE IN.	SIZE (MM)	NEW YORK STATE SPEC. GRADATION LIMITS [percent passing]	COMPUTED GRADATION WITH TEN PERCENT COMBINED ASH* [percent passing]		
			MAXIMUM	MEAN	MINIMUM
1.5	38.1	100	100.0	100.0	100.0
1	25.4	95 - 100	100.0	99.3	98.6
0.5	12.7	70 - 90	79.5	78.3	76.4
0.25	6.35	48 - 74	61.6	59.2	57.6
0.125	3.175	32 - 62	44.7	42.5	41.1
No. 20	0.84	15 - 39	33.3	32.0	31.3
No. 40	0.42	8 - 27	18.5	17.6	17.1
No. 80	0.21	4 - 16	7.2	6.5	6.2
No. 200	0.074	2 - 8	5.1	4.7	4.5

\* Computed gradation is based on aggregate design gradation being used at private asphalt facilities in New York City, comprising ninety percent of a NYSDOT Type 3 Binder Mix and combined ash comprising ten percent of the mix.

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**Key Words:** Ash; Fly Ash; Bottom Ash; Combined Ash; Materials Recovery; Recycling; Residue

## ABSTRACT

The total chlorine and water-soluble chloride contents of the components of municipal solid waste (MSW) have been determined from sampling studies carried out at two sites, Baltimore County, Maryland and Brooklyn, New York for a 3-day period. The total chloride contents of the MSW samples from Baltimore County, Maryland and Brooklyn, New York are 140 and 200 mg/kg, respectively.

The component which contributed the largest fraction to the chlorine content is Baltimore County, Maryland was the paper fraction (0.25 mg/kg or 10% of the total chlorine) while in Brooklyn, New York the plastic fraction provided the major contribution (2.40 mg/kg or 12% of the total chlorine). A detailed discussion is provided in both text and tables.

## INTRODUCTION

During the late 1970s and early 1980s, polychlorinated dibenz-p-dioxins (PCDD's) and polychlorinated dibenzofurans (PCDF's) have been listed as the precursors of air and low gas of a number of incineration facilities in the U.S. on a range in the parts per billion to parts per trillion range (1,2). The resulting cancer risk has seriously drawn attention to the problem of chlorinated organic pollutants in the precipitates of air and the gas of incinerating facilities as shown by the chlorine content of each component

of the municipal waste. A detailed discussion of the literature showed that a study of the distribution of chlorine among various components of municipal solid waste (MSW) had been carried out in Great Britain (3,4). The major portion of the chlorine content of the waste systems and their functions, of MSW for a 3-day period as well as data on the chlorine content of all waste components from one day's sampling. The evaluation of their results suggested that a more detailed study of the chlorine content of MSW was warranted. Hence, during the past year a local climate and water-soluble chloride content study was carried out by the National Bureau of Standards (NBS) over a 3-day period on MSW from each of two sites, Baltimore County, Maryland and Brooklyn, New York. The results of the two studies are presented in this paper.

## SAMPLING MUNICIPAL SOLID WASTE

Baltimore, Maryland, and South Brooklyn, Baltimore County, Maryland

During the 3-day period of the study, the MSW was

collected from the MSW plant and was prepared to reduce the particle size to that of a fine powder (less than 100 microns).

The components analyzed in this paper are included in parentheses to describe the significant parameters, such as chlorine, water-soluble chloride, and sulfur, by the National Bureau of Standards.