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DEVELOPMENT OF CRITERIA FOR UTILIZATION OF MWC RESIDUES IN CONSTRUCTION APPLICATIONS

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ABSTRACT

Technical recommendations for the utilization of municipal waste combustion (MWC) residues in construction applications are under development. Technical criteria must consider the entire life cycle of ash utilization from ash generation through use and ultimate disposal. Initial priorities focus on the use of bottom ash without grate siftings (grate ash) as a replacement for aggregate in asphalt for paving, or, as an aggregate replacement in portland cement based concrete used in shoreline protection and artificial reefs.

INTRODUCTION

Management of residues generated from the combustion of municipal waste is one of the items under consideration in RCRA reauthorization. Currently, since there are no federal guidelines, each state determines under what conditions, if at all, municipal waste combustion (MWC) residue may be utilized as a secondary product, rather than disposed of in landfills. RCRA reauthorization or other legislation may require the USEPA to promulgate rules and guidelines for the utilization of MWC residues. In anticipation of this, the USEPA Risk Reduction Engineering Laboratory (RREL) is conducting research through a cooperative agreement with Rutgers University on technical requirements for environmentally sound utilization of MWC residues. This research will provide recommendations to support the USEPA Office of Solid Waste in developing guidelines for MWC residue utilization. The focus of this paper is to considerations and various approaches to utilization criteria.

Municipal waste combustors generate two principal types of residues: (i) bottom ash, including ash or slag retained on the combustion grates (referred to in this paper as "grate ash") and grate siftings collected from the primary combustion chamber, and (ii) air pollution control (APC) residues, including fly ash and acid gas scrubber residue, collected from air pollution control devices. Relatively small quantities of residues produced by the periodic cleaning of boiler and economizer tubes may be mixed either with the APC residues or bottom ash. These residues from deposits on boiler and economizer tubes can be considerably enriched in more volatile metals such as cadmium, zinc and lead. Bottom ash and APC residues typically are generated at nominal mass ratios of 9:1, respectively. Grate ash typically represents greater than 85 percent of the total bottom ash generated. APC residues typically contain higher concentrations of soluble salts and specific metals, such as cadmium, lead, mercury, and zinc, than bottom ash. In addition, the physical properties of bottom ash and APC residues are significantly different. Currently, most MWC facilities in the United States mix bottom ash with APC residues for collection and disposal. This mixed residue stream is referred to as "combined ash". Separate management of bottom ash and APC residues may be appropriate for certain utilization scenarios. This is most frequently considered to examine the potential for utilization or reduced disposal requirements for bottom ash. Bottom ash constitutes the majority of the residue stream but contains substantially lower concentrations of regulated metals and soluble salts. Separate management of bottom ash may result in the requirement of revising or developing new management strategies for the APC residues.

Utilization of MWC residues is being considered for a variety of applications. Interest in utilization principally is motivated by (i) the potential for extending existing ash landfill capacity, (ii) the potential for reduced disposal costs, and (iii) replacement of the diminishing supply of natural materials in some regions for which MWC residuals potentially could be substituted. Secondary effects of ash utilization may be (i) reduced environmental impact, (ii) improved ash quality, and, (iii) improved product quality where ash is substituted for natural aggregate. Reduced environmental impact may result because utilization scenarios may have more stringent requirements than disposal. For example, increased contaminant immobilization may occur because of ash encapsulation in either portland cement or asphalt for utilization. Improved ash quality may result because motivation would exist for reducing contaminant concentrations in ash and maintaining ash quality control to facilitate utilization. This may be achieved through combustion facility operation or separation of specific components from the waste stream. Under the current disposal scenario, no motivation exists to control or improve ash quality.

Primary applications under consideration is use of the MWC residues as (i) an aggregate substitute in bituminous pavement, (ii) an aggregate substitute in portland cement based marine applications such as artificial reefs and shoreline protection, (iii) as daily cover for municipal waste landfills, or, (iv) granular fill material for embankments. Almost all of these applications, except use as daily landfill cover, would involve some degree of ash treatment, either physical or chemical, either in preparation for or as a consequence of utilization. For example, most applications would require screening of ash to achieve desired particle size gradation or would result in ash encapsulation in another matrix. This paper focuses on considerations for ash utilization in pavement and marine applications.

A typical pavement consists of the following layers or a subset combinations of layers depending on design (listed from the top driving surface down): a shim/leveling course, a wearing/surface course, a binder course, a base course, a sub-base course, a compacted subgrade, and a natural subgrade. The shim/leveling course is placed on the surface to level ruts and depression and typically consists of a fine grain sand. The wearing/surface course is the top 0.5 to 1.5 inch and the binder course is below the binder course. The binder course serves as the bottom portion of the roadbed if the wearing course is less than four inches thick.. Otherwise it will be placed between the wearing course and the base course. The base course is normally the lower portion of the pavement. However, a sub-base may be required and is placed directly below the base. The pavement is built from the bottom to the top on a subgrade that has been prepared by compaction. The entire roadbed is placed on natural subgrade. Applications in the marine environment include shoreline protection and artificial reefs. These involve the use of the MWC residues mixed with portland cement to form concrete structures. Shoreline protection is the process of creating physical resistance to storm disruptions, such as storm events, natural erosion, and boat wakes. Examples of shoreline protection are bulkheads, sea walls, breakwaters, jetties, and piers. Artificial reefs are constructed to provide structures for the growth of marine organism while additionally serving as shoreline protection.

Utilization criteria also must consider potential impacts in addition to those during actual use and competition from other residue sources. Potential impacts include evaluation of the entire residue utilization life cycle, from ash generation, to actual use and through post-use deposition. Criteria developed for MWC residues should be consistent with criteria for utilization of other waste residues, such as coal ash, in similar applications. This will permit common market and environmental factors to decide the appropriate application and extent of utilization of various potential materials.

UTILIZATION LIFE CYCLE CONSIDERATIONS

The typical projected life cycle of MWC residues during utilization includes the following stages:

1. Ash generation (production at the MWC facility);
2. Physical processing;
3. Stockpiling;
4. Manufacture;
5. Use in designated application; and,
6. Post-utilization management and disposal.

Potential ash impacts and considerations are essentially common independent of utilization application from the time of ash generation to the point of manufacturing. Subsequent stages in the life cycle are significantly more application dependent because of the nature of the material in which the ash will be used and exposure scenario during use. For example, utilization in portland cement applications will have different effects on contaminant release than utilization in bituminous pavement. The following sections discuss to potential impacts and approaches for criteria for each stage.

Ash Type Selection and Elements of Concern

Bottom ash without grate siftings or boiler ash currently is considered to have the greatest potential for utilization and therefore has the highest priority development of criteria. This ash type is considered to have the greatest potential for utilization because it typically has the lowest content of leachable metals of concern (e.g., lead, cadmium, mercury, etc.) and soluble salts. In addition, this ash fraction has physical properties similar to natural aggregates and represents approximately 80 volume percent (ca. 70 wt %) of the total residues generated. Grate siftings are excluded because of the content of fine particulates and relatively high contents of lead and aluminum. Boiler ash is excluded because of the potential for relatively high content of more volatile metals such as cadmium and zinc. APC residues are excluded because of high soluble salt content (ca. 40-60 wt %) and relatively high contents of metals of concern such as cadmium, lead, zinc and mercury.

Table 1 presents the chemical elements and species concern which have been identified to be present in bottom ash in significant concentrations. These elements and species were selected based on either current regulatory guidelines for drinking water or solid waste management, potential aquatic life toxicity or potential engineering effects.

Ash Generation

Ash generation is defined as the production of the residues to be utilized at the MWC facility. This stage is the most critical for quality control. The intent at this stage should be to produce as uniform a product (ash) as possible that will permit utilization after subsequent processing. This will minimize the amount of processed ash that would be rejected as unacceptable at later stages or require disposal. Critical testing parameters during this stage would be loss on ignition (LOI), alkalinity, total leachable salts, leaching potential or availability of key elements, and moisture. LOI serves as an indicator of combustion completeness and residual organic matter. Alkalinity or acid neutralization capacity provides a measure of the material behavior in the environment because of leaching of potentially toxic metals is strongly a function of pH. Development of a pH titration curve also would permit estimation of the contributions of hydroxide, bicarbonate and carbonate buffer systems.

Total leachable salts is an important parameter because total salt loadings can adversely effect soil and potable water resources. Total salt content also can adversely effect the durability of portland cement based products. The leaching potential, or availability, of key elements is important as threshold values for acceptance based on projected impact at the utilization scenario. Here, availability is recommended rather than total concentration because fractions of each element of concern may be bound in mineral forms that would make it unleachable or biologically unavailable under the normal extremes of environmental conditions. An example of this would be lead or chromium bound in a silicate matrix. Furthermore, current methods (SW-846) recommended for total analysis do not provide true total concentrations and revised methods to do so are significantly more cumbersome and costly. Moisture content is important to insure that excessive freely draining water does not exist while moisture is high enough to prevent fugitive dust problems and allow proper aging of residues to proceed (see "stockpiling").

The frequency of testing to be carried out needs to be developed based on a statistical evaluation of the acceptable range and variation of critical parameters. Acceptance criteria should establish not only the mean but also the acceptable variance of analytical results that limit quantity of material beyond the threshold limits that would render an entire lot of material unacceptable. Thus, testing at this stage would be for screening and quality control purposes and would be based on prior knowledge and detailed characterization of the class of residue to be evaluated. Specific thresholds should be based on projected impacts for each utilization scenario. Different utilization scenarios may have different acceptance thresholds.

Physical Processing

Physical processing of ash is defined as mechanical processing such as ferrous and non-ferrous metal removal, and, crushing and screening to control the particle size gradation of the material to be utilized. Removal of oversized material is necessary to facilitate subsequent processing into appropriate products (e.g., asphalt paving material or concrete forms) and would be based on the specific utilization scenario. Removal of fines may be necessary to minimize fugitive dust, and attendant controls, during subsequent stages. These operations may occur either at the MWC facility or at the stockpiling location. The principal environmental and occupational health impact concerns during this stage would be a consequence of fugitive dust. Recommendations to minimize these effects are that physical processing operations be carried out in enclosed facilities and that an occupational health assessment be carried out to insure worker safety.

Stockpiling

Stockpiling of ash is carried out for several reasons. First, during stockpiling, aging reactions occur within the ash which further stabilize the material. These reactions include oxidation, hydration and carbonation (fixation or uptake of atmospheric carbon dioxide) reactions. Oxidation of reduced metals typically result in less leachable forms. Carbon dioxide uptake results in a pH shift of the material from typically greater than eleven to more neutral pH, e.g., less than 9. This process also results in respeciation of some elements from hydroxides to carbonates. The net result of this process is a shift in the pH domain and speciation of the material to a less leachable regime for metals such as lead and cadmium. Hydration reactions typically result in swelling of the material. These swelling reactions must be allowed to progress prior to utilization to avoid detrimental effects on the structural durability of the final products. Exact intervals required for sufficient ash aging have yet to be defined, but preliminary finding indicate a period between three and six months.

A second reason for ash stockpiling is to allow for storage of the material because of seasonal demand. For example, most paving applications will able to utilize the material only six to eight months out of the year depending on local climate.

Potential environmental or health impacts from stockpiling can be a consequence of fugitive dust, precipitation runoff, leachate or site access. Fugitive dust can be controlled by limiting the fraction of fine material (less than 200 mesh) permitted in the stockpile and maintaining a minimum moisture content (greater than approximately 10 percent). Minimum moisture content also will facilitate ash aging processes. All runoff and leachate from the stockpile should be collected and treated if necessary. Applicable storm water and local regulations may be sufficient to address these concerns. Site access should be controlled to avoid unwanted exposure by trespassers such as playing children.

Minimum ash stockpiling intervals should be established based on ash aging requirements. Maximum storage intervals should be based on the local annual climatic cycle. Consideration must be given if the aging process period and the seasonal demand period are mismatched. For example, in the northeast U.S. ash generated in July may have to be stockpiled until the following April for paving applications. Maximum ash stockpile quantities can be based either on annual use or demonstrated prior agreements for use with the entity receiving the ash after stockpiling.

Manufacturing

Manufacturing is defined as the processing of the ash into the final product form. This stage for paving applications would include ash drying and blending with asphalt at the asphalt plant, and placement of the pavement. This stage for portland cement applications would include mixing with portland cement, water and natural aggregate and forming into final structures such as blocks. Ash handling requirements at this stage, and during subsequent stages, should conform with standard handling procedures for materials which the ash is replacing to the greatest extent possible.

Potential environmental or health impacts during the manufacturing stage could result either from fugitive dust or drying process emissions. Asphalt production will require drying of the ash prior to blending with other aggregates and asphalt. Aggregate drying typically is carried out at approximately 200°F. This temperature is not high enough to volatilize metals of concern, but may cause some entrainment of fine particles in the drying air stream potentially increasing air emissions. Fugitive dust and air emissions impacts most likely can be minimized by limiting the fraction of fines in the ash stream.

Use Applications

General Approach. A general approach for selection of acceptable utilization applications and overall control of utilization can be classified by the following steps:

i. Detailed ash characterization
ii. Detailed evaluation of impacts from proposed application
iii. Ash screening and quality control
iv. Verification of Ash characterization
v. Categorically approved utilization for certain applications with limited restrictions.

Detailed ash characterization would require determination of the statistical variation of the ash to be utilized, including composition, leaching and physical characteristics. Acceptance limits for key parameters and statistical evaluation methods would be established. These key parameters would have to be indicative the materials performance during use. After the variability of key characteristics has been determined, only a reduced set of analyses for quality control would be required at the time of ash generation. Ash characteristics and behavior would be verified prior to use. An initial set of potential quality control parameters has been presented in the section entitled "Ash Generation." This approach is possible because it has been demonstrated that combustion residues from similar types of MWC facilities exhibit common characteristics. Thus, only quality control and screening for non-characteristic properties is required.

Evaluation of impacts from proposed applications and potential approaches to criteria are presented in the sections that follow. For utilization to be practical, extensive permitting should not be required for categorically approved applications which meet predefined restrictions. Predefined restrictions may include restrictions on location of ash utilization and maximum quantities allowable. Record keeping should be required with regard to the location, quantity and nature of each utilization application.

Two primary routes for environmental impact require consideration for most applications. The first route is through particle transport followed by either incorporation into soil or sediment, or food chain uptake. Food chain uptake is a much greater concern for marine applications. The principal controls over particle transport are through limiting direct abrasion on surfaces containing ash and through requiring specific product durability.

The second exposure route is through leaching followed by impact either on groundwater, surface water or soil resources. Contaminant release through leaching can be viewed as being comprised of two components, contaminant release potential and contaminant release rate. Establishing limits on cumulative contaminant release over a fixed time interval is a potential approach for limiting environmental impacts for applications which have a finite use period. The cumulative contaminant release could be projected based on integration of release rate and release potential data for defined geometries. This projection could include application specific information such as mean temperatures and precipitation to provide translation of laboratory data to field scenarios. Cumulative contaminant release would be the most important parameter for elements or species of concern that accumulation in the surrounding environment. Release rate or flux would be the most important parameter for non-accumulating elements or species (e.g., sodium, chloride). Release potential would be the limiting parameter when the utilization scenario is a permanent placement of the ash. This would be the case for marine applications.

Paving Applications. Table 2 presents a summary of utilization priorities developed in cooperation with an advisory committee selected to assist in the development of criteria. The primary paving applications considered were use of MWC residues in the wearing course (roadway surface), binder course, base and embankments. Options were to use ash which has been physically processed and aged (i) as a granular material (ii) directly incorporated in asphalt, (iii) further solidified or chemically stabilized and used as a granular material, or, (iv) further solidified or chemically stabilized and incorporated in asphalt.

Applications using ash without further treatment as an aggregate replacement in asphalt used for binder or base courses were given the highest priority. It was considered that significant reductions in potential contaminant release would be realized as a consequence of ash incorporation into asphalt. Further emphasis was given to these applications because both would have at least an impermeable asphalt layer above the utilized material, if not both above and below. Lower priority was given to use of ash in the wearing course because of potential abrasion and direct environmental exposure. Concern also was expressed about dust generated during milling of the wearing course during maintenance and repaving operations. Use of granular material in the wearing course was considered unacceptable. Use of granular material in embankments was considered to be of lowest potential because it represented the greatest potential environmental impact from release of salts. Use of ash incorporated into asphalt for embankments was not considered a practical option because asphalt based materials are not typically used in that application. Use of treated ash (e.g., ash which had been further solidified or chemically treated) generally was ranked lower than use of untreated ash because additional processing requirements and economic concerns.

Marine Applications. The two primary marine applications under consideration are ash utilization in shoreline protection and artificial reefs. The principal purpose of shoreline protection is to minimize coastal erosion while the principal purpose of artificial reefs is to enhance the quantity and diversity of marine biota at the reef location. Both applications would utilize ash through replacement of natural aggregate in defined portland cement based structures (e.g., blocks or other defined geometries).

The marine environment can be considered more environmentally sensitive than the paving applications because of direct contact of marine biota with the application structure and the sediment and water column in the immediate vicinity of the application. The principal mechanisms for environmental impact in the marine environment would be through leaching and particle transport. Particle transport is much more important in the marine environment than in the paving applications because it may be manifested through (i) erosion and biota uptake from the water column, (ii) erosion and biota uptake in local sediments or (iii) direct particle uptake by surface attached biota. In all cases, food chain magnification of specific contaminants must be considered. Emphasis on particle transport also increases requirements for structural durability of ash containing materials.

Definition of priority utilization scenarios for the marine environment is complex because of the variety of marine environments and ecologically sensitive areas that exist. Primary variables are the salinity, intensity of wave energy, and the degree of water circulation or flushing. Lowest potential impact areas would be areas of high salinity and a high degree of water circulation. Sensitive areas such as coral reefs or highly productive estuaries should be avoided. Table 3 summarizes some environmental considerations for selection of application scenarios.

Application Restrictions. This type of potential restriction would limit the type of ash to be utilized and the specific utilization application. An example would be restriction of grate ash use to binder and base course layers in paving applications. For marine applications, an analogous limitation would be for use in defined structures either for shoreline protection or artificial reefs. The goal of this type of restriction is to facilitate development of criteria for highest priority applications first and to allow for revisions to criteria as more performance data becomes available.

Location Restrictions. This type of potential restriction would exclude ash utilization in environmentally sensitive areas. It also could be used to control site accessibility or provide for safety margins based on projected impacts. Examples for protection of sensitive areas include prohibiting ash utilization in wetlands areas or near coral reefs. Examples for control of site access or provide for additional safety margins are limiting use to applications on landfills or in industrially zoned area, or, requiring a minimum distance from paving applications to groundwater supplies.

Quantity Restrictions. This type of potential restriction could be used to limit the maximum quantity of ash to be used in a single location before more extensive review or permitting would be required.

Record Keeping and Monitoring Requirements. Records should be required to be maintained detailing each utilization application. Information required should include ash characteristics, type of use and location of application. This would allow for future investigation of application performance. Routine environmental monitoring should be required only during pilot-scale evaluations of potential applications or for applications which exceed certain quantity restrictions. Extensive monitoring of every point of use would be impractical and prohibitive.

Reuse and Disposal

Paving Applications. Roads, parking lots and other paving applications are considered to have a finite application period. This period may be defined in terms of years or decades depending on the specific scenario. Asphalt pavement frequently is recycled into new paving material. Controls should be established that limit use of recycled ash containing materials to applications approved for initial utilization. Disposal of ash containing materials should be in conformance with applicable guideline for similar materials not containing ash.

Marine Applications. Shoreline protection installations and artificial reefs are considered permanent structures. Therefore, criteria for environmental acceptability should consider the utilization scenario as the ultimate disposition of the material.

CONCLUSIONS

Development of technical recommendations for criteria for utilization of MWC residues is in progress. Initial recommendations will focus on application scenarios of highest potential use with minimum negative environmental impact. Current applications being considered are use of ash in binder and base courses for paving, and, in portland cement structures for shoreline protection and artificial reefs. Initial recommendations will focus on utilization of grate ash (bottom ash without grate siftings) only.

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Table 1. Chemical Parameters of Concern in Bottom Ash.

Pb ^{1,7}	Cd ^{1,7}	Ba ^{1,7}	K ^{3}
Cu ^{2}	Hg ^{1,7}	Ag ^{1,7}	Na ^{3,5}
Zn ^{2}	As ^{1,7}	Cr ^{1,7}	Ca ^{3}
Al ^{3}	Se ^{7}	Mo?	Mg ^{3}
SO_4 ^{4,5,6}	Cl ^{4}	TDS ^{4}	Br
Expansive Oxides ^{5}	LOI ^{2,3,5}	NO_3	pH and alkalinity ^{2,3}

[1] Primary Drinking Water Standards

[2] Aquatic life effects

[3] Geochemical Parameters (effects on surrounding environment)

[4] Secondary Drinking Water Standards

[5] Engineering swelling and other effects

[6] SO_4 Attachment on other materials (e.g. concrete) - Total (as delivered to asphalt plant)

[7] RCRA regulated

Table 2. Utilization Priorities for Grate Ash in Paving Applications.

Road Application	Untreated in Asphalt	Untreated in Granular	Treated in Asphalt	Treated in Granular
Wearing Course	5	NO	4	NO
Binder Course	1 A	NO	1 C	NO
Base Course	1 B	3	NO	2
Embankment (Granular)	NO	7	NO	6

KEY

1A - 1C is the highest priority use, while 7 is the lowest priority for utilization

A "NO" indicates a decision not to utilize ash in the application.

Table 3. Environmental Considerations for Marine Applications.

Location Conditions	Rationale
Biological Impact	potential for application to impact marine species
Circulation/Flushing of Water Body	dispersal of leachate
Climate	influence on distribution of marine organisms
Coral Reefs	biologically sensitive area
Estuaries	biologically sensitive, vital area for reproductive cycle of all marine organisms
High Physical Energy	potential for increased erosion
High salinity	high salinity may effect durability of structure
Proximity to Biota	any structure placed in the water will attract organisms
Recoverability	must be able to retrieve the test structure
Remediation and Reversibility	design of experiment should include a contingency plan that specifically states what will be done if the experiment fails
Sensitive Areas	need to define which areas too biologically sensitive for marine ash utilization
Shoreline or Open Marine	easier access for testing and remediation

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