THE CHARACTERISTICS OF TWO-STAGE MUNICIPAL COMBUSTOR ASH (Example: Harford County Resource Recovery Facility in Maryland)

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INTRODUCTION AND BACKGROUND

During the second half of 1983, the Northeast Maryland Waste Disposal Authority (NEM) commenced with development of the Harford County Resource Recovery Facility (HCRRF). Technical help was provided by Beaumont Environmental Inc. (BEI) under a contract of limited agency.

A triad of interrelated technical issues surfaced which included waste composition, steam generation and ash production. The process which connects all three is incineration. For any given waste, it is desirable to generate the greatest amount of steam and at the same time produce the least amount of ash. In order to keep ash production down, two important criteria must be met: excellent burn-out and efficient management of the ash-water system.

During the negotiating process, it became clear that the two-stage combustor technology offered by Consumat would be the best solution for Harford County. In the resultant Service Agreement, the Company agreed to make two guarantees which would affect the ash [1]. First, the Company would not exceed an annual average specific ash rate or SAR of 0.450. Second, the Company would keep the putrescible content to 0.3% by wet weight, or less. For testing, the ASME Method A was to be used [2]. A limit on the amount of unburnt carbon was not included. This may have been a shortcoming in the Service Agreement.

In August 1992, the ash was extensively tested for the first time [3]. However, the recycling ordinance was rather new at that time and truly representative waste was not yet available. Consequently, the decision was made to mount a new test in June '93. It was dubbed "Ash Test II."

It is the purpose of this paper to present the procedures and results of this more recent test. Moreover, a key input will be provided to the "Boiler As a Calorimeter" (BAC) analysis which is proceeding on a parallel track [4]. Finally, the margins of the Company's performance in the ash area will be established. Perhaps the question "Has recycling improved performance?" will be answered.

FIELD PHASE

During the week of June 7, 1993, the annual emission test program was conducted at the HCRRF. As during the prior year, an ash test was scheduled to coincide with the emission test. The procedure for collecting and processing the various ash samples is illustrated in Figure 1. This procedure was to be applied once in the morning and once in the afternoon for each of the four combustors. During every session, each incinerator was to be sampled once. Thus, the final sample represented the composite of eight individual samples. Of course, only the undersized screened fraction went into building the composite sample.

LAB PHASE

Classification of Freshly Discharged Ash

There were two classification sequences, i.e. one in the morning and one in the afternoon. During each sequence, separate buckets of freshly discharged ash were collected by means of a wheel loader. The latter was positioned so

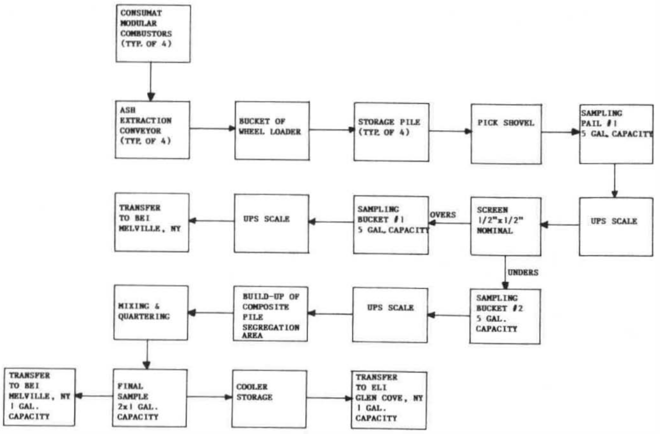


FIG. 1 SAMPLE COLLECTION AND FIELD PROCESSING PROCEDURE

that the ash from a given discharge tower would drop directly into the bucket. The average amount thus collected was estimated at:

$$4\ \text{yrd}^3 \times 27\ [\text{ft}^3/\text{yrd}^3] \times 54\ [\text{Lb}/\text{ft}^3]$$

$$\times\, 0.70 \approx 4,000\ \text{Lbs}$$

The factor 0.70 denotes the degree to which the bucket was filled during an average operation. The bulk density of 54 [Lb/ft^3] was experimentally determined for poured and not packed material. The buckets were dumped onto the clean floor in segregated areas. From each pile, enough material was withdrawn, one shovel at a time and from a different location, to fill a five gallon pail. A total of 8 individual samples were obtained, so that each combustor was probed twice during the course of the day. The total amount of ash moved was estimated at $8\times4,000 = 32,000$ Lb.

The pails were dumped onto the nominal $\frac{1}{2}'' \times \frac{1}{2}''$ screen for classification into "overs" and "unders." The detailed results may be found in the report on Ash Test II [5]. However, compared to Ash Test I during the prior year, a much larger amount was classified, i.e. 291 Lb versus 32 Lb [3]. During classification, it was noted that the ash was very wet, which may explain why the bulk density was so high.

The overs were sealed into large heavy-duty Ziploc bags immediately after weighing, one separate bag for each individual sample. On the other hand, the unders were dumped indiscriminately onto the floor in a segregated area. Thus, over the course of the day, a single large and composite pile of unders was accumulated. Towards the end of the day, this pile was mixed and quartered in accordance with recommended procedures (ASTM-D346-78). One quarter was then arbitrarily selected for taking the samples needed for lab analyses.

BEI Processing and Testing of Undersized Ash Particles

A container filled with wet undersized ash was removed from the quartered pile, closed off with a lid and transported to the BEI lab in Melville, NY.

After weighing in the unopened condition, the containers were emptied into eight shallow steel trays. These trays were placed into an indirectly gas-fired wall oven, which had been preheated to approximately 225°F. The trays were retained in the oven for about 39 hours with the temperature remaining at 225°F. The only disruptions to the drying cycle were occasional stirrings with a spoon. These occurred at 5 to 10 hour intervals. Great care was exercised during stirring to prevent fly ash particles from becoming airborne. Fly ash particles appeared to be fairly fine in consistency and they became distinctly visible after the first drying interval.

Upon completion of the drying cycle, the oven temperature was brought down gradually to room temperature over a six hour period. All trays were weighed before going onto the "roasting" procedure and the average moisture content was found to be 49.72%. On several occasions, it was observed that bone-dry ash would not have a stable weight when exposed to ambient conditions. It has long been suspected by us that ash, especially fine ash, is capable of adsorbing moisture from the ambient air, thus increasing its weight. This phenomenon is particularly pronounced during humid summer weather.

The roasting process was performed in a makeshift outdoor fireplace with a suitable grate. For illustrative details, refer to Figure 2. One tray at a time was placed on the grate and heated with three Benz-O-matic torches. The first had a wide flame and was positioned underneath the grate for indirect heating. The other two had spot flames and were directed over the top of the tray for ignition. The position of the spot flames was varied by causing them to travel back and forth at slow motion. From time to time, the spot flames were turned away to allow for stirring up the ash bed with a spoon. This procedure was continued long enough to ensure that the ash particles were exposed to a minimum of 20 minutes to the heat of all three flames.

After roasting, the trays were covered and allowed to cool down to a lukewarm condition (safe to the touch). Once again, all trays were weighed. Generally, the results indicated an average weight loss of 12.51% on a dry weight basis. Subsequently, the trays were stored for several days in an open room. In the end, the bone-dry and roasted residuals were placed back in the original container. Following reweighing, a gain of 4.5% was determined. Also, through drying and roasting, the original volume had shrunk by about 42%. Thus, the original bulk density of the unders had dropped from 54.70 to 31.96 Lb/ft^3.

Given the improvised equipment, it was not possible to separate and keep separate all components perfectly.

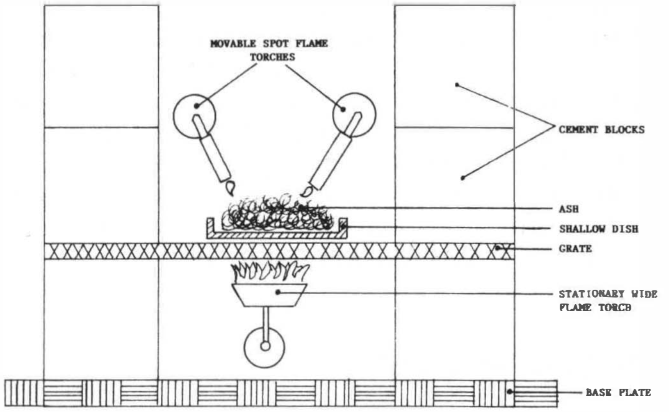


FIG. 2 BEI ROASTER FOR ASH SAMPLES

Keeping all equipment clean was another problem. Due to extensive handling, the ash particles (especially those called fines) were probably heavily aerated. Furthermore, the classification test was done in an outdoor environment on a hot and humid summer day.

After completing the test, all of the components were recombined and reweighed for check purposes. In light of all the handling discussed above, it comes as no surprise that there was a 6.7% gain in weight. We are inclined to believe that most of this was caused by the readsorption of airborne moisture onto the fine ash particles.

ELI Processing and Testing of Undersized Ash Particles

Since Environmental Laboratories Inc. (ELI) was already under contract for the APC testing, it was convenient to ask them to do certain parts of the ash work as well. A single sample of undersized ash particles was to be tested for ferrous metal content, loss on ignition (LOI), moisture and putrescible content. Of these, the LOI was intended to be a measure of unburnt combustibles left in the ash.

ELI received a 1-gallon sample of composite undersized particles which came from the same quarter of the field pile as BEI's. Subsequently, ELI reported 0.42% of ferrous content, 8.25% LOI, 50.62% moisture and 0.13% putrescibles. All were in the "as-received" condition. On a dry basis, the ferrous comes to 0.85%, the LOI to 16.71% and the putrescibles to 0.26% by weight, respectively.

By comparison, BEI found 0.40% of ferrous, 6.29% of LOI equivalent and 49.72% of moisture in the "as-received" condition. Although these results are of the same order of magnitude, they are not exactly identical. Of course, there are substantial differences in the methods employed by BEI and ELI. Nevertheless, the ELI results tend to confirm the adequacy of BEI's work.

BEI Processing and Testing of Oversized Ash Particles

During the morning of the ash test day, four raw ash samples were collected and processed. Each sample came from a different incinerator. After being screened and weighed, the oversized particles were dumped into heavy duty plastic zippered bags. The screen used was of $\frac{1}{2}'' \times \frac{1}{2}''$ nominal size with an open area of 0.220 square inches.

The total amount of oversized ash particles came to a net of 53.37 Lb. Because of the extensive moisture present, some of the undersized particles remained attached to the oversized particles. In other words, the oversized particles were not entirely clean. The second set of four samples which was taken during the afternoon session behaved similarly to the first set. Therefore, it was decided not to bother any further with the second set.

The four bags were then transported to BEI's premises for further processing and analysis. When unloading the four plastic bags, fine droplets of condensate were observed on the inside of each bag. After about six days of continued storage, the oversized particles were weighed again while still inside the bags. The total came to only 50.22 Lb. Assuming that the plastic bags were truly impervious to water, it can be deduced that some 6% was lost as fines and/or water during the initial transfer from the buckets to the bags.

Next, the oversized were placed in plastic tote boxes and exposed to air and sun drying effects for 3 days. Every day, the boxes were carried outside and set down in the sun. The contents of the boxes were stirred twice a day with a large spatula. All along, it was believed that the oversized particles were virtually free of putrescible matter. Therefore, no adverse effects due to prolonged storage were expected.

Afterwards, the tote boxes were stored in an open shed with a roof over it for another 10 days. At that time, the first sample of oversized particles was transferred into four shallow trays and weighed again. This transfer was necessary in order to facilitate the oven-drying procedure which followed.

As with the undersized particles before, the oven was preheated to 225°F in all cases. After insertion, the shallow trays remained in the oven for 20 hours before going through a staged cool-down. About $2\frac{1}{2}$ hours later, the first tray was removed and weighed. This same tray was then loaded immediately into the BEI roaster which was already previously described.

The remaining three trays were handled the same way. The successive weight losses following the various procedures were recorded and the original moisture content of 23.57% weight was found by back calculations.

At a minimum, the roasting period came to twenty minutes net. The three other trays were processed, one after the other, in the same manner. The trays were then covered and allowed to cool down for about $\frac{3}{4}$ hour. Unfortunately, BEI did not have any dessicators which would have prevented any potential adsorption of air-borne moisture onto the dried and roasted ash particles. While still warm, the trays were weighed again. On the same day, after completing all procedures for the first sample, the second sample was loaded into the oven for drying. On the following day all of the procedures explained above were repeated for the second sample. Afterwards, the third and fourth samples were processed the same way.

During roasting, some fine dust and/or soot was generated. Most of this was captured within the confines of the roaster. It was brushed back into the trays. Except for some very fine particles which may have become permanently airborne and escaped with the circulation air, the final weight is believed to be reasonably accurate. On the premise that any possible weight changes due to moisture adsorption or desorption can be neglected, the weight difference between drying and roasting can be ascribed to the loss of volatiles. This difference in terms of the original total of 53.37 Lb in the "as-received" condition represents 3.96%. Although there is no proof that all of the volatiles were of organic origin, it is assumed that the majority were made up of unburnt material. Thus, this value takes on importance for BAC determinations in another report [4].

After the roasting process, the remaining oversized particles were stored again for approximately two days in their original plastic bags. By visual examination, it was determined that drying and roasting had also produced considerable amounts of new fines. Some of these had simply survived the original field screening process because they were embedded in the water film which covered the oversized particles. However, others were created "de novo" in the BEI roaster as a result of combusting leftover unburnt combustible material.

In order to quantify these fines, we opted to rescreen the oversized particles with a $\frac{1}{2}'' \times \frac{1}{2}''$ nominal screen with an open area of 0.112 square inches. (Note: The BEI screen had much thicker wires than the field screen.) The "unders" from this rescreening process were considered to be gross fines. With the aid of a magnet, magnetic particles were removed. Other fine particles which were discernible as either non-magnetic metal or glass were pulled out with a pair of tweezers. Likewise, any visible pieces of charcoal were taken out, although they did not amount to much on a weight basis. Net fines is what remained of the fines after all the picking was complete. Compared to the loss in volatiles, this gain is disproportionately bigger, suggesting that the larger amount were old fines carried over during the field screening process. However, in the absence of detailed chemical analyses, this statement should be regarded as speculative.

On the other hand, the "overs" were sorted directly on the screen. Non-magnetic material was identified visually by its color and physical contours. Some of it appeared to be melted, at least in part. Glass was identified by color, reflectivity and its jagged edges. What was left on the screen after the picking was regarded as clinkers.

It is interesting to note that compared to Ash Test I, there were big changes in the glass and clinker components. Glass was down by about 51% and clinkers up by about 64% (referred to the dry reporting basis) [5]. This difference is amplified by the fact that during Ash Test I the oversized fraction accounted only for 18% of total ash, compared to 40% during Ash Test II [3].

ANALYTICAL PHASE

Significance of Flyash Component

In the HCRRF, flyash is separated from the exiting flue gas by means of electrostatic precipitators (ESP's). After separation, the flyash particles are collected on the electrodes from which they are dumped periodically into hoppers underneath the ESP's. The hoppers in turn are connected to a slurry system whose purpose is to transport the flyash particles into the ash quench tanks. Reclaimed water serves as the liquid medium. Thus, the ash which is ultimately removed to the landfill contains both bottom and flyash.

From the early test work at Little Rock, it was reported that two-stage combustors could meet the federal particulate emission standard of 0.08 grain/dscf corrected to 12% of CO_2 without the aid of a control device. Thus, we assumed that influent loadings to the HCRRF ESP's would essentially be in the same order of magnitude.

Effluent loadings were taken from the stack tests which were conducted concurrently with the ash tests during August '92 and June '93. By relying on the differential in particulate loadings and reported stack gas flow rates, the production of flyash was estimated. The result indicated that about 0.3% of total ash weight is due to flyash. (Note: This percentage may increase in the future when acid gas scrubbers are installed.)

Surprisingly, this is a rather small amount and therefore no further research was deemed necessary. Apparently, this is one of the trade-offs with two-stage combustors: flyash production is low while the amount of combustibles which remain in the bottom ash is relatively high. With waterwall combustors, the opposite is true.

Putrescible Matter Determination

The results of laboratory testing are presented in Table 1. For comparison purposes, putrescible matter determinations made during the acceptance test in January 1988 were also entered. On the basis of total putrescible matter (TPM), the test results are similar.

The results of Ash Test II seemed to demonstrate that at least on the test day the HCRRF was in compliance with the limit set in the Service Agreement. Actually, there was

TABLE 1 PUTRESCIBLE MATTERS IN UNDERSIZED ASH

Parameter	Acceptance Test		Ash Test II
	Burn No. 1 1-5-88	Burns Nos. 2-8 1-6/12-88	6-9-93
Allowable Limit	0.300	0.300	0.300
Carbohydrates	N.A.	N.A.	0.005
Lipids	N.A.	N.A.	0.033
Proteins	N.A.	N.A.	0.089
TPM	0.163	0.050	0.127
Limit Depletion	54.3	16.7	42.3

TABLE 2 COMPOSITION OF UNIFIED ASH SAMPLE

Component	Wet Basis			Dry Basis		
	Overs (0.3961)	Unders (0.6039)	Unified (1.0000)	Overs (0.3961)	Unders (0.6039)	Unified (1.0000)
Moisture	9.326	30.026	39.352	-	-	-
Magnetic Metal	7.445	0.210	7.655	9.739	0.417	10.156
Non-magnetic Metal	0.657	0.011	0.668	0.860	0.021	0.881
Glass	3.572	1.074	4.646	4.672	2.135	6.807
Clinkers	11.799	0.749	12.548	15.433	1.490	16.923
Fines	5.048	24.457	29.505	6.603	48.639	55.242
Charcoal	0.193	0.069	0.262	0.252	0.137	0.389
Volatiles	1.567	3.799	5.366	2.050	7.555	9.605
Totals	39.607	60.395	100.002	39.609	60.394	100.003

even a safety margin of 42% left relative to the guarantee value of 0.3% by wet weight in Schedule 7 to the Service Agreement. This good result is also corroborated in some indirect way by the fact that, with 5.63% by wet weight, unburnt combustible matter left in the ash was also low.

Additional comfort may be taken from the fact that TPM testing was done only on the undersized fraction rather than on total ash. At first sight this seems to be a paradox, but it can be explained by the following reasoning:

- Putrescible matter represents a portion of combustible matter which is left in the ash after combustion.
- The undersized fraction with 60.39% made up the majority of the ash. Its content of combustible matter was 6.41% (by wet weight).
- The oversized fraction with 39.61% made up the minority of the ash. Its content of combustible matter was 4.44% (by wet weight).

Assuming that putrescible matter is proportional to combustible matter, it can then be inferred that there must have been less putrescible matter in the oversized fraction than in the undersized fraction. Thus, the oversized fraction acts as a diluent to the putrescible content in total ash.

Neglecting any possible change in the relative standings of the carbohydrate, lipid and protein components to each other, the test value of TPM = 0.127% (by wet weight) can be used for the following estimate:

$$TPM_{TA} = 0.6039 \times 0.127 + 0.3961 \times 127$$

$$\times (4.4 \div 6.41) = 0.1115 \text{ in} [\%] \text{wet weight}$$

The Service Agreement does not draw a distinction between undersized and oversized fractions. It recognizes only total ash. Therefore, it can be suggested that, at least on the test day, the guaranteed limit was even less depleted than indicated in Table 1.

Development of Compositional Model for Ash

In Table 2, the composition of the unified ash sample is worked up. The overs fraction of 0.3961 and the unders fraction of 0.6039 are used as the weighting factors. A graphic presentation of how Table 2 was developed is depicted in Figure 3. In order to make the results most useful, Table 2 presents two ash compositional models, i.e. one on the wet basis and the other on the dry basis.

Figure 4 shows the same results in pie chart format. For purposes of simplification, charcoal and volatiles are combined into a single slice. Because the charcoal is less than one percent, the error is minor. The fact that unburnt combustible matter (expressed here as volatiles) amounted to only 5.63% on a wet weight basis shows a substantial improvement over the results obtained during the previous Ash Test I. In the latter unburnt combustibles accounted for 12.13% on a wet basis [3].

Development of Compositional Model for MSW

In theory, it may be possible to develop a model for the composition of the MSW fired in the incinerators by using the ash model as a point of departure.

A weak spot in the analysis is the fact that during Ash Test II the ash generation rate was not experimentally verified. Instead, the decision was made to simply use the specific ash rate (SAR) for the entire month of June. This SAR is readily available from BEI's computer program for monitoring HCRRF operations. This program is based on monthly inputs from the operating company [6]. The reason why this approach was deemed acceptable is that last year during Ash Test I, the 3-day experimental SAR equaled exactly the monthly SAR.

Since ash and MSW contain different amounts of moisture, it is advantageous to begin the analysis on the dry basis. The monthly SAR for June '93 came to 0.4489 Lb ash/Lb MSW (which is a little higher than the 0.4114 Lb

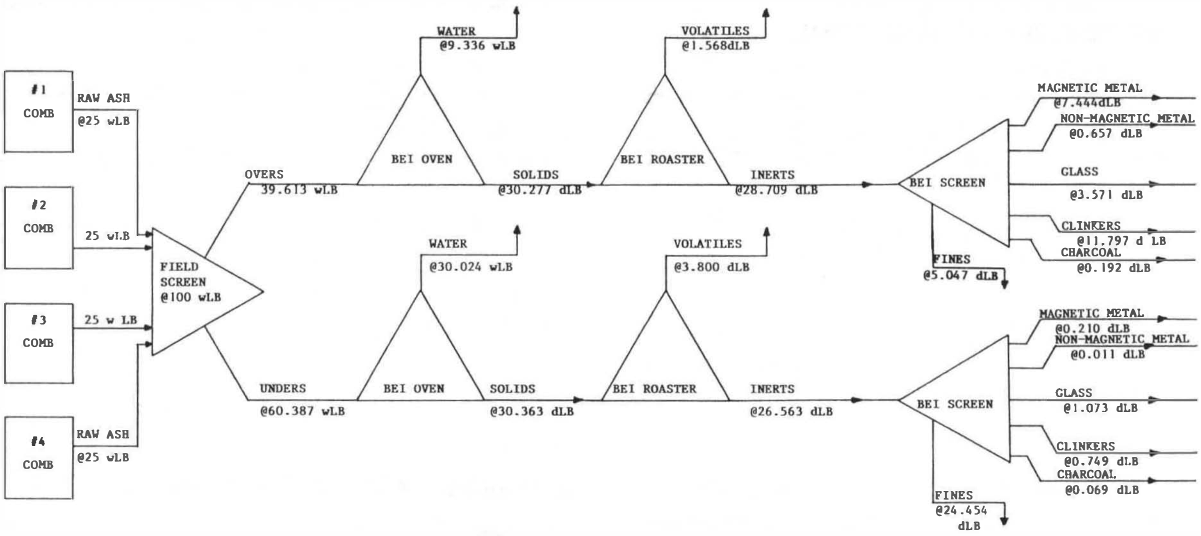
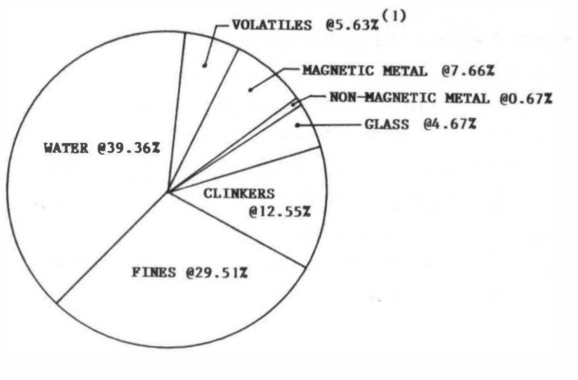
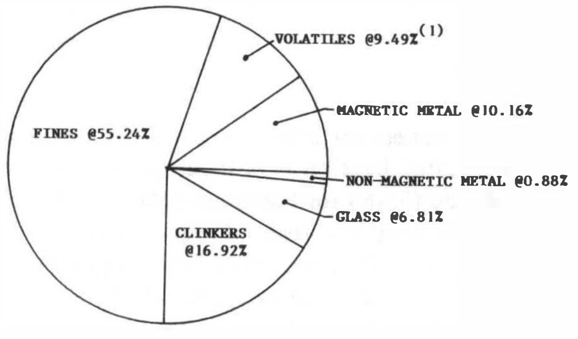


FIG. 3 SCHEMATIC FOR PROCESSING ASH
(BASIS: 100 wLB OF RAW ASH)



(a) Wet Basis



(b) Dry Basis

FIG. 4 COMPOSITIONAL ANALYSIS FOR ASH
Note: (1) Includes Charcoal

ash/Lb MSW observed during August '92). After subtracting 39.35% of moisture, each 1 Lb of MSW fired in the "as-received" condition will generate 0.2722 dLb of dry ash.

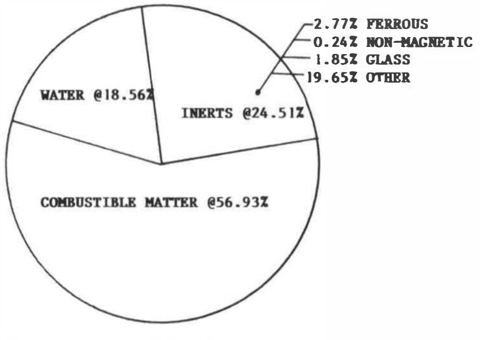
As the next step, charcoal and volatiles need to be dropped out because they are due to incomplete combustion. What is left then is the sum of the inerts, which comes to 0.2450 dLb per 1 Lb of MSW fired in the "as-received" condition. The breakdown of the inerts into magnetic metal, non-magnetic metal and glass is shown in Figure 5.

At this point in the ash analysis, a cross-connection needs to be made to the BAC analysis. The latter will yield the amounts of moisture and combustible organics which must have been in the MSW. Hydrogen and moisture are fall-outs from the BAC water balance, while carbon can be derived from the stack gas measurements [4].

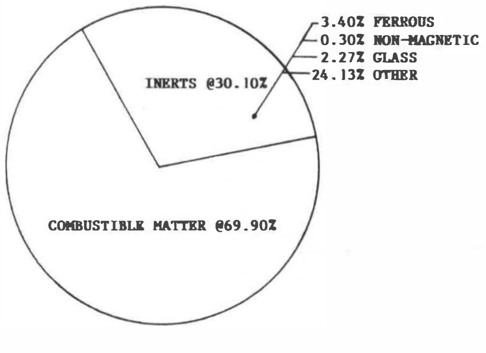
Such a cross-connection was made and the resultant carbon balance indicates a carbon content of 24.30% for the MSW in the "as-received" condition. By assuming that the majority of the combustibles were cellulosic in nature, a 54.67% content of combustible matter was back-calculated. The moisture content of MSW was then obtained by difference.

The cellulose model can be carried further in order to calculate the oxygen concentration needed for the ultimate analysis. Thus, 26.98% oxygen was computed. The contents of hydrogen and nitrogen can be back-calculated from the nitrogen and water balances which are furnished as part of the BAC in a separate report [4].

For the interim, we have extrapolated 3.64% hydrogen, 0.58% nitrogen and 0.10% sulfur from the literature. Now the higher heating value can be estimated by using the Og-



(a) Wet Basis



(b) Dry Basis

FIG. 5 COMPOSITIONAL ANALYSIS FOR MSW

den formula that was found to be useful on past occasions:

$$\text{HHV} = 495.27(\%\text{H}) + 1.49.76(\%\text{C}) + 45(\%\text{S})$$

$$+ 27(\%\text{N}) - 46.44(\%\text{O})$$

By substituting into the formula, the HHV = 4,209 Btu/wLb was determined.

It should be emphasized that this is not only an estimate, but it is also a rather preliminary one. Better data is expected to become available from the BAC analysis. In the meantime, there is yet another telltale sign of poor fuel quality: the specific steaming rate during the month of June '93 was low as well. In fact, with only 2.527 Lb of steam/Lb of waste fired, it posted a low for the most recent 12-month period.

For the better part, the SSR is proportional to the HHV. In its original proposal, the designer and manufacturer of the HCRRF, i.e. Consumat, estimated an SSR = 2.653 Lb steam/Lb of waste when operating at 100% MCR and firing MSW (with no tires added) at an average HHV = 4,500 Btu/wLb. By using the ratio of SSR's as the multiplier, the $\text{HHV} = [2.527 \div 2.653] \times 4,500 = 4,286$ Btu/wLb is found. The latter is fairly close to the value previously established based on the ash analysis.

Ash-Water System

The ash-water system deals with the interfaces of ash and water. It starts with the ash sumps in the bottom of the Lower Chambers (LC) and terminates with the ash piles on the floor of the ash hall. The ash ejector shrouds, quench tanks and ash conveyors are other steps in between. The flyash slurry and transport system is a sort of sidestream. Furthermore, solids are removed by filtering in the water reclamation system. These are then dumped onto the ash pile. Boiler blow-down solids are also added to the ash mix.

The water part of the ash-water balance must also be viewed within the larger context of the overall water balance of the entire facility. Thus far, it was assumed that on the wastewater side there would not be much (if any) excess water in need of dumping. At least this would be the case under most sets of operating conditions.

However, in reality it is not always possible to maintain a perfect balance in the waste water management system. There just has to be a dependable outlet for excess water. For practical reasons, the ash-water system was considered for a dual role, i.e. the removal of both unwanted solids and water. Consequently, excess waste water removal is being accomplished simply by pumping it over to the ash pile. Regrettably, at the present, there appears to be no incentive to do any better. This disadvantage is further discussed below.

Sources of Ash Water

The ash-water system is illustrated in Figure 6. Bottom ash comes first into contact with recycled water in the ash sump. Here the ash is doused prior to each dump cycle with water which is issued from an array of spray nozzles. The idea is to cool down a given packet of accumulated ash prior to its ejection through the ash shroud into the quench tank. Depending on conditions, ash particles may be at a temperature of 1,300 to 1,600°F. The spray water lowers this temperature before the ash is actually dumped. This avoids violent boiling and steaming in the quench tank.

Although there are no measurements, it stands to reason that the ash particles pick up most of their water upon submersion in the quench tank. Make-up water to the quench tank is predominantly recycled water from the water reclamation system. Originally, this water may have been used first for housekeeping purposes. Other portions are backwash from the water softeners and blowdown from the boilers. In case of an imbalance, potable water may be added, too.

Unfortunately, no individual meters are installed which would permit quantification of how much is taken from one source or another. The two major unknowns are the flow rates of ash spray and make-up water. The first was

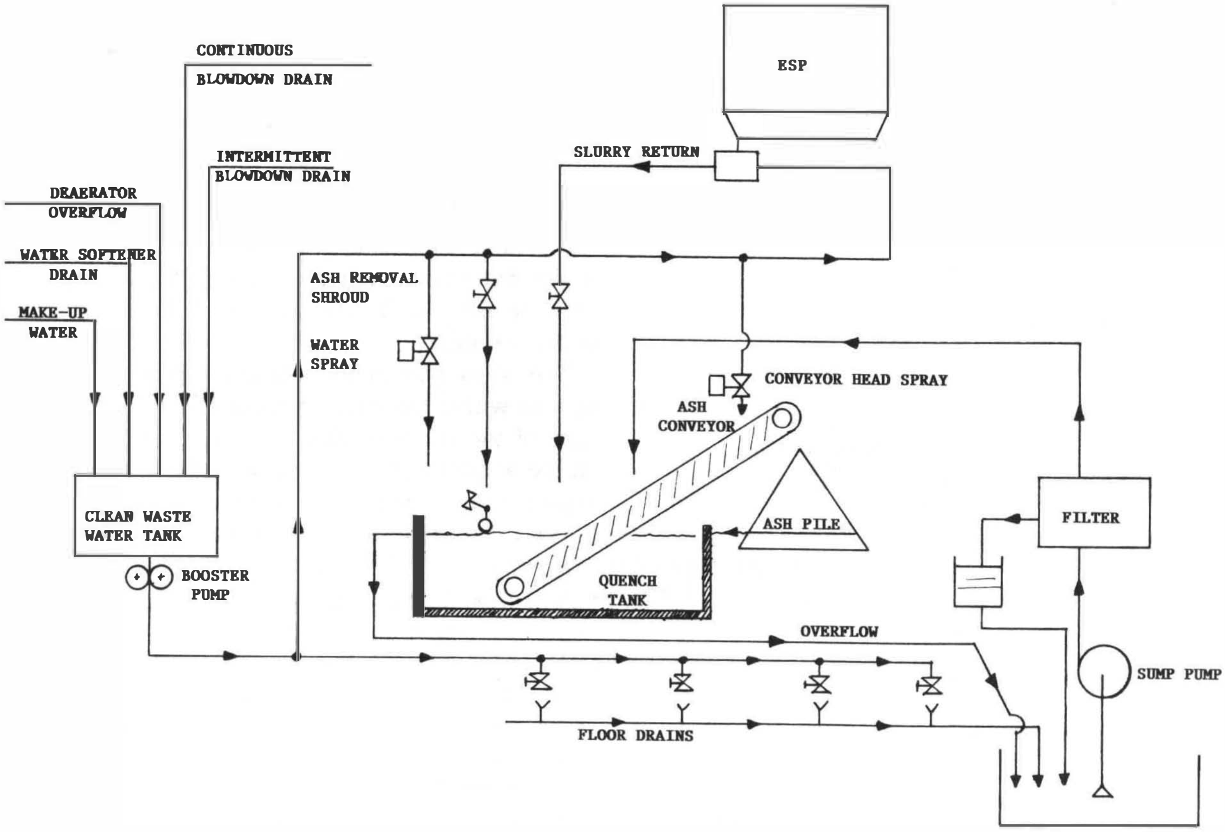


FIG. 6 FLOW SCHEMATIC FOR ASH-WATER SYSTEM

resolved analytically while the second was determined by using the weir boxes on the quench tank as an improvised flow metering device.

The height of the crest in the weir boxes was measured as a fairly steady value of $\frac{1}{2}$ inch for both the August '92 and June '93 tests. The temperature of water in the quench tank was also monitored periodically. It averaged about 111°F during the August '92 test and about 124°F during the June '93 test, respectively.

With the crest height and water temperature as a given, the formula for rectangular weirs recommended by the ASME for "Fluid Meters" was applied. The results indicated that the overflow attained an average rate of about 19 gpm per quench tank or 76 gpm for the entire facility [5].

Ash-Water Balance

For the ash-water balance, all four combustor quench tanks were considered as a single but larger facility quench tank. The latter forms the centerpiece of the balance for which the inputs must equal the outputs. In order to simplify the analysis, external water losses due to evaporation, spillage and/or runoff were neglected.

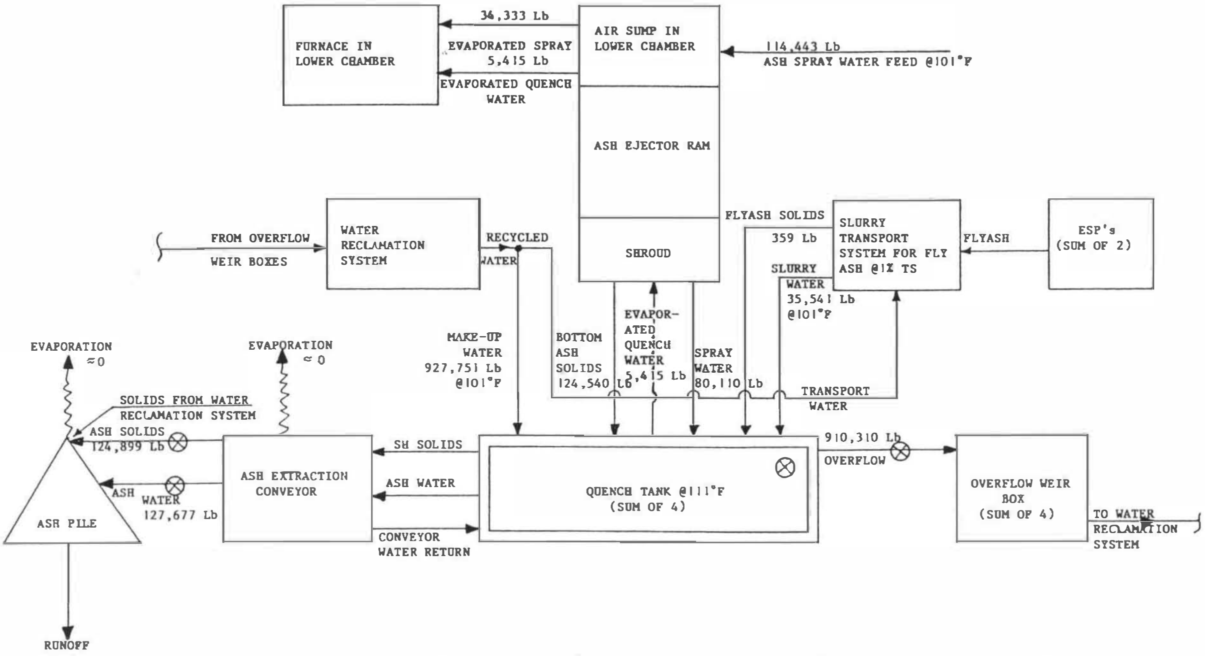
In Figure 7, the mass balance for the August '92 test period is shown. The numerical entries for solids and water are the test totals as expressed in pounds. The net amounts of solids and water removed to the ash pile are largely based on the experimental determinations made during the lab phase and the compositional model for ash.

Complete knowledge of the ash-water system is a prerequisite for carrying out the heat loss calculations for the BAC analysis. Another benefit is that now the water balance for the complete facility combustion system can be completed. Actually, since all other water components were already calculated as part of the BAC analysis, it is now possible to "back calculate" the amount of free water which was contained in the fuel as fired. The numerical answer was 20.57% by weight, which may be interpreted as fairly dry fuel.

OPERATIONAL PHASE

Specific Ash Rate (SAR)

For any given period of time, the SAR can be determined as the number which results from the division of the fuel tonnage fired by ash tonnage produced. Thus, the



Notes: (1) Totals for 8x3=24 hours of testing during August 1992. The temperatures are averages. Mass balance refers to facility basis.
(2) Solids from economizer flyash and boiler blow-down are neglected.
(3) Locations marked ⊗ were used for measurements or sampling.
(4) For ash spray water, it was assumed that 30% would flash into lower chamber and 70% would drain into quench tank.

August 23, 1993

FIG. 7 SCHEMATIC FOR MASS BALANCE IN ASH HANDLING SYSTEM

SAR represents the average for a given time period. For reporting purposes, an operating month or an operating year are the time periods which are most conveniently used. The SAR can be expressed in wLb ash/wLb fuel or WST ash/WST fuel. (Note: The "w" stands for "wet" which is identical with "as-received condition.") Thus the SAR is reported on a wet basis.

The SAR is not a constant ratio but rather a variable which depends on a number of input parameters which are also variable. The first of these involve the compositional break-down of the fuel, its proximate analysis and heating value. Next comes the rate at which the fuel is fed into the combustor as well as its agitation and retention time there. Other considerations are the temperature settings of the combustor and how much and where combustion air is blown in. In short, the degree to which the burn-out of combustible matter is accomplished is of great significance.

After combustion, the entrainment of water becomes a major factor. The first contact with water takes place inside the ash sump where the ash is sprayed with water prior to its dumping. The second contact is effected in the quench tank upon submersion. Some of the excess water may run off the conveyor or the ash pile. In addition, some water may evaporate, depending on ambient air conditions. However, any such evaporation is very difficult to quantify and no estimates were attempted as part of this paper.

Generally, the Company reports on a monthly basis on the inputs to and the outputs from the HCRRF. The inputs are the tonnages of waste and tires. The outputs are the tonnages of ash and rejects. BEI transfers the monthly totals to its spreadsheet which then automatically calculates the SAR as it relates to the net amount of fuel fired [6]. To date, 68 monthly averages have been computed.

Seasonal Variations in Ash Production

It has been suspected for a long time that ash production in the HCRRF follows a seasonal profile. Figure 8 shows average monthly ash production expressed as a percentage of annual ash totals. For the summer months, i.e. May through September, the profile is relatively smooth and concave. In contrast, for the winter months two separate peaks are indicated. The first of these occurs in December and the second in March/April.

In the same figure, average monthly fuel consumption expressed as a percentage of annual fuel totals is also entered. Some similarity between the ash and fuel profiles is readily discernible. In fact, both demonstrate higher values for the winter and lower values for the summer. The

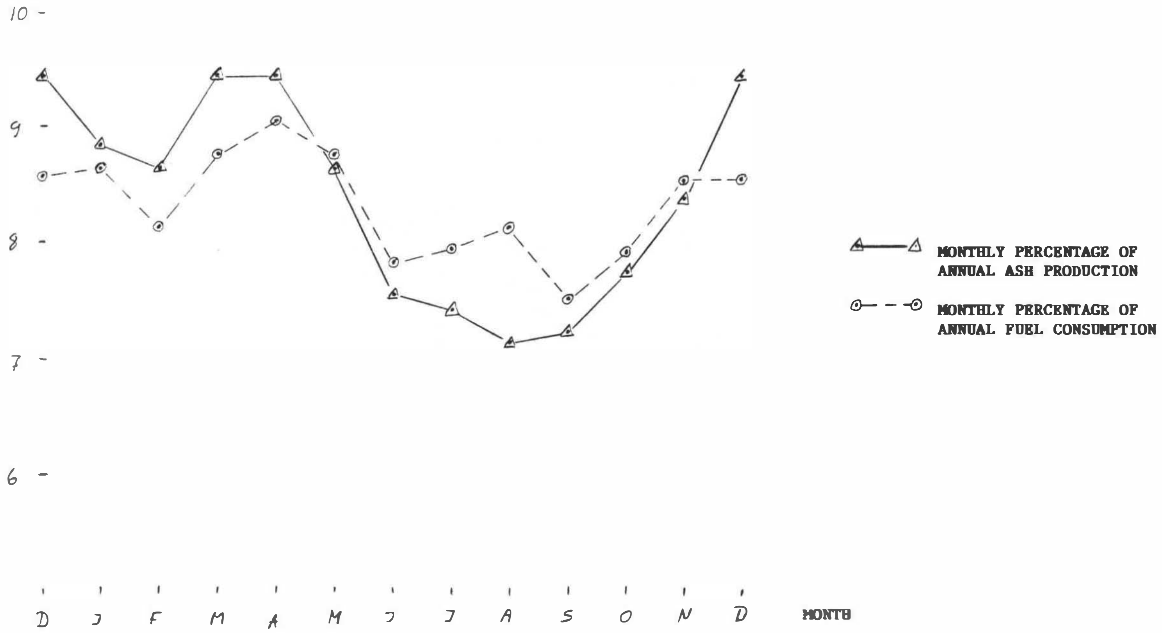


FIG. 8 SEASONAL VARIATION IN ASH PRODUCTION AND FUEL CONSUMPTION

immediate explanation can be furnished by referring to the Army's changing steam demand. It follows that during the winter when the Army needs more steam, fuel is fired at a higher rate and ash is produced at a higher rate as well.

However, the two profiles in Figure 8 are not congruent. On the contrary, in some instances the two profiles appear to move a bit in opposite directions. Furthermore, several of the peaks do not truly coincide. As discussed before, the SAR is the one expression which connects ash and fuel. If it were a constant, then the two profiles would have to be congruent. The fact is that they are not, which suggests that other factors must be at work.

How does the SAR vary during the course of a typical operating year? By referring to Figure 9, it can be gleaned that the winter SAR's are substantially higher than the summer SAR's. The lone exception is November, during which a small drop is experienced. The figure strongly suggests that the SAR is a seasonal phenomenon in the HCRRF. It should be noted that during a typical operating year, the actual SAR exceeds the annual ash guarantee for four of the winter months.

Is it possible that the compositional properties of the fuel change significantly in a manner which influences the SAR? This challenge can be tackled by bringing the specific steaming rate (or SSR) into play. The latter reflects strongly on the combustible content in the fuel. Thus, it can be reasoned that if the variations in the SAR are due to fuel compositional changes, then the SSR should vary in a similar fashion.

In order to find out, the seasonal SSR was superimposed on the seasonal SAR in Figure 9. The result points once again to a well-pronounced seasonal profile. All winter months exceed the annual average, while all summer months fall below it. This can be no accident. Instead, there must be a definable reason and the Company's known practice of enhancing the winter fuel value by adding waste tires emerges as the most likely explanation. Accordingly, the following hypothesis can be formulated:

- During the winter, the Army buys more steam and therefore the Company wants to enhance the heating value of the fuel.
- The SSR goes up accordingly, which proves that fuel enhancement is working.
- Because of the tire addition, the SSR pulls the SAR up with it. Tires have different ashing properties than regular MSW.

This hypothesis is further explored below.

Just how does the SAR vary in relation to the SSR? Is there a simple function which also takes seasonal factors into consideration? In order to find out, the multi-year average monthly SSR's and SAR's were extracted from the data base for constructing the plot shown in Figure 10.

Two separate fields can readily be seen. The first is to the lower left corner and represents the summer months. The second is to the upper right corner and represents the winter months. From the application of a computer program for best curve fitting, the equation $SAR = 19.119 (SSR)^{0.8335}$ in [%] was derived with a correlation factor of 90.5%.

This function can be used with reasonable confidence for predicting the SAR if the SSR is known. However,

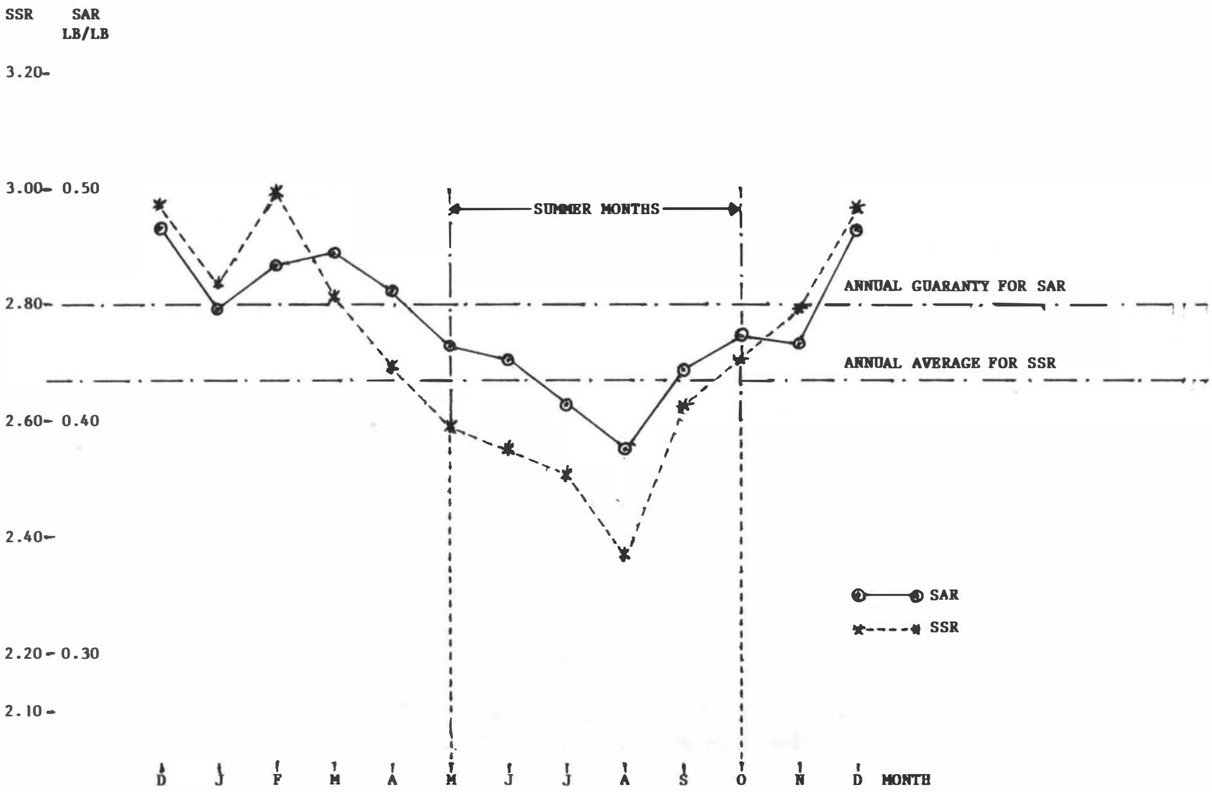


FIG. 9 6-YEAR SEASONAL PROFILES FOR SAR AND SSR

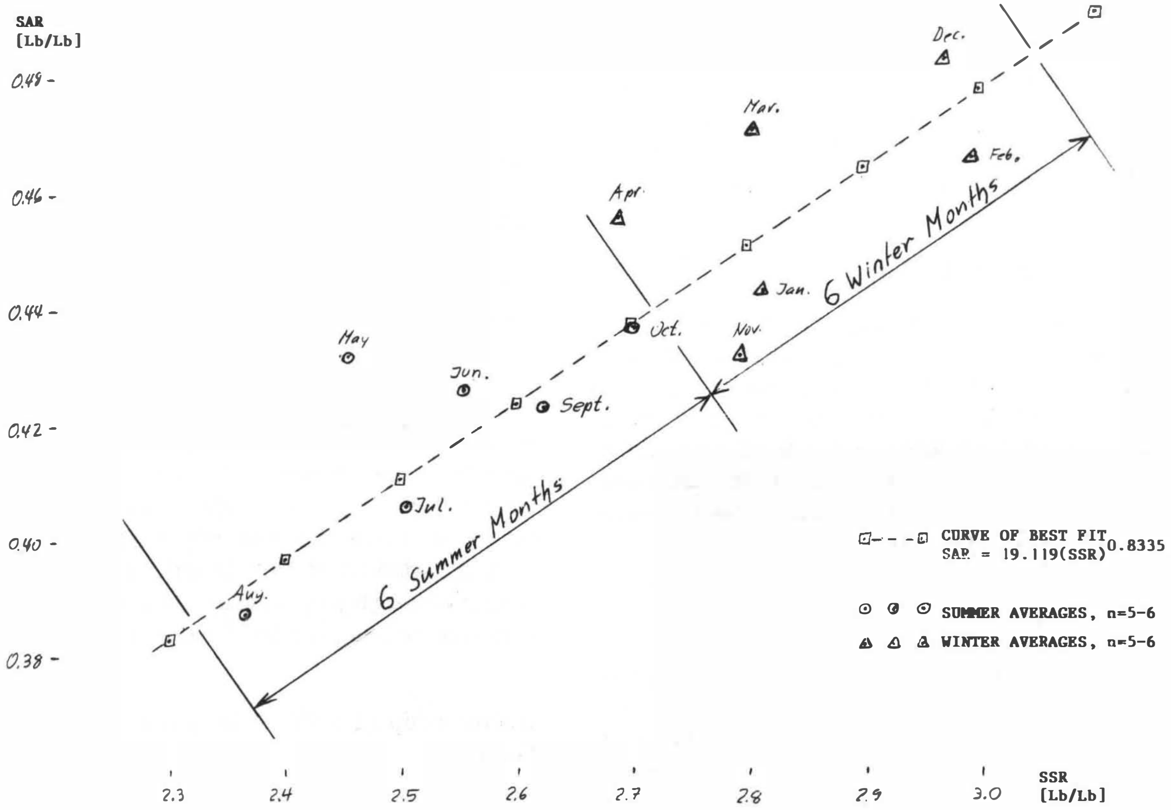


FIG. 10 CORRELATION OF MONTHLY SAR's AND SSR's

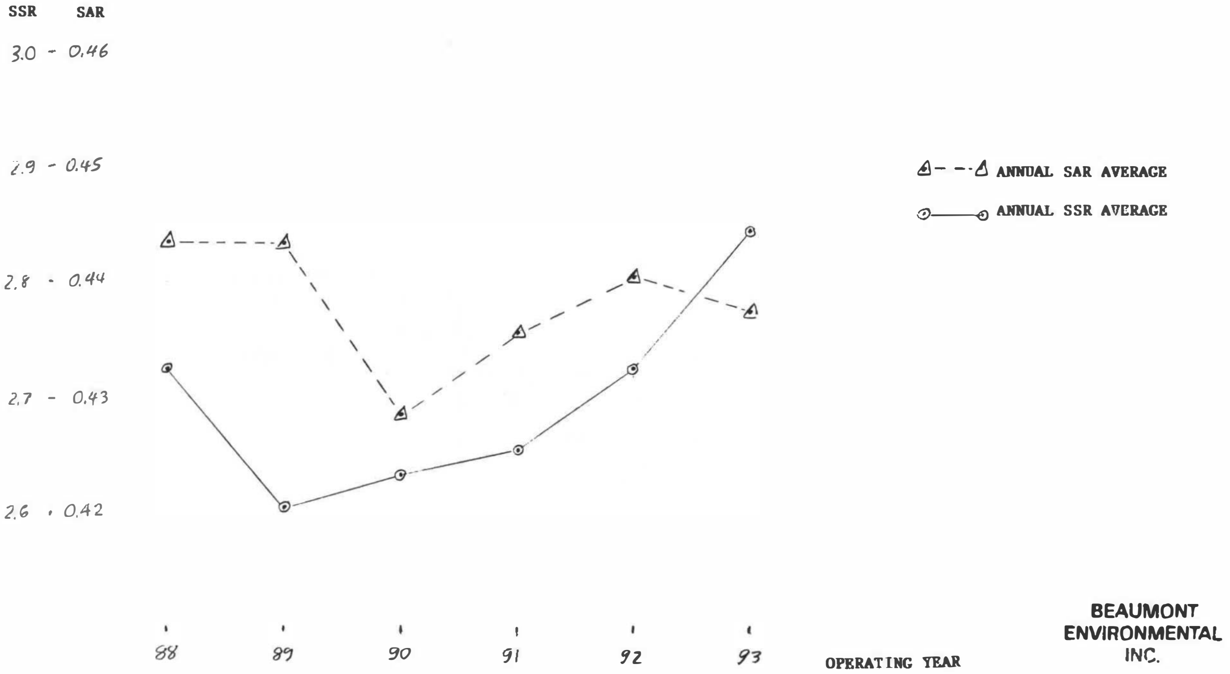


FIG. 11 TRENDLINES FOR ANNUAL SAR & SSR
(Note: Data for 1993 are incomplete)

two points of caution are in order. First, the function was derived from multi-year averages. Consequently, in any one individual month the estimate may not necessarily agree with actual weigh data. Second, steam production and waste firing are more accurately monitored than ash removal. The latter is subject to inventory and logistics disturbances which tend to distort part of the data base. Thus, the prediction obtained from the SSR may be better than the SAR derived from a monthly tonnage report.

Tire Impact on Ash Production

Notwithstanding any dirt from handling in the landfill and left-over wheel rims from the original user, waste tires appear to have a high content of combustibles. A typical proximate analysis shows a combustible content of nearly 95% by wet weight (after removal of any beads and cords). The accompanying HHV might be 16,000 Btu/wLb [7]. Both values are considerably higher than those for regular waste. Accordingly, one would expect that the addition of tires to regular waste would lead to a reduction in ash production. The latter would then manifest itself in a reduced SAR.

However, the multi-year HCRRF experience suggests that the opposite is true. For a comparison of average winter SAR with average summer SAR, it can be stated that without exception, all winter numbers are higher than the corresponding summer numbers. The difference is in the order of 4 to 19% by wet weight and one can only speculate on the reasons.

At some point in the future, scientific research should be conducted which would permit a more rigorous analysis. Most likely this would entail laboratory testing.

Trends in Ash Production

From the data previously developed, the annual averages for the SAR and SSR were taken and plotted in Figure 11. To some extent, it can be seen that, over the 6 operating years, the SAR mimics the SSR. During the '89–'90 period both dropped at first and then recovered. During the most recent years, i.e. '91 and '92, both climbed. Although the year '93 is incomplete and normalized data was used, continued growth of the SSR is virtually assured. On the other hand, the SAR seems to point downward.

One possible explanation for SSR growth may be derived from the fact that during 1992, the Company performed extensive maintenance. The boiler heat transfer surfaces were cleaned to the point where thermal efficiency increased independently of any fuel enhancement from the addition of tires. In order to ensure that the efficiency would stay up, new access ports were added which permit more intensive and frequent cleaning in the future.

Relationship of SAR to Annual Performance Guaranty

From Table 3, it can be deduced that thus far the HCRRF has met the annual ash guarantee of the Service Agreement during every operating year. However, the

TABLE 3 ANNUAL PERFORMANCE FACTORS

Operating Year	Availability Factor AFg	Utilization Factor UFg	Load Factor LFg	Capacity Factor PCFg	Specific Ash Rate SAR	Ash Guaranty Margin δ %	Annual Throughput STPY
1988	0.9911	0.9672	0.8857	0.8581	0.4432	1.51	112,366
1989	0.9715	0.9700	0.9573	0.9271	0.4431	1.53	121,805
1990	0.9523	0.9513	0.9407	0.8952	0.4285	4.75	117,690
1991	0.9563	0.9558	0.9436	0.9018	0.4359	3.13	118,514
1992	0.9336	0.9336	0.9058	0.8471	0.4404	2.13	111,497
1993	0.9621	0.9590	0.9499	0.9107	0.4373	2.82	115,109
Σ	5.7669	5.7369	5.5830	5.3400	2.6284		696,981
n	6	6	6	6	6		6
$\bar{x}$	0.9612	0.9562	0.9305	0.8900	0.4381		116,163
x_{max}	0.9911	0.9700	0.9573	0.9271	0.4432		121,805
x_{min}	0.9336	0.9336	0.8857	0.8581	0.4285		111,497
R	0.0575	0.0364	0.0716	0.0690	0.0147		10,308
RR	5.98	3.81	7.69	7.75	3.36		8.87

margin was not a very comfortable one. For example, during '88 and '89, the margin was only 1.5% of the allowable SAR = 0.450. In fact, if the allowable SAR were to be applied on a monthly or seasonal basis, the HCRRF would be in violation during most winter months.

In this connection, it can also be stated that presently annual compliance is accomplished only by virtue of the fact that lower summer SAR's tend to balance higher winter SAR's. In the preceding sections, the case has been made that tire addition appears to be the culprit. Presently, plans are being discussed to produce more steam in the future for the Army during the summer months. Technically, this may be feasible, but the ash problem would most likely impose a serious constraint. The latter depends mostly on what additional fuel would be fired in order to boost steam production. It can hardly be the consumption of more waste tires. Instead, either more regular MSW must be fired, or some other type of waste must be obtained which has normal ashing characteristics. Preferably, this supplemental fuel would be very high in Btu's and low in ash generation.

Thus, the following potential remedies may be considered.

- Find other supplemental waste which kicks up Btu's but exhibits normal ashing properties.
- One example would be chips of air-dried wastewood which contain virtually no sulfur. Their ash amounts usually to one percent or less. Typically, its HHV might equal 6,000 Btu/wLb. Thus, wastewood could act at the same time as a mild Btu booster and as a powerful ash suppressor.
- Install the proposed ash burn-out beam in order to reduce or eliminate unburnt combustible matter in the ash.
- Modify the ash handling system to reduce the amount of water removed with the ash. This may require installation of a wastewater treatment system. Trommeling and/or screening the ash in the presence of forced convection air stream could also help by evaporating some of the moisture.
- Add magnetic separators in order to pull out ferrous metal for sale to the scrap market. This would lighten the remaining ash.
- Renegotiate the ash guarantee upwards. (Note: SAR = 0.500 would be the number to shoot for.)
- Ask the Maryland Department of the Environment (MDE) to raise the daily throughput limit which was put into the operating permit. (Note: The ESP's have enough margin to handle the extra particulate load.)

In addition to the above, there is yet another concern. It is almost certain that, in the future, the MDE will require the control of acid gases amongst other pollutants in the flue gas discharged through the HCRRF stack. One likely control strategy will be the addition of chemical scrubbers. Their products of reaction will be solids which become an addition to the flyash presently removed. Thus, the SAR will increase further, which may lead to yet another conflict with the annual ash guarantee. As a result, one or more of the above remedies will become a necessity rather than an option.

CONCLUSIONS AND RECOMMENDATIONS

(*1*) The quantity and quality of ash produced is influenced by a variety of conditions, some of which relate to waste composition. Others relate to plant operating conditions such as management of the quench and wastewater systems.

(*2*) The ashing properties of waste tires are markedly different from those of regular MSW. The addition of waste tires causes an increase in the specific ash rate, or SAR.

(*3*) The ashing properties of waste tires should be investigated further, especially with regard to the suspected capacity of tire ash particles for adsorbing excessive amounts of quench water. Perhaps they act like activated carbon.

(*4*) Btu boosters other than tires which do not adversely affect the rate of ash generation should be considered. Waste wood appears to be a promising candidate.

(*5*) Upgrading of the ash handling system, especially with regard to more effective dewatering, should become a priority matter.

(*6*) The addition of trommels and screens would serve many purposes. It would break up large particles, homogenize the ash, increase the bulk density and drive off moisture. The latter aspect can be improved further by adding fans for convective currents.

(*7*) The addition of an industrial type of wastewater treatment system would alleviate the present practice of using the ash pile as a "blotter" or a wastewater removal device.

(*8*) By performing special analyses for ash spray and quench tank overflow, it was possible to set up balances for ash water and ash solids.

(*9*) The "ash roaster" developed by BEI for Ash Test I and II appeared to work reasonably well as a field test apparatus.

(*10*) The test methodology for Ash Test II was an improvement over the one used last year. Better results facilitated setting up the ash compositional model. Screening and sorting methods worked fairly well, although further improvements are desirable.

(*11*) Through fairly close agreement between some ELI and BEI test results, greater confidence has been gained in BEI's improvised procedures.

(*12*) The quality of ash from Test II showed definite improvements over that from Test I. Most noticeably, the ash had a decidedly better burn-out.

(*13*) There was only a minor amount of flyash which had a negligible impact on the investigation. Therefore, flyash does not merit much attention from the quantitative point of view in the future unless acid gas control scrubbers are installed.

(*14*) The residue generation guaranty has been and is being met on an annual basis. However, the margin is rather small and there is the danger that it may interfere with the desire to generate more steam by adding more tires in the future.

(*15*) A strong correlation was found between the specific ash (SAR) and steaming rates (SSR). Both are subject to annual and seasonal fluctuations. It was even possible to find a multi-variable relationship which ties the SAR to the SSR and rubber content (RC) in the waste: SAR = f(SSR; RC).

(*16*) Monthly averages for the SAR were found to follow a strong seasonal profile which showed good repeatability. In contrast, annual averages did not show a clear-cut trend. It seems that from '92 to '93 there has been a small decrease, but only time will tell if this phenomenon can be attributed to the source separation and recycling of materials.

(*17*) Thus far, the ash functions were not tested with regard to climatological influences, such as ambient air temperature and humidity. A probe into climatology at a future date is recommended.

(*18*) Although it has not yet been entirely proven, we succeeded in using the ash model for developing a related waste model.

(*19*) Ferrous scrap appears to be present at about 3% by wet weight in waste in the "as-received" condition. Its presence in the ash amounted to about 8% by wet weight. By adding magnetic separators, about 85 to 90% of this scrap can be removed for sale to the scrap market. Moreover, such recycling would lower both the SAR and the ash guarantee depletion amount.

(*20*) The results of Ash Test II provided significant input to development of the BAC method which is proceeding on a parallel track. Examples are the carbon, nitrogen and water balances.

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[1] Schedule 7 to "Service Agreement Between Northeast Maryland Waste Disposal Authority and Waste Energy Partners Limited Partnership," Baltimore, MD, April 1986.

[2] American Society of Mechanical Engineers, "Performance Test Code PTC.33-1978 for Large Incinerators," Section 7.3 Putrescible Matter Determination Method A, New York, NY, 1979.

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