MASS FIRED ENERGY CONVERSION EFFICIENCY, EMISSIONS, AND CAPACITY WITH A HOMOGENEOUS LOW ASH FUEL

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ABSTRACT

The effects upon energy recovery mass burn incineration from firing a homogeneous low ash presorted fuel are examined in this research supported by the U.S. Department of Energy. Waste profiles, boiler efficiency, flue gas emissions, steam production, incinerator availability, and waste handling capacity are examined. An economic analysis is included. The analyses are based upon 32 months operation of a mass burn energy recovery facility fired with municipal solid waste pretreated by materials recovery processing.

SUMMARY

Research supported by the U.S. Department of Energy under Contract Number DE-AC05-84ER80177 is investigating effects of preburn materials recovery processing upon energy recovery mass burn incineration of municipal solid waste (MSW). The first phase of the research has been completed and is reported herein.

Table summarizes research carried out at the National Recovery Technologies, Inc. (NRT) materials recovery plant and the Resource Authority of Sumner County (RASCO) mass burn energy recovery facility in Gallatin, Tennessee. The NRT system removes inerts from municipal waste prior to incineration in the mass fired energy recovery units. For both untreated MSW and for processed NRT fuel, determinations were made of waste profiles, boiler efficiency, flue gas emissions, steam production, incinerator availability, and waste handling capacity. An economic analyses is presented.

INTRODUCTION

In June 1984 at the ASME Eleventh Biennial National Waste Processing Conference, we reported observed effects of front-end materials processing at the Gallatin, Tennessee mass fired facility [1]. The data covered 14 months of operation from March 1982 through April 1983. This report updates the study through October 1984 for a total of 32 months of operation. Details of test procedures and data analyses are reported in Ref. [2].

FACILITIES DESCRIPTION

The Resource Authority of Sumner County, Tennessee (RASCO) and National Recovery Technologies, Inc. (NRT) in early 1982 began a unique experiment in waste-to-energy conversion. RASCO operates a 200 TPD (182 tpd) mass burn waste-to-energy facility serving all of Sumner County. NRT operates a 150 TPD

TABLE 1 EFFECTS UPON MASS BURN ENERGY RECOVERY INCINERATION FROM MATERIALS RECOVERY PREPROCESSING

	Relative Increase with Processed Fuel
Boiler Efficiency	9.5%
Steaming Rate	12%
Incinerator Availability	10%
Facility Solid Waste Disposal Capacity	20%
Annual Rate of Return for Materials Recovery Investment	66%
Reductions in Unabated Flue Gas Emissions:	% Reduction
Nonmethane Hydrocarbons	75.0%
Fluorides	74.8%
Cadmium	72.9%
Ammonia	72.7%
Chromium	63.3%
Carbon Monoxide	63.1%
Lead	51.8%
Nitrogen Oxides	41.8%
Arsenic	34.0%
Particulates	30.8%

(136 tpd) materials recovery facility in conjunction with the RASCO facility. Municipal solid waste preprocessed by the materials recovery facility is burned in the RASCO incinerators.

The waste-to-energy incineration facility in Gallatin consists of two incinerator/boiler lines utilizing the Westinghouse/O'Connor waterwall rotary combustor technology with ancillary materials handling equipment and electrostatic precipitator gas cleanup. The facility produces process steam for nearby industrial users and cogenerates electricity which is purchased by the Tennessee Valley Authority. The facility is described in detail in Ref. [3].

Refuse brought to the RASCO facility is stored in a 550 ton (500 t) storage pit. An overhead bridge crane transfers it to the input hopper of the NRT materials recovery facility. The refuse is processed through the NRT system for removal of aluminum, steel, glass and other noncombustibles from the waste stream. The enhanced fuel is then returned to RASCO for feeding the energy recovery incinerators. The NRT materials recovery facility is described in detail in a companion paper presented at this conference [4] and in Ref. [5].

MUNICIPAL SOLID WASTE PROFILE ANALYSES

During the week of October 1, 1984, five tests were performed at the NRT materials recovery facility in Gallatin to profile the residential waste stream received at the facility and the output fractions from the materials recovery facility. In each test approximately 1000 lb (454 kg) of waste were first tested for moisture content. The waste was then processed through the materials recovery facility and the various output fractions tested for moisture content. Each output fraction was then handsorted. A total of 4802 lb (2178 kg) of material was analyzed. Input MSW and output fuel analyses from the testing is shown in Table 2.

The proximate analyses were constructed for each output fraction utilizing moisture content and handsorted weights. Waste stream combustibles were categorized as newsprint, other paper, textiles, plastics, food waste, wood, yard waste, and sweepings. Noncombustible categories were steel cans, other steel, aluminum cans, other aluminum, other nonferrous metals, glass/grit and construction refuse. The analysis reflects inclusion of air knife clean-up of the glass/grit fraction. The waste characterization program reported by Hollander et al. [6] and waste constituent proximate analysis values published in Ref. [7] were most useful for this construction. The test data is reported in detail in Ref. [2]. Table 3 shows the weight of various components of the waste streams per one million Btu heat content.

ASME BOILER EFFICIENCY TESTS

ASME boiler efficiency tests under Power Test Code 4.1 were performed at the RASCO facility on October 8, 1984. The first test, from 0300 to 0800, was made firing unprocessed MSW. The second test, from 1900 to 2400, was made firing the same combustor on NRT processed fuel. In both cases boiler efficiencies were calculated for the input/output, heat loss, and calorimeter methods. The test data and calculations are detailed in Ref. [2]. The test results are shown in Table 4. For comparison, Table 4 includes approximated boiler efficiency increase from analysis of long term operating data at the RASCO facility (Table 6).

The boiler efficiency testing shows an average increase in absolute boiler efficiency of 6.1% when firing with processed fuel which is in general agreement with industry experience with RDF fired boilers. This absolute increase translates to a relative boiler efficiency increase of 9.5% as compared to mass firing with MSW.

TABLE 2 SOLID WASTE PROXIMATE ANALYSES 4802 [lb (2178 kg) Input Sample]

	INPUT MSW		NRT FUEL	
	as received	dry basis	as received	dry basis
% Volatiles	41.20%	59.97%	54.46%	76.07%
% Fixed Carbon	4.44%	6.46%	5.85%	8.17%
% Ash & Inerts	23.06%	33.56%	11.28%	15.76%
% Sulfur	0.09%	0.12%	0.11%	0.15%
% Moisture	31.3%	0.0%	28.4%	0.0%
HHV BTU/lb	4448	6475	5865	8191
(kJ/kg)	(10,346)	(15,061)	(13,642)	(19,052)

TABLE 3 lb/MILLION Btu (kg/1000 MJ)

	INPUT MSW	NRT FUEL	NRT/MSW
Volatiles	92.6 (39.8)	92.9 (39.9)	1.00
Carbon	10.0 (4.30)	10.0 (4.30)	1.00
Sulfur	0.2 (0.09)	0.2 (0.09)	1.00
Ash & Inerts	51.8 (22.3)	19.2 (8.26)	0.37
Moisture	70.4 (30.3)	48.4 (20.8)	0.69
Total Weight/Million BTU	225.0 (96.8)	170.7 (73.4)	0.76

CONTRIBUTION OF INDIVIDUAL COMBUSTION PROCESS FACTORS TO BOILER EFFICIENCY INCREASES WITH PROCESSED FUEL

Several combustion parameters were examined to deterine their average contributions to changes in boiler efficiency observed when burning processed and unprocessed fuels. The fuel profiles from handsorting 2.4 tons (2.2 t) of refuse during the testing period were used in these analyses. Flue gas and ash residue analyses were derived from the ASME boiler efficiency tests. Excess air values were 50% for MSW and 40% for NRT fuel as taken from control room instruments during the 10/04/84 ASME boiler tests. Table 5 summarizes the findings for both absolute and relative efficiency increase. Details of the analyses are given in Ref. [2].

The relative efficiency gain of 10.4% is in agreement with the ASME boiler efficiency tests reported in the previous section.

FLUE GAS EMISSIONS

During the ASME boiler efficiency tests, flue gas emissions factors were measured. The measurements show nearly all emissions factors are reduced when burning processed fuel. The data are in good agreement with measurements taken in February 1983 and reported by NRT at the ASME 1984 National Waste Processing Conference in June 1984 [1] (see Fig. 1).

LONG TERM OBSERVATIONS OF BOILER EFFICIENCY, STEAM PRODUCTION, AND INCINERATOR AVAILABILITY

The RASCO management maintains data providing an operating history of the Gallatin facility since full scale operation began in March 1982. A graph of pounds of steam produced per pound of waste received at the facility is shown in Fig. 2. Each data point is the average of monthly values grouped into 20% intervals of percentage processing of received waste for materials recovery. The data shown in the accompanying Table 6 is taken from intercepts of the least squares fit with the 0% and 100% processing axes. Boiler efficiency increases are approximated using the input/output method assuming that incoming MSW has an average heat content of 4500 Btu/lb (10,467 kJ/kg).

The graph of incinerator steam production rate in Fig. 3 shows the average pounds of steam produced per hour by a unit incinerator correlated with materials recovery. The intercepts of the least squares fit through the data points (Table 7) give steam production rates of 22,385 lb/hr (10154 kg/h) of steam for burning processed fuel and 19,968 lb/hr (9057 kg/h) when burning unprocessed MSW. The 12% increase in steaming rate with processed fuel is in good agreement with steaming rates observed in the boiler efficiency tests.

Figure 4 and Table 8 show on-line reliability of a unit incineration train correlated with materials processing. Only unscheduled outages of equipment in the incineration train which halted incinerator operation are used to determine on-line reliability. Standby status is not included in the analysis. Table 9 is constructed to demonstrate how on-line reliability is determined. The outages include all components such as ash handling equipment, feed hopper, combustor, etc.

The data is graphed in Fig. 4. The least squares fit is drawn through all data points except the 0% materials processing point. This fit is presented because data for operation with 0% processed fuel is from initial RASCO facility operation in early through mid-1982 before the NRT facility came on-line. Since there was likely a learning curve for the RASCO operators during this initial operating period it is possible that the 0% data point may be skewed. Therefore the least

TABLE 4 BOILER EFFICIENCY COMPARISONS: NRT FUEL TO MSW

TEST METHOD	ABSOLUTE EFFICIENCY INCREASE W/NRT FUEL	RELATIVE EFFICIENCY INCREASE W/NRT FUEL
Input/Output (*)	6.9%	10.6%
Heat Loss (**)	5.3%	8.1%
Calorimeter	6.0%	9.5%
Long Term Data	6.2%	9.7%
Averages	6.1%	9.5%

* Boiler efficiency (%) for the input/output method is defined as:

[(Heat Absorbed by Working Fluids)/(Heat in Fuel + Heat Credits)] x 100%

** Boiler efficiency (%) for the heat loss method is defined as:

100% x [1 - (Heat Losses)/(Heat in Fuel + Heat Credits)]

squares fit considers only data after the NRT facility came on-line. The on-line reliability values in Table 8 are taken from intercepts of the least squares fit with the 0% and 100% processing axes. Scheduled maintenance is then factored in to give availability. Availabilities on each fuel assuming a manufacturer's guarantee of 85% for operation on MSW are also shown. The NRT reliability for this case is extrapolated as percentage of difference between NRT measured reliability and MSW measured reliability (as compared to 100% reliability) which is then applied to manufacturer's guarantee reliability.

The RASCO facility through the date of this analysis operated at approximately 76% rated capacity. In 1984 the average throughput was 130 TPD (118 tpd) with rated capacity for manufacturer's guarantee at 170 TPD (154 tpd). Therefore it is not possible to determine reliability directly from the ratio of operating hours to actual hours elapsed. Some time is spent with an incinerator on standby status. This being the case, reliability is determined from the ratio of operating hours to elapsed hours during which the incinerator is called upon to operate.

The reliability determination is made from the RASCO control room daily operating record for hours on-line. Table 9 is constructed to demonstrate how reliability would be determined over the two week period shown. For the day before or after an incinerator is off-line, the called upon hours are equal to operating hours as long as the operating hours are 6 hr or less. If operating hours are greater than 6, then called upon hours are assigned the value of 24. This procedure provides 6 hr overlap for scheduled bringing of incinerators on-line or off-line at midnight which is RASCO's ordinary time for scheduling such events.

TABLE 5 INCREMENTAL INCREASES IN BOILER EFFICIENCY WITH NRT PROCESSED FUEL

EFFICIENCY INCREASE SOURCE	ABSOLUTE EFFICIENCY INCREASE	RELATIVE EFFICIENCY INCREASE
Moisture Reduction	2.8%	4.0%
Fuel Burnout	2.5%	3.6%
Reduced Excess Air Usage	1.9%	2.7%
Sensible Heat Loss to Ash	0.1%	0.1%
Net Efficiency Increase	7.3%	10.4%

ASH HANDLING REQUIREMENTS

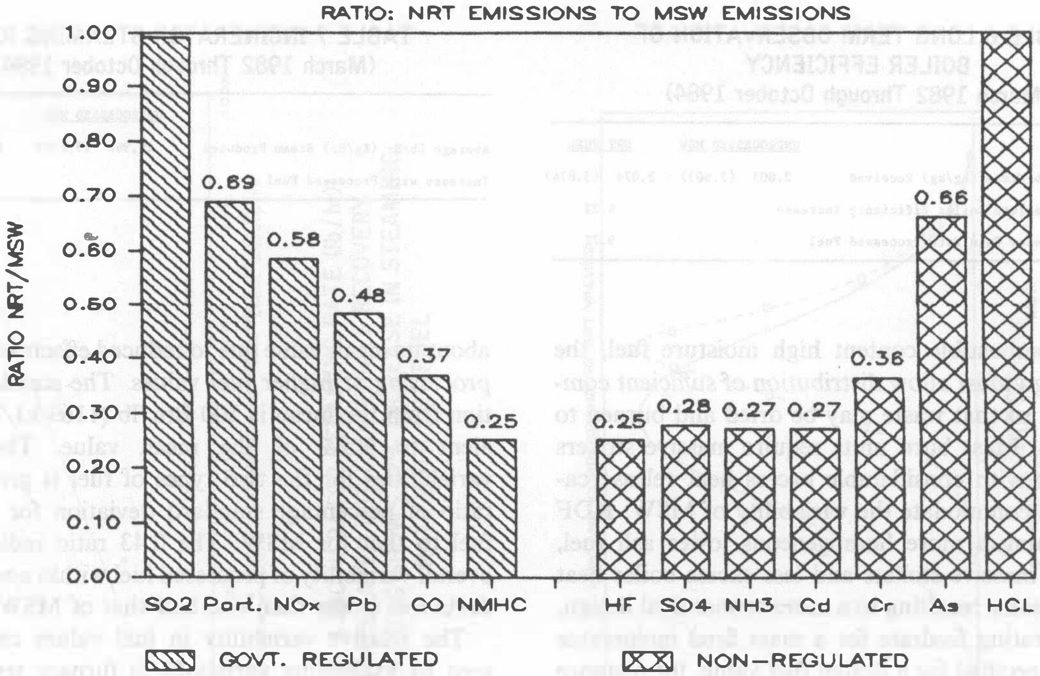
Since startup early in 1982 the submerged ash drag systems at the RASCO facility have been observed to operate with fewer outages when the incinerators are burning processed fuel. In an August 1983 test, when burning MSW, the average steam flow between interruptions was 800,000 lb (362,880 kg). When burning NRT fuel the average steam flow between interruptions was 2,000,000 lb (907,200 kg).

Since the August 1983 test, both ash drag units have been replaced by modified heavier units with bottom return. With the heavier units in place a review of plant operating records was made for the months of September and October 1984. Monthly unit operating summaries and daily operator's logs were reviewed to document ash drag outage times and durations. Direct labor costs for ash drag maintenance when burning NRT fuel was found to be reduced by $0.53/ton ($0.58/t) received waste when burning NRT fuel (Table 10).

FUEL VARIABILITY, INCINERATOR OPERATING SETPOINTS, AND FEEDRATE

The design operating feedrate of a municipal waste incinerator is largely dependent upon boiler heat release capacity, stoker mass and heat release capacities, and fuel variability. Ideal operation maximizes waste throughput and energy recovery while minimizing excursions over boiler maximum design heat release limits and stoker loading limits due to fuel variability.

The ability of a mass fired incinerator to handle heterogeneous fuel is a unique feature. MSW may vary from such a low value as 2000 Btu/lb (4652 kJ/kg) to a high value such as 7500 Btu/lb (17,445 kJ/kg) with seasonal variations, waste sources, moisture, etc. An incinerator should be capable of burning MSW as it varies over this range. At stoker design rating, the boiler must have sufficient excess capacity to absorb heat released by combustion of high Btu fuel. Likewise,



FLUE GAS UNABATED EMISSIONS FACTORS
Comparison NRT Fuel to MSW

Regulated Pollutants		NRT FUEL (Lb/Ton)	MSW FUEL (Lb/Ton)	RATIO NRT/MSW
Sulfur Dioxide	SO2	2.77	2.80	0.99
Particulates	Part.	29.4	42.5	0.69
Nitrogen Oxides	NOx	1.28	2.20	0.58
Lead	Pb	0.13	0.27	0.48
Carbon Monoxide	CO	1.66	4.50	0.37
Complex Hydrocarbons	NMHC	0.06	0.23	0.25
Non-Regulated Pollutants				
Hydrogen Fluoride	HF	0.008	0.031	0.25
Sulfates	SO4	0.27	0.97	0.28
Ammonia	NH3	0.033	0.121	0.27
Cadmium	Cd	0.0064	0.0236	0.27
Chromium	Cr	0.0029	0.0079	0.36
Arsenic	As	0.0021	0.0032	0.66
Hydrogen Chloride	HCL	6.2	5.3	1.17

MSW measurements from California Waste Management Board testing (Cooper Engineers) of Feb 7 to 11, 1983, at Gallatin TN under Contract No. S936-400LG. NRT measurements are averages from Cooper Engineers testing of Feb 10, 1983 and U.S. Dept. of Energy sponsored testing of Oct 8, 1984, under Contract No. DE-AC05-84ER80177, both at Gallatin TN.

Data in pounds of pollutant per ton of MSW processed. Measurements are prior to emissions control equipment and are not direct air releases.

FIG. 1 REDUCTIONS IN UNABATED EMISSIONS

TABLE 6 LONG TERM OBSERVATION OF BOILER EFFICIENCY (March 1982 Through October 1984)

	UNPROCESSED MSW	NRT FUEL
Lbs Steam per Lb Waste (kg/kg) Received	2.803 (2.803)	3.074 (3.074)
Approximated Absolute Boiler Efficiency Increase		6.2%
Relative Efficiency Gain With Processed Fuel		9.7%

TABLE 7 INCINERATOR STEAMING RATE (March 1982 Through October 1984)

	UNPROCESSED MSW	NRT FUEL
Average Lb/Hr (Kg/Hr) Steam Produced	19,968 (9,057)	22,385 (10,154)
Increase with Processed Fuel		12.1%

for low combustible content high moisture fuel, the boiler design must allow distribution of sufficient combustion air so that waste may be dried and burned to completion. Mass burn units require massive stokers and boilers with considerable excess heat release capacity to accommodate the variability of MSW. RDF units, burning a more homogeneous lower ash fuel, utilize less massive stokers and less excess boiler heat release capacity resulting in a more economical design.

The operating feedrate for a mass fired incinerator is usually specified for a design fuel value, for instance 4500 Btu/lb (10,467 kJ/kg). This feedrate provides heat release prudently under the safe operating limit of the boiler and stoker so that excursions due to hotter fuel are within tolerance. Excess capacity provided in the design is a function of fuel variability. The lower the variation in expected fuel values the lower the required excess capacity and consequently the closer the incinerator can operate to boiler design capacity.

These principles can be applied to operation of a mass fired incinerator on processed fuel obtained from presorting of the waste. Figure 5 shows fuel value distributions for NRT processed fuel derived from a normal (Gaussian) distribution of as-received MSW centered about an average fuel value of 4500 Btu/lb (10,467 kJ/kg). For purposes of this analysis a normal distribution in MSW fuel value gives a reasonable representation of fuel variability encountered in mass fired incineration operation. The processed fuel values shown result from processing the MSW values through the materials recovery system. The resulting distribution for processed fuel is essentially compressed into the upper half of the MSW fuel distribution. This indicates that processed fuel exhibits about one-half the variability in heat content as does MSW. The processed fuel profile is centered about a mean fuel value of 5284 Btu/lb (12,291 kJ/kg).

The MSW normal distribution and resulting processed fuel distribution shown in Fig. 5 yield percentage deviations from their mean values as shown in Fig. 6. One standard deviation from the mean for MSW is 1000 Btu/lb (2326 kJ/kg), equal to 22% of the mean value. The processed fuel profile is slightly asymmetric about its mean value due to reduced effects of materials processing at higher fuel values. The standard deviation from the mean is 500 Btu/lb (1163 kJ/kg) equivalent to 9.5% of the mean value. The relative variabilities for the two types of fuel is given by the ratio of percentage standard deviation for processed fuel to that for MSW. The 0.43 ratio indicates that overall variability of processed fuel within one standard deviation is less than one-half that of MSW.

The relative variability in fuel values can also be seen by examining variations in furnace temperature when firing with MSW and with processed fuel. Reduced variations in processed fuel heating value should result in similar reductions in furnace temperature variation during incineration. Figures 7 and 8 show furnace temperatures taken at 5 min intervals at Gallatin during the ASME boiler tests of October 8, 1984. For MSW the percentage standard deviation from the mean furnace temperature is 10%. For NRT fuel this deviation is 5%. Their variability ratio of one-half is in close agreement with the variability ratio of 0.43 obtained above by comparing standard deviations for the Fig. 6 fuel distribution profiles.

An incinerator's performance guarantee level is generally below heat release design capacity due to fuel variability. The amount of excess capacity supplied is a direct function of the expected degree of variability. In Fig. 9 this relationship is shown as the curve marked by + points for an incinerator at Gallatin. The mass-fired guarantee feedrate is 85 TPD (77.1 tpd) for MSW averaging 4500 Btu/lb (10,467 kJ/kg). The vertical line at 38,900,000 Btu/hr (41,039,000 kJ/h) is the incinerator design heat release capacity which is 22% in excess of performance guarantee average heat release of 31,875,000 Btu/hr (33,628,000 kJ/h).

It is interesting that the excess capacity is almost exactly equal to the excess heat released from burning 5500 Btu/lb (12,793 kJ/kg) MSW at the 4500 Btu/lb (10,467 kJ/kg) guarantee feedrate of 85 TPD (77.2 tpd). This upper fuel value corresponds to one standard deviation (1000 Btu/lb, 2326 kJ/kg) above the 4500 Btu/lb (10,467 kJ/kg) mean for a normal distribution of MSW fuel values. Thus the incinerator is essentially

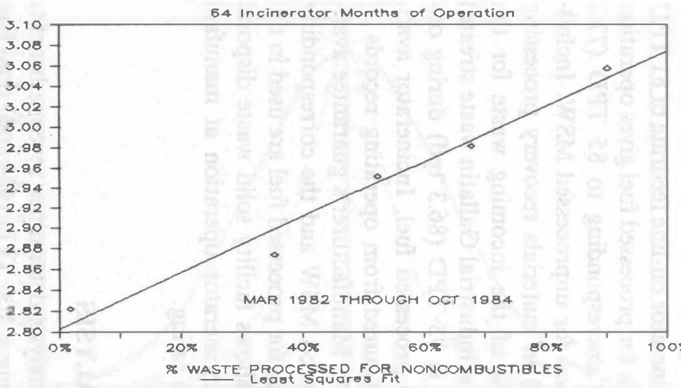


FIG. 2 LONG TERM AVERAGES OF BOILER EFFICIENCY, EXPRESSED AS POUNDS OF STEAM PRODUCED PER POUND OF WASTE RECEIVED AT THE RASCO FACILITY, CORRELATED WITH MATERIALS RECOVERY AT THE FACILITY

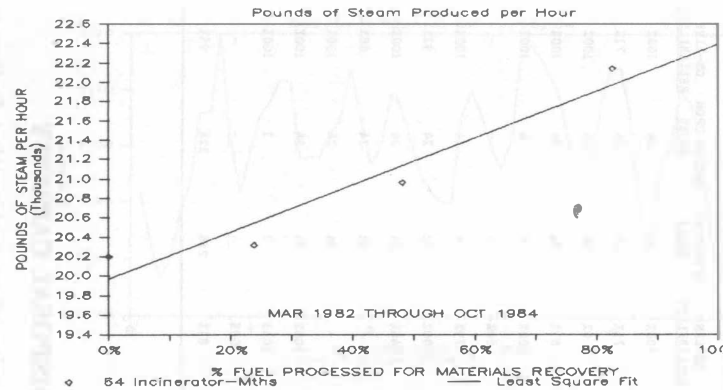


FIG. 3 INCINERATOR STEAMING RATE (lb/hr) CORRELATED WITH MATERIALS RECOVERY PROCESSING SHOWS 12% INCREASE IN STEAMING RATE WITH NRT FUEL

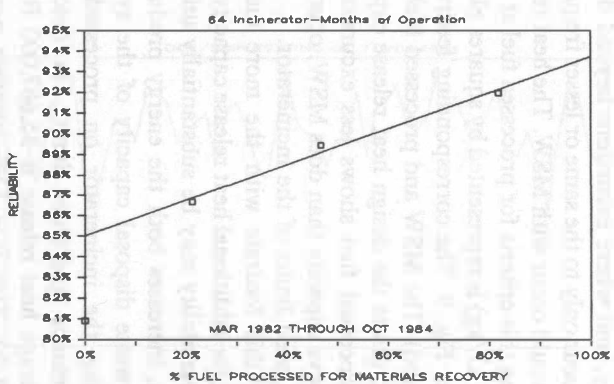


FIG. 4 LONG TERM OBSERVATIONS OF INCINERATOR ON-LINE RELIABILITY CORRELATED WITH MATERIALS RECOVERY PROCESSING

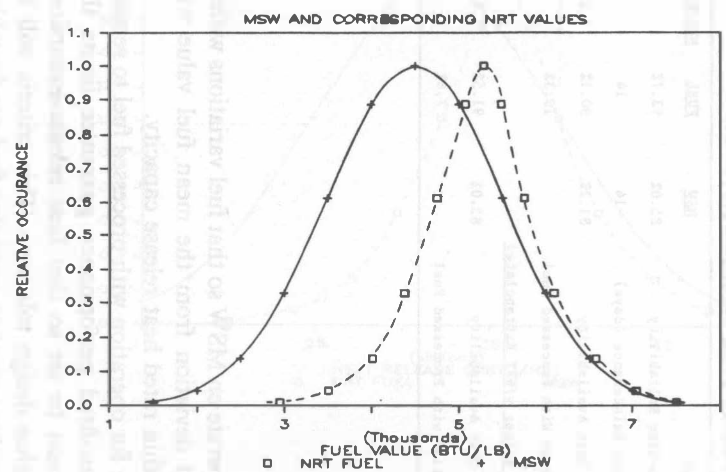


FIG. 5 VARIATION IN FUEL VALUE FOR MSW AND CORRESPONDING PROCESSED FUEL

TABLE 8 LONG TERM OBSERVATION OF INCINERATOR AVAILABILITY (March 1982 Through October 1984)

Measured Values	MSW	FUEL	NRT/MSW
Incinerator On-Line Reliability	85.0%	93.7%	
Annual Scheduled Maintenance (days)	14	14	
Annual Single Unit Availability	81.7%	90.1%	1.103
Relative Increase With Processed Fuel		10.3%	
MSW Guarantee Values w/NRT Extrapolated			
Annual Single Unit Availability	85.0%	91.5%	1.076
Relative Increase with Processed Fuel		7.6%	

rated to operate on MSW so that fuel variations within a standard deviation from the mean fuel value will remain within rated heat release capacity.

In order for operation with processed fuel to remain within mass-fired performance guarantee limits the feedrate must be set so that heat release excursions remain within design tolerance. This criteria will be satisfied for this case at an operating feedrate for which heat release excursions within one standard deviation of processed fuel mean value do not exceed design heat release capacity, and where excursions beyond design capacity will occur only to the same or lesser frequency and extent as would occur with MSW. The heat release profile satisfying this criteria for processed fuel at 5284 Btu/lb (12,291 kJ/kg) is represented by squares plotted on the graph in Fig. 9. The corresponding feedrate is 81 TPD (73.5 tpd). The MSW and processed fuel profiles in Fig. 9 cross at the design heat release capacity value. Since processed fuel shows less excursions in heat release above capacity than does MSW, operation will be within rated limits of the incinerator.

In firing at this feedrate with the more uniform processed fuel, the additional heat release capacity built in for MSW variability may be substantially utilized. This, in effect, increases both the energy production capacity and waste disposal capacity of the system. When operating the incinerator on processed fuel within performance guarantee limits, as described above, the average heat release is 35,667,000 Btu/hr (37,600,000 kJ/h). This is a 12% increase over the MSW average of 31,875,000 Btu/hr (33,603,000 kJ/h). Thus, ignoring other factors such as boiler efficiency and availability, the incinerator will be able to produce 12% more steam when operating on processed fuel as compared to operation on MSW (Table 11).

TABLE 9 RELIABILITY DETERMINATION EXAMPLE

	UNIT #1			UNIT #2		
DAY	OPERATING HOURS	CALLED UPON HOURS	ON-LINE RELIABILITY	OPERATING HOURS	CALLED UPON HOURS	ON-LINE RELIABILITY
1	24	24	100%	24	24	100%
2	18	24	75%	17	24	71%
3	-	24	0%	24	24	100%
4	20	24	83%	24	24	100%
5	24	24	100%	6	6	100%
6	24	24	100%	-	-	-
7	19	24	79%	4	4	100%
8	24	24	100%	22	24	92%
9	11	24	46%	24	24	100%
10	-	-	-	21	24	88%
11	-	-	-	24	24	100%
12	3	3	100%	24	24	100%
13	24	24	100%	2	2	100%
14	24	24	100%	-	-	-
Total	215	267	81%	216	228	95%

SOLID WASTE DISPOSAL CAPACITY

The disposal capacity of an incineration facility is determined by on-line operating throughput rate and incinerator availability. In the above section it was determined that incinerator on-line feedrate of 81 TPD (73.5 tpd) at Gallatin for processed fuel gives operation within design limit corresponding to 85 TPD (77.1 tpd) on-line operation for unprocessed MSW. Including weight removed in materials recovery processing (approximately 15% of the incoming waste for the 40% commercial and industrial Gallatin waste stream) the waste disposed is 95 TPD (86.3 tpd) during on-line operation with processed fuel. Incinerator availability has been measured from operating records of the facility (Table 8). Manufacturer's guarantee availability for operation on MSW and the corresponding measured availability for processed fuel are used in the analysis. Table 12 shows facility solid waste disposal capacity for dual incinerator operation at manufacturer's performance rating.

ECONOMIC ANALYSIS

This economic analysis determines revenue benefits derived from utilizing a 500 TPD (454 tpd) dual-line materials recovery facility matched to a 420 TPD (381 tpd) mass burn recovery facility. The analysis compares capital and operating costs of the materials recovery facility to potential revenue benefits realized by

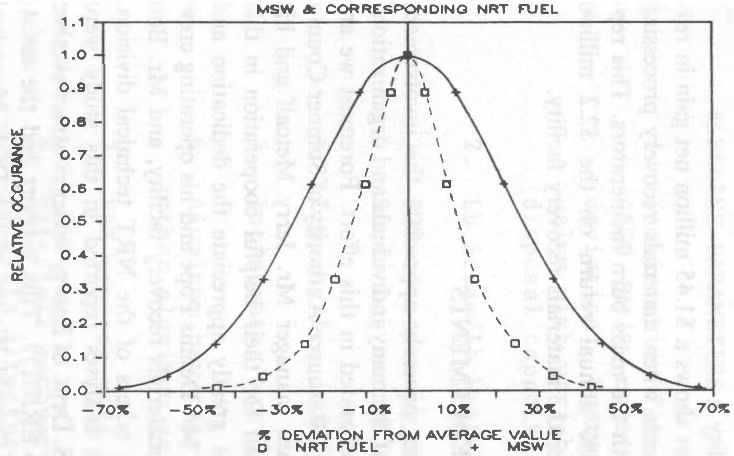


FIG. 6 PERCENTAGE DEVIATION IN FUEL VALUE FOR NORMAL DISTRIBUTION WITH MSW AND FOR CORRESPONDING PROCESSED FUEL VALUES. MSW STANDARD DEVIATION FROM THE MEAN IS 22%; FOR PROCESSED FUEL IT IS 9.5%.

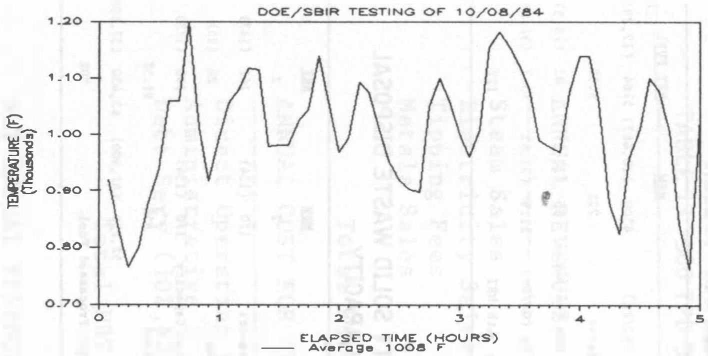


FIG. 7 FURNACE TEMPERATURES FOR FIRING WITH UNPROCESSED MSW TAKEN AT 5 min INTERVALS DURING ASME BOILER TESTING OF OCTOBER 8, 1984

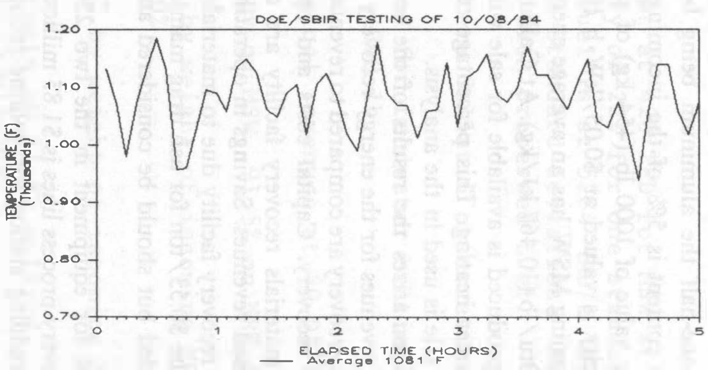


FIG. 8 FURNACE TEMPERATURES FOR FIRING WITH PROCESSED FUEL TAKEN AT 5 min INTERVALS DURING ASME BOILER TESTING OF OCTOBER 8, 1984

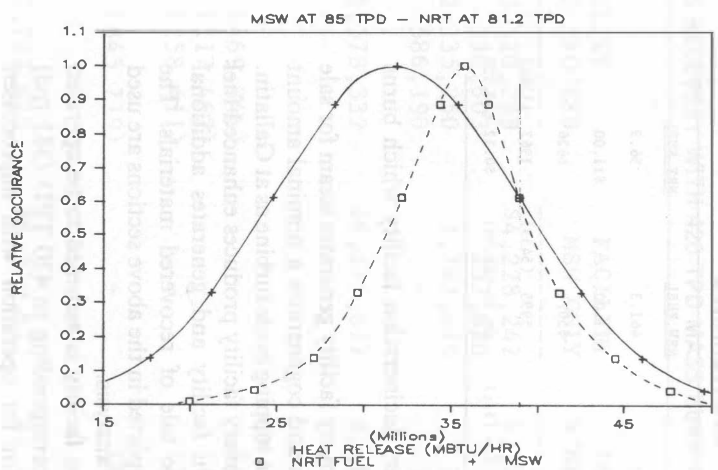


FIG. 9 VARIABILITY IN HEAT RELEASE OF MSW AND PROCESSED FUEL DURING OPERATION WITHIN DESIGN SPECIFICATIONS. AVERAGE HEAT RELEASE IS 12% GREATER WITH PROCESSED FUEL.

TABLE 10 DIRECT LABOR COSTS FOR ASH DRAG MAINTENANCE

	MSW FUEL	NRT FUEL
Ash Drag Outages (Hrs)	461.3	56.9
Direct Labor ($/Hr)	$11.00	$11.00
Total Direct Labor	$5074	$626
Tons (t) MSW Disposed	5995 (5439)	1967 (1784)
Direct Labor Cost - $/Ton ($/t)	$0.85 ($0.94)	$0.32 ($0.35)

the energy recovery incineration facility which burns the processed fuel.

The energy recovery facility generates steam for sale to industrial users and cogenerates a nominal amount of electricity with a topping cycle turbine as at Gallatin. The materials recovery facility produces enhanced fuel for the mass burn facility and generates additional revenues from the sale of recovered materials. The research results reported in the above sections are used as a basis for the analysis.

The incineration facility is assumed to be operated at full capacity corresponding to 420 TPD (381 tpd) average throughput for operation with unprocessed MSW. Operation with processed fuel is at 500 TPD (454 tpd) of MSW received which includes the 20% gain in disposal capacity discussed earlier. It is assumed that aluminum content is 0.8% of the incoming waste stream with one-half the aluminum being beverage cans. Ferrous content is 5% of the incoming waste. The economic value of 1000 lb (454 kg) of steam is $6.00, electricity is valued at $0.05/kW·h ($0.014/MJ), and incoming MSW has an average energy content of 4500 Btu/lb (10,467 kJ/kg). At Gallatin 82% of the steam produced is available for sale with 18% used in feedwater heating. This percentage of steam produced for sale is used in the analysis.

Table 13 summarizes the results of the economic analysis. The revenues for the energy recovery facility with materials recovery are compared to revenues without materials recovery. Capital costs and operating costs of the materials recovery facility are charged against increased revenues. Savings in operating costs of the energy recovery facility due to materials recovery, such as the $0.53/ton for ash drag maintenance, are not included but should be considered an added benefit.

Capital cost for equipment in the two 250 TPD materials recovery process lines is $1.85 million which includes a shredding station for volume reduction of the ferrous product. An additional $0.35 million is provided for a structure to house the materials recovery

TABLE 11 FEEDRATE, FUEL VARIABILITY, AND HEAT RELEASE COMPARISON

	MSW		NRT FUEL	
Average Fuel Value - BTU/lb (kJ/kg)	4500	(10,467)	5284	(12,291)
Standard Deviation in Fuel Value	22%		9.5%	
Fuel Throughput TPD (tpd) - MSW Guarantee	85	(77.1)	81	(73.5)
Average Heat Release - MBTU/Hr (GJ/Hr)	31.9	(33.6)	35.7	(37.6)
Net Increase in Heat Release with NRT			12%	

TABLE 12 FACILITY SOLID WASTE DISPOSAL CAPACITY

	MSW		NRT	
Number of Incinerators	2		2	
TPD (tpd) Fuel Through Incinerators	170	(154)	162	(147)
TPD (tpd) Removed in Processing	-		28	(25)
Total TPD (tpd) On-line Disposal Capacity	170	(154)	190	(173)
Unit Availability (MSW Guarantee)	85%		91.5%	
Annual Capacity (Tons)	52,750	(47,900)	63,450	(57,600)
Net Gain in Annual Capacity with Processed Fuel			20%	

facility. It is assumed that the mass burn facility tipping floor or storage pit will be used for waste inventory and that the mass burn front end loaders or cranes will provide feed to the input hopper of the materials recovery facility.

The analysis shows a $1.45 million net gain in revenues after costs when materials recovery processing is utilized with the mass burn incinerators. This represents a 66% annual return on the $2.2 million investment for the materials recovery facility.

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TABLE 13 500 TPD DUAL-LINE MATERIALS RECOVERY WITH 420 TPD MASS BURN FACILITY

ANNUAL REVENUES	FACILITY WITH NRT PROCESS	FACILITY MSW ONLY	INCREASE W/NRT FUEL
Steam Sales	$5,520,289	$4,228,247	$1,292,042
Electricity Sales	336,603	257,820	78,783
Tipping Fees	2,135,250	1,793,610	341,640
Metals Sales	586,190	-	586,190
Total Revenues	$8,578,332	$6,279,677	$2,298,655
ANNUAL COST FOR NRT OPERATION			
Direct Operating Cost	(469,846)	-	(469,846)
Administrative @ 25% operating	(117,462)	-	(117,462)
Debt Serv (10%,$2.2 mil,20 yr)	(258,411)	-	(258,411)
Total NRT Cost	(845,719)	-	(845,719)
NET ANNUAL REVENUE	$7,732,613	$6,279,677	$1,452,936
ANNUAL RATE OF RETURN ON MATERIALS RECOVERY CAPITAL INVESTMENT			66%

BASELINE PARAMETERS:

1. Incineration facility design throughput at 420 TPD for MSW at 4500 Btu/lb mean value with variability of 22% for one standard deviation. Operation with processed fuel is at 5284 Btu/lb mean value with variability of 9.5% for one standard deviation. MSW disposal capacity is increased by 20% with processed fuel.
2. Lb Steam/Lb Waste received from long term Gallatin observations.
3. 82% of steam produced is sold (18% used for feedwater heating). Steam has economic value of $6.00 per 1000 lb.
4. Tipping fee is $11.70 per ton. Electrical revenues at $0.05/kWh.
5. Incinerator has 85% annual availability on MSW, 91.5% on NRT fuel.
6. Aluminum beverage can content is 0.4% by weight of incoming MSW, other aluminum at 0.4%, ferrous at 5.0%.
7. NRT process will remove an average 15% by weight of incoming MSW.
8. Materials recovery equipment capital costs at $1.85 million, facility structure capital costs at $0.35 million.

TABLE 13 (Cont'd) 500 TPD DUAL-LINE MATERIALS RECOVERY WITH 420 TPD MASS BURN FACILITY

WASTE PROCESSED	Average MSW Throughput (TPD)	Annual MSW Throughput (TPY)	Incinerator Availability (%)	Capacity Gain with Processed Fuel (%)
MSW Facility Alone	420	153,300	85.0%	-
With NRT Process	500	182,500	91.5%	20%

Metals Recovery	Input MSW	% Content	Recovery Eff.	Ton/Year
Aluminum Cans	182,500	0.4%	70%	511
Other Aluminum	182,500	0.4%	35%	256
Ferrous	182,500	5.0%	80%	7,300

PROJECTED REVENUES

Steam Sales	MSW (TPY)	Lb Steam per Lb of MSW	Sales-$6/kLb @ 82% Sold	Increased Revenue
MSW Facility Alone	153,300	2.803	$4,228,247	-
With NRT Process	182,500	3.074	5,520,289	$1,292,042

Electricity Sales	Steam-kLb/yr	KWH/yr	Sales-$.05/kwh	Increase
MSW Facility Alone	859,400	5,156,399	$257,820	-
With NRT Process	1,122,010	6,732,060	336,603	$78,783

Tipping Fees	MSW (TPY)	$/Ton	Revenue	Increase
MSW Facility Alone	153,300	$11.70	$1,793,610	-
With NRT Process	182,500	$11.70	2,135,250	$341,640

Metal Sales	Metals (TPY)	Value/Ton	Revenue	Increase
Aluminum cans	511	$640	$327,040	$327,040
Other Aluminum	256	300	76,650	76,650
Ferrous	7300	25	182,500	182,500

MATERIALS RECOVERY DIRECT OPERATING COSTS		Annual Total
Direct Labor Salaries	$1.63 per ton	$297,475
Labor Overhead @ 15%	0.24 per ton	44,621
Supplies & Maintenance	0.50 per ton	91,250
Utilities	0.20 per ton	36,500
Total Direct Operating Costs	$2.57 per ton	$469,846

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