UNCLASSIFIED

AD NUMBER

ADB017044

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; NOV 1976. Other requests shall be referred to Civil Engineering Lab., Naval Construction Battalion Center, Port Hueneme, CA 93043.

AUTHORITY

Naval Civil Engineering Lab ltr dtd 3 Feb 1986

THIS PAGE IS UNCLASSIFIED

② ⑫

CR 77.009

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

OPERATIONAL TESTING OF A SYSTEM FOR SOLID WASTE TO ENERGY CONVERSION

November 1976

An Investigation Conducted by

SYSTEMS TECHNOLOGY CORPORATION
Xenia, Ohio

N68305-76-C-0007

Distribution limited to U.S. Government Agencies only; Test and Evaluation; November 1976. Other requests for this document must be referred to Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, California 93043.

393 018

(18) CEL

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

(19) CR-77.009

2. GOVT ACCESSION NO.

(9) 3. RECIPIENT'S CATALOG NUMBER

(6) 4. OPERATIONAL TESTING OF A SYSTEM FOR SOLID WASTE TO ENERGY CONVERSION.

5. TYPE OF REPORT & PERIOD COVERED
Final Rept.,
~~November 1976~~

6. PERFORMING ORG. REPORT NUMBER

(10) 7. H. Kleinhenz
H. Gregor Rigo

8. CONTRACT OR GRANT NUMBER(s)
(15) N68305-76-C-0007 NEW

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Systems Technology Corporation
245 North Valley Road
Xenia, Ohio 45385

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
62765N; ZF57.571.001.
01.005

11. CONTROLLING OFFICE NAME AND ADDRESS
Civil Enginnering Laboratory
Naval Construction Battalion Center
Port Hueneme, CA 93043

(11) 12. Nov[redacted]76

13. 24

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
Naval Facilities Engineering Command
200 Stovall Street
Alexandria, VA 22332

(12) 25p.

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government Agencies only; Test and Evaluation; November 1976. Other requests for this document must be referred to Civil Engineering Laboratory, NCBC, Port Hueneme, CA 93043.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(16) F57571

18.

(17) ZF57571001

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Energy, resources, fuels, solid waste

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A performance evaluation based on 48 hours monitoring of a packaged heat recovery incinerator installation is presented. The evaluation includes heat balance analysis, stack emissions, and general observations. The heat balance data is of greatest significance since it will allow extrapolation of heat balances for other operating conditions.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

393018

4B

TABLE OF CONTENTS

SECTION PAGE

1.0 INTRODUCTION

This test was conducted to provide quantitative data for evaluating the performance of package heat recovery boiler-refuse incinerator combinations. This performance evaluation included an analysis of the boiler heat balance, characterization of the stack emissions, and overall performance observations.

The tested unit was a controlled air incinerator manufactured by Kelly, Inc. coupled to a York-Shipley fire tube boiler. The incinerator burns batch charges of refuse in a controlled air-fixed bed primary combustion chamber (furnace) to pyrolyze the waste and minimize ash losses. Pyrolysis products are burned to completion in an afterburner and the hot gas passed through a boiler to recover the sensible heat. I.I.A. type 0 refuse was burned during the test, e.g., the fuel consisted primarily of wood, paper, and cardboard.

Necessary data was collected to enable Systech to perform a boiler heat balance in accordance with the A.S.M.E. Power Test Code. The results from this energy balance were used to define the unaccounted-for and R/C (radiation and convection) loss variables needed to mathematically predict incinerator-boiler performance. Using the R/C and unaccounted-for loss estimate of 34 percent of the input found in this study heat, preliminary engineering estimates of system thermodynamic performance can now be made.

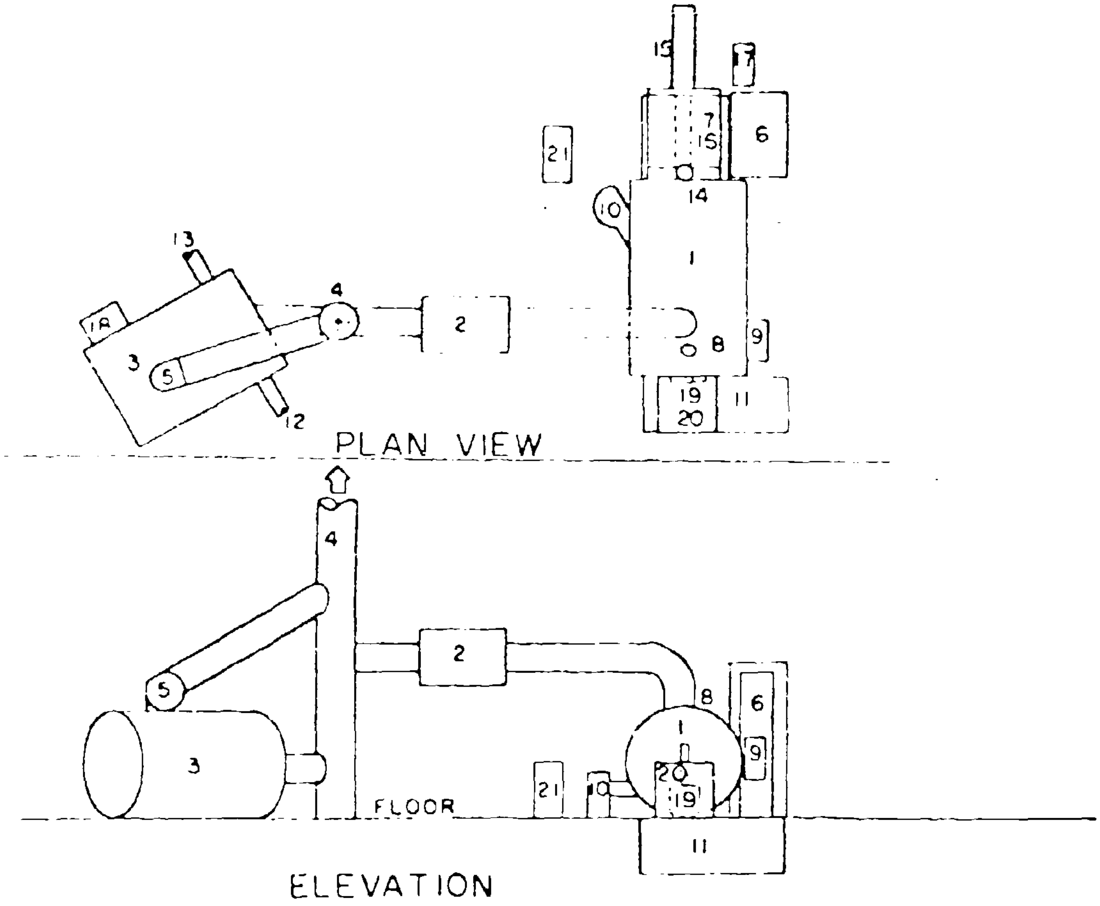
Boiler performance and incinerator emissions data were collected simultaneously for 48 hours. Particulates, NO_x, SO_2, Chlorides, and Hydrocarbons were monitored. The unit's temperature history and fuel charging rate were logged. Export hot water production was monitored.

2.0 SUMMARY OF THE TEST CONDUCTED ON THE XEROX PLANT COLUMBUS, OHIO

2.1 OPERATION OF THE SYSTEM

The incinerator boiler system was built by the Kelly Corporation of Milwaukee, Wisconsin. Figure 1 is a schematic of Kelly Model 1280 controlled air incinerator equipped with a semi-automatic ram charger and a heat recovery, three-pass, fire-tube boiler manufactured by York-Shipley.

The operating sequence for the unit is as follows: collection containers filled with rubbish are placed in the hydraulically operated dumper (6). From a control panel (17), the operator activates the hydraulic dumper which lifts the containers and empties them into the 2.7 cubic yard charging bin (7). After filling the charging hopper, the operator initiates an automatic cycle which closed a door over the charging bin, opens the refractory line guillotine door (14) between the furnace and the hopper and activates an automatic sequence where a hydraulic pump is turned on (9) which causes the hydraulic charging ram (15) to push the rubbish charge into the primary burning chamber (1). The automatic cycle terminates when the ram returns to the start position. The charging door automatically closes and the bin door re-opens



1. Primary Chamber
2. Afterburner
3. HTHW Generator
4. Stack
5. I.D. Fan
6. Dumper
7. Charging-bin
8. Quench Spray
9. Quench Control
10. F.D. Fan
11. Ash Pit
12. Hot Water Outlet
13. Feed Water Inlet
14. Charging Door
15. Hydraulic Ram
16. Ash Ram
17. Dumper & Charging Control
18. I.D. Fan Control
19. Ash Door
20. Ash Hood
21. Hydraulic Pump

FIGURE 1 INCINERATOR/HTHW GENERATOR SCHEMATIC ready to receive more refuse. Some of the charge is combusted to pyrolyze the rest of the waste in the primary chamber. Unmodulated underfire air is supplied by a forced draft fan (10) through two perforated channel diffusers in the floor of the primary chamber. Over-temperature conditions in the primary chamber are controlled (9) by a water spray system (8). The partially combusted gases leave the primary chamber and pass into the afterburner (2) centered above the primary chamber. Unmodulated air is mixed with the primary chamber gases through a perforated wall mixing section. The air-gas mixture is burned with 3.4 gallons of No. 2 fuel oil per hour to form relatively clean, high temperature, flue gas from the low Btu, CO rich, pyrolysis gas generated in the primary chamber. This flue gas is drawn into the boiler (3) by an induced draft fan (5). In the boiler, the flue gas gives up a large part of its available heat to the boiler feed water (13). The high temperature hot water is used to heat (12) the Xerox Plant.

When heat is not being recovered from the flue gas, the ID fan does not operate and the flue gas passes directly up stack. The ID fan is controlled (18) by a pyrometer which senses breaching temperature. When the breaching temperature exceeds 450°, the ID fan is activated and heat recovery commences.

Ash is removed through a refractory faced guillotine door (19) located opposite the charging door. Ash is forced through this 3 X 3 door by a 12" ϕ, refractory tipped hydraulic ram (16) which protrudes upon command from the back of the primary chamber parallel to the bottom of the primary chamber. The ash is rammed into an ash cart located below a hood in the ash pit (11). The hood (20) on the end of the incinerator covers the cart and contains a water spray system for quenching the ash.

2.2 TEST PROCEDURE

2.2.1 Heat Recovery Performance

The incinerator/boiler performance was evaluated using a modified form of the ASME power test code. Relevant incinerator/boiler data was collected on an hourly basis throughout the 48 hour test. Data was collected to enable a complete thermodynamic characterization of all input and output streams from the unit. This included combustion air and fuel, product water and applied power.

To characterize boiler output, water flow rate and temperature rise are the unknowns to be measured. Feed and product water temperatures were read with mercury thermometers mounted at the hot water generator's inlet and outlet. The water flow rate was measured with an impact tube rotometer mounted in the feed water line.

Gas flows need to be characterized to assess some of the heat fluxes across system boundaries. Thermocouples built into the incinerator control system were used to monitor the mixed gas temperatures in the primary chamber and afterburner for use by other researchers evaluating R/C losses. The afterburner temperature was assumed to be essentially equivalent to the boiler inlet gas temperature and was read at the boiler inlet temperature readout (the two thermocouples were adjacent) to assess heat into the boiler. The boiler outlet gas temperature was measured with a portable K-type thermocouple and the drop used to calculate heat exchanger effectiveness. Gas flow rate was calculated from pitot-traverses recorded during the stack sampling using EPA Method 2. Ambient conditions were determined using a sling psycrometer.

Electrical power used by the system is a small but measurable system energy loss. Totalizing timers were attached to the various electric motors to measure operating time. These results were combined with split core transformer ammeter readings of the current in the motor supply lines to provide electrical power usage data.

Quench water is used by the unit to control over temperature conditions and represents a potentially significant energy loss when the vaporized water leaves the stack. A totalizing timer was attached to the quench water control and a rotometer read during several quench cycles to determine the amount of water introduced into the primary chamber during the test.

The amount of No. 2 fuel oil used by the afterburner was measured by dip-sticking the fuel storage tank before and after the test. This tactic was employed because the fuel supply line could not be directly monitored and the constant displacement fuel pump recycled all unused fuel back into the storage tank. Even though the recycle was measured with a totalizing meter, the vendor did not know fuel delivery rate from the pump at the measured return line flow rates. Hence, dip-sticking was the most accurate available measurement.

2.2.2 Material Burned

The weight, density, composition, and firing time of the rubbish-fuel are all necessary parameters to characterize fuel input and was recorded throughout the 48 hour test. A Fairbanks-Morris beam scale was used to weigh the refuse in pre-tared collection containers. Linear measurements of the displacement of the refuse in the collection containers from the cart top provided volume and, after data reduction, density data. A 35 mm color slide was taken of each charge and used to identify refuse composition. Photo-sorts were not performed because each charge was essentially "pure" material. The time at which each charge was placed into the incinerator was recorded to provide a loading rate history. Samples of major refuse components were collected and returned to Systech's central lab in Xenia, Ohio to determine its heating value and moisture content.

2.2.3 Emissions Data

The emissions characteristics of the incinerator were monitored on a 4 hour cycle throughout the entire 48 hour test. A Joy Manufacturing Company Emissions Parameter Analyzer (stack sampling train) was used to sample the particulate, SO_x, and chloride emissions. The sampling train and analysis methods were in accordance with EPA Methods 2, 3, 4, 5, and 8. Chlorides were determine utilizing the Intersociety Committee Manual Method Number 201. NO_x emissions were determined utilizing EPA Method 7. Hydrocarbon emissions were measured on-site using a portable gas chromatograph with flame ionization detector.

2.2.4 Reliability

System reliability is a major cost consideration that impacts on capital costs through redundancy requirements and operating and maintenance costs. Throughout the test period, attention was paid to all necessary maintenance actions. Since none were performed, no log was actually prepared.

3.0 RESULTS OF TEST

Complete data collected during the 48 test are printed in the Data Log supplied to CEL under separate cover. A summary of that data and its results are tabulated in the following pages.

3.1 BOILER PERFORMANCE

Figure 2 tabulates the major energy flows to the incinerator which were used to calculate the boiler heat balance shown in Figure 3. Figure 4 tabulates the relevant fuel properties. Throughout the test, the incinerator operated at approximately 1/3 of capacity due to unavailability of fuel (the unit was oversized for the application). A relatively consistant boiler temperature rise of 10F was maintained with excursions of up to 30F being observed during high charging rate periods. The unit burnt the refuse-fuel to 99$^+$ percent completion and recovered 28 percent of the input heat. Since the unit was operating at an average of 515 percent excess air, this recovery rate is as expected.

Of principal importance, the unaccounted for and R/C losses from the unit were evaluated and found to be 23.9 percent of heat input. Assuming improved afterburner and air control design to eliminate the excessive stack gas losses while maintaining good burnout, up to 60 percent boiler efficiencies for these units should be obtainable if radiation and convection losses from the breeching can be minimized.

NEW BALANCE SHEET

MAJOR ENERGY FLOWS

INPUTS

		MBtu	%
RUBBISH INPUT		105	82
FUEL OIL INPUT		22.9	18
	TOTAL	127.9	

*OUTPUTS

	MBtu	%
HOT WATER GENERATED	36.5	29
DRY FLUE GAS	19.1	15
TEMP. CONTROL SPRAY	16.8	13
HUMIDITY	0.5	<1
MOISTURE IN RUBBISH	2.7	2
COMBUSTION OF HYDROGEN H_2O	8.9	7
R/C LOSSES	30.6	24
	115.1	

TOTAL ELECTRICAL ENERGY USAGE 1.84 MBtu

* <10% unaccounted

FIGURE 2 MAJOR ENERGY FLOWS

EB

JOB: Navy-Xerox 351 DATE: April 1976 TEST NO. Average

DATA SUMMARY - BOILER

16

48 hr. Average

		DATA SHEET		
1.	Pressure In Boiler	EBI	18	psia
2.	Water Temp. At Boiler Outlet	EBI	174.7	°F
3.	Feedwater Temperature	EBI	164.7	°F
4.	Ambient Temperature	EBI	80	°F
5.	Temperature Of Fuel Rubbish	EBI	70	°F
6.	Temperature Of Fuel Oil	EBI	70	°F
7.	Flue Gas Temperature	EBI	230	°F
8.	Enthalpy Of Water Out Of Unit		142	Btu/lb
9.	Enthalpy Of Feedwater		132	Btu/lb
10.	Dry Ash (Pit And Fly Ash)	EB3 P4	.114	lb/lb
11.	Heating Value Of Ash	EB3	-0-	Btu/lb
12.	Carbon Burned Per lb. Carbon[1]		1.0	lb/lb
13.	Rate Of Refuse Fuel Firing	EB2	305	lb/hr
14.	Rate Of Fuel Oil Firing	EB4	24.7	lb/hr
15.	HTHW Generator Water Flow Rate	EB4	76013	lb/hr
16.	Total Heat Input ⑬ x ㊵ + ⑭ x ㊶		2.66×10^6	Btu/hr
17.	Total Useful Heat Output ⑮ x [⑧-⑨]		$.76 \times 10^6$	Btu/hr
18.	Excess Air[2]		515	%
19.	Flue Gas Analysis CO_2	G1	2.35	% Vol
20.	O_2	G1	18.44	% Vol
21.	CO	G1	-0-	% Vol
22.	N_2	G1	79.21	% Vol
23.	HC	G4	130	PPM
24.	SO_2	G7	1.46×10^{-6} lb/DSCF	PPM

FIGURE 3 INCINERATOR-BOILER HEAT BALANCE

EB52

JOB: Navy-Xerox 351 DATE: April 1976 TEST NO. Average

		DATA SHEET		
25.	Ultimate Analysis Of Refuse: C	ULTI	48.61	% Wt.
26.	Cl	ULTI	-	% Wt.
27.	H_2	ULTI	6.36	% Wt.
28.	O_2	ULTI	40.20	% Wt.
29.	N_2	ULTI	.29	% Wt.
30.	S	ULTI	.17	% Wt.
31.	Ash	ULTI	4.32	% Wt.
32.	H_2O	ULTI	15.00	% Wt.
33.	Theoretical Air	ULTI	5.69	lb/lb
34.	Heat Loss Due To Dry Flue Gas[4]		15	Percent Of Input
35.	Heat Loss Due To Moisture In Fuel[5]		2	Percent Of Input
36.	Heat Loss Due To H_2O from H_2[6]		7	Percent Of Input
37.	Heat Loss Due To Unburned Fuel[7]		-0-	Percent Of Input
38.	Unmeasured & R/C Losses ㊴-㉟-㊱-㊲		47	Percent Of Input
39.	Total Losses 1 - ㊵		71	Percent Of Input
40.	Efficiency ⑰/⑯ X 100		29	%
41.	HHV Of Rubbish	ULTI	7177	Btu/lb
42.	HHV Of Fuel Oil	HHV1	19,178	Btu/lb
43.	Enthalpy Of Water At Flue Gas T		1157	Btu/lb
44.	Enthalpy Of WATer At Amb. T.		48	Btu/lb
45.	Electrical Power Usage	E1	125.7	Btu/lb

Avg/ HHV = 8928 Btu/lb (including oil)

*Quench Water Heat Loss = .35 M Btu/hr = 13%

Humidity Sensible Heat Loss = <1%

R/C Losses = .63 MBtu/hr = 24%

FIGURE 3 INCINERATOR-BOILER HEAT BALANCE (CONT'D)

MATERIAL	FRACTION OF INPUT (%)	H.H.V.* (Btu/lb)	MOISTURE (%)
PAPER	53	6,800	10
WOOD	26	7,800	12
CARDBOARD	21	7,300	12

*As Received

Total Rubbish-Fuel - 14,629 lb.

Total Rubbish Volume - 2,358 ft^3

Avg. Density - 6.2 lb/ft^3

NO. 2 FUEL OIL

Amt. Used - 164 gal.

H.H.V. - 140,000 Btu/gal.

ASH SUMMARY

Ash Wt. - 1,665 lb.

H.H.V. - 0 Btu/lb.

Ash Fraction - .114 lb. ash/ lb. rubbish

FIGURE 4 FUEL SUMMARY

Throughout the test period the afterburner failed to rise above its set point (1750F). As a result, fuel oil was consumed continuously through the two 0.6 gph and one 1.0 gph oil burners in the afterburner. A fuel Mizer control on the afterburner was supposed to modulate the fuel consumption to approximately half of the wide open value. Unexpectedly, average consumption was 3.4 gph.

3.2 EMISSIONS

Figure 5 summarizes the emissions data supplied to the Navy under separate cover. Due to the large amount of excess air induced into the afterburner, the temperatures were not high enough to burn all the hydrocarbons to completion. CO_2 levels ranging between 1 and 6.2 percent were observed while hydrocarbon emissions ranged from 32 to 333 PPM.

Examination of the filter showed that the fly ash was black, hence, it was also carbonaceous to some extent. (The bottom ash from the incinerator was a light grey after burn-out.) The measured particulate emissions rate was between 2 and 6 times allowable (Federal New Source Standards). Reducing the excess air would probably raise after burner temperatures, CO_2 and reduce the total gas flow. A properly operating unit is expected to comply with regulations.

TEST NUMBER	1	2	3	4	5	6	7
START TIME	8:06 pm	12:11 am	4:06 am	7:45 am	11:55 am	3:30 pm	6:55 pm
END TIME	11:00 pm	3:30 am	7:10 am	10:35 am	2:45 pm	6:33 pm	9:58 pm
PARTICULATE (gr/dSCF)	.0550	.0228	.0339	---	.0285	.0345	.0460
CO_2 (%)	5.3	.8	1.0	1.8	1.0	3.4	3.4
gr/dSCF @ 12% CO_2	.125	.342	.407	---	.342	.122	.162
HCl (ppm)	9.00	---	6.75	---	6.21	---	21.0
H_2SO_4 (gr/dSCF)	---	.0018	---	---	---	.0041	---
SO_2 (ppm)	---	7.8	---	9.6	---	11.5	---
NO_x Time	9:14 pm	1:00 am	5:00 am	8:40 am	12:30 pm	*_____	8:00 pm
NO_x (ppm)	5	5	3	4	2	< 8	10
HC Time	9:45 pm	2:06 am	4:44 am	10:10 am	1:30 pm	4:15 pm	9:03 pm
HC (ppm)	49.3	70.9	32.6	144	76.8	333	305

*EPA Method 7; NO_x otherwise determined with Dreager Tube.

FIGURE 5 EMISSIONS DATA SUMMARY

TEST NUMBER	8	9	10	11	12	13	
START TIME	10:30 pm	1:55 am	5:35 am	9:03 am	12:28 pm	4:00 pm	
END TIME	1:33 am	5:00 am	8:39 am	12:15 pm	3:30 pm	7:03 pm	
PARTICULATE (gr/dSCF)	.0213	.0200	.0418	.0276	.0223	.0264	
CO_2 (%)	1.6	1.2	1.2	2.6	1.3	6.2	
gr/dSCF @ 12% CO_2	.159	.200	.418	.127	.206	.051	
HCl (ppm)	---	3.6	---	6.5	---	1.8	
H_2SO_4 (gr/dSCF)	.0008	---	.0011	---	.0013	---	
SO_2 (ppm)	6.5	---	6.6	---	11.6	---	
NO_x Time	---	2:45 am	6:30 am	10:48 am	* ____	* ____	
NO_x (ppm)	---	3	2	7	< 8	< 8	
HC Time	12:45 am	---	8:30 am	9:35 am	2:20 pm	4:20 pm	
HC (ppm)	208	---	31.9	49.9	77.9	185	

FIGURE 5 EMISSIONS DATA SUMMARY (CONT'D)

As expected, SO_x, acid mist, NO_x and HCL emissions are all low. Hence, no environmental hazard from them is expected.

3.3 RELIABILITY

Very little maintenance was required on the system during the 48 hour test.

A minor problem was encountered prior to the test. A piece of 2 inch angle iron about 2 feet long became lodged below the ash removal door. This prevented the door from closing. In order to remove the angle iron the operator removed the ash cart, entered the ash pit, and using a piece of wood, dislodged the angle iron. This presented a potentially hazardous situation to the operator and required removal of fugitive ash from the pit area.

After the test, Xerox allowed the fuel bed to burn down. On Monday, the unit was opened up and manually cleaned out prior to light-off. It is unknown whether manual clean out is a routine unit requirement or an operator peculiarity.

4.0 CONCLUSIONS

Throughout the test the unit accepted waste and generated hot water. The particulate emissions were excessive, but that is probably attributable to; (1) un-modulated underfire air; (2) un-controlled after-burner air; and (3) under-firing of the unit.

The test did establish that the NO_x, SO_x , acid mist and chloride emissions are low and probably environmentally safe.

The major boiler efficiency unknown for these units (R/C and unaccounted for losses) was quantified as 34 percent.

5.0 RECOMMENDATIONS

From the Xerox test, several recommendations can be made:

(1) Unit selection should be based on actual, weighed, refuse tonnage not an estimate. Because the tested unit was loaded at 1/3 of capacity while burning all available waste, its efficiency was very low.

(2) Air supplies to controlled air units should have automatic controls to provide proper placement and amount. Air should be modulated between underfire, afterburner and waste as a function of fuel type and loading rate.

(3) The test was inconclusive on ash handling. Additional monitoring of a unit burning municipal waste for a period of 2 to 4 weeks is warranted. Air emissions need be analyzed only once during the time the unit's operation is being witnessed and throughput and combustion product composition monitored.