DISPOSAL OF OMR HIGH BOILERS
BY COMBUSTION

By
R. R. STIENS

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ABSTRACT

Under the influence of radiation, the coolant-moderator in an organic moderated reactor slowly decomposes to form high molecular weight polymers (high boilers) and a mixture of gases and light hydrocarbons as waste products. This report describes work carried out on the improvement and subsequent operation of a prototype waste-polymer combustion process. Operation of the improved unit employing a "Vortex" burner^{*} has confirmed the feasibility of combustion as a disposal method. It was determined that fuel temperatures of 400°F and combustion air temperatures of 300°F were required for successful operation. The quantity of ash resulting from the combustion was established to be less than 0.5 wt % of the original polymer. It was determined that the efficiency of the primary dust collector varied from approximately 90 to 99%, and that there was no detectable particulate matter in the gas leaving the absolute filter. Attempted activity-balance calculations proved unsuccessful due to extreme difficulties in measurement of the low-level activity of the stack gas.

In an effort to further improve and simplify the process system, preliminary evaluation of another burner was carried out. A cost estimate of the combustion process using the "Vortex" burner was prepared, based on data obtained from the Piqua, Ohio, organic reactor power plant design, and operating data from the current combustion prototype. Results indicated a net cost of 1.8 ¢/lb for burning the polymer in a Piqua-size plant.

^{*}Thermal Research and Engineering Corporation, Conshohocken, Penna.

I. INTRODUCTION

Under the influence of radiation, the coolant-moderator in an organic moderated reactor (OMR) slowly decomposes to form high molecular-weight polymers (high boilers) and a mixture of gases and light hydrocarbons as waste products. The gases and light ends are continuously removed from the system to reduce the vapor pressure of the coolant thus allowing operation of the reactor at low pressure. Methods of separating these decomposition gases from the coolant have previously been developed.¹

The high boiler (HB) content of the coolant must be maintained at a preset value in order to control the physical properties of the coolant, and maintain favorable heat transfer qualities. The polymer is separated from the coolant by means of a continuous distillation system.²

Four basic methods for handling the HB were considered:

- 1) Burial of the HB
- 2) Combustion of the HB with subsequent burial of the resulting ash
- 3) Chemical and/or thermal reconstitution of the HB to useful coolant
- 4) Recovery of useful coolant fractions from the HB by high-temperature, vacuum distillation.

No work was carried out under this project on Methods 3 and 4, as work in this area is being carried out by others and is reported elsewhere.^{3, 4} Direct burial offers no reduction in the volume of material requiring ultimate disposal, and results in a higher disposal cost than burning.* As a result of these considerations, a process was developed utilizing combustion as the primary method of disposal.

*See Appendix B

II. HIGH BOILER COMBUSTION SYSTEM

A. REVIEW OF PRIOR WORK

Most of the experimental work was carried out in the full scale prototype of the HB combustion system to be employed at the Piqua, Ohio organic moderated power plant. A detailed description of the original prototype system has been previously reported.⁵ The original system consisted basically of a horizontal return-tube boiler with two identical burners mounted beneath the pressure vessel. One burner was used to burn conventional fuel oil; the other, the waste polymer. The fuel oil burner was used to preheat the combustion chamber prior to burning the HB; and also allowed the boiler to be utilized as a conventional steam generating unit during the time when experimental work was not being performed. The hot combustion gas exhausting from the boiler was passed through an air-to-air heat exchanger to preheat the incoming combustion air. After the combustion chamber and combustion air reached the required temperature, the HB was introduced into the fuel oil flame through the second burner. After the HB flame was established, the fuel oil supply was shut off.

Results of early combustion runs indicated that the design of the burners was unsatisfactory. The combustion, both of conventional fuel oil and HB, was unstable; and a large amount of excess air was required to obtain a smokeless flame. During the HB combustion runs, the quantity of excess air varied from 160 to 285 %. Several unsuccessful attempts were made to modify the burner nozzle in an effort to improve the atomization of the HB.

B. MODIFICATION OF ORIGINAL COMBUSTION SYSTEM

As a result of the difficulties associated with the operation of the original burners, an investigation was made to gain information on burning equipment designed specifically to handle asphaltic type wastes. One of the most promising burners reviewed at that time was termed a "Vortex" burner (Thermal Research and Engineering Corporation, Conshohocken, Pennsylvania), and had been successfully applied to the disposal of heavy industrial wastes. A preliminary test was made at the manufacturer's laboratory. Since it was not feasible to fire the burner at their plant with radioactive HB, the test was made using "Montar-9" (Monsanto Chemical Co.), a pyrolytic tar resulting from the production of terphenyls. Throughout the test-firing, the burner gave satisfactory

performance over the entire operating range without using preheated combustion air. A cutaway view of the unit is shown in Figure 1, and a detail of the burner gun in Figure 2.

Based on these tests, a similar unit was obtained, and the original HB burning prototype was modified for its installation. In the current system, the one burner is used for the combustion of both conventional fuel oil and HB. The basic flow scheme for the system is shown in Figure 3; the control scheme, in Figure 4. Figure 5 illustrates the burner assembly installed in the boiler.

C. OPERATING EXPERIENCE WITH "VORTEX" BURNER

As mentioned above, in the present system, both fuel oil and HB are burned through the same nozzle. With this arrangement, the boiler is initially fired with the fuel oil to preheat the combustion chamber and to provide a source of preheated combustion air. HB is gradually introduced into the fuel-oil stream, and a mixture of the two fuels is burned for a short period of time. The ratio of HB to fuel oil is gradually increased until the material going to the burner is pure HB. This method has resulted in a smooth changeover from oil to HB with a minimum amount of smoking and flame instability.

Following initial checkout of the burner with fuel oil, HB was charged to the supply tank and circulated through the system, bypassing the burner. During this period, considerable difficulty was experienced with the operation of the electrically traced Fischer-Porter flow-meter in the HB feed line (refer to Figure 4). It became apparent that the viscosity of the HB flowing through the meter was considerably higher than the meter was designed for. Efforts to reduce the heat loss from and to supply additional heat to the system in an attempt to reduce the viscosity of the HB proved unsuccessful. It was learned that due to the particular float design employed in the meter, the effect of changing fluid viscosity resulted in a large change of meter reading, and that it was not possible to predict exactly what this effect would be. As a result of these factors, all HB flow rates shown in this report were determined by measuring the rate of change of the level of the HB in the supply tank.

During later stages of the development work, a Brooks-style MPTX-50 Model 3611J, 0.1 - 1.0 gpm, steam-jacketed rotameter was installed in the HB feed-line to the burner. Although this meter had operated satisfactorily in metering

Figure 1. "Vortex" Burner (Thermal Research and Engineering Corporation)

Figure 2. Burner Gun for "Vortex" Burner

Figure 3. Basic Flow Diagram of HB Burning System

Figure 4. Control Diagram of HB Burning System

Figure 5. "Vortex" Burner Installation in HRT Boiler

HB-coolant mixtures and showed somewhat improved performance over the original Fischer Porter meter, it was still not completely reliable in this application using 100% HB.

During the initial combustion run, the flowmeter was bypassed, and constant flow maintained by manually setting the flow-control valve and the pump-discharge pressure. The burner performed well for approximately 1 hr at which time it was noted that coke was being deposited on the refractory brick of the combustion chamber. With the exception of this coking problem, the burner performed satisfactorily with a clean, stable flame.

As a result of this experience, a set of experimental runs was initiated to determine which variable, or combination of variables, was responsible for the formation of the coke. The results of the first series of tests are shown in Table I. It can be seen that increasing the temperature of the HB and combustion air, and increasing the atomizing steam flow-rate individually, resulted in

TABLE I
PRELIMINARY HB BURNING CONDITIONS

Run No.	HB Rate (lb/hr)	HB Temp (°F)	Air Temp (°F)	Air Flow* (SCFM)	Atomizing Steam Flow (lb/hr)	Remarks
1	54	410	370	380	15	Very rapid coke buildup
2	54	410	370	380	19	Very rapid coke buildup
3	54	410	370	380	21	Very rapid coke buildup
4	54	385	325	385	19	Very rapid coke buildup
5	54	440	370	380	19	Very rapid coke buildup
6	54	475	350	380	19	Very rapid coke buildup
7	54	385	325	385	19	Very rapid coke buildup
8	54	385	325	450	19	Slight coke buildup
9	54	410	315	450	19	Very slight coke buildup
10	54	410	315	450	19	Very slight coke buildup

*at 32°F and 1 atmosphere pressure

no reduction in the quantity of coke formed. However, increasing the flow-rate of the combustion air reduced the coking even at low HB temperatures. When the HB temperature was increased, in conjunction with increased air-flow, the amount of coke formation was further decreased. It was also learned that the performance of the burner could be improved by increasing the HB flow-rate to 70-85 lb/hr and replacing the original burner tip with one containing smaller

orifices, thus increasing the back-pressure at the nozzle. With the modified burner tip, a series of combustion runs was made to evaluate the performance of the unit. A summary of the operating conditions for these runs is presented in Table II.

During the time these tests were being carried out, arrangements were made to obtain a smaller burner gun designed to produce the required back-pressure at the desired firing rates.

At the completion of the above mentioned series of runs, the burner gun was removed and replaced with the smaller capacity unit. A similar series of runs was made to evaluate the performance of this burner. These results are shown in Table III. It was not possible, even with this burner, to obtain the low flow rates desired. However, it was possible to reduce the excess air required from over 100 to approximately 80%.

The results of these tests, particularly of the extended runs listed in Table II, demonstrate, first, that employing combustion as a method of disposal is feasible; and, second, that the existing process system and burning equipment is satisfactory for maintaining stable combustion of the High Boiler. The only factor that prevented continuing the combustion runs beyond the 18-1/2 hr shown in Table II was lack of facilities for melting HB at the required rate.

TABLE II
COMBUSTION CONDITIONS WITH MODIFIED BURNER NOZZLE

Run No.	Length of Run (hr)	Average HB Flow Rate (lb/hr)	HB Pressure at Burner (psig)	Atomizing Steam Pressure at Burner (psig)	Atomizing Steam Flow (lb/hr)	Orsat Analysis of Stack Gas (%)			Average Excess Air (%)
						CO ₂	O ₂	N ₂	
1	3	72	40	40	40	10.0	11.8	78.2	130
2	11	72	40	40	42	7.0	12.2	80.8	132
3	9	73	40	40	42	6.7	12.3	81.0	133
4	18.5	67	40	40	42	4.8	12.0	83.2	120

TABLE III
COMBUSTION CONDITIONS WITH REDESIGNED BURNER GUN

Length of Run (hr)	Average HB Flow Rate (lb/hr)	HB Pressure at Burner (psig)	Atomizing Steam Pressure at Burner (psig)	Atomizing Steam Flow (lb/hr)	Orsat Analysis of Stack Gas (%)			Average Excess Air (%)
					CO ₂	O ₂	N ₂	
4	80	30	30	33	8.3	9.6	82.1	80
6	83.3	30	30	35	7.9	9.9	82.2	82.5

III. EXHAUST GAS CLEANUP STUDIES

A. DESCRIPTION OF COLLECTION EQUIPMENT

Combustion products containing particles of radioactive flyash or soot must be cleaned before discharge to the atmosphere. A two-stage dust collection system is provided. The first, or primary, collector is a conventional industrial dust collector employing cloth bags as the filtration medium. Dust-laden air enters the collector housing; the air passes through the filter tubes and the particulate matter is retained on the outside surface of the tubes. Clean air is thus withdrawn from inside the filter tubes (Figure 6), and exhausted through the collector discharge port. The particulate matter is removed from the filter cloth by a jet of high-pressure air introduced through a nozzle and venturi mounted above each filter tube. This jet pulls additional secondary air by the jet-pump principle into the filter tube, thus producing a sufficient reverse flow to clean the filter cloth. The particulate matter removed from the tubes is collected in a hopper at the bottom of the collector, and discharged through a rotary valve.

The effluent gas from the primary collector is passed through a "Cambridge" absolute filter before discharging to the stack. This filter consists of a glass-asbestos filter paper formed into a multi-pleated construction. Corrugated metal separators are inserted between the pleats to allow passage of the air. The air passes down the openings formed by the corrugations on one side of the filtering medium, through the filter, and out through the openings formed by the corrugations on the other side (See Figure 7). This type of filter has an efficiency of 99.95% or better, based on 0.3 micron particles.

B. USE OF FELTED DACRON FILTER BAGS

During the design of the original HB burning system, it was anticipated that the HB could be burned successfully with approximately 20 to 25% of excess air. It was planned to cool the stack gas, prior to filtration, by drawing ambient air into the exhaust duct prior to the primary collector. In this manner the exhaust gas could be cooled to 275°F before entering the collector. At this design temperature, it would have been possible to employ dacron or orlon cloth as the filter medium in the primary collector. Previous tests conducted with an experimental collector employing dacron bags had demonstrated the efficiency of

Figure 6. Flow Schematic "Mikro Pulsaire" Dust Collector

Figure 7. Detail of End View "Cambridge" Absolute Filter

this material as a filter medium. The details of these tests have been reported previously,⁵ and only the results are included here (Figure 8) for comparison purposes. The average particle size of the dust entering the filter was 1.1 microns, as determined by microscopic counting methods, and the results indicate a definite increase in collector efficiency with increasing dust concentration in the gas entering the collector.

Figure 8. Primary Dust Collector Efficiency

As a result of the large amount of excess air eventually required for successful combustion, it was not possible to draw additional cooling air into the system as previously planned. The capacity of the stack-blower was not large enough to handle any additional air. A test was then conducted to determine the maximum gas temperature that the dacron could withstand. Small patches (approximately 1-in. square) of material were heated in an electric oven and visually inspected after being maintained at a given temperature for approximately 16 hr. The material maintained its strength to 400°F. However, at approximately 425°F it underwent a rapid decomposition.* All flexibility had disappeared, and the fabric had become yellow in color and very brittle. Obviously, such characteristics rendered it unsuitable for the present system, and a material capable of withstanding higher temperatures was sought.

*Maximum safe operating temperatures for the dacron cloth as recommended by various suppliers was 250 to 275°F.^{6,7}

C. USE OF WOVEN GLASS FILTER BAGS

Investigation of dust-collection literature indicated that filter bags made from woven-glass fibers had been successfully applied to the filtration of exhaust gas from installations such as cement kilns, smelters, and foundries. Several fabricators were contacted in an effort to locate one to custom-make a set of filter tubes to fit the existing collector. A set of "Maco-Glas 600"* glass fabric bags was obtained and installed in the primary collector. Operation of the collector on the hot-combustion gas demonstrated that the material could withstand the high temperatures satisfactorily, but could not withstand the repeated cleaning cycle during which each tube was subjected to a short blast of 100-psig air. After several days of operation, the glass fiber had fractured. As seen from Figure 9, the rips or fractures in the fabric occurred near the top of the bag, where the sharpest blast of compressed air was received during the cleaning cycle.

Three steps were taken to eliminate this problem. First, the original bags were replaced with a set made of heavier material ("Maco-604" glass bags). Second, the compressed air used for cleaning the bags was reduced in pressure to 50 psig. Third, the automatic cleaning cycle was eliminated, and the bags were cleaned only when the pressure-drop across the collector reached 5 to 6 in. of H₂O. Following these changes, the unit gave satisfactory performance with no apparent wear on the glass bags.

Throughout the combustion runs previously described, dust samples were removed from the exhaust gas, before and after the primary filter as well as the absolute filter, to obtain information on the efficiency of the collection system. In each case, any particulate matter in the gas stream discharging from the absolute filter was not measurable. This confirms the extremely high efficiency that was previously reported for this type of filter.

The efficiency of the primary collector was dependent on the dust concentration in the inlet stream. The efficiency curve for the glass filters, as shown in Figure 8, is only slightly lower than that reported for the felted dacron bags. The lower efficiency can be partially accounted for by the fact that the average particle size of the dust entering the collector during this series of tests was smaller than during the testing of the dacron bags (0.4 vs 1.1 microns). The

*Menardi & Company, El Segundo, Calif.

Figure 9. Torn Woven Glass Filter Bags

Figure 10. Particle Size Distribution Curve of HB Burner Exhaust Gas

smaller particle size is due to the more efficient atomization obtained with the "Vortex" burner. The particle size distribution curve is shown in Figure 10. During each test the automatic cleaning cycle was not employed. The cleaning mechanism was manually activated only when the pressure drop across the collector reached 5 in. of H_2O . In each case the dust samples were taken when the pressure drop was approximately 3 in. of H_2O . Therefore, the effect of the dust adhering to the filter surface should be the same in each case. The results of these tests are shown in Table IV and Figure 8.

TABLE IV
EFFICIENCY OF GLASS CLOTH FILTER BAGS

Run	Dust Loading Collector Inlet (grains/1000 ft ³)	Dust Loading Collector Outlet (grains/1000 ft ³)	Efficiency (%) $\frac{(\text{Col 2} - \text{Col 3})}{(\text{Col 2})} (100)$
1	11.3	0.62	94.5
2	11.0	0.60	94.5
3	3.77	0.63	83.5
4	2.65	0.27	89.5
5	1.60	0.21	87.0
6	100.0	0.30	99.7

The cleanup of the exhaust gas can also be seen in Figure 11, which shows disks through which a known volume of exhaust gas has been filtered. In each case the volume of gas filtered is the same. The samples were removed before and after the primary filter, and after the absolute filter and illustrates the efficiency of the units.

Analysis of the dust removed in the primary collector showed the material to be approximately 83% unburned carbon. The remainder of the ash was composed of inorganic material originating primarily from corrosion of the carbon steel exhaust-gas system.

Figure 11. Dust Samples from Exhaust Gas System

IV. RADIOACTIVITY MEASUREMENTS

A. PROCEDURES

Of major importance in the combustion of any radioactive or contaminated material is the distribution of the radioactivity throughout the combustion system. In this process, there are two possible means of activity leaving the system. Gaseous activity is discharged through the stack, and activity associated with the particulate matter is removed by the dust-collection system. A major effort was made to obtain an activity balance around the system. During each combustion run, the total exhaust gas stream was passed through the dust-collection system before being discharged to the stack. During the run, gas samples were periodically taken from the stack. At the end of the run, the dust collector was cleaned and emptied, and the particulate matter weighed and sampled. Gas and particulate samples, as well as samples of the HB burned were submitted to Nuclear Science and Engineering Corporation, Pittsburgh, Penna., in duplicate for radio-isotopic analysis.

B. RESULTS

The results of the duplicate analyses are shown in Table V. It can be seen that the results for the HB and the dust are in close agreement within the duplicate samples. In addition, the analyses of the HB samples are in good agreement

TABLE V
ISOTOPIC ANALYSIS OF HB BURNING SAMPLES

(HB removed from OMRE August 17, 1959; burned May 26, 1960)

Isotope	Specific Activity At Time of Burning					
	HB Activity ($\mu\text{c/gm HB}$)		Dust Activity ($\mu\text{c/gm dust}$)		Gas Activity ($\mu\text{c/cc gas}$)	
P ³²	1.91×10^{-4}	0.57×10^{-4}	3.2×10^{-4}	2.9×10^{-4}	$<6.8 \times 10^{-7}$	$<8.3 \times 10^{-7}$
S ³⁵	7.0×10^{-2}	6.0×10^{-2}	1.0×10^{-2}	0.98×10^{-2}	$<1.7 \times 10^{-7}$	$<9.4 \times 10^{-7}$
Fe ⁵⁹	3.17×10^{-4}	4.0×10^{-4}	1.4×10^{-2}	1.35×10^{-2}	1.2×10^{-5}	No analysis
Mn ⁵⁴	2.96×10^{-3}	3.0×10^{-3}	3.1×10^{-1}	3.3×10^{-1}	1.6×10^{-7}	No analysis
C ¹⁴	4.45×10^{-2}	4.6×10^{-2}	6.18×10^{-2}	6.2×10^{-2}	9.0×10^{-7}	5.1×10^{-7}

(within a factor of 10) with results obtained by other laboratories on material removed from the OMRE during the same period of time. However, there is some discrepancy in the analysis of the duplicate gas samples. In addition, in some cases, the reported concentrations were considerably higher than theoretically possible based on the quantity of HB burned, and the quantity of stack-gas produced. As a result of the discrepancy in the gas analyses no accurate activity balance was completed. The balance based on the reported results is shown in Table VI. It is believed that the discrepancy in the gas samples is largely due

TABLE VI
ACTIVITY BALANCE FROM HB BURNING RUN
(based on activity measurements listed in Table V)

Isotope	Activity Into System (μc)	Activity Out In Dust (μc)	Activity Out In Gas (μc)
P ³²	12.9	0.08	<916
S ³⁵	476.0	2.63	<230
Fe ⁵⁹	21.5	3.55	1620
Mn ⁵⁴	201.0	77.5	216
C ¹⁴	3030	17.1	1210

to sampling techniques. The gas samples were withdrawn as grab samples from the exhaust stack down stream of the absolute filter. It is thus possible that the samples were not representative of the flowing gas stream. In addition, it is possible that minute quantities of particulate matter may have passed through the absolute filter, collected on the walls of the exhaust stack, and were subsequently drawn into the sample bomb. Previous work on the measurement of the radioactivity associated with small particles removed from the OMRE coolant indicate that the total iron activity present in the gas samples could have been produced from 0.6 μgm of iron particles. Although pressure-drop measurements across the filter system failed to indicate the presence of holes in the filters, it is possible that such small quantities of material could leak through the filters without detection.

Another error in the activity balance on the system was introduced due to the inability to obtain a sample of, and determine the quantity of material collected

on the absolute filter following each run. However, since it was shown that the primary filter was 90 to 99% efficient on the removal of the particulate matter from the gas stream, the error introduced by ignoring the material collected on the absolute filter is small.

Calculations were then made, based on analysis of the HB, to determine what the maximum concentration of the various isotopes could be in the stack gas. In these calculations, a zero filter efficiency and zero dilution were assumed. Results of these calculations as well as the maximum permissible concentration for the isotopes in air are shown in Table VII. Since in any commercial power

TABLE VII
CALCULATED STACK GAS ACTIVITY
(decay time of HB 9 months)

Isotope	Activity (dpm/gm)	Half Life	Half Lives Elapsed in 9 Months Storage	Activity After 9-month Decay ($\mu\text{c/gm}$)	Activity in Stack Gas ($\mu\text{c/cc}$)*	MPC in Air ⁸ ($\mu\text{c/cc}$)
P ³²	8.6×10^5	14.3 days	18.8	7.5×10^{-7}	3.75×10^{-11}	1.4×10^{-8}
Fe ⁵⁹	7.5×10^4	45.1 days	6.0	5.1×10^{-4}	2.55×10^{-8}	1.5×10^{-9}
S ³⁵	1.3×10^5	87.1 days	3.1	6.9×10^{-3}	3.45×10^{-7}	1×10^{-7}
Mn ⁵⁴	7.1×10^4	300 days	0.9	1.7×10^{-2}	8.5×10^{-7}	1×10^{-8}
C ¹⁴	1.0×10^5	5600 years	0.0	4.5×10^{-2}	2.25×10^{-6}	5×10^{-8}

*Based on producing 2×10^{-4} cc of combustion gas per gm of HB burned, and on zero filtration efficiency (see Appendix A)

reactor installation large quantities of plant ventilation air would be available for use as dilution air, it can be seen that the isotopes studied would not exceed their allowable concentration.

V. PERFORMANCE TESTING OF UTAH HYDRO BURNER

A. DESCRIPTION OF BURNER

Although the existing burner has given satisfactory performance, it requires large quantities of excess air and is sensitive to minor fluctuations in fuel and air flow rates. An investigation of several other burner designs was conducted to determine if any showed promise of giving improved performance. Of the burners investigated, only one seems to offer any possibility of bettering the performance of the existing unit. The design of this burner is unique in several ways. It employs the standard technique of using steam to atomize the fuel. However, the outstanding feature of this burner, and one not encountered before in the survey of burners, is the use of superheated steam for atomization of the fuel. Atomizing steam at approximately 100 psig is introduced to a superheating coil that is an integral part of the burner. This coil, fabricated from Type 304 stainless steel, is exposed to the flame and the steam is heated to approximately 1000 to 1200°F before mixing with the fuel. A view of the burner assembly is shown in Figure 12. It is felt that this high temperature, and a slightly negative pressure in the nozzle, result in partial thermal cracking of the fuel to lighter hydrocarbons which give more stable, cleaner combustion. The burner also offers other potential advantages. The type of nozzle employed should not be susceptible to clogging or plugging. A diagram of the nozzle is shown in Figure 13. The burner also requires no forced draft system, and can operate satisfactorily on a natural draft stack.

B. TEST RESULTS

In order to evaluate this burner, a performance test was scheduled at the manufacturer's laboratory. Since it was not feasible to fire the burner at their plant on radioactive HB, the test was made on Montar-9. The burner to be tested was mounted on the front face of a combustion chamber consisting of a steel tank lined with refractory brick and having an exhaust stack on the far end. In order to preheat the refractory lining of the furnace, the burner was first fired on conventional fuel oil. Following the preheat period the fuel oil was cut off from the burner, and preparations made for firing with the Montar. The drum of Montar was supported on a metal framework containing three gas-burners for heating the tar. The drum and heater assembly was mounted on a

Figure 12. "Hydro" Burner (Utah Hydro Corp.)

platform scale to enable burning rates to be determined by the rate of change of the drum weight. The recirculating lines were made from lengths of unheated and uninsulated rubber hose. The only source of heat for the Montar was the gas-burners under the melt-drum. The material was circulated by means of an unheated Viking gear pump. Throughout the run, a large amount of material was being bypassed back to the drum, with only a small stream being fed to the burner. Initially, some difficulty was experienced with the Montar freezing in the uninsulated valves. This problem was overcome by installing a short section of steam-tracing around the valves and covering them with a thin layer of insulation. After establishing the flame with the Montar, the fuel rate was adjusted to give a small amount of smoke in the stack gas. The fuel rate was then gradually decreased until the smoke was eliminated. As the run continued, and

Figure 13. Burner Nozzle for "Hydro" Burner

the temperature of the firebox and atomizing steam increased, it was possible to increase the fuel rate to the burner and still maintain a perfectly clean stack gas. The operating conditions for these test runs are shown in Table VIII.

TABLE VIII
UTAH HYDRO BURNER TEST RESULTS

Fuel Temp to Burner (°F)	Steam Temp to Superheating Coil (°F)	Steam Temp from Super- heating Coil (°F)	Stack Temp (°F)	Flue Gas Analysis* (%)			Excess Air (%)
				CO ₂	O ₂	CO	
320	340	960	500	10.4	9.4	0.0	76
320	330	950	600	8.9	8.3	0.0	60.5
320	325	1120	650	11.8	6.4	0.6	39.4
320	330	1160	700	16.8	1.2	0.2	4.9
320	330	1170	700	16.6	0.8	0.2	3.3
320	330	1170	800	15.0	2.4	0.0	12.2

*Analysis made by Orsat apparatus, remainder of gas stream was N₂.

During the testing period, dust samples were removed from the stack gas. The samples showed no black carbon deposit but were red-brown in color. It was originally believed that the color was due to fine particles of refractory brick or cement from the combustion chamber. The samples were subsequently submitted for laboratory analysis to determine the nature of the deposits.* The samples were washed with hot hydrochloric acid which dissolved most of the deposit. The resulting solution showed the presence of large quantities of iron. The washings were concentrated to a small volume by evaporation and examined with a microscope. This showed a few black particles but it did not appear that they were carbon. There were also brown particles present which were assumed to be iron oxide. Spectrographic analysis of another dust sample failed to show any significant quantities of aluminum thus indicating that the deposit was not particles of firebrick; but did show a considerable quantity of iron. Apparently the brown color was due to iron oxide resulting from impurities in the Montar. Of major significance, however, is the absence of any carbon particles, indicating complete combustion of the Montar. This quality of combustion has not been achieved to date with any other burner.

*Truesdail Laboratories Inc., Los Angeles, Calif.

VI. ECONOMICS OF COMBUSTION PROCESS

To evaluate the economics of utilizing combustion as a method of disposal for high boilers, a cost estimate for the process was prepared. This estimate is based on a 45.5 thermal megawatt reactor (similar to that of the Piqua, Ohio reactor plant); also on information obtained from the Piqua project and from the operation of the HB burning prototype.

The estimate is based on burning 216,000 lb of HB per year at a rate of 60 lb/hr. It is assumed that any ash or particulate matter removed from the stack gas stream is to be shipped to a government-owned burial ground for final disposal. All capital equipment is depreciated on a straight-line basis over a period of twenty five years. Since the equipment will be contaminated at the end of this period, no salvage value has been assumed.

These calculations (Appendix B) indicate a net cost for burning of 1.80 ¢/lb of HB with the current combustion system. Assuming that the entire supply of HB is shipped to a government-owned dumping ground, it is estimated that the incurred cost would be approximately 4.8 ¢/lb of HB.^{*} It is thus possible, in a Piqua-scale plant, to realize a saving of 3.0 ¢/lb of HB by utilizing combustion as the method of disposal. For comparison purposes, it is estimated that the cost of disposing of non-radioactive waste as sanitary landfill would be approximately 0.1 ¢/lb of material.⁹

It should be pointed out that as the size of the reactor plant and thus the quantity of HB increases, the cost per pound for burning will decrease. The capital equipment and operating costs for a larger combustion system would increase by a small percentage, thus decreasing the cost per pound. However, the total annual cost for burial would increase essentially in direct proportion to the amount of material handled, keeping the cost per pound the same.

As a result of this estimate, it appears that combustion can offer definite savings as a method of HB disposal. By incorporating into the system a burner that gives cleaner, more efficient combustion it may be possible to further reduce the cost of burning by eliminating the primary dust collection system currently required.

^{*}This cost is based on shipping the waste to a government-owned dump site with no costs included for the value of the real estate. If it becomes necessary to ship the material to a licensed disposal contractor, the cost per drum is expected to be approximately \$50 per drum, or 12 ¢/lb. In this case, the savings to be realized by combustion would amount to approximately 10.2 ¢/lb.

VII. RECOMMENDATIONS AND CONCLUSIONS

Based on the experimental work described in this report, the following conclusions and recommendations are made.

- a) Operation of the improved HB burning system has shown the feasibility of employing combustion as a dependable method of disposal of HB on a continuous basis, and has demonstrated the dependability of the system components.
- b) Although the current HB burner has demonstrated its reliability, it is recommended that in future OMR designs consideration be given to the incorporation of the Utah Hydro burner described in this report. Prior to actual inclusion in any plant system, the burner could be field-tested in the prototype equipment previously described, with high boiler as the fuel.
- c) Dust-collection studies verified that the particulate matter present in the exhaust gas stream could be removed by conventional dust-collection equipment.
- d) Estimates of the cost for burning and burying HB indicate that a savings of 3.0 ¢/lb of HB can be realized by utilizing combustion as the method of disposal.
- e) As a result of the difficulties encountered in obtaining meaningful isotopic analyses of the exhaust gas stream, it is recommended that, prior to burning, each batch of the high boiler be subjected to radio-assay and the isotopic concentrations in the discharge gas be calculated to insure that the MPC is not exceeded.
- f) As a result of the difficulty experienced with measurement of high boiler flow, it is recommended that additional investigations be carried out to locate and test a flow-meter capable of measuring low flows of OMR high boiler.

APPENDIX A DILUTION FACTOR AVAILABLE FROM BURNING

Average Composition of High Boiler

94.25% (w) carbon
5.77% (w) hydrogen

Basis: 100 gm high boiler

$$\frac{94.25 \text{ gm C}}{12} = 7.85 \text{ gmol C}$$

$$\frac{5.77 \text{ gm H}}{2} = 2.88 \text{ gmol H}_2$$

Assume reactions are:

7.85 gmol C requires 7.85 gmol O₂

2.88 gmol H₂ requires 1.44 gmol O₂

Total O₂ required = 9.29 gmol

$$\text{Air required} = \frac{9.29}{0.21} = 44.2 \text{ gmol}$$

Supply 100% excess air

$$(44.2) (2.0) = 88.4 \text{ gmol air}$$

$$(88.4) (0.21) = 18.5 \text{ gmol O}_2$$

$$(88.4) (0.79) = 69.9 \text{ gmol N}_2$$

Exhaust gas composition

9.3 gmol O₂

69.9 gmol N₂

7.8 gmol CO₂

2.9 gmol H₂O

89.9 gmol gas/100 gm HB

$$\frac{(8.99 \times 10^1 \text{ gmol gas})}{(100 \text{ gm HB})} \quad \frac{(2.24 \times 10^1 \text{ liters})}{(\text{gmol})} \quad \frac{(1000 \text{ cc})}{(\text{liter})} = \frac{2.0 \times 10^4 \text{ cc gas}}{\text{gm HB}}$$

APPENDIX B

ECONOMICS OF HB BURNING PROCESS EMPLOYING THERMAL-"VORTEX" BURNER IN PIQUA SCALE PLANT

I. SUMMARY OF COST ESTIMATE

Depreciation of equipment	\$1109/yr
Plant Maintenance	950
Plant operator	1125
Power cost	711
Replacement of absolute filter	300
Replacement of primary collector bags	120
Disposal of ash	120
	<hr/> \$4435/yr
Credit for reclaimed heat	<hr/> \$ 620/yr
Total cost to burn 216,000 lb HB	\$3815/yr
Net cost of burning = $\frac{3815}{216,000} =$	\$0.018/lb
Cost of burial on government land	\$10,400/yr or \$0.048/lb
Net saving by combustion for Piqua-size plant	\$0.030/lb

II. CAPITAL COSTS

<u>Item</u>	<u>Material</u>	<u>Labor for Installation</u>	<u>Total Installed Cost</u>
Boiler	\$4174	\$850	\$ 5024
Skids for mounting boiler	171	--	171
Insulation & jacket for boiler	257	--	257
Water level controller	905	--	905
Control panel	975	--	975
Burner assembly	1265	--	1265
Instrumentation	5064	592	5656
Piping			6309
Flue gas cooler	1319	130	1449
Flue gas dust collector	2314	130	2444
Absolute filter	727	110	837
High boiler pump	412	160	572
Forced draft blower	490	160	650
Induced draft blower	400	120	520
Propane tank & controls	700	--	700
			<hr/> \$27734

Depreciate installation over 25 yr; and assume no salvage value, as equipment will be radioactive.

$$\text{Depreciation/year} = 27,734/25 = \$1,109/\text{yr}$$

III. OPERATING COSTS

Plan to operate unit continuously at HB rate of 60 lb/hr for 150 days/yr.

- A. Routine plant maintenance (excluding filter costs but including miscellaneous supplies)

Manpower: (1 hr/day) (150 op. days/yr) (\$5/hr) = \$750
Supplies: \$200
\$950/yr

- B. Plant operation:

Operations call for 1/2 man-hr/shift or 1 1/2 man-hr/day for 150 days/yr.
(1.5 hr/day) (150 op. days/yr) (\$5/hr) = \$1125/yr

- C. Power costs

HB pump=	1/4 hp
Forced draft blower	3 hp
Induced draft blower	10 hp
Total power requirements	<u>13 1/4 hp</u>

$(13 \frac{1}{4} \text{ hp})(0.7455 \text{ kw/hp})(24 \text{ hr/day})(150 \text{ op. days/yr})(\$0.02/\text{kw-hr}) = \$711/\text{yr}$

- D. Replacement of absolute filters

Cost of replacement filters = \$100/unit
Replace unit 3 times per yr
Cost = \$300/yr

- E. Replacement of glass bags in primary collector

Cost of replacement bags - \$60/change
Replace twice per yr
Cost = \$120/yr

- F. Disposal of ash from combustion

HB burned = (60 lb/hr)(24 hr/day)(150 op. days/hr) = 216,000 lb/yr

Ash resulting from combustion is approximately 0.35% wt
 $(216,000)(0.0035) = 756 \text{ lb ash/yr}$

Bulk density of ash is 46 lb/ft³

$(756 \text{ lb/yr})(1 \text{ ft}^3/46 \text{ lb})(\frac{7.48 \text{ gal}}{\text{ft}^3}) = 123 \text{ gal./yr}$

Allow four 55-gal. drums for disposal of ash and any required concrete shielding.

Cost of drums	\$10 ea	\$40
Cost of filling & shipping	\$20 ea	<u>80</u>
		\$120/yr

IV. CREDIT FROM COMBUSTION

Total HB burned/yr = 216,000 lb/yr

Estimated heat released = $(216,000 \text{ lb/yr})(18,000 \text{ Btu/lb}) = 3.88 \times 10^9 \text{ Btu}$

Assume boiler is 80% efficient

Heat reclaimed = $(3.88 \times 10^9)(0.80) = 3.10 \times 10^9 \text{ Btu/yr}$

Credit claimed for reclaimed heat = $\$0.20/10^6 \text{ Btu}$

$(\$0.20/10^6 \text{ Btu})(3.10 \times 10^9 \text{ Btu/yr}) = \$620/\text{year credit}$

V. COST OF DISPOSAL BY BURIAL ON GOVERNMENT OWNED LAND

$(216,000 \text{ lb/yr})(1 \text{ gal}/8.33 \text{ lb}) = 25,900 \text{ gal./yr}$

Put material into 55-gal. drums: 50 gal./drum

$(25,900 \text{ gal./yr})(1 \text{ drum}/50 \text{ gal.}) = 520 \text{ drums/yr}$

$(520 \text{ drums/yr})(\$20/\text{drum}) = \$10,400/\text{yr}$

$(\$10,400/\text{yr})(1 \text{ yr}/216,000 \text{ lb}) = \$0.048/\text{lb}$

VI. SAVINGS REALIZED BY COMBUSTION

$(\$0.03/\text{lb})(216,000 \text{ lb/yr}) = \$6480/\text{yr savings}$

$(11.4 \text{ Mw})(10^3 \text{ kw/Mw})(24 \text{ hr/day})(365 \text{ days/yr})(0.8) = 0.8 \times 10^8 \text{ kw hr/yr}$
based on an 0.80 utilization factor

$$\frac{\$6.48 \times 10^3/\text{yr}}{0.8 \times 10^8 \text{ kw hr/yr}} = \$8.0 \times 10^{-5}/\text{kw hr}$$

Savings = 0.08 mil/kw hr

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