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Pyrolysis-Incineration of Simulated Combustible Alpha Wastes

October 1975

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Battelle
Pacific Northwest Laboratories

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PYROLYSIS - INCINERATION OF
SIMULATED COMBUSTIBLE ALPHA WASTES

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October 1975

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SUMMARY

Design, fabrication, and installation of a unit to demonstrate pyrolysis-incineration of simulated alpha wastes are described in this report. The main reactor in the unit is a cylinder 7 ft long, lined with refractory in the lower 5-1/2 ft to give an effective inside diameter of about 11 in. An auger conveys simulated waste to the reactor from a lock hopper. A mechanical distributor at the top of the vertical cylinder spreads and packs the feed in the reactor, and a continuous rotary grate and star valve remove ash from the reactor. Further details of the unit are given in the Description of Pyrolysis-Incineration Facility, page 7.

Four experimental runs, using simulated alpha wastes, were completed in the demonstration unit during FY-75. Average processing rates of 27 lb/hr were achieved. The waste components were shredded to an average size of 4 in. and were mixed in the proper proportion just prior to addition to the reactor. The ash content of the simulated waste was 3.6 wt%.

The composition of the off-gas from the process was determined using a gas chromatograph. Condensates (or tars) were collected during a 12-hr run and totaled 18% of the weight of the simulated feed that was processed. These tars had a calorific heating value of 9380 cal/g and a viscosity of 750 cp at 50°C. Ash content of these tars was 0.3 wt%.

Ash collected during a 12-hr run appeared dark gray in color and had a bulk tap density of 0.76 g/cm³. The ash was found to contain 13 wt% unburned carbon. This unburned material represents 0.5 wt% of the waste treated in the process, which means that 99.5% of the waste was destroyed in the process. For this particular waste composition and ash content, the volume reduction factor was 140.

Work continues on process development with the demonstration unit. Design of a system for burning and cleaning the gases produced in the process, and operation of the unit continuously over periods of several days are current efforts.

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INTRODUCTION

Low-level radioactive solid wastes, the so-called alpha wastes, are defined as those solid materials containing plutonium or other long-lived alpha emitters in concentrations greater than $10 \mu\text{Ci/kg}$, but with low enough external radiation levels to handle directly without supplementary shielding (surface dose rates of less than 10 mrem/hr). The criterion of $10 \mu\text{Ci/kg}$ was selected since this is the upper range of alpha-emitting isotopes in naturally occurring deposits. Wastes containing less than $10 \mu\text{Ci/kg}$ can presumably be disposed of in carefully selected burial grounds, whereas the alpha waste must be stored, or processed, to offer maximum assurance of permanent containment. The principal objective of this work is to develop a safe, efficient process for the volume reduction of combustible alpha wastes as a precursor to ultimate disposal of the residue.

Alpha wastes, which arise mainly from fuel preparation and fabrication plants and, to a lesser extent, from fuel reprocessing plants,⁽¹⁾ consist of a wide variety of solid materials. They include items made from cloth, wood, paper, plastics, rubber, glass, metal, and ceramic as well as salts and sludge from treatment of liquid waste streams and filters from gas cleanup systems. Densities of the uncompacted wastes vary from about 0.03 g/cm^3 to 3 g/cm^3 . It is estimated that approximately 1/2 to 2/3 of these wastes by volume are combustible and potentially can be incinerated to reduce volume and weight by factors of 50 and 20, respectively. The average content of transuranic elements in the wastes is about 9 g/m^3 .⁽²⁾ It is estimated that in the year 2000 alone, the generated volume of alpha wastes will be about $240,000 \text{ m}^3$.⁽³⁾ Fuel losses with the alpha wastes are estimated to total about 0.9%. It is extremely important that research and development find efficient methods to reduce the volume of these wastes.

Two-stage starved-air combustion of alpha waste is being studied at the Los Alamos Scientific Laboratory. An industrially-available controlled-air incinerator has been tested with non-radioactive, combustible materials and is being modified to permit processing of contaminated alpha wastes.⁽⁴⁾

Partial combustion of alpha wastes in a fluidized bed of Na_2CO_3 at temperatures below 600°C is under development at Rocky Flats.⁽⁵⁾ The Na_2CO_3 retains the chlorides released from the wastes during combustion.

Atomic International of Canoga Park has developed a molten salt process which uses a molten salt to burn organic materials, trap inorganic substances including transuranics, and react with chlorides and other acids generated during combustion. The melt is subsequently treated in an aqueous system to produce ash which includes the transuranics, salt which is recycled to the combustor, and solid sodium chloride for disposal.⁽⁶⁾

Volume reduction by acid digestion is under development at the Westinghouse Hanford Engineering Development Laboratory. Up to 5 kg/hr of non-radioactive combustible waste have been processed in their test unit. Acid digestion uses hot concentrated sulfuric and nitric acids to convert combustible wastes into inert residue having less than 4% of the original waste volume.⁽⁷⁾

Pyrolysis-incineration of combustible alpha wastes is being developed at the Battelle-Northwest laboratory. Our process name is derived from reactions that occur in a deep fixed bed confined in a cylindrical retort; pyrolysis of the waste occurs in the upper part of the bed and incineration of the carbonaceous residue from pyrolysis occurs in the lower part of the bed. Approximately 20% of stoichiometric air required for combustion of the waste is added to the main reactor which results in low gas flow rates and very little carryover of inorganic ash constituents.

All the heat required for the process is generated from reaction of the carbonaceous residue with air. Volatile pyrolysis products including gases and condensable liquids can be destroyed in a secondary gas-liquid burner.

This report describes the design of the process demonstration unit and presents results obtained during initial operation of the unit. Results of fixation of ash typical of that generated in the process are reported in a paper presented at the 80th National AIChE Meeting.⁽⁸⁾

CONCLUSIONS

Operation of the pyrolysis-incineration demonstration unit for the volume reduction of simulated alpha wastes has resulted in the following conclusions:

- Channeling, or bypassing of gases through the refuse bed in the reactor, can be reduced through proper use of the mechanical distributor.
- Average processing rates with simulated wastes of 27 lb/hr can be attained in the unit.
- Tar properties (viscosity, calorific value, and ash content) make the tars amenable to handling by combustion with the gases produced in the pyrolysis-incineration reactor.
- For the simulated refuse processed (bulk density of 8 lb/ft³ with a 3.6 wt% ash content) a volume reduction factor of 140 was achieved.
- Ash collected during the final run was dark gray in color and had an unburned carbon content of 13 wt%, representing 0.5 wt% of the carbon in the original waste processed.
- The only operating problem was the plugging of the off-gas line with rags; this can be corrected by design modification of the off-gas line and distributor.

RECOMMENDATIONS

Results to date in operation of the process demonstration unit lead to the following recommendations for further work:

- The off-gas lines and distributor should be modified to prevent plugging of the line with waste feed materials such as rags.
- Modifications should be made to inject steam with the air into the reactor, and also, to automatically control the air flow to increase operating flexibility in control of reactor temperatures, if necessary.
- After modifications have been made, the unit should be operated for periods of greater than two days to determine the true steady-state conditions and the long term trends in operating parameters.
- Ash generated during the extended operation should be studied and characterized to establish methods for converting the ash to a low leachable form suitable for terminal storage.
- Addition of chemicals such as caustic and lime to the reactor with the waste material should be studied for their effect on chloride retention and product yield.

DESCRIPTION OF THE PYROLYSIS-INCINERATION FACILITY

Overall System

The assembled components of the main reactor are shown in the photograph in Figure 1. The system for combustion of gases produced is not shown.

Air under positive pressure enters below the grate at the bottom of the reactor vessel. Outlet gases flow from the top of the reactor, pass through a water scrubber and are combusted in a secondary burner (not shown). Average air flow rates are from 5 to 25 scfm.

Off-gas flows are from 20 to 50 scfm. Solid waste of a maximum size of 4 in. is fed into the top of the reactor. Ash is removed through a rotary grate and star valve at the base of the unit.

The reactor vessel is suspended from a platform to 10 ft above ground. The major supporting framework is constructed of 4 in. x 4 in. x 0.187 in. ASTM A500 Type B square tubing. The elevated platform provides a work area of 6 ft by 8-3/4 ft and is constructed of 1 in. thick open steel grating. The platform also has OSHA-approved hand rails and safety chains at the ladder entry. A 500 lb capacity hand winch is installed on the side of the platform to transport waste to the feed hopper.

Solid Waste Feed System

The system for feeding the solid waste into the reactor vessel consists of four parts:

1. Hopper
2. Isolation slide valve
3. Feed auger
4. Hydraulic controls

The solid waste is fed into a feed hopper after being lifted to the work platform with the hand winch. The hopper is constructed of 12-gauge ASTM A415 carbon steel. The top end of the hopper is approximately

FIGURE 1. Assembled Components of Main Reactor

2 ft x 2 ft with a capacity of 5.7 ft³, enough to fill the reactor vessel once. The lid of the hopper is gasketed and attached with spring-loaded fasteners; the hopper can be purged with inert gas to prevent the addition of air into the top of the reactor. An agitation rod positioned in the lid of the hopper assists the flow of waste from the hopper to the auger.

Directly beneath the waste hopper is a 10 in. knife gate valve. This valve isolates the hopper from the reactor vessel so that the hopper can be filled while the unit is in operation. The gate valve is bolted to a 10 in. pipe tee section which houses a horizontal 9 in. diameter screw (auger) with a 9 in. pitch. The auger is approximately 30 in. long; when rotated it feeds the waste into the top of the reactor.

The auger is directly coupled to a hydraulic motor. The hydraulic motor operates at approximately 750 psia, has a displacement of 9.9 in.³/revolution, and is controlled by a 4-way manually operated valve and a flow control valve. The motor generates a torque of 1050 in.-lb and rotates the auger at approximately 40 rpm. The auger is shown before installation in Figure 2.

Reactor Vessel

The design criteria for a reactor vessel suited to this process include the following:

- a) The vessel should be a single vertical section between 1 and 2 ft in diameter and 4 to 8 ft long.
- b) The inside of the vessel should be lined with high-temperature refractory.
- c) The vessel must be designed to operate at small positive gauge pressures and at temperatures ranging from 100 to 1400°C.
- d) The vessel construction should facilitate easy inspection and maintenance.

FIGURE 2. Feed Auger

- e) The upper levels of waste in the vessel must be distributed and compacted to prevent air channeling.
- f) Means to record temperatures and pressures must be available.
- g) The vessel must be equipped with a proper pressure relief system.

Based on these criteria, the vessel was designed at PNL and built by Wilkens and Associates of Tacoma, Washington. The vessel consists of a 7 ft section of ASTM A36 Schedule 40, 20 in. carbon steel pipe. The pipe has 150 lb flanges at both ends. The pipe also has a 10 in. opening for the waste feed and a 3 in. opening for the off-gas line. The pipe is lined with 1 in.-thick KAOWOOL^(a) insulation plus a 3 in. layer of KAOTAB CS^(b) castable refractory. The refractory is 95% alumina, rated for service at 1800°C. The refractory is supported by a 4 in. x 3-1/2 in. x 1/2 in. circle angle section welded at the base of the vessel. The effective inside diameter of the vessel after refractory installation is about 11 in.

The vessel is shown prior to installation in Figure 3. A closeup of the upper section of the vessel after mounting is shown in Figure 4. The top of the refractory lining is depicted in Figure 5. The vessel is fitted with two test ports for access to the reactor and inspection of the refractory. Seven in-line 1/4 in. holes for thermocouples or pressure taps were drilled in the vessel at 8 in. spacing. The bottom of the vertical retort and the thermocouple penetrations are shown in Figure 6.

The thermocouples used to record temperatures in the vessel are chromel-alumel with Inconel sheaths. They are mounted flush with the inner surface of the refractory and are coated with a layer of Saureisen potting ceramic at the tip of the thermocouple.

The top of the reactor vessel is fitted with a 20 in. diameter blind flange, with an opening for a pressure relief system. This system consists of a 4 in. diameter aluminum rupture disc, coated with Teflon to prevent corrosion, rated at a pressure of 15 psig. The required pressure relief

a. Trademark of Babcock and Wilcox.
b. Trademark of Babcock and Wilcox.

FIGURE 3. Vessel Prior to Installation

FIGURE 4. Closeup of Vessel After Mounting

FIGURE 5. Top of Refractory Lining

FIGURE 6. Vertical Retort Bottom, and Thermocouple Penetrations

area was sized based on a report by Marx Isaacs⁽⁹⁾ of an air-hydrocarbon explosion at an oil refinery. The area downstream of the rupture disc is a vertical standpipe fitted with a flapper valve to isolate the system from the atmosphere after the disc has ruptured and pressure relief has been accomplished.

Compaction-Distribution System

Prior to design and construction of this pyrolysis-incineration facility, we knew that the major problem with the pyrolysis process was the tendency for air to channel through the solid waste bed. Significant air channeling reduces the process efficiency. A compaction-distribution mechanism was designed to a) continually disturb the top layer of the solid waste bed thereby eliminating channeling in that area, and b) place a minimal load on the bed to maintain bed uniformity.

The compaction and distribution are accomplished with a cylindrical plate having eight angularly slotted holes and rabble arms. When this plate shown in Figure 7, is rotated, the rabble arms distribute the bed and the angular slotted holes allow gas through without significant transfer of waste to the top of the plate. The shaft that carries the compaction-distribution plate is a 4-1/2 ft-long section of 2 in. by 0.25 in. wall carbon steel tube, ASTM A513-70 Type 5. The shaft is hollow so that cooling lines to the lower shaft and compaction-distribution plate may be installed, if needed.

The rotary motion of this mechanism is accomplished through a chain drive (5.5:1) to a hydraulic motor with a 9.9 in.³/revolution displacement and a rated pressure of 2000 psi. The average speed of rotation for the plate is 2.5 rpm; controls for this motor are located on an operator's panel at ground level.

The vertical motion of the compaction-distribution plate is accomplished by a 3 in. bore hydraulic cylinder with a 46 in. stroke. The cylinder translates the plate, shaft, and rotary drive motor through a cantilevered

FIGURE 7. Compaction - Distribution Plate

framework which is held by roller guides along the side of the reactor. This arrangement minimizes the overall height of the unit (and, thus, the size of glove box required to house the unit). The cylinder is controlled so that the upward and downward speeds are independently adjustable and the limits of travel are adjusted by limit switches. The mechanism can also be operated in a constant load mode. Plate rotation and translation can occur simultaneously.

Ash Discharge System

In order to obtain continuous system operation, ash discharge at a slow and uniform flow rate is desired. A grate has been designed to allow this function. The grate is housed in an 18 in. pipe bolted to the bottom of the vessel, having a funnel-shaped outlet which reduces to a 6 in. pipe flange.

The grate is made up of three circular steel rings (ASME SA85) which are stacked vertically at a uniform spacing of 0.750 in. The top plate has a 6.5 in. diameter, the intermediate plate 10 in. and the bottom plate 16.75 in. These plates are mounted eccentrically on a common center support. Slow rotation of this grate allows upward air flow through the center, forces downward ash flow through the center, and crushes any agglomerated ash on the side walls. A plan view of the actual grate is shown in Figure 8.

The grate is driven by a set of bevel gears with a 4:1 reduction. The pinion gear is mounted on a horizontal drive shaft which passes through the wall of the grate assembly. The drive shaft is rotated by a rotary oscillating actuator (100° travel), a pair of limit switches, and a ratchet mechanism. The limit switches reverse the direction of the actuator and the ratchet causes the grate to rotate intermittently in one direction. The grate direction can be reversed. The average rotational speed of the grate is 0.04 rpm and produces a torque of 6400 in.-lb at 1000 psig hydraulic pressure.

FIGURE 8. Ash Discharge Grate

After the ash passes through the grate, it collects in the funnel beneath the grate and is then discharged from the system by a 6 in. rotary discharge valve. This valve operates like a revolving door and has eight fluted vanes with a floating seal. The rotor and seal assembly is constructed of cast iron and is rated for service up to 750°F. The valve is operated at 44 rpm, can pass ash particles up to 2.5 in. in size, and has a maximum capacity of 2.9 ft³/min at that speed.

The valve is driven by a hydraulic motor similar to that used on the feed auger. A flow control valve and a pressure reducing valve regulate the speed and torque of the discharge valve. An instantaneous reversing feature has been installed to handle any jamming of the valve. All controls are located on the operator's panel at ground level.

The ash discharged from the rotating valve is collected in an ash hopper. The hopper is connected to the outlet of the valve with a flexible asbestos boot. The hoppers are 2 ft x 2 ft in cross section and have a 4 ft³ capacity. They are mounted on wheels for ease of movement. These hoppers are shown in Figure 9.

Air Supply System

Air is supplied to the system through a 1 in. diameter line by a blower which is rated at 750 scfm at 160 in. H₂O. This blower is used for another test facility; only a portion of the flow is required for the pyrolysis-incineration installation. A gate valve controls air flow, and instrumentation is provided to measure line pressure, air flow, and air temperature. The air enters the system under the grate at two points 180° apart.

Off-Gas System

Off-gas from the reactor passes through a 3 in. insulated line to a water scrubber with a baffle plate which forces the gas to bubble through an aqueous solution. The temperature of the off-gas is measured at the inlet and outlet of the scrubber. The flow rate of the gas is measured

FIGURE 9. Ash Hoppers

with a 2 in. Annubar^(a) downstream of the scrubber. A 304 stainless steel demister pad has been installed at the outlet of the scrubber. The off-gas continues through a 2 in. line, passes through two aluminum flame arrestors, and is burned in a low Btu gas burner.

Hydraulic System

The hydraulic supply which drives the feed auger, compaction-distribution plate, ash grate, and ash discharge valve is provided by a Racine 10 gpm pump^(b) which is a variable volume, pressure compensated unit.

The pump operates from 300 to 1000 psi, is supplied by a 30 gal reservoir, and is driven by a 7.5 hp electric motor. A hydraulic system was chosen for the following reasons:

1. Accurate speed control of components.
2. Accurate and variable torque control.
3. Wide range of available operating speeds.
4. Built-in stall protection.
5. Instantaneous reverse rotation capability.

a. Product of Ellison Instrument Division, Dieterich Standard Corporation, Zanesville, Ohio.

b. Product of Racine Hydraulic Co., Racine, Wisconsin.

OPERATION OF THE PYROLYSIS-INCINERATION FACILITY

The following sections describe the startup and operating procedure used to process simulated alpha wastes, and present the results obtained in the operations.

Startup Procedure

Startup of the process is effected to simulate as closely as possible the conditions that will exist in the reactor at steady state, namely an ash layer on the grate, a combustion zone above the char zone, and a preheat zone at the top. These conditions cannot be duplicated at startup, but conditions can be created that will initiate the process and result in a rapid approach to steady state.

The ash layer is created by adding about 1-1/2 ft³ of ash and/or vermiculite to the reactor. This quantity of ash is sufficient for an ash depth of about 1 ft above the top plate of the grate, which locates the top of the ash layer at about the point of the lowest thermocouple along the side of the reactor. The ash serves to establish the ash zone and to protect the grate from the hot combustion zone. Ash is withdrawn throughout the run at a rate that will approximately maintain the initial ash layer thickness.

After ash addition, the secondary burner for combustion of the gases generated in the reactor is started and operated at a temperature of 1200°F. The autoignition temperature for low Btu gas such as that generated in the reactor with an air blast is approximately 1000°F.

The combustion zone in the reactor is now created by adding ignited charcoal briquettes, such as used for home barbeques. These are lit in an identical manner to have a white ash layer on each briquette. The hot charcoal is added through the feed hopper with the top cover and valve open and the feed auger activated. Usually about 10 lb of charcoal are added to establish the combustion zone.

Immediately after addition of the ignited charcoal, coke, or more charcoal, is added to the reactor to establish a char zone with a thickness of between 1 and 2 ft. Either coke or charcoal may be used for this purpose; the metallurgical coke is preferred because of its high mechanical strength. The valve and cover on the feed lock hopper are now closed, and air flow at the desired rate for the run is started through the reactor to sustain combustion of the charcoal and initiate combustion of the coke.

After about 2 hr of burning of the charcoal and coke to establish the combustion zone and hot char zone and to preheat the reactor, the simulated alpha waste is added to the reactor. Waste is added by filling the lock hopper, closing the top cover, purging the chamber with N_2 , opening the hopper valve, and with the distributor at its top position activating the feed auger to convey the feed from the feed hopper to the reactor. After the hopper is empty, the valve is closed, and the feed is compacted and distributed into the reactor. Addition of simulated waste is continued until the reactor is filled to the top of the refractory as determined by the position of the distributor. At this point, startup is completed, and the condition of the reactor is approximately that shown schematically in Figure 10. Pyrolysis of the feed may not have started as of this time; its onset can be determined by analysis of the off-gas as indicated by the presence of hydrocarbons.

Conditions used after startup and observations that were made during the runs are described in the following section.

Description of Runs

Four runs were completed with the PDU using simulated alpha waste. The composition of the simulated waste used in the runs is shown in Table 1. The indicated waste components were shredded into approximately 4 in. pieces in a cutter-type shredder at the Saturn Manufacturing facility in Salem, Oregon. The shredded waste components are shown in Figure 11. These individual components are mixed in 25 lb batches to give the composition shown in Table 1.

FIGURE 10. Condition in Reactor After Startup

FIGURE 11. Composition of Simulated Alpha Waste

Table 1. Simulated Waste Composition

<u>Component</u>	<u>Weight %</u>
Paper	15
Rags	15
Wood	10
Latex Rubber	5
Hypalon Rubber	10
Neoprene Rubber	10
PVC	20
Polyethylene	15

Conditions used for startup prior to feed addition in the four runs are shown in Table 2. Startup procedure was discussed in the previous section.

Table 2. Initial Run Conditions

<u>Run</u>	<u>Initial Wt. Ash, lb</u>	<u>Wt of Ignited Charcoal, lb</u>	<u>Wt of Unignited Charcoal, lb</u>	<u>Wt Coke, lb</u>	<u>Air Flow Rate, scfm</u>
1	25	20	--	--	5
2	25	10	--	35	10-14
3	37.5	12	13	23	10-14
4	23	11	--	47	10-14

In each of the runs, simulated waste in 10 to 15 lb batches is added to the reactor (as described in the preceding section) when the refuse level subsides to about 2 ft below the top of the refractory (3 ft below the top cover). Conditions monitored during the run include the reactor temperatures at 7 points along the side of the reactor (see equipment description); the ash receiver temperature; the temperature and pressure of the inlet air and off-gas; the pressure drop on inlet and outlet flow measurement devices; and the composition of the off-gas.

In run 1, the distributor was operated at a downward pressure that resulted in a compaction force of about 2600 lb/ft^2 on the material in the reactor. In total, 125 lb of simulated waste were added to the reactor over an 8 hr period with an air flow rate of 5 scfm. At the end of the run, the reactor was opened and the unreacted material was removed.

A view of the material in the reactor is shown in Figure 12. The material was only partially reacted; 100 lb of the 125 lb added remained compacted in the reactor at a density of about 50 lb/ft^3 . It was apparent that too high of a compaction force had been used to distribute and compact the feed. In subsequent runs, the compaction force was adjusted to pack the material at a force of about 130 lb/ft^2 .

The operability of the equipment was demonstrated in Run 1. Since very little pyrolysis of the waste occurred, few tars were generated, as is evident from the lean condition of the reactor (Figure 12) at the end of the run.

In run 2, the air flow rate was increased to 10 to 14 scfm. The flow rate varied depending on the amount that the bed of material was compacted, which affected the pressure drop across the bed. The run was terminated prematurely because of a faulty rupture disc in the pressure release line. Inspection of the disc after the run revealed that actually no rupture disc had been installed and only packing paper on the rupture disc flange was present; no failure had occurred, only the paper had disintegrated. A total of 64 lb of waste was added in 2.5 hr after a 3 hr startup period, and 21 lb of partially decomposed material remained in the reactor. The conditions of the top of the reactor and the distributor at the end of run 2 are shown in Figures 13 and 14, respectively. It is obvious from comparing Figures 13 and 14 that significant pyrolytic decomposition of the waste had occurred.

Except for the missing rupture disc, run 2 was smooth and trouble free. The distributor was found to be extremely useful in determining the amount

FIGURE 12. Condition in Reactor at End of Run 1

FIGURE 13. Top of Reactor at End of Run 2

FIGURE 14. Distributor at End of Run 2

of material in the reactor. The distributor was operated intermittently, i.e., it was used mainly to pack the waste immediately after its addition to the reactor and was then withdrawn to its top position.

Run 3 conditions essentially duplicated run 2 with the exception of the distributor operation. The distributor was used not only to compact the waste, but to spread the waste continuously. During the time between batch waste additions, the distributor was operated so that it rode on the bed of refuse and rotated to spread the top of the refuse bed. The operation was conducted in this manner to prevent any open channels in loosely packed material from developing during processing. Waste added to the reactor in the 6 hr of operation totaled 186 lb. No waste was added during the last hour of operation to allow the material in the reactor to burn out. Considerable sooty-type carbonaceous deposits resulted from this burning-out period when the filtering action of the refuse bed was not present. Examples of these carbonaceous deposits are given in Figures 15 and 16, which show the condition of the top of the reactor and the distributor, respectively, at the end of run 3.

Run 4 duplicated the conditions of run 3 and was an attempt to operate the unit for 24 hr, or long enough to process the remaining 825 lb of simulated waste. After 12 hr of operation and the addition of 355 lb of simulated waste, the run had to be terminated because the off-gas line had plugged. At the time, it was thought that tars and condensate had plugged the line; however, subsequent inspection showed that rags had plugged the line at the top of the reactor. This is shown in Figure 17. The off-gas line was relatively clear, as might be expected since the rags acted as a filter. Apparently, waste is conveyed to the reactor at a point very close to the off-gas line, as evident in Figure 17, and shredded rags in the simulated waste were carried to the vicinity of the off-gas line from the waste feed inlet by the distributor. Another view of the top of the reactor at the end of run 4 showing the rag-plugged line and the top of the refuse bed is shown in Figure 18. The condition of the distributor at the end of

FIGURE 15. Top of Reactor at End of Run 3

FIGURE 16. Distributor at End of Run 3

FIGURE 17. Rags Plugging the Off-Gas Line

FIGURE 18. Rag-Plugged Line and Tcp of Refuse Bed at End of Run 4

run 4 is shown in Figure 19. It should be noted that no waste additions were made during the final hour of run 4 while attempts were being made to establish normal air flow into the reactor. Maximum pressure noted in the reactor after the off-gas lines plugged was about 3 psig. The air supply fan can generate only 4 to 5 psig.

In the following section, results obtained from the four runs described above are presented. The results include processing rates, gas compositions, processing yields, and characterization of the condensate, or tar, produced.

Operating Results

Average processing rates were determined for the four runs by weighing the amount of waste added during each run and the amount of material left partially processed in the reactor at the end of each run. The results of these determinations are shown in Table 3. The low rate of 3 lb/hr observed in the first run resulted from the high pressures used to compact the refuse in the reactor. The combustion zone was actually quenched by the addition and compaction of the waste at composition pressures as high as 2600 lb/ft².

Table 3. Average Processing Rates

<u>Run</u>	<u>Rate, lb/hr</u>
1	3
2	17
3	27
4	23

An average rate of 17 lb/hr was attained in run 2 while average rates were 27 and 23 lb/hr in runs 3 and 4, respectively. An average feed rate of 27 lb/hr was achieved over the last 11 hr of run 4, but slow rates during the first 3 hr reduced the average to 23 lb/hr. Instantaneous rates were higher than the average rates, but the instrumentation was unreliable

FIGURE 19. Distributor at End of Run 4

to determine these rates accurately because of probe plugging by tars. At times during runs 3 and 4, feed addition rates to maintain the desired refuse level in the reactor were 40 lb/hr.

The improvement in processing rate from run 2 to runs 3 and 4 resulted from use of the compactor to distribute the waste continuously in the reactor rather than intermittently as was done in run 2. The distributor pressure used in runs 2, 3, and 4 was sufficient to exert a force of 130 lb/ft^2 on the refuse bed. Occasionally, a greater force was used to distribute the waste and give the desired pressure drop through the refuse bed. In runs 3 and 4 the distributor was operated to rake the top of the refuse bed continuously between waste additions, whereas in run 2 the waste was simply packed after each addition.

Continuous agitation of the bed reduced channeling of gases through the bed and improved processing rates. The effect is also reflected in the gas composition on a dry basis obtained in runs 2, 3, and 4, and shown in Table 4 along with the gas heating values. The low heating values of the gases generated in run 2 indicate that considerable channeling occurred; the higher heating values in runs 3 and 4 indicate that channeling was reduced by continuous distribution of the refuse bed with the mechanical agitator. It should be noted that the gas compositions vary considerably over short time periods and that the above compositions represent the true composition over a very short period of time. No attempt was made to identify changes in composition at different times after charging of a new batch of feed.

Attempts were made to determine the concentration of chloride in the off-gas by scrubbing a known volume in caustic solution and analyzing the solution for chloride. All samples showed essentially no chloride or sulfur. Apparently the volume of gas treated was too small for chloride detection since the presence of chloride in the gas stream is certain. Determinations of the moisture content of the off-gas were unsuccessful because scrubber solution was sucked back into the desiccant column used to collect water.

Table 4. Gas Composition in Runs 2 and 3

Run	Time	H ₂	CO ₂	C ₂ H ₄	C ₂ H ₆	O ₂ -Ar	N ₂	CH ₄	CO	C ₃ H ₈	Heating Value of Gas, Btu/scf*
2	1200	3.4	20.3	0.1	0.03	0.8	72.3	--	3	--	24
	1330	4.7	18.0	0.07	--	0.8	67.3	--	8.2	--	45
	1400	4.2	15.5	0.07	0.02	0.8	67.2	--	12.2	--	57
3	1320	5.5	8.0	0.1	0.1	0.8	60.1	0.1	26.1	--	112
	1400	3.6	9.1	0.2	0.1	0.8	61.8	0.1	24.3	--	101
	1430	7.1	10.8	1.3	0.2	0.8	60.8	1.0	18.8	--	124
	1615	11.1	14.0	1.8	0.3	0.6	56.6	1.4	12.5	0.4	141
4	1050	3.7	11.2	--	--	0.7	60.3	--	24.1	--	79
	1225	4.0	10.5	0.04	--	0.7	63.0	--	21.7	--	88
	1425	5.4	11.6	0.3	0.1	0.7	61.1	0.3	20.5	--	98
	1700	7.0	13.1	0.2	0.2	1.5	61.5	0.3	16.1	--	89
	2005	8.9	12.6	0.5	0.2	0.9	60.5	0.3	16.1	--	100
	2220	8.6	11.2	0.7	0.4	0.7	61.3	1.3	15.9	--	116

*scf at 32°F, 1 atm.

Assuming the off-gas is saturated with moisture, the water content varied from 8 to 36 volume percent in run 3. The actual value is probably around 10 percent for the bulk of the run.

The gases produced were burned at 1200°F in a secondary burner without any visible smoke. The exception to this occurred at the end of run 3 when the refuse bed had completely burned through, and the filtering action of the fresh feed was lost. A white smoke was noted emitting from the stack at this time.

Inputs and outputs of liquid and solid streams for run 4 are shown in Table 5. The carbonaceous residue represents incompletely burned waste that remained in the reactor at the time of shutdown.

Table 5. Run 4 Material Inputs and Outputs

	<u>Ash</u>	<u>Coke</u>	<u>Waste</u>	<u>Condensate</u>	<u>Carbonaceous Residue</u>
Input, lb	25	47	355	0	0
Output, lb	28.5	0	0	62.5	60.5

Inspection of the residue revealed that pyrolysis of the feed components was complete so that it can be assumed no more tars would result from further processing of the residue. For this particular run, the condensate (or tar) yield was 18 percent of the weight of the waste fed to the reactor. These tars can be destroyed (burned) during secondary combustion of the off-gas.

The condensate (or tar) generated in run 4 had a calorific value of 9380 cal/g (16,900 Btu/lb) and an ash content of 0.3 wt%. Its viscosity as a function of temperature and char rate (spindle rpm) determined with a Brookfield Viscometer^(a) is presented in Table 6.

Table 6. Viscosity of Tars Produced in Run 4

<u>Temperature</u> <u>°C</u>	<u>Speed of Spindle</u> <u>rpm</u>	<u>Viscosity</u> <u>cp</u>
57	20	115
	50	87
50	10	750
38	10	8,400
	5	13,200
	2.5	21,600

a. Product of the Brookfield Engineering Laboratories, Stoughton, Massachusetts.

Non-Newtonian properties of the condensate are evident in Table 6 from the changes in viscosity with spindle speed at a given temperature. The data on viscosity, calorific value and ash content show that the tars could be destroyed by burning separately or with the gases generated in the pyrolysis-incineration reactor.

Condensate collected during operations in runs 1, 2, and 3 showed a higher viscosity (300 to 400 cp at 75°C), a higher ash content (2.6 wt%) and a lower calorific value (8,650 cal/g) than tar from run 4. The condensate was generated mainly during runs 2 and 3 since only 25 lb of waste was destroyed in run 1, and portions remained in the trap for over a week during the conduct of runs 2 and 3. The filtering action of the waste was lost at the end of run 3, which could have resulted in carryover of ash and thus created a high ash content of the tar. Moisture in the tar appeared to increase viscosity and, of course, would decrease the calorific value. Moisture was very difficult to remove from the tars of runs 2 and 3, probably because it had been in contact with the scrub solution in the trap for over a week. The tar collected in run 4 was separated from the scrub solution within two days after the run was completed. Run 4 tar, therefore, best represents the condensate generated during pyrolysis-incineration of simulated alpha wastes.

The ash content of components used to simulate alpha waste are shown in Table 7. Latex rubber and polyethylene had less than 0.1% ash. From the values given in Tables 1 and 7, the ash content of the simulated waste is calculated to be 3.6 wt%.

Table 7. Ash Content of Waste Components

<u>Component</u>	<u>Wt % Ash</u>
Paper	0.5
Rags	0.6
Wood	1.2
Hypalon Rubber	12.1
Neoprene Rubber	20.5
PVC	0.3

Considering that about 25 lb of ash were added initially to start a run, isolation of the ash generated from pyrolysis-incineration of simulated waste was almost impossible. In run 4 during processing of 355 lb of simulated waste, some ash that differed in appearance from the ash added to start the run was collected and is shown in Figure 19. The ash was dark gray in color and has the size distribution shown in Table 8. The carbon content of the ash as determined by exposure of 1g to 950°C in a muffle furnace for 2 hr was 13 wt%.

The bulk tap density of the residue (ash) was 0.76 g/cm³ (47 lb/ft³). The volume reduction factor for the simulated waste which had a bulk density of about 8 lb/ft³ (0.13 g/cm³) and an ash content of 3.6 wt% is shown in the following:

$$\begin{aligned} \text{Volume Reduction} &= \frac{\text{ft}^3 \text{ waste}}{\text{ft}^3 \text{ residue}} = \frac{47 \text{ lb residue}}{\text{ft}^3 \text{ residue}} \times \frac{0.87 \text{ lb ash}}{1 \text{ lb residue}} \times \frac{100 \text{ lb waste}}{3.6 \text{ lb ash}} \\ &\times \frac{\text{ft}^3 \text{ waste}}{8 \text{ lb waste}} = 143 \frac{\text{ft}^3 \text{ waste}}{\text{ft}^3 \text{ residue}} \end{aligned}$$

Table 8. Size Distribution of Ash

<u>Tyler Mesh Size</u>	<u>Wt% Ash</u>
+20	21.8
-20+60	39.4
-60+115	19.4
-115+200	8.6
-200	10.8

Temperature profiles in the reactor at different times during run 4 are shown in Figure 20. The numbers on the abscissa in Figure 20 refer to thermocouples equally spaced vertically along the wall of the reactor at 8 in. spacings; point 7 is 1-1/2 ft from the bottom flange and point 1 is 1-1/2 ft from the top flange. A considerable change in temperature profile with time is apparent. Larger runs will be needed to determine the course of the temperature changes. Only local temperatures along one side of the reactor are recorded. It is highly probable that the profile varies across the reactor cross section as well as vertically.

FIGURE 20. Reactor Temperature Profile for Run 4

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