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CHARACTERISTICS OF THE MOBILE FIELD USE SYSTEM FOR THE DETOXIFICATION/INCINERATION OF RESIDUALS FROM OIL AND HAZARDOUS MATERIAL SPILL CLEAN-UP OPERATIONS*

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Summary

The Mobile ERIC is a complex thermal and chemical processing plant capable of detoxification of hazardous organic spills and contaminated debris at remote locations throughout the United States. It is designed to handle moderate spills in an efficient manner without undue restriction concerning the physical nature of the input wastes.

Introduction

Moderate size oil and hazardous material spills occur annually throughout the United States and are of such a nature that they pose serious and difficult problems for the clean-up techniques available at this time. A very large number of these materials can be effectively destroyed thermally if proper temperature, dwell time and excess oxygen are provided.

A program for the design, construction and demonstration of a mobile detoxification/incineration system has been undertaken to cleanse the debris, soil and waters of contaminates from spills of:

(a) Crude bunker fuels, distillates, table oils, emulsified oils, waste oils, etc.;

(b) Hazardous materials cited in Table 116. 4A of the *Federal Register*, Volume 43, No. 49, Pages 10481—6, March 13, 1978;

(c) Hazardous materials cited in the United States Coast Guard CHRIS List CG446-2, January, 1974;

(d) Viscous liquids and mixtures such as paint, creosote, monomers and partially polymerized plastics,etc.;

(e) Waste, sludges and bottoms from chemical and petrochemical industries;

(f) Pesticides, including pure active ingredients, mixtures, formulated powders and sprays;

(g) Combustible containers which have been contaminated with these hazardous materials.

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It should be noted that some of the materials in the above list, particularly inorganics and/or heavy metals are not amenable to incineration and hence must be excluded as unsuitable candidates for thermal decomposition. Specifically, mercury and arsenic bearing compounds are excluded. On the other hand, the controversial highly chlorinated carbon substances and pesticides such as Kepone, TCDD, PCB, malathion, zineb and Agent Orange have been assessed and therefore included in the list of compounds amenable to the thermal decomposition process.

System description

The Mobile ERIC (Environmental Restoration Incinerator Complex) is composed of three heavy-duty commercial type highway trailers mounted with the equipment and components necessary to adequately decompose the hazardous spilled materials along with the debris, soil, shrubs, lumber, seaweed and so forth that may be associated with such spills. Each trailer is designed for over-the-road transport by commercial semi-trailer/tractors in addition to portability off the road as long as a reasonable road bed exists.

The three trailers essentially represent the fundamental sub-systems necessary to accomplish the work. Trailer No. 1 consists of a shredder, stoker and rotary kiln which, of course, is the primary incineration unit. Although the system will have capability for both controlled atmosphere and excess air modes of operation it is intended to operate in excess air modes at high temperature with long kiln residence times for the solids that are non-combustible. Solid materials that have been shredded can be hydraulically ram fed into the kiln while sludges or liquids can be directly injected into the incinerator floor. Residual ash is automatically removed from the discharge end of the kiln. Exhaust gases pass from the incinerator breech through a flue into the afterburner on Trailer No. 2.

Trailer No. 2 consists of the excess air afterburner which will provide both temperature, dwell time and oxygen levels suitable for destroying the hazardous materials already cited. Specifically, the unit is a 52″ I.D. by 36′ long refractory lined tubular afterburner with a molar flow venturi nozzle to insure the required dwell time control. The gases leaving the afterburner are cooled by water quenching in a wetted throat venturi elbow. Excess water is separated at a ground level sump before being ducted to the scrubbing equipment.

Trailer No. 3 is essentially a gas stream processing trailer which includes a particle scrubber for removal of fly ash and sub-micron size phosphorous pentoxide. Next the gas stream is passed through a mass transfer scrubber or absorber tower for removal of SO_2 and HCl. The absorber tower has a mist elimination system section at the exit end. Induced draft is provided by a diesel driven blower prior to sound suppression and the stack release. In addition to the gas stream processing equipment, Trailer No. 3 incorporates a diesel driven alternator with sufficient capacity to operate the system at remote sites without requiring a utility power source.

Fig. 1 is an artist's rendition of the system under construction.

System parameters

The basic design concepts incorporated in the Mobile ERIC system include, but are not limited to, the following:

(a) All components must be suitable and compatible with both over-the-road and off-the-road shock and vibration loads.

(b) The system must be capable of processing solids, liquids and sludges with or without BTU content.

(c) Kiln temperatures of 1800° F to insure volatilization of HM's with one hour dwell for solids in order to assure clean ash residuals.

(d) Afterburner minimum temperatures of 2012° F per Federal Regulations of PCB's.

(e) Afterburner two second dwells to insure thermal decomposition of pesticides and poly-chlorinated biphenals per Federal Regulations.

(f) Excess O_2 above 3% per Federal Regulations.

(g) Particle scrubbing sufficient to effectively meet a 10% permanent plume opacity when decomposing organic phosphates that will generate P_2O_5.

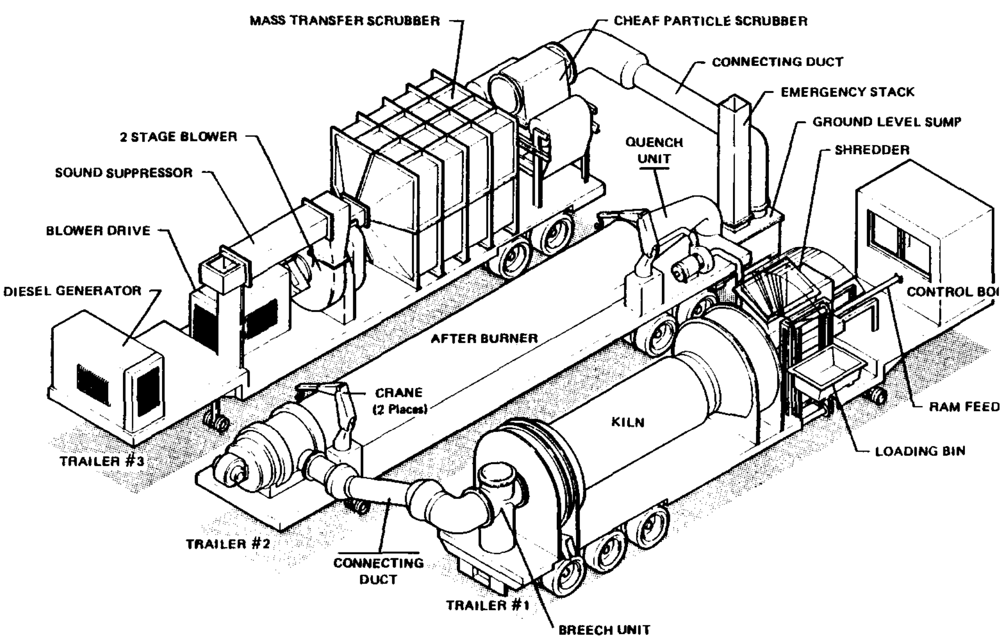

Fig. 1. Artist's rendition of mobile environmental incinerator complex (trailers normally in-line).

(h) An absorber scrubber to effectively meet SO_2 and HCl emission constraints for incinerators at various locations.

Each sub-system of the total design was analyzed for trade-offs, cost and compatibility with the above established requirements. The individual sub-system characteristics are as follows.

Loader

The loader design consists of several ground level nestable loading hoppers that can be filled at remote areas with debris and solids to be processed through the shredder. These ground level loading hoppers are transportable by either forklift or boom type overhead carriers with hooks. The bins are loaded onto the extended forks of the loading mechanism and are mechanically/hydraulically lifted up to the edge of the shredder hopper where the ground level hopper is rotated and dumped into the main hopper. The ground level hopper is returned to a vertical position, where it, in conjunction with a fabric dust cover, acts as a seal for preventing excessive dusting. The fabric section acts as a potential explosion relief should some type of explosive material inadvertently enter the shredder hopper. The enclosed area above the shredder hopper is vented to the primary kiln so that the shredder hopper is effectively under negative pressure for improved dust control.

Shredder

The shredder is basically a shear type counter rotating shaft unit with 1″ teeth capable of processing a very wide range of materials. The shredder's capability for debris processing includes 55 gallon containers, radial tires, wood pallets, batteries, brittle and soft metals, such as lead or aluminum, 4″ × 4″ fence posts, small logs, shrubs, sand, gravel, dirt, paper and other items of trash. The system will automatically reverse for jam clearing and does not require manual clearing unless the item causing a jam is of non-shreddable nature; e.g., steel gears, shafts, large rocks and so forth. The potential for drawing through long shredded pieces such as wire, metal strapping or slender sticks is recognized. In order to compensate for this problem, three transaxial plate bars are being installed to prevent excessively long, slender objects from being generated.

Ram feed sub-system

A ram feeder processes all solid wastes into the kiln. The ram feeder is hydraulically operated with a 3¼″ diameter by 121″ stroke cylinder. It has the capacity of ramming up to 2 ft^3 in 30 sec as well as partial volumes over longer periods. The rate of ram feed will be determined by the characteristics of the material being destroyed and will be easily field controlled for both volume and speed.

The ram cylinder rod is protected from the shredder by a sliding steel-cover plate which is attached and moves with the ram face thereby sealing off the ram through from the shredder intermediate hopper and preventing shredded debris from piling up behind the advancing ram During shredding the ram will be positioned such that the trough will be closed to the shredder and the ram face will provide an additional barrier to the kiln atmosphere in addition to the two swing gates which are operated independently but sequentially, as the ram advances and retracts. The ram cover plate will limit the amount of material volume that the shredder can process to the volume between the cover plate and the rotating jaws and in effect reduce potential trough overfill and ram jam-ups. This controlled volume represents 75% of the volume in the fully opened ram trough. The leading edge of the ram will have a shearing edge to further reduce potential ram jam-ups.

The solids volume feed control will be effected by controlling the ram pullback position so that the kiln can be charged frequently with partial loads and thereby reduce combustion transients or localized starved air conditions to the kiln. Swing-up gates have been incorporated in the trough bottom to isolate the shredder from the kiln atmosphere. Each swing gate functions sequentially as the ram advances and retracts. Swing gates were chosen in order to avoid slots and slide grooves which can be easily fouled with sand, dirt, oil or debris. Slot and groove fouling would essentially render such gates inoperable. Additionally, the elimination of slots and grooves reduces ambient air leaks into the kiln and eliminates potential hazardous material leaks to the ground. Gate position switches control and limit ram movement in order to prevent the possibilities of uncontrolled air entering the kiln. The gate closest to the kiln will be an insulated, sandwich construction faced with Inconel 671. The ram trough section in the kiln atmosphere will also be made of Inconel 671 for corrosion and heat considerations.

Sludge and liquid feed

Most sludges and liquid feed stocks will be introduced into the kiln via a sludge port at the end of the solids feed ram trough. The port is 2½″ pipe capable of being rod cleared if caking or carbonization occurs. Liquid waste may or may not have BTU heating values.

Two separate pump types will be used to conveniently handle these materials.

The first type of pump will be a standard air operated drum ram used mostly for light viscosity, easily pumped, relatively clean liquids. It will be used to transfer materials directly from drums or containers without requiring dumping into an intermediate hopper. Heavier viscosity materials may be pumped by adding a special ram attachment to the suction which forces the sludge into the pump suction. The system is rated for materials with contaminants up to approximately 1/4″ in diameter without blocking. However, we will provide a suction strainer with 1/8″ mesh screen.

The second system is designed for sludges and liquids with large contaminant particles and solids. The design incorporates a heated sludge tank with a 1″ mesh screen strainer utilizing an opposed piston pump. The in-line positive displacement piston pump is capable of jam-free performance with debris and particles as large as sanitary napkins.

Hydraulic power unit

The primary hydraulic unit of the shredder will consist of a 50 HP electric motor driven, variable volume hydraulic pump which is horsepower compensated to eliminate excessive power demands. This approach allows a higher maximum pressure setting during low volumes without exceeding the 50 HP limitation just prior to the jam reversing condition. It also provides a larger quantity of oil flow during low hydraulic pressure demand. The net effect of this system results in the shredder running faster when lightly loaded and slower when heavily loaded but with a resultant shear force that is up to 33% greater than normally available with a standard 100 HP motor driven fixed volume pump. Additionally the normally supplied fixed volume pump results in peak HP demands of 144 HP during the high pressure, high shear load periods.

Kiln

The kiln design incorporates the largest possible unit compatible with trailer space, weight and axle loading constraints imposed by over-the-road limitation and state highway regulations. It is a refractory lined, direct fired, co-current flow, sloped bottom unit with physical dimensions that are 52″ I.D. × 16″ long resulting in an effective volume of 236 ft^3. It will be lined with 6″ thick A.P. Green Kast-O-Lite 30 refractory which was chosen for it's over-the-road capabilities in conjunction with a good performance experience record, low weight and reasonable k factor. The kiln is fired with two 4″ maxom burners each of which is capable of 12:1 turn down ratios and close fuel/air ratio compliance throughout the range. These burners have high-turbulence and short flames which enable us to incorporate standard heat recovery and mixing chains starting approximately 4′ from the burners. The chains will induce gas stream turbulence as well as solids mixing and heat transfer into the solids.

A co-current flow of solids and gases was chosen because it is compatible to all expected waste materials anticipated. Counter-current flow has serious disadvantages with heat release in the breeching for volatile fuel laden soil.

The kiln slope angle will be achieved and controlled by leveling jacks. This angle coupled with rotational speed will provide a predetermined residence time for solids. Volatilization of liquids introduced via the sludge port is expected within the first 4′ due to the relatively high temperature (1800° F) of the operation.

Kiln breeching and duct to afterburners

The kiln breeching section is made of Inconel 601 and incorporates a blast relief door capable of reducing damage in the event of a minor kiln explosion. This section also includes a sight port for observation of the kiln interior activities during operation.

Inter-trailer ducting is also fabricated from Inconel 601 which was selected for its high temperature strength and corrosive resistance. The ducting includes an expansion joint capable of providing a 12″ length adjustment in addition to a 20° misalignment. The ducting will be supported by means of adjustable guy cables from a trailer mounted mast and boom

Afterburner

The afterburner is basically a 52″ I.D. × 36′ long refractory lined (Kast-O-Lite 30) tube with gases entering axially through the end which are then directed radially by means of vanes to induce a spiral swirl. Two tangentially fired oil burners will bring the gases up to approximately 2150°F and induce an additional circumferential swirl and mixing action. Excess air will enter between the burner and the refractory wall to help protect the walls from flame scrubbing as well as provide the necessary excess oxygen ratios required for effective and efficient detoxification reactions.

The afterburner is designed to ensure compliance with the May 24, 1977 issue of the *Federal Register* proposed rules for PCB destruction which establishes a minimum two second dwell, 2012°F temperature and 3% excess oxygen. This oxygen level has been interpreted to mean a minimum since it corresponds to approximately 15—20% excess air over stochiometric requirements for many fuels. Lower oxygen levels could conflict with good combustion practices since many incinerators presently operate with much higher excess air ratios in order to avoid incomplete combustion with visable smoke.

Excess air ratios above 20% adversely impact fuel requirements simply because the excess air must be heated to the desired high temperature. Since excess air is supplied for its oxygen content, it is important to recognize its diminishing capabilities and its maximum limitations. Fig. 2 shows the relationship between oxygen content and excess air.

Some toxic waste thermal destruction systems currently utilize very high excess air ratios. The Mobile ERIC system is designed to operate between 20—50% excess air which is easily adjustable and controllable by the operator. It is important to note that turbulence is not considered in the proposed PCB rule; however, it is of utmost importance in oxygen molecule/toxic molecule contact potential during the high temperature detoxification process. This afterburner design further ensures mixing by utilizing a gas stream design velocity of 15′ per second which results in a Reynolds Number of:

$$N\rho = VDp/\mu \sim 30{,}000$$

Turbulence is a certainty at Reynolds Numbers greater than 2,000 and such turbulence will result in mixing and increased molecular contact.

Quench

Quenching of the 2050°F gas stream is necessary for both particle and

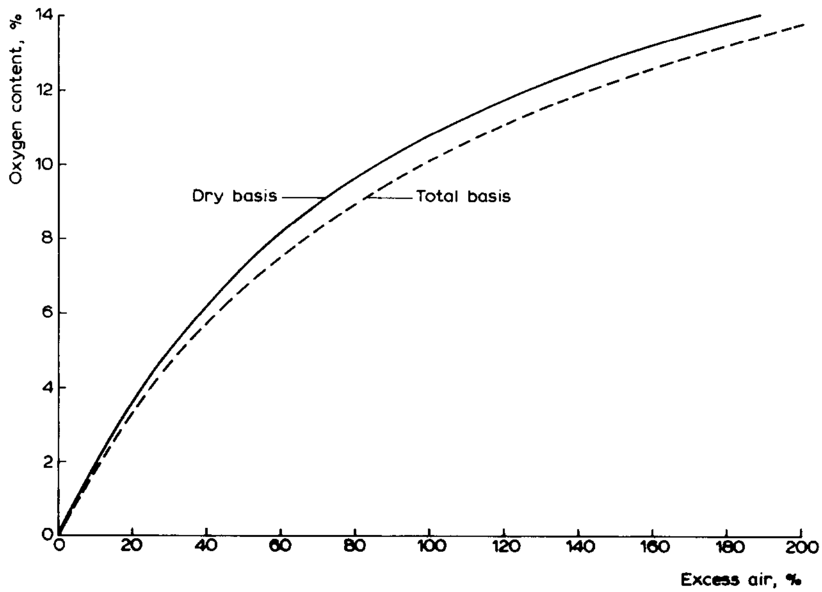

Fig. 2. Oxygen content vs. excess air.

mass transfer or absorber scrubbing. This quenching will be accomplished in a wetted throat venturi elbow using both fresh and recirculated water. A bleed will continuously purge the system of precipitated solids as well as control acid build-up.

The quench water nozzles are designed to deliver approximately 34 GPM total which is twice the value required to bring the gas stream down to a saturation temperature of approximately 175° F. All nozzles are shielded and protected from the direct impingement of the hot gas stream.

The venturi elbow will be connected to a ground level water separator sump which also includes an emergency stack and damper arrangement considered necessary to protect the downstream scrubber system components in the event of a quench water failure. This emergency system will activate whenever the gas stream exceeds a safe limit of 350° F. In order to reduce emergency stack activation frequencies, a 300 gallon air pressurized reserve water tank has been designed into the system. This supply is sufficient for approximately 20 min of operation without pumps or additional make-up water.

Interconnecting ducting and expansion joints from the ground sump to Trailer No. 3 are similar to the design utilized between the kiln and afterburner but will be constructed of Inconel 625 instead of 601 for improved wet corrosion resistance.

Particle scrubber

Basically the particle scrubber will be capable of 95% P_2O_5 removal to meet a permanent plume opacity of less than 10% during detoxification of organophosphate compounds. Such opacity is directly related to the greater light scattering ability of sub-micron size P_2O_5 particles. Since we do not know what size these particles will be, we must assume 0.2 micron and design for needed removal.

In order to accomplish such a removal capability, a Cleanable High Efficiency Air Filter (CHEAF) will be utilized which requires only 30″ of pressure drop in lieu of an estimated 60″ for high energy venturi scrubbing. Because we are dealing with a 175° F saturated gas stream up to 5,000′ elevation (Denver) the induced draft blower equivalent static pressure requirements were reduced from approximately 150″ H_2O with a venturi to a more manageable 90″ H_2O requirement with the CHEAF.

The CHEAF has the added feature of effectively removing fly ash particulate and requiring very low l/g ratios thereby reducing fluid circulation pump loads. It uses a wetted glass fiber filter pad available in 100′ rolls. A pressure differential sensing device controls a motor to advance the filter pad as required when plugging starts to occur thereby eliminating shuttdowns for filter pad changes. New rolls of material are spliced onto existing rolls without difficulty. The contaminated rolls can be buried in a refuse dump.

The effectiveness of CHEAF units were evaluated by the EPA in reports: EPA-650/I-76-058a (July 1975) and EPA-600/2-76-202 (July 1976).

Absorber/mass transfer scrubber

The absorber/mass transfer scrubber will be a horizontal cross flow packed tower which incorporates a particle scrubber fluid separator, a mass transfer media section and a final demister section. A horizontal pack tower appears to be the only reasonable approach suitable for trailer mounting at the gas stream flow rates involved, even though it is not as efficient as the vertical counter-flow type.

This design includes a coarse vane type fluid separator in the initial section to separate excessive liquid droplets carried over from the CHEAF particle scrubber. No attempt is being made to capture all of the liquid particles. The central section will consist of a 4½′ wide × 5′ high bed of 2″ Intalox plastic saddles 8′ in depth irrigated with a 5% NaOH scrubbing fluid and capable of reducing SO_2 concentration from 10,000 PPM to 300 PPM. This mass transfer section will also be able to reduce HCl levels from 10,000 PPM to 200 PPM. The 9,000 ACFM saturated gas stream will require a liquid rate of 20 GPM/1,000 ACFM, in order to achieve these low contaminant concentrations.

The vessel structures include effluent storage capacity at the base and will be fabricated from fiberglass reinforced plastic utilizing a Bisphenol "A" base resin with alternate layers of woven roving and chopped strand fiberglass meeting U.S. Bureau of Standard Specificaion PS 15-69. The unit will be reinforced with steel angles to withstand 45″ H_2O negative pressure.

The system is complete with NaOH tanks and ground level effluent storage tanks.

Blower and drive

An induced draft of 43″ negative water pressure is necessary to operate the system without danger of toxic material leakage at the kiln or intermediate points and to accomplish the gas stream scrubbing requirements. In order to achieve this actual pressure drop at elevation ranging from sea level to 5,000′ the blower must be capable of producing an equivalent static pressure from 70—90″ H_2O.

A modified, single-stage blower speed modulated up to 3,600 RPM will meet the variable pressure requirements. This blower will be driven by a stock 125 HP diesel engine coupled through a fluid clutch and 2:1 step-up gear box. The engine will provide the required speed adjustment for the various pressure drops.

A return gas duct from the blower to the particle scrubber inlet has been incorporated in order to provide for the pressure control necessary to compensate for feed and combustion transients in the kiln. A kiln transient could result in a positive pressure causing spillage of toxic gases.

Kiln pressure change will provide the control signal which will cause a control value in the duct to change which in turn will result in an afterburner and kiln gas flow rate change without changing the flow rates through the gas processing sub-system or blower.

Sound suppression and stack

Blower sound suppression will be accomplished with commercial attenuators in the outlet ducting to the stack. This attenuator will reduce the sound level down to 85 db at 5′ from the source. In addition to the commercial in-line unit, an enclosure box will be required around the blower housing in order to achieve the 85 db level desired.

A short 10′ tilt-up stack is included in the design for gas exhaust dispersion purposes.

Trailers

All equipment will be carried on three semi-trailers equipped with air suspension for reduced road shock loads. These trailers are specifically designed for this application. Trailer 1, which carries the kiln, is a three-axle unit (due to the load distribution) while Trailers No. 2 and No. 3 are tandem axle flat-beds. The beds and support structures are designed for minimizing deflection, not minimizing tare weight as is normal for highway equipment. Each unit is 45′ long and when pulled by a cab-over tractor will meet both length and weight requirements in most interstate highways. Trailer No. 1 will be a permit load in a few states due to the axle configuration.

Additional equipment

Other items of equipment include a diesel alternator set for all electrical requirements, effluent tanks, water and fuel tanks, pumps, on-board hoist, emergency lighting and other operating tools.

Control system

The control system will be a rugged industrial grade programmable controller utilizing relay ladder logic. This system is therefore capable of being programmed by personnel familiar with standard electrical diagrams. The operator will not need computer language such as FORTRAN or COBOL. A visual display provides the operator with both critical operating data, adjustments being made by the controller at a given moment, and alarms that are both visual and audible. The audible alarms are dual level so that operating personnel can distinguish between critical conditions requiring rapid attention and emergency demands for shut down procedural action.

The controller will scan all pertinent operating conditions several times a second, compare these data to standard operating data in the memory bank, indicate the control adjustment required and provide a visual display of the adjustment in-process. Extreme or abnormal conditions will trigger a buzzer alarm signifying rapid operator attention. Dangerous and very critical system failures will result in both an emergency horn and flashing lights on each trailer so that no matter where an operator is, he will be alerted to the emergency.

The control system is sufficiently sophisticated to allow high level throughput with reasonable fuel economy.

Capacities

The system design has been refined to provide the maximum practical capacity compatible with highway requirements, regulatory constraints, unknown feed stock variations and fuel economies. System components are matched in capacity for hazardous material detoxification necessitating a two second dwell, 2050°F temperature and 3% oxygen level.

Capacities are directly affected by subsystem limitations which manifest themselves in various ways depending on the type and physical properties of the waste feed stock being processed. The shredder, kiln, afterburner and gas treatment sub-systems are individually or together utilized to full capacity depending upon these feed stock characteristics. Capacities are intimately and severely impacted by both heat loss and excess air requirements.

Figs. 3—7 graphically show some of these interrelationships. The capacity graphs are based on the concept that, for most wastes handled, there is a mixture of sand, water and oil that will demonstrate an equivalent behavior in the system. To use the graphs, oil content is considered separately, e.g., a mixture of 80% dry sand, 10% water and 10% oil is treated as two wastes: 1/10 the weight is oil and 9/10 the weight is sand with 11.1% moisture. Throughput is determined from whichever portion is limiting.

The interplay of the various limits is best shown on the graph shown in Fig. 3. This graph shows the several approximate limits: three ash residence time limits, kiln burner limit and afterburner flow (or dwell) limit. The burning volume limit in the kiln is not shown on this particular graph — it is shown separately (Fig. 4).

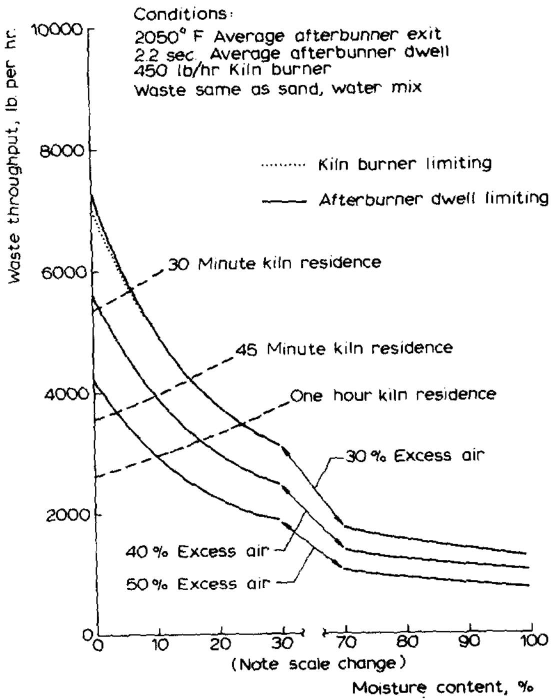

Fig. 3. Waste throughput vs. moisture content.

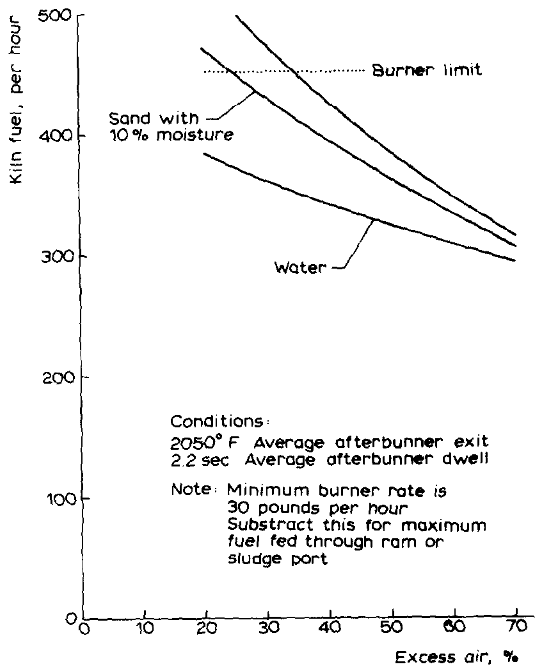

Fig. 4. Kiln fuel vs. excess air.

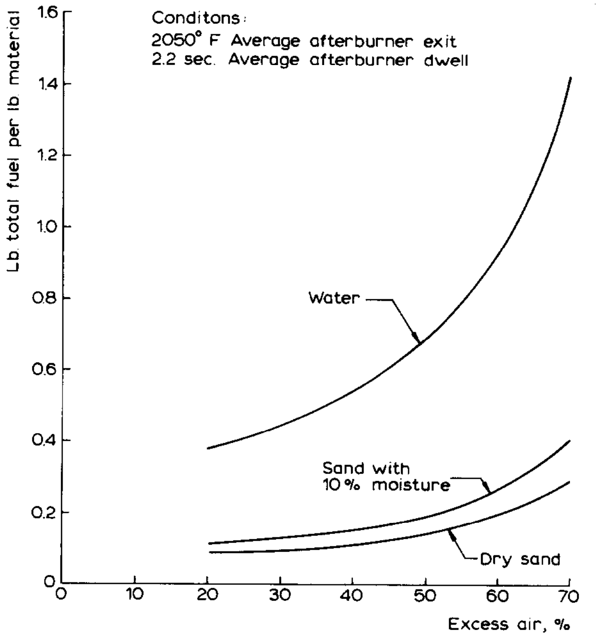

Fig. 5. Fuel use vs. excess air.

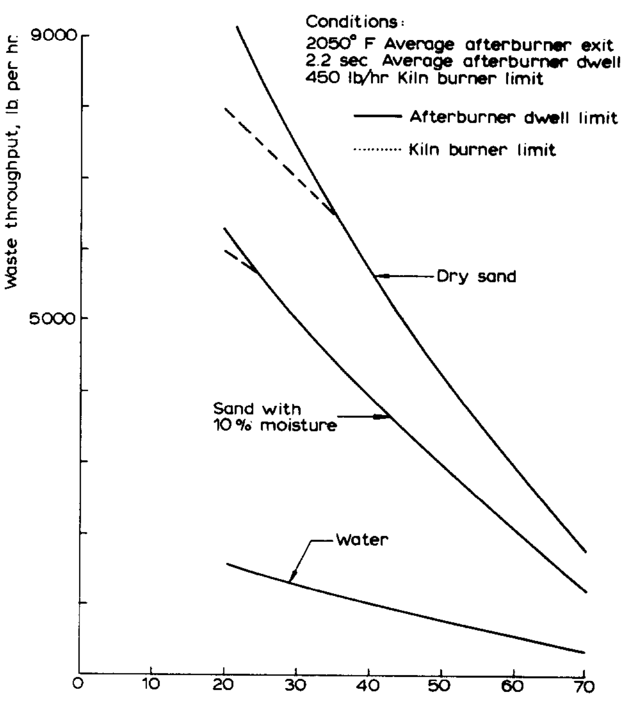

Fig. 6. Waste throughput vs. excess air.

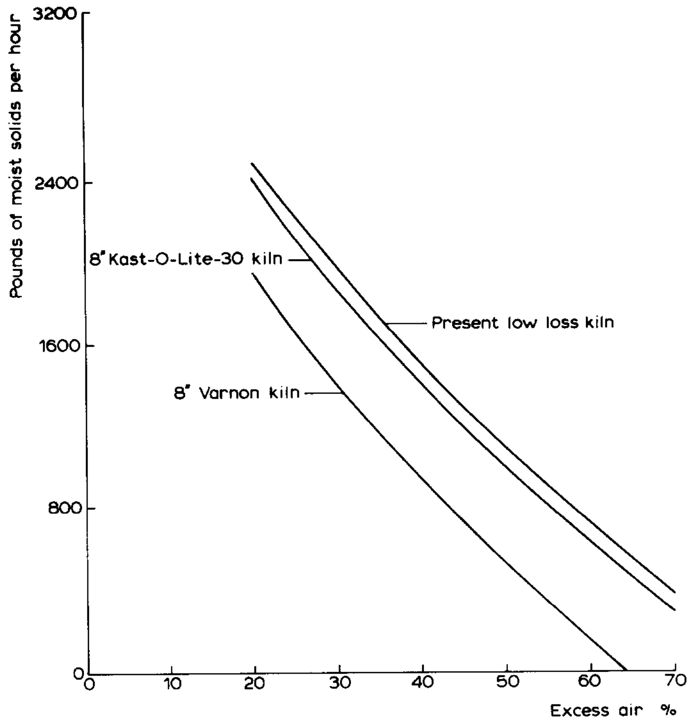

Fig. 7. Moist (10%) solids capacity, hazardous burn vs. excess air. Former 34 inch afterburner.

Shredder and ram capacity is a direct function of waste material bulk density and shear strength. Assuming a bulk density of moist sand requiring no shearing, the sub-system will deliver up to 240/ft^3 /h or approximately 24,000 pounds per hour; however, if bulk density dropped to 5 pounds/f^3 with zero heating value this sub-system would limit throughput.

The kiln however can limit in three ways: (1) Solids (or ash) can occupy 10—15% (12.5% typically) of the drum and the time required to remove a toxic material (expressed as ash residence time) determines the maximum volumetric rate for ash; (2) The oil burner has a maximum firing rate; and (3) Since each pound of fuel provides a volume of flame, the kiln volume limits the rate of that fuel. The afterburner requires a minimum gas residence (or dwell) time and this restricts the gas flow rate.

For dry materials, the graph (Fig. 3) shows the importance of the kiln capacity and the ash residence time. Dry material containing a toxic substance requiring an ash residence time of one hour and capable of being destroyed with 30% overall excess air will be limited to about 2,600 pounds per hour by the residence times requirement. For wastes that are mostly water the graph shows afterburner flow to be limiting.

Two of the limits for fuel value are shown on the graph of Fig. 4. When fuel-containing materials are introduced via the ram or sludge port, the burning volume in the kiln can become the feed rate limiter. Using an allowable design heat release rate of 36,000 BTU/h/ft^3, the fuel value so introduced is limited to 470 pounds of oil per hour. For wastes containing less than 5% oil, fuel content is not limiting and above 30% oil, the fuel content will definitely limit. For throughput between 5—30% each case must be independently analyzed.

The graphs illustrate the effect of excess air. Higher excess air values reduce capacity drastically for sand-water. Higher values also increase the amount of fuel needed per pound of waste, an undesirable fact when clean fuel is being used. Because of the adverse effects of high excess air values, the design has strived to keep excess air requirements to a moderate nominal value in the range of 20—60%.

The afterburner limits by virtue of the temperature and dwell requirements. Lower afterburner temperature will decrease fuel combustion product volumes and allow increased kiln throughput to be processed.

The gas stream processing equipment is sensitive to gas velocity constraints and/or pressure drop and thereby makes volume adjustments impractical in a mobile system. This same constraint holds true for the blower and blower drive. As such, the volume flow rate has been selected at 7,200 SCFM which is compatible with the kiln and afterburner during hazardous material detoxification constraints.

Acknowledgement

This project is being performed under Environmental Protection Agency Contract No. 68-03-2515, title "Design, construction and demonstration of a mobile, field-use system for the detoxification/incineration of residuals from oil and hazardous material spill clean-up operations".