Present and Future Disposal Methods for Industrial Solid and Liquid Wastes

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ABSTRACT

Some present and possibly future waste disposal methods involving substantial immediate volume reduction of waste processed.

This paper discusses data on solid waste disposal methods used in the plastics industry as obtained in a recent questionnaire survey of the polymer production and plastics fabrication sections of this industry.

Regional facilities for collective incineration are described briefly. Facilities used by a large chemical company in disposing of its plastic and other solid and liquid waste materials are also described.

Open pit incinerators and their operation are discussed briefly. Mention is made of other commercially-available industrial incinerators used to handle high Btu plastic wastes.

Some future incineration techniques are discussed. Included here are: suspension burning; melting with auxiliary fuel ("slagging" or "total" incineration) and fluid bed combustion. Pyrolysis techniques are discussed in reasonable detail as a future method of volume reduction of industrial waste with built-in air pollution control.

Several other methods of waste disposal under study now for probable future use are discussed briefly. Included here are: the Black-Clawson "Hydropulping" process; the Hercules combination process of digestor-pyrolysis-residue separation as being designed for use by one of the counties in the State of Delaware; and the recently-publicized Aluminum Association proposed process wherein refuse is subjected to shredding, fiber reclamation, magnetic separation, incineration or pyrolysis, noncombustible residue separation, screen and air-classification and waste-water treatment procedure. Air pollution controls on this process concept are also discussed very briefly.

DATA ON SOLID WASTE DISPOSAL FOR THE PLASTICS INDUSTRY

The entire plastics industry was considered to be 8-1/2 million tons in terms of U.S. consumption in 1969. The sales of the "big three" polymer types - the olefins, PVC, and the styrenes - represent about 5.36 million tons or 63% of the total industry.

Our sample constituted 68% of the "big three" volume and the estimated total scrap produced by the manufacturers of these three materials, based on individual scrap rates, is 52,500 tons per year. This represents 0.98% of the total U.S. production of olefins, PVC and styrene.

If it can be assumed (very roughly) that the other 37% of the U.S. plastics industry generates scrap at the same rate at the basic polymer production level, we can assume that the industry generated approximately 83,000 tons of totally unusable refuse in 1969.

By the same consideration, if it can be assumed that the cost of disposal holds true for the entire industry, then using the average cost of disposal calculated

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for the "big three", $17.40 per ton, it follows that the entire plastics industry paid roughly $1,450,000 for disposal of polymeric refuse in 1969. It is notable that the big three alone paid approximately $913,000 to dispose of their 52,500 tons of refuse.

Generally, the results of this survey indicate that the U.S. plastics industry is largely disposing of scrap by means of landfill, if not at their own site, then by contract to private or municipal agencies. Roughly 15% of all contacted use controlled incineration and claim to be able to meet current state and local pollution codes. This is commendable in view of the national rate of incineration of 9%. Logically, too, most of the plastics industry's users of incinerators, however, are the very large polymer manufacturers who are normally the leaders in innovative and advanced technology and who are able to dispose of relatively large amounts along with accumulations of other plant, laboratory and office wastes generated in the course of normal operating hours. For those whose operations do not justify the investment required in equipment and other things, the collection agency is a real help in removal of solid wastes from plant property.

Finally, if the figure of 83,000 tons of solid waste generated by polymer producers, ahead of any conversion operations, is added to the 380,000 tons of fabrication waste arrived at as described above, one obtains a total of 463,000 tons. This is a little less than 12% of all plastics solid waste (4 million tons) in the United States in 1969-1970. It is unfortunate that the sample, while it was quite adequate and representative from the standpoint of polymer producers, is insufficient from the standpoint of polymer users or fabricators. The number of replies, in relation to the invitation to participate, was much smaller, even on a percentage basis, and also was short on the total number of invitations sent to fabricators. To make the best use of the data which did come in from fabricators, averages and familiarity with general operating procedures were utilized to try to present logical data. It cannot be said that the data actually obtained from fabricators was strong enough to be considered a true survey. The data obtained from polymer producers is believed to be accurate enough to be considered strong enough to stand as a survey [1].

EQUIPMENT MANUFACTURERS

In addition to the survey made of polymer producers and fabricators, a secondary survey was made among equipment manufacturers. Of those replying to the survey, 50% were manufacturers of incinerators, either municipal or industrial; 35% made compacting, size reduction or other grinding-shredding equipment; and 15% made conveyors, scrubbers, cyclones and other handling equipment.

INCINERATOR MANUFACTURERS

All who replied made industrial incinerators, 65% making both municipal and industrial, and 35% making only industrial types. Eighty percent indicated that their incinerators would handle plastics, the other 20% did not give this information. Seventy-five percent indicated that their equipment would handle PVC, depending on the quantity of this material in a given mix. Only 10% stated that their equipment would not handle plastics, the remaining 15% hedged on the question without giving an answer useful in the survey.

Eighty percent of the replies indicated that their equipment would meet pollution control regulations. Only 5% were not supplied with pollution control devices.

In capacities, only three replies were from manufacturers of incinerators in excess of 500 tons/day. Nine made incinerators with capacities of over 100 but less than 500 tons/day. Eleven made them with capacities of more than 10 but less than 100 tons/day. Eight made them only with capacities up to 10 tons/day.

Costs were widely varying covering a range of $4 to $9.20/ton.

NONINCINERATOR EQUIPMENT

In this category, 70% of the sample made compactors or other size reduction equipment and 30% made conveyors, scrubbers, cyclones, and other handling equipment. Of the compactor portion of the sample, approximately 80% made either compactors alone or both compactors and comminuting equipment. About 50% of the sample made only comminuting equipment.

In regard to the ability of the equipment to handle plastics, 100% of the compactor-comminuting portion of the sample stated that their equipment would handle plastics without problems.

Capacity-wise, these ran from as little as one ton/day to 600 tons/day; cost-wise, depending on capacities and work done, these ranged from $0.60 to $6.00 per ton.

In the general equipment sector, (scrubbers, cyclones, etc.), all expected their equipment to be used where plastics were involved. All indicated that where scrubbers, cyclones or other precipitators were concerned, codes could easily be met. Capacity-wise, some of these equipment manufacturers go from small units up to the largest ones for municipal incineration.

The sample did not contain enough respondents to obtain meaningful cost data. Further, where replies were received, the most common comment was "too variable. . . job would have to be studied."

As general comments on the equipment manufacturers' role in the disposal of plastics solid waste, it appears that there is good equipment available, good data on operational problems, various state and local codes can be met but cost estimates leave a great deal to be desired.

INDUSTRIAL INCINERATORS

While plastics industrial solid wastes are estimated to be less than 12% of the total of all plastics solid waste generated–in 1969 estimated at less than 500,000 tons–some producing companies may wish to dispose of their own wastes. Incinerators built to consume these relatively small quantities may be difficult to justify economically unless there are other type wastes to be disposed of concurrently.

In many cases, depending on plant locations, type of refuse to be disposed of and other factors, management might be well advised to compare the cost of disposal by hauling to a regional plant operated by an outside contractor versus the capital investment required and operating costs of disposal plants on their own premises. The regional facility will very frequently be able to assume an investment in equipment and other expenditures that simply cannot be justified by a single, average-size industrial plant. Further, such enterprises are able to take the full responsibility for the operation insofar as the solid waste disposal is concerned.

While there are several types of incinerators which are effective for industrial solid wastes, those which do not have grates which plug easily seem to be more widely used where plastics are involved. Rotary kiln types have been used successfully both in the U.S. and in Europe in the incineration of solid wastes containing relatively high proportions of plastic materials (up to 30% of the charge weight). Today, equipment and methods are available to treat industrial wastes for disposal without adding to either air or water pollution problems in the vicinity. Of course, residues of up to 25% of the charge are common, depending on the amount of combustible material. Provision for disposal of residue is necessary.

Such a facility is described in detail [2]. The rotary kiln or rotary incinerator consists of a revolving refractory-lined cylinder, slightly inclined to the horizontal, supported by two riding rings resting on two trunnion rolls each, with the trunnion roll bearings mounted on a structural steel base. On each side of one of the riding rings, a flanged trunnion roll holds the cylinder in its proper longitudinal position. The cylinder is rotated by means of power-driven trunnion rolls with a through-shaft, which extends through two trunnion rolls on one side of the cylinder and is directly coupled to a helical gear speed reducer driven by an electric motor.

The inside of the cylinder is refractory lined along its entire length, suitable for the required operating temperatures and for the various waste materials to be handled.

The flow of waste material through the incinerator kiln is controlled by the slope of the cylinder to the horizontal, its rotational speed, and the velocity of the gases going through it. The revolving cylinder imparts a rolling and mixing action to the material, which produced complete and thorough waste volatilization.

The rotary kiln is equipped with furnace temperature control, temperature recorders, furnace-draft indicator, and a high furnace-temperature alarm.

The kiln can also operate by burning liquid wastes and solid wastes on a limited capacity.

No heat recovery has been incorporated in the installation. Heat recovery can be accomplished through the addition of a waste-heat-recovery boiler to generate steam or through the direct use of the high-temperature flue gases in a process requiring external heat source.

Future installations should incorporate the addition of a steam boiler or the direct use of high-temperature flue gas for reheat, drying or tempering furnaces.

Predictions of the extent of air pollution from operation of this incinerator installation are extremely difficult to make because the types of wastes to be burned will vary with the contracts for the waste disposal obtained.

Where there is a demand for such services, industrial wastes and refuse (liquid as well as solid wastes) can be collected by and disposed of by companies equipped to handle large volumes of wastes generated by several factories located within reasonable transportation ranges. For example, in Canada, Goodfellow Enterprises has handled industrial wastes in the highly-industrialized Sarnia, Ontario locality and, in the United States, Rollins-Purle, Inc. is reported to be building facilities in several industrialized areas in Eastern, Southern and Western sections of the country. Equipment to handle all types of wastes, both solid and liquid, is planned for all of these locations. Others who are active in systems-oriented disposal plants are said to be Chemtrol Pollution Services, Consolidated

Oxidation Process Enterprises, Pollution Controls and Industrial Services of America. Others who have developed systems are Westinghouse and Ecology, Inc. Since the industrial solid waste portion of the plastics industry does not appear, with a few exceptions, to be large enough for most companies in this industry to justify the expense of such installations, investigation of their availability on contract arrangement would appear to be of interest.

In the disposal of industrial wastes, including liquids [3], Dow Chemical Co. operates facilities to incinerate waste products from a large number of chemical processing plants located on 46 acres at Midland, Michigan. Plastics burned have included polystyrene (resin and foam), PVC and a number of others.

Primary incineration units [3] used for disposal of solid wastes consist of a 65 $\bar{M}$ Btu/hr. rotary kiln incinerator which is used for the incineration of chemical refuse and liquid residues and an 81 $\bar{M}$ Btu/hr. liquid residue incinerator. These units are backed up by one 32 $\bar{M}$ Btu/hr. Hooker liquid residue incinerator, a 56 $\bar{M}$ Btu/hr. Bigelow Liptak liquid residue incinerator, and a 65 $\bar{M}$ Btu/hr. vertical liquid residue incinerator. All water wastes resulting from these operations are routed to water waste treatment facilities. In addition to these facilities, also operated is a landfill area which covers 200 acres.

In terms of today's dollars, well over six million dollars are invested in incineration equipment alone at the Midland plant [3].

Literature reviewed includes the development of open pit incineration for solid waste disposal [4, 5] as used by many DuPont company plants. While quite a number of these units are in use or are being built, the author states that complete experience with every possible solid waste has not been obtained nor have full quantitative measurements of possible air pollution been attempted on other than an experimental unit.

The author [5] is president of Thermal Research and Engineering Corporation, Conshohocken, Pa., who is undertaking, with DuPont's cooperation, the construction of the open pit incinerator for interested companies. It is distinguished from conventional types by its open top, and features a system of closely spaced nozzles admitting a screen of high velocity air over the combustion zone. With a variety of solid industrial wastes, results show high burning rates, leading to complete combustion and high flame temperature.

The author [5] states that the more important criteria of a solid waste incinerator for general purposes are the following: lack of heat absorbing surfaces, non-uniform fuel supply, grates not suitable, low level of labor and maintenance and no "standard" packaged units. The author claims that the open pit incinerator offers solutions to these criteria because it provides use of sky to absorb heat, offers simplified fuel handling, no grates needed with 100% overfire air, no need for skilled labor or high maintenance and low investment.

Industrial incinerators to handle high Btu waste plastics are mentioned [1]. One such is the Combustall, offered by Air Preheater Co. (sub. of Combustion Engineering,) Wellsville, New York. Complete data has been obtained from the manufacturer. Briefly, chamber and after-burner design, all metallic and refractory materials and burners are designed to burning requirements of high Btu materials. Four sizes, from 3 to 6 cu. yds. capacity per batch are listed as available. Another type, the Consumat, is offered by Virginia Combustion Co., Alexandria, Va. This operates on the minimum air principle (or "starved air") for combustion. Four sizes (125 to 760 cu. ft. capacities) are offered.

There are limitations on the amount of plastics per load, particularly PVC, on which the data provided are quite definite. Other types, suitable for industrial incineration, have been covered elsewhere in the survey.

SOME FUTURE INCINERATION TECHNIQUES

Some of the more novel approaches to incineration of industrial and municipal refuse under experimentation are suspension burning, melting with auxiliary fuel, pyrolysis, fluid bed combustion and pressurized burning.

Melting of the incombustible residue can be accomplished if the heat release of the burning refuse is augmented by burning it with a high quality fuel like coke in a properly designed refractory chamber. The melted residue, including metals and minerals, can be run into a water bath where it solidifies and fractures into coarse crystals which are probably the ultimate in cleanliness, compactness and desirability as a residue. This method is "Total Incineration".

Total incineration is defined in this survey as the conversion of refuse to solidified slag and flue gases, the latter including mainly carbon dioxide, oxygen, nitrogen, and water vapor. The slag by-product represents the lowest possible volume of ash residue. Such stonelike slag does not require a large residue-disposal site as is necessary for the disposal of "bonfire ash" from present incinerators. Therefore, the total incineration plant can be located in a heavy industrial area and closer to the source of municipal refuse than the conventional incinerator, because of the need for less space.

In contrast to conventional incineration, which produces a "bonfire ash" at furnace temperatures in the order of 1800°F, all or part of the total incineration system must operate at temperature approaching 3000°F in order to convert the ash residue to a liquid slag that can be drained from the furnace and solidified. This slag either can be quenched in water to form a granular material or can be allowed to cool slowly in a pit to produce a solid mass, which can subsequently be broken into lavalike lumps, similar in size to crushed stone.

The principal objectives of total incineration are:

1) Maximum volume reduction of solid waste (approximating 97.5 percent);

2) Complete combustion or oxidation of all combustible materials, producing a solidified slag that is sterile, free of putrescible matter, compact, dense, and strong;

3) Elimination of the necessity for a large residue-disposal operation adjacent to the incinerator; and

4) Complete oxidation of the gaseous products of incineration with discharge to the atmosphere after adequate treatment for air-pollution control.

Fusion of the incombustible residue can be accomplished either by operating the incineration process at temperatures above the melting temperature of the ash residue or by melting the ash in a separate device subsequent to conventional incineration. Temperatures in excess of 2600 to 2800°F are required for fusion, with the actual temperature depending upon the composition of the ash in the refuse. However, to insure adequate fluidity of the slag, a temperature approaching 3000°F should be maintained.

Air pollution from total incineration systems can be controlled with conventional air pollution control devices. Costs for such air pollution control systems are uncertain inasmuch as total incineration systems may produce higher particulate loadings (higher efficiency required) but lower flue gas volume flows than conventional incineration.

The operation of total incineration systems will require new and additional skills of plant operating personnel.

Suspension burning [6] widely used in power boilers, consists of blowing finely divided fuel into a vortex pattern in a furnace chamber so that it burns while suspended in the turbulent air stream. It is efficient and can provide high heat release, in a relatively small volume, without the necessity for supporting a burning fuel bed or a grate or hearth. It is to be presumed that if refuse were the fuel, it would have to undergo controlled proportioning (comminuting). Plastics have heat release values of 125-150,000 Btu/cu. ft.

Another type of suspension burning is discussed [6]. This involved tangential firing. The term "tangential" derives from the method used to introduce the fuel into the furnace, in this case refuse and combustion air. Pneumatic lines deliver refuse to each elevation of tangential nozzles, one line per corner. The refuse and the heated combustion air are directed tangentially to an imaginary cylinder in the center of the furnace. Fuel and air are mixed in a single fireball. This proceudre precludes the possibility of poor distribution of fuel and air; it also permits operation with less excess air, thereby reducing the size of the flue gas cleaning equipment. The refuse nozzles can be tilted upward or downward to accommodate variations in refuse characteristics and load. With tangential firing, the fuel particles have a longer residence time in the hottest furnace zone, thereby assuring complete combustion of waste fuels with low heat content.

As the burning refuse particles spin downward, additional preheated combustion air is introduced in the lower furnace through multiple rows of tangential nozzles. This continues the combustion process and maintains particle momentum. Since the larger refuse particles will not be completely burned in suspension, a small grate may be required in the bottom of the furnace to complete combustion of the larger particles and to remove ash.

Oil or gas firing is usually included for use during startup and as a secondary fuel.

Fluidized beds function on the principle that beds of solid particles can be set in motion by passing a stream of gas under controlled conditions up through the solid particles making up the bed [7]. Generally, it can be said that fluid beds will burn anything that can be fed into them. Solid wastes with a minimum of free surface water are blown into the reactor, whereas dryer materials can be fed by means of a sealing type screw conveyor. Semiplastic sludges might be fed by a progressing cavity pump. Thermoplastic materials like grease are most readily fed by first being melted and then centrifugally pumped.

The fluidized bed zone contains the fluidized medium—inert material such as sand or pelletized ash. Bed depth is controlled to give the desired residence time for the incineration conditions. A fluid bed incineration system will normally consist of the following components: [7]

- The fluid bed reactor, made up of a plenum chamber, and orifice plate, a fluid bed or combustion zone and a disengagement or free board zone.
- A main air supply furnishing air for both fluidization and oxidation (combustion).

– A primary dust collection system.
– A secondary dust collection or gas scrubbing system.
– A feed and product discharge system.
– Instrumentation to make the system automatic in operation.

Another example of fluid bed incineration is described. This is an attempt to develop a new incineration system to burn municipal refuse and expand the resulting hot gases through a gas turbine to produce mechanical power. Experimental tests are being conducted at present, with full-scale prototype to burn 400 tons of refuse per day in fluidized bed planned for 1972. Refuse is fed into the bed where a temperature of 1500 to 1650°F is maintained. Combustion air at 100 psi and about 600°F is admitted into the bottom of the bed. Exhaust gases pass into a cleaning system and then to a gas turbine which will drive a compressor and an electrical generator. After passage through the turbine the still-hot gases will be used to heat the drying air or can pass through a boiler to produce steam. Two problem areas are (1) development of a combustor capable of operating reliably under high pressure, and (2) removing particles and corrosives from the hot gases to ensure adequate life for the turbine blades. The next phase of the CPU-400 Project is to investigate the design and operation of a large-scale fluid bed burning refuse unit fed by a realistic solid waste processing system.

PYROLYSIS

Pyrolysis, as a process, is essentially that of reforming–gasifying the decomposable portions of the waste by controlled heat. Prior to the experimentation on municipal refuse, pyrolysis was confined to the carbonization and thermolysis of waste wood from wood processing plants and to the coking of coal. These latter two feed materials had a great deal more to offer from the uniformity standpoint than did refuse which can (and does) contain such a variety of materials as paper, leaves and grass, wood, rags (i.e. textile materials), rubber, plastic, garbage, metal and glass in varying amounts.

In 1965, the Utilities Department of the City of San Diego, California with partial support from HEW, USPHS, began a three-year study for the disposal of solid municipal wastes, investigating the feasibility of pyrolysis as an economic method of decreasing the volume of solid municipal wastes and for producing useful by-products. Pyrolysis of solid wastes appeared to be promising because life of sanitary landfills could be extended substantially (assuming not more than 50% solid residue to be disposed of after pyrolysis treatment), engineering calculations indicated the process should be self-fueling and the by-products of the process might have some commercial value.

The author's conclusions indicate that the volume reduction of the refuse put through the pyrolysis process is in excess of 50%; once started the process is likely to be self-sustaining; the inert solids are satisfactory fill material; the other products yielded by the process may constitute materials for a salvage market; and the capital cost of large scale equipment is estimated at about 67% of those for incineration.

The Destrugas process, originating in Denmark by G. Borggreen, is covered in [8]. It is mentioned here because it appears to be the only commercial example of the pyrolysis process which the survey found. The Kolding plant was built and began operating in January, 1967. It was test run for nine months during which time 3000 tons of "garbage" had been destructed–the gases produced amounted to 1.2 million cubic meters. Due to lack of funds for further testing, Destrugas Ltd. asked the Karl Kroyer Company to carry on the project. The latter company has built a pilot plant at Holmstrup, Funen to develop the process further.

Further to U.S. effort in the pyrolysis field, pyrolysis is defined as the "chemical change brought about by the action of heat"–it should also be thought of as destructive distillation in the absence of oxygen or other oxidants. A carrier gas, other than oxygen, of course, is utilized. Variations in effluent products are due to changes in operating conditions, such as temperature, rate of temperature increase, gas flow, feed material and other parameters. The variability in ratios of both gaseous and liquid products depends on the nature of the original organic compounds. Oxygenated molecules present in the waste will produce higher percentages of CO, CO_2 and O_2 while proteins, polyurethanes and other nitrogenated compounds will produce nitrogen gas or ammonia. Higher ratios of polymeric hydrocarbons should produce more methane, ethane and other paraffins. The char consists of carbonaceous material fused with glass and other inerts.

Quoting from [9],

> "In order to elucidate the parameters involved in the pyrolysis process and provide the inputs needed for a detailed economic evaluation, a bench-scale project was initiated. Following a one-year laboratory study a detailed evaluation was undertaken to determine the economics of a commercial size plant.

The apparatus used to conduct the refuse pyrolysis experiments consisted of a stainless steel retort and train of cold-traps capable of operation under reduced pressures. The composition of the laboratory refuse mixture was based on reported values with the exclusion of inorganic material to facilitate handling. For each run, the retort was charged with 100 grams of the previously prepared (shredded and dried) refuse mixture. The retort was then placed in a furnace preheated to 500°F. The temperature of both the charge at its center and the furnace were subsequently monitored by a recording potentiometer. The heating rate was calculated as the average time required to raise the temperature of the charge from 212°F to 1700°F."

Pyrolysis of the refuse mix gave rise to four basic products: gases, water, organic liquids and char. The product distribution was found to vary with changes in the heating rate. At slow heating rates, 5-20°F/min. the char make was up due to the longer retention time in the retort. Faster rates, 40-70°F/min., gave higher liquid yields due to faster removal of the distillates and less coking. In addition, the gaseous fraction increased due to further cracking.

Gas product distribution as a function of heating rate and composition of the gas produced was observed to change considerably as the run progressed. Based on the nature of the gas distribution, it would appear possible to segregate a fuel-rich or hydrogen-rich stream. More likely, the total gas produced would be used as fuel to sustain the pyrolysis process during operation.

Since these gases are free of sulfur, chlorine and particulate matter, their burning will not contribute to air pollution.

The organic liquid portion, representing the potential source of synthetic crude, was of primary interest. The liquids were separated into three fractions, water-soluble volatiles, water-soluble and water-insoluble non-volatiles. The water-soluble volatile portion, while representing about 10% of the organic make, does contain valuable petro-chemicals. The water-insoluble non-volatiles, a black, tarry material, formed an average 85% of the organic liquid fraction. It consists mainly of oxygenated compounds: esters and acids. The other major product is a high ash char having a heat value of slightly more than 10,000 Btu/lb.

The commercial size refuse pyrolysis plant consists of the following unit sections: feed storage and preparation, pyrolysis, product separation and storage.

Plant considerations range from the underground storage capability through initial salvage operation, feed preparation to the pyrolysis chamber itself. After volume reduction by 50% in the rotary kiln, the products are separated into gases, liquids, and char, which are then upgraded to salable products. The gas may be sold or utilized as fuel in the operation of the system.

A review of pyrolysis techniques indicates that such systems have been developed to operate over a wide range of conditions, including those presumed necessary for solid waste pyrolysis. For example, both fluid bed and non-fluid bed systems collect a solid product using the gas and/or liquid products to provide the necessary heat. However, other systems have been designed to maximize the yield of the liquid or gaseous fractions.

Thus, there is a wealth of analogous technology applicable to the pyrolysis of solid materials including operating and economic data. It remains to (1) select the process best suited for solid waste pyrolysis (modifying as necessary), (2) further delineate the economics of such a process, and (3) demonstrate its use on solid wastes in a pilot or demonstration plant.

OTHER METHODS

There are a number of other disposal methods under study at present in the U.S. These range from completely experimental to large size pilot operations. None has reached the status of a commercial operation suitable for municipal use, although some may reach this stage within the next five years. While it will not be possible to list all of these methods, some of those under development and not mentioned elsewhere in the survey are:

THE BLACK-CLAWSON PROCESS [10]

A method of separation which has reached the pilot plant stage is the so-called "Hydropulping" process of the Black-Clawson Company, manufacturers of paper-making machinery. By passing all municipal refuse into a little-modified pulping tank, in which pumps and impellers induce a strong vortex and associated mixing and tearing, the paper products break down and are recovered by filtering the resulting pulp through a succession of perforated-screen and slotted classifiers. A 5/8 inch dia. hole screen is used first to take out the glass, cans and so forth and subsequently a screen with 1/8 inch dia. holes and another with 0.014 inch slits are used to select fibers and to reject flakes, rubber-like balls (from, for example, pressure-sensitive adhesive backings) and pieces of plastic film.

Subsequently a close screen (150-mesh wire) is used to retain the desired fibers and to reject the fines. The fiber is dewatered and thickened and baled for use in a paper mill.

The ferrous cans are recovered magnetically and the glass from bottles broken in the pulper is screened out.

The Black-Clawson process is thus a complete binary branches system. (There are additional binary sorters on the metal and glass branches designed to yield products with as little contamination as possible.) [10] Over 50% of the incoming feed is sorted into reclaimable materials. Including income from these products, economic predictions made by Black-Clawson are for refuse-treatment costs of 70 cents per ton for a 500-tons-per-day plant and a net income of 90 cents per ton if the volume is 1,000 tons per day. If these projections are borne out in practice the whole solid-waste picture would be transformed, and steady markets for secondary pulp, glass cullet and cans would need to be assured.

COMBINED DIGESTOR-PYROLYSIS-RESIDUE SEPARATION PROCESS

A $1 million contract for design and engineering work for the plant was signed in July 1970 after negotiations were completed between Hercules and the State of Delaware [1].

The proposed $10 million plant should begin procesing 500 tons of domestic and industrial refuse per day within two years after signing of the design contract. The demonstration plant will also dispose of 70 tons of sewage sludge per day. Future expansion plans call for a doubling of the plant's capacity.

After removal of ferrous metals, the refuse and sewage will be converted into a humus compound, and various oils and tars. The humus compound is an excellent additive for soil treatment and may be developed in the future as an animal food additive.

The oils and tars can be sold as fuels or used to fuel the plant itself. Company officials envision the plant to become self-sustaining, or even profitable, after a shakedown period.

Employing approximately 50 people, the plant will dispose of automobile tires, bulk plastics and paper as easily as other wastes. It will be practically odorless and will operate well within federal regulations governing air and water pollution.

The proposed plant is based on three key developments. The first is a digester system for converting organic waste materials to a high-quality sanitary humus. The digestion operation will also accept sewage sludge as feed material which becomes part of the sanitary humus product after digestion.

The second development is the application of pyrolysis techniques to the controlled decomposition of organic solid wastes, such as rubber and plastics. In pyrolysis, substances are subjected to high temperatures without the presence of oxygen so that they cannot ignite. The Hercules design will pyrolyze only the nondigestible materials, yielding the oils and tars that can be used as fuels.

The third key development is a residue separation system. The feed to this system will consist of the inorganic residue separated from the digester discharge. The separation of the metals, glass and grit will be accomplished by a series of screeners, gravity tables, and associated separation equipment.

ALUMINUM ASSOCIATION DISPOSAL PROCESS

This process is described in detail [11] and elsewhere in recent literature. While it is much more suited to the needs of municipal incineration, small capacity units would appear to be suited for almost any type of industrial waste short of explosive or radioactive materials.

Very briefly, the system has in its operation almost all of the processing characteristics of disposal by shredding, separation, incineration, pyrolysis, non-combustible reclamation, waste water treatment and other principles including residue disposal. Refuse is first put through shredders, then through magnetic separation, then to storage silos or into process, then to incinerator fitted with steam generation equipment or to pyrolysis unit, non-combustible matter from incinerator or pyrolysis to Bureau of Mines separation (residue) unit for separation into ferrous metal, clear glass, colored glass, and sand. Prior to entering the main processing line, refuse goes through a fiber reclamation system. Following magnetic separation, the fractions can be put through screen and air classification.

Air pollution control equipment is provided for the incinerators, the pyrolysis unit and ventilation of the plant in general. An electrostatic precipitator with two compartments protects the atmosphere from particulate matter emitted from the incinerators. A packed tower scrubber (in series with the precipitator) removes sulfur compounds, chlorides and odors. The tower uses a solution of sodium carbonate, sodium hydroxide or potassium permanganate. Other air pollution control equipment to be specified in the plant design include venturi scrubber baghouses and fabric filter collectors. For example, a venturi scrubber is used to remove kiln emissions from the pyrolysis unit. Other areas of the projected plant are protected by fabric filter collectors.

Costs of the completed plant with facilities discussed [11] is projected at $15 million capital investment and it will require 10 acres of land. Capacity is stated to be [11] 2,500 tons per week. Demonstration funds are being sought and several urban areas, including Washington, D.C. are under consideration [11] for the site.

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