

[54] **DISPOSAL OF WASTE PLASTIC AND
RECOVERY OF VALUABLE PRODUCTS
THEREFROM**

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[58] Field of Search 23/154, 155, 152, 1 R; 423/481, 488, 659; 201/25, 32, 36; 260/669 R, 683 R

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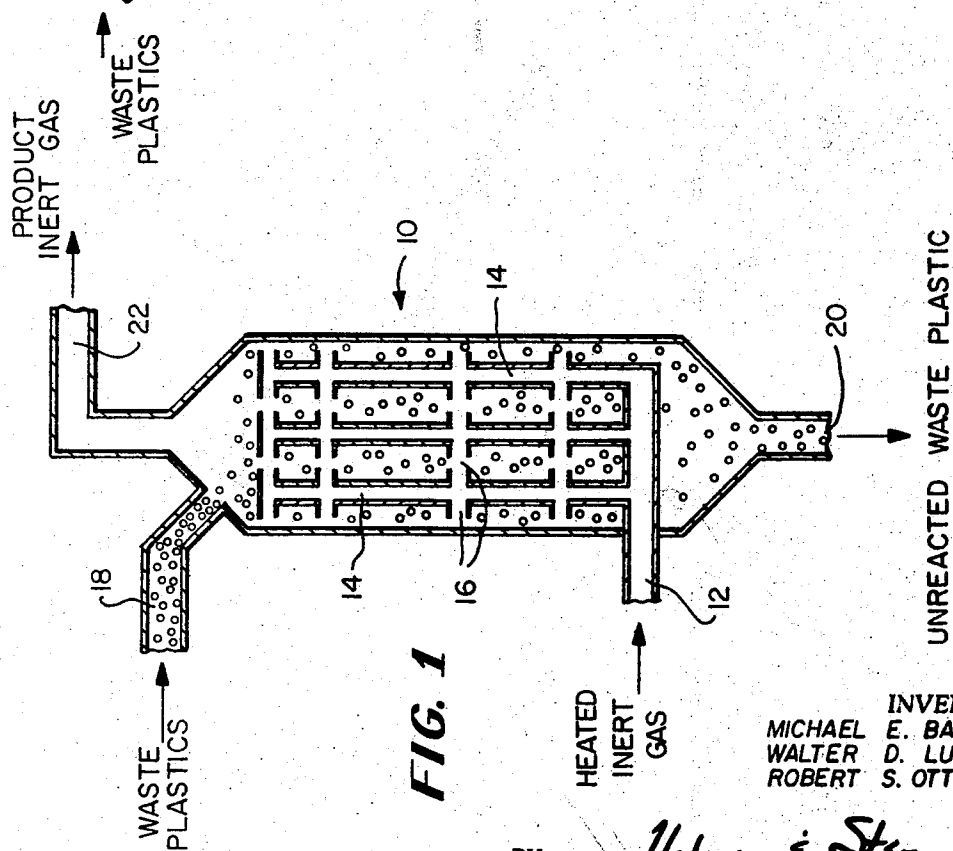
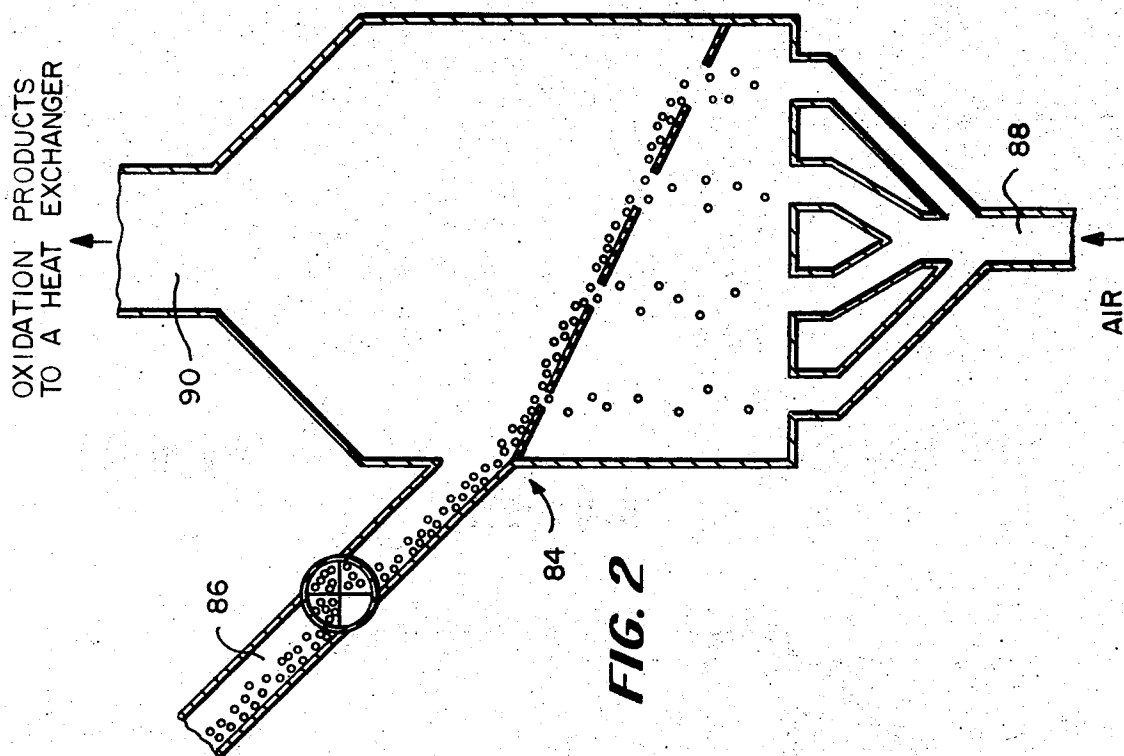
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[57]

ABSTRACT

A method of disposing of waste plastic without polluting the environment by passing the plastic to a reactor, heating the plastic in the presence of a gas to at least the decomposition temperature of the plastic, and recovering decomposition products therefrom. The preferred embodiment utilizes a heated inert carrier gas as the source of heat.

5 Claims, 5 Drawing Figures



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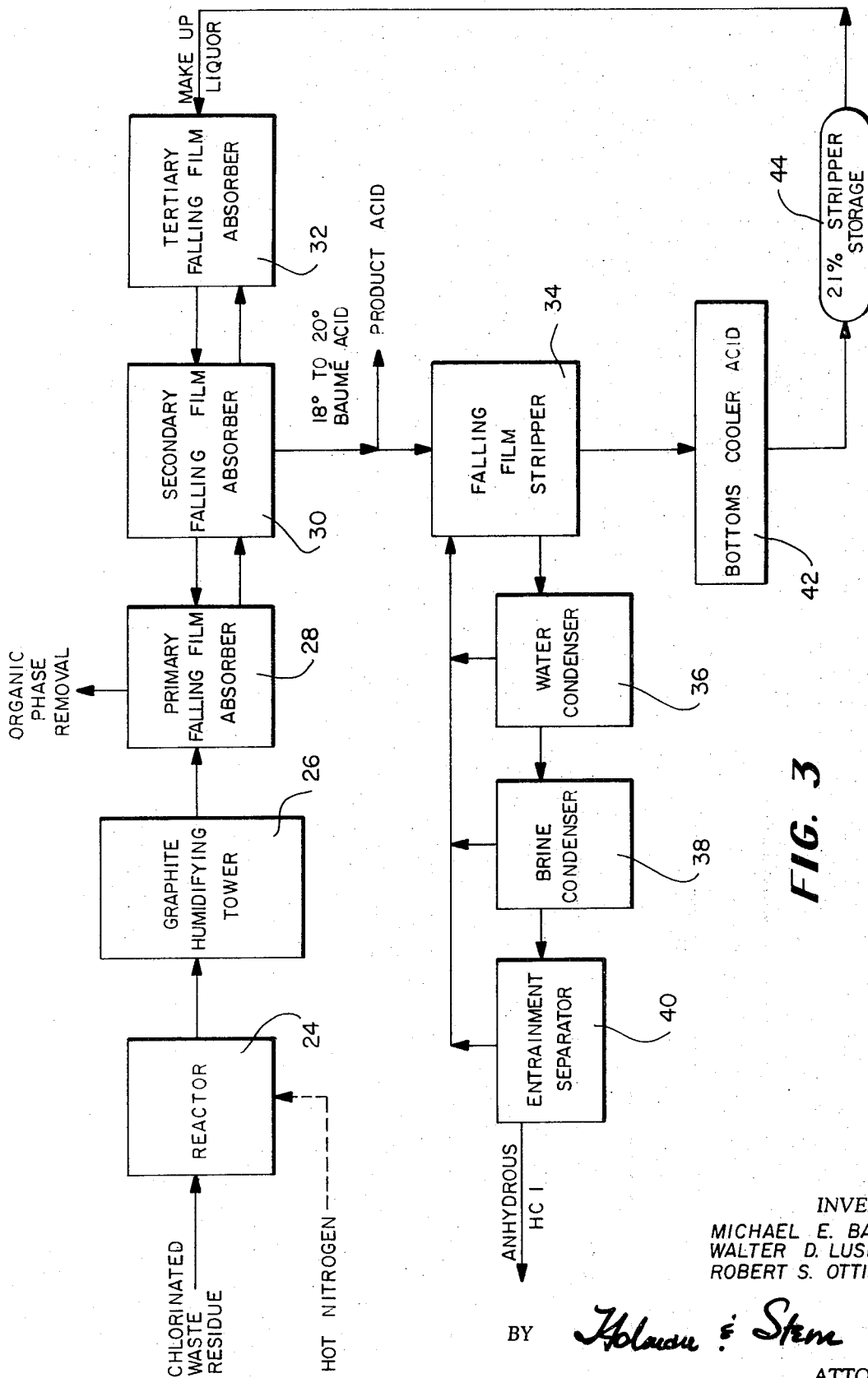


FIG. 3

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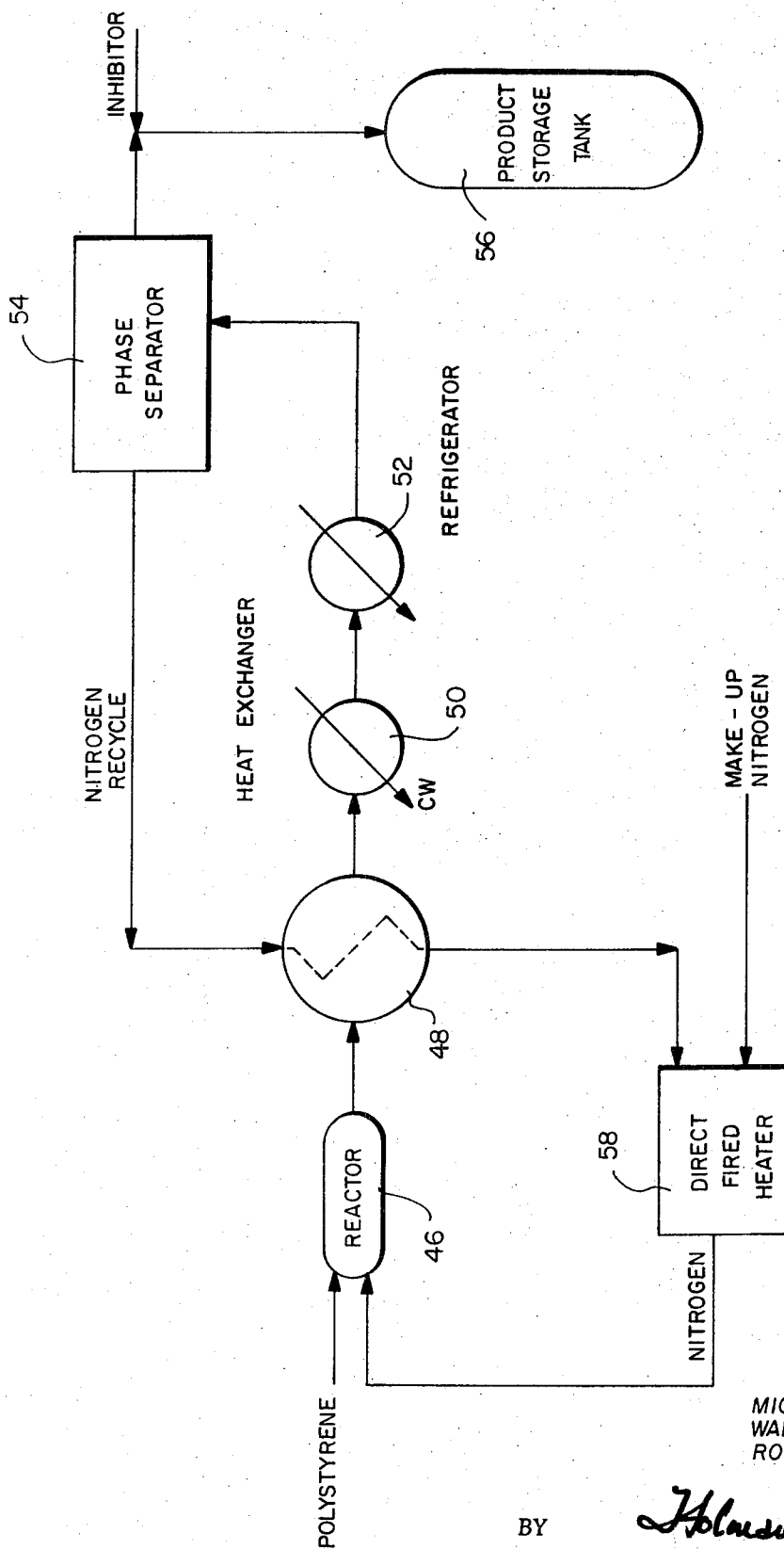


FIG. 4

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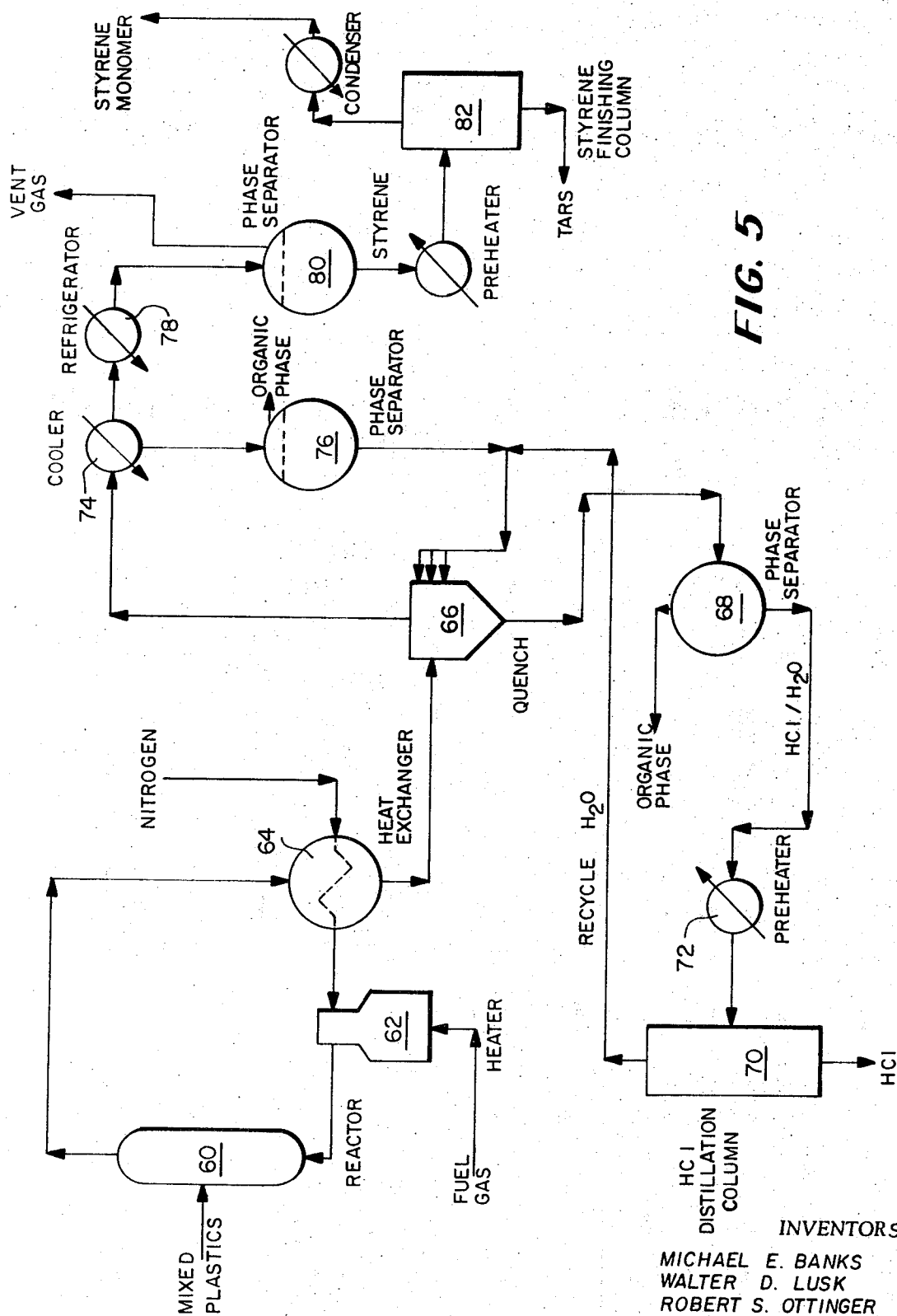


FIG. 5

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DISPOSAL OF WASTE PLASTIC AND RECOVERY OF VALUABLE PRODUCTS THEREFROM

BACKGROUND OF THE INVENTION

This invention relates to the disposal of waste plastic without polluting the environment, and more particularly to a method of thermally decomposing waste plastic and recovering the decomposition products thereof.

Various methods have traditionally been used for the disposal of solid waste material over the years. These methods can be broadly classified in two categories, namely destruction by burning and disposal into the environment by either dumping into the sea or burying on land. Each of these methods in general contributes to the pollution of the environment and is, therefore, undesirable. An increasingly large percentage of solid wastes is occupied by various plastics which have rapidly displaced other materials in a modern technological society. The disadvantages associated with disposal of plastics in the traditional manner are manifest. If plastics are merely dumped into the ocean or other waterways, or are buried or used for so-called "sanitary land fill," they represent pollution in a very basic sense. These materials are not bio-degradable and, therefore, remain in an unchanged state. On the other hand, if plastics are incinerated they form products which, when released to the atmosphere, represent a grave danger to the community. These combustion products, depending on the type of plastic involved, include hydrogen cyanide, hydrogen chloride gas, various nitrogen oxides, and the like. Thus, it is abundantly clear that methods and means must be developed for the disposal of plastic waste without polluting the environment.

Accordingly, it is a primary object of the present invention to provide a method of disposing of waste plastic without polluting the environment which is free of the aforementioned and other such disadvantages.

It is another primary object of the present invention to provide a method of disposing of waste plastic without polluting the environment and recovering certain by-products of the disposal.

It is a further object of the present invention to provide a method of disposing of waste plastic by thermal degradation without polluting the environment and recovering the degradation products thereof.

It is still another object of the present invention to provide a method of disposing of waste plastics either of a single type or a mixture of plastics, without polluting the environment by thermal degradation thereof and recovery of degradation products.

It is yet another object of the present invention to provide a method of disposing of waste plastics without polluting the environment by heating the same in the presence of an inert carrier gas to at least the decomposition temperature of the plastic and recovering the decomposition products thereof.

DETAILED DESCRIPTION OF THE INVENTION

This invention will be better understood, and objects other than those set forth will become apparent, after reading the following detailed description thereof. Such description refers to the annexed drawings presenting preferred and illustrative embodiments of the invention.

In the drawings:

FIG. 1 is a schematic elevational view of a semi-continuous reactor suitable for use in one embodiment of the present invention;

FIG. 2 is a schematic elevational view of a combustion reactor suitable for use in another embodiment of the present invention;

FIG. 3 is a schematic flow diagram of the various steps according to a preferred embodiment of the present invention;

FIG. 4 is a flow diagram of the steps according to another embodiment of the present invention; and

FIG. 5 is a flow diagram of the steps according to another embodiment of the present invention.

In its most basic aspect, the present invention involves a method of disposing of waste plastic without polluting the environment by thermally degrading the same in a reactor and recovering certain decomposition products thereof which have economic value while combusting other decomposition products for the recovery of heat value. The present invention involves the disposal of waste plastics which fall into various categories. Basically, the importance of the present inventive method in relation to the various categories of plastic is dictated by the commercial importance of the types of plastic themselves. For instance, it has been found that the typical plastics waste for disposal comprises, on the average, approximately 50 percent polyvinyl chloride, approximately 30 percent polystyrene, and the remainder, or approximately 20 percent, various other plastics such as polyethylene, polypropylene, polyesters, polyacrylics, and the like. Thus, for the most part, the waste plastics fall into three important categories, namely, poly(halogenated hydrocarbons), poly(straight chain olefins), and poly(vinyl aromatics). The representative, and most commercially important members of these three categories are polyvinyl chloride, polyethylene, and polystyrene, respectively. Accordingly, these three particular plastics will be discussed herein as exemplary members of the categories embraced by the instant invention and should not be considered limiting thereof.

It has been found that when polyvinyl chloride is heated to at least the decomposition temperature thereof, hydrogen chloride and a hydrocarbon mixture are obtained as the decomposition product. When polystyrene is heated to at least the decomposition temperature thereof, the only decomposition product is monomeric styrene. If a mixture of plastics, such as that typically found in waste plastics, is heated to at least the decomposition temperature of all the constituents thereof, the decomposition products will comprise hydrogen chloride, monomeric styrene, and a mixture of hydrocarbons. These relationships, of course, are based on the thermal decomposition of these materials in a non-oxidizing atmosphere. If mixed plastics are heated to at least the decomposition temperature thereof in the presence of air, the decomposition products will be hydrogen chloride and heat.

In the thermal decomposition of these plastics in a non-oxidizing, or inert, atmosphere, a particular predominant distribution of decomposition products was found. The primary products produced at equilibrium for the three plastic types vary with carbon-hydrogen ratio in the original plastic material as can be seen in Table I.

TABLE I

Polyethylene	Polystyrene	Polyvinyl Chloride
H_2 C_6H_6 CH_4 C_2H_4	C_6H_6 $CH_2CH C_6H_5$ C_2H_2	HCl C_6H_6 $CH_2CH C_6H_4$ C_2H_2

Primary thermal decomposition products at equilibrium for the three plastic types.

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zene and hydrogen chloride. This is similar to the polystyrene and polyethylene decomposition, except that no hydrogen chloride can be formed in the first two systems. A decomposition path analysis was run on polyvinyl chloride excluding benzene from forming. This run indicated that chlorine substituted ethylenes and toluene are formed. Another run deleting the above as possible products yielded ethyl benzene as the next level of feasible products.

TABLE II

	*POLYSTYRENE	POLYETHYLENE	POLYVINYL CHLORIDE
RELATIVE FREE ENERGY OF SYSTEM ↑	$CH_3C_6H_5$ trans $CH_3CHCHC_6H_5$ cis $CH_3CHCHC_6H_5$ ortho $CH_3C_6H_4CHCH_2$ meta $CH_3C_6H_4CHCH_2$ para $CH_3C_6H_4CHCH_2$ C_6H_6 $CH_2CHC_6H_5$	CH_3CH_3 $CH_3CH_2CH_3$ $CH_3C_6H_5$ $C_2H_5C_6H_5$ ortho $CH_3C_6H_4CH_3$ meta $CH_3C_6H_4CH_3$ para $CH_3C_6H_4CH_3$ CH_4 C_6H_6	$\{HCl\}$ $\{C_2H_5C_6H_5\}$ $\{HCl\}$ $\{CH_3C_6H_5\}$ $\{CHClCCl_2\}$ $\{CCl_2CCl_2\}$ $\{C_6H_6\}$ $\{HCl\}$

*at 800°C. in place of 500°C.

The relative amounts of the various products naturally vary as a function of temperature and pressure; the amounts of the unsaturated aliphatics increasing as temperature increases and decreasing with increasing pressure. Benzene appears to be particularly favored in the polystyrene and polyvinyl chloride systems. The polystyrene is stoichiometric to benzene, and the polyvinyl chloride is also stoichiometric to benzene when hydrogen chloride is formed.

The non-oxidizing atmosphere is provided by any inert gas which also serves as a carrier gas. While the present invention is not limited thereto, it has been found that nitrogen and steam are the two preferred inert carrier gases for use in this aspect of the present invention.

The polystyrene thermal decomposition equilibrium results indicate that benzene is in equilibrium with styrene at 800°C. and 1 atmosphere pressure. This equilibrium mixture represents a minimum of the relative system free energy, or in other words, the most probable distribution of species at equilibrium. When benzene is not allowed to form, the reaction yields a new product distribution which can be seen in Table II. The new product distribution represents a higher system free energy, which may be interpreted to mean that these products are similar to the actual intermediates in the benzene from polystyrene reaction. The possible intermediates include toluene, the cis-trans 1-phenyl-1-propylene and the ortho-meta-para methyl-styrene.

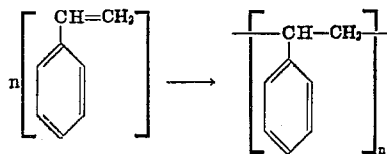
Polyethylene equilibrium results, like polystyrene results, show conversion of the given plastic to benzene at 500°C. and 1 atmosphere. However, the feasible reaction intermediates are for the most part different as shown in Table II. Toluene is the only species that appears in both cases. In addition to toluene, the feasible intermediates include ethane, propane, ethyl benzene, and ortho-meta-para dimethyl benzene. The major co-products of the thermal decomposition of polyvinyl chloride at 500°C. and 1 atmosphere pressure are ben-

Feasible Reaction Path Species
Thermal Decomposition
500°C., 1 ATM

The compounds in the higher relative free energy ranges are found in significant quantities at equilibrium only when the lower energy products are deleted from consideration.

A kinetic analysis of thermally decomposing polystyrene, polyethylene, and polyvinyl chloride waste plastics was made by determining the physical and chemical properties of the reactants and the decomposition mechanism. The results are presented herein as concentrations of reaction products and nitrogen gas, which was the heat source, as a function of time. From these data, the reactor geometry and heat requirements were defined.

Since the kinetic behavior of a chemical system is strongly dependent upon the physical and chemical properties of the reactants, in order to realistically treat these time dependent characteristics of the polystyrene decomposition reaction, certain physical and chemical properties of waste polystyrene were determined. Styrene may be polymerized by free radical initiators in several ways. Generally, the reaction is



The polymerization may be in solution or in an emulsion system which latter term as used herein includes a suspension polymerization system. Cationic catalysts could be used as well as anionic catalysts. The polymerization proceeds readily using a Ziegler-type catalyst which produces a stereospecific polymer having physical properties different from those of the free radical

produced polystyrene. Styrene polymerizes to give a head to tail sequence in the polymer chain. Of course, the reaction conditions and choice of catalyst can be controlled to produce a polymer having the desired characteristics. In determining the kinetic behavior of the system, the following properties of polystyrene were determined:

1. Polystyrene waste plastic contains thermally active sites ("weak links"), which are randomly distributed within each molecule;

2. Waste polystyrene is heterogeneous with respect to initial chain size;

3. The reactant plastic can be characterized by an initial "most probable" molecular weight distribution;

4. Plastic fed to the reactor is selected at random, that is, no distinction is made on the basis of degree of polymerization, molecular weight, and the like;

5. It is homogeneous with respect to monomer type, i.e., polystyrene only.

Initially, the decomposition of commercial polystyrene occurs by a random mechanism due to weak links formed in the polymerization reaction. When a weak link is broken, a number of monomers are split off. This phase continues until the weak links are exhausted. During this rapid initial period, inhibitors are produced to give rise to an induction period which is very pronounced at 352°C. and below. Above 402°C. the induction period is not experimentally evidenced for either unfractionated or fractionated samples.

A depolymerization reaction occurs at the end of the induction period by the following mechanism:

chain end initiation reaction, transfer reactions, propagation reaction, and termination reaction. Transfer reactions are at a trace level for temperatures between 427°C. and 727°C. which means high styrene monomer yield with 100 percent selectivity.

The grams of styrene produced per gram of polystyrene as a function of the solid residence time (that is, the residence time of the solid waste plastic material), were determined for a broad range of temperatures. As expected, the higher the temperature, the faster the rate. The increase in rate, however, must be balanced against heat requirements as a practical matter. The heat necessary to maintain an isothermal reactor is supplied by hot nitrogen gas which is preheated to 1,500°K., or 1,227°C. At 92 percent conversion, the reactor requires a total of 15.5 grams of nitrogen per gram of styrene when the initial nitrogen is at 1,500°K. This may be compared with 82.0 grams of nitrogen per gram of styrene at 1,000°K., or 727°C., initial nitrogen temperature. The quantity of nitrogen at 1,500°K. required per gram of styrene produced increases with reactor temperature at fixed conversion. The economies in nitrogen gas at the higher conversion is due to the fixed amount of nitrogen required to bring the waste plastic from ambient temperature to reactor temperature.

The reactor residence time-heat requirement tradeoff, the required conversion, and the physical properties of unreacted waste plastic dictate the necessary solid residence time and as such, the total volume. From this, an economical reactor system and associated process were designed and used to estimate the costs for processing each pound of waste polystyrene.

As expected in a kinetic study, the physical/chemical properties of waste polyethylene are important in characterizing its time dependent nature. Although a simple

linear structure is present almost exclusively in low pressure polyethylene, it has been found that high pressure polyethylene has its linear structure interrupted by branching. It has been determined that the high pressure polyethylene has a branch point present on the average for every 50 carbon atoms. Furthermore, spectroscopic investigation has shown that high pressure polyethylene contains carbonyl and peroxide groups and a small amount of unsaturation. The molecular weight distribution of high pressure polyethylene generally ranges between 22,000 and 25,000, while low pressure polyethylene has a molecular weight distribution of from as low as 20,000 to as high as 3 million. Additional physical properties of waste polyethylene are equivalent to the ones listed for polystyrene. The decomposition reaction mechanism for polyethylene, however, proceeds in a different fashion from that of polystyrene. Polystyrene degrades into monomeric styrene between about 427°C. and about 727°C. Reaction products resulting from polyethylene contain little monomer but primarily paraffins with up to 50 carbon atoms depending on the temperature. The degradation reaction for temperatures between 387°C. and 437°C. appear to be of zero order over a large range of percent weight loss. The mechanism probably consists of splitting off large molecular fragments in rapid succession once the chain is initiated.

An analysis was made to characterize the polyethylene system. The quantity of product produced versus residence time with a polymer of 822 average degrees of polymerization varies strongly with temperature. Temperatures between 412°C. and 437°C. were found to be practical reactor temperatures, considering heat input requirements and residence times. The rate was found to be affected by the average degree of polymerization, but inasmuch as it is impossible to determine waste polyethylene average degree of polymerization a priori, its effect must be considered parametrically in designing the reactor. The effect of average degree of polymerization over a range of 571 to 3,000 units was examined and the heat versus rate or conversion was studied for the reactor design. The product distribution for a polyethylene thermal degradation system was calculated at about 437°C. and is set forth in Table III. The relative concentrations of species is approximately constant at each conversion.

TABLE III

COMPONENT	(10 ⁺²) GRAMS/SECOND
C ₂ H ₄	1.8
C ₂ H ₆	5.5
C ₃ H ₄	0.15
C ₃ H ₆	3.25
C ₃ H ₈	9.60
C ₄ H ₆	19.90
C ₄ H ₁₀	15.85
C ₅ H ₈	0.35
C ₅ H ₁₀	7.65
C ₅ H ₁₂	6.40
C ₆ H ₁₀	.40
C ₆ H ₁₂	3.95
C ₆ H ₁₄	1.65
C ₇ H ₁₄	.30
C ₇ H ₁₆	.60
N ₂	T_{N₂} = 1500°K T_{N₂} = 1000°K 191.00
Unreacted Polyethylene	520.40
	22.65

Polyethylene Thermal Decomposition

437°C. reactor temperature
3000 second residence time
1.0 g/sec polyethylene feed

Polyvinyl chloride is essentially a linear polymer of "head to tail" configuration. A small amount of branching is present which is probably composed of carbon and chlorine atoms. The general properties of waste polyvinyl chloride material are the same as those discussed for polystyrene.

The thermal degradation of polyvinyl chloride is primarily a dehydrochlorination reaction. After a short initial period, hydrogen chloride is evolved under a mechanism of approximately three-halves order in the fraction of undegraded units. Following hydrogen chloride evolution, a secondary decomposition occurs which yields numerous organic products as shown in Table IV.

TABLE IV

COMPONENT	(10 ⁺²) GRAMS/SECOND
HCl	51.00
C ₂ H ₄	7.18
C ₂ H ₆	3.71
C ₃ H ₆	1.28
C ₃ H ₈	1.97
C ₄ H ₈	4.16
C ₄ H ₁₀	2.12
C ₅ H ₁₀	3.63
C ₅ H ₁₂	1.13
C ₆ H ₆	5.67
C ₆ H ₁₂	0.83
C ₆ H ₁₄	0.91
C ₇ H ₈	3.02
C ₇ H ₁₀	1.29
C ₂ H ₄ Cl ₂	1.44
H ₂	0.23
CH ₄	1.44
N ₂ { T _{N2} = 1500°K	127.62
T _{N2} = 1000°K	344.90
Unreacted Polyvinyl Chloride	9.00
Polyvinyl Chloride Thermal Decomposition	
437°C. reactor temperature	
255 seconds residence time	
1 g/sec polyvinyl chloride	

tial 1.2 grams per gram of waste plastic polymer necessary to raise the temperature from ambient temperature to 450°C.

Attention is now directed to FIG. 1 wherein there is shown a semi-continuous moving-bed reactor designed for use with the method of the present invention. The reactor, generally designated by the numeral 10 is operated isothermally by supplying hot inert carrier gas such as nitrogen or steam at various points throughout the reactor. The gas enters inlet 12 and is conducted throughout the reactor by conduit 14 to be emitted at a plurality of locations by suitable injector means 16. Waste plastic is fed continuously from above at intake 18 and is contacted by the hot gas throughout the reactor. Any unreacted solid material is removed in a batch fashion at outlet 20. During removal of unreacted material, auxiliary reactors are switched on-stream. The degradation products and the inert gas are drawn off at outlet 22 for further processing to be discussed in more detail hereinbelow. The specific dimensions of the reactor for each of the individual decomposition systems is summarized in Table V.

TABLE V

Reactor Geometry For a Waste Plastic/Nitrogen Decomposition Reactor*					
Reactant	Temperature	Per Cent Converted	Radius (cm)	Length (cm)	Volume (cm ³)
Polyvinyl Chloride	723°K	85%	10	95	2.99×10 ⁴
Polystyrene	873°K	90%	30	115	3.25×10 ⁵
Polyethylene	710°K	75%	30	190	5.37×10 ⁵
ADP = 822	700°K				
Polyethylene		75%	30	230	6.51×10 ⁵
ADP = 571		75%	30	500	1.41×10 ⁶
ADP = 900		75%	30	565	1.60×10 ⁶
ADP = 3000		50%	30		

- * All data is based on 1.25 million pounds of plastic annually
- "ADP" signifies average degree of polymerization
- The nitrogen input was held at 1500°K

The effect of temperature on the hydrogen chloride and on the hydrocarbon reaction were examined to determine feasible reaction conditions, the net result is that the reaction is commercially feasible above about 402°C. Selecting 450°C. as the nominal case, the hydrogen chloride and hydrocarbon product evolution was examined as a function of solid residence time. Here the hydrogen chloride is the predominant product at all residence times. The overall reaction is exothermic due to the predominance of the exothermic hydrogen chloride stage over the endothermic organic evolution stage. As such, no nitrogen is required after the ini-

Kinetic analyses were made of the systems for thermally degrading waste plastics according to the present invention using both nitrogen and steam as the inert carrier gas. A determination was also made whether partially oxidized compounds such as alcohol, glycols, ethers, aldehydes, and ketones were potential products in the steam system. It was found that no significant quantities of these chemicals were produced under the conditions studied. A potential of steam reforming reaction systems producing carbon monoxide and hydrogen exist, but such systems would require a catalyst.

The waste plastic/steam systems without catalysts gave kinetic results which were similar to the waste plastics/nitrogen systems in that the product distributions were essentially the same for each system. It should be noted that steam has a higher heat capacity than nitrogen, thereby reducing the carrier gas concentration necessary, and hence reactor gas volume, for the reaction. For example, the polyvinyl chloride decomposition reactor operating isothermally at 723°K. requires 0.9 mole at 1,500°K. as compared to 0.7 mole of steam at 1,500°K. A nitrogen/steam comparison was calculated for a variety of thermal decompositions systems and conditions, the results of the comparison being set forth in Table VI.

TABLE VI

Amount of Indicated Heat Source* Necessary for the Specified Conversion		Steam
Nitrogen		
Polystyrene, 823°K	Grams	Grams
Converted 55%	9.35	4.47
50%	9.13	4.38
25%	7.96	3.82
Polyvinyl Chloride, 673°K	Grams	Grams
Converted 90%	1.14	.58
75%	1.04	.55
50%	1.00	.53
Polyethylene, 685°K ADP 822		
Converted 75%	1.75	.86
50%	1.51	.74

* ● 1500°K heat source temperature
● 1 gram plastic

A fourth waste plastic/steam system, having an equal weight mixture of polystyrene, polyethylene, and polyvinyl chloride, was run. The product distribution was determined and is set forth in Table VII. The reactor design was that shown in FIG. 1, the geometries being set forth in Table VIII.

TABLE VII

Mixture Reaction Products At 700°K and 4400 Seconds Solid Residence Time			
Basis: 1 gram of mixture, with equal parts (by weight) of polyvinyl chloride, polyethylene and polystyrene			
Product	Grams (×10 ³)	Product	Grams (×10 ³)
CH ₄	1.00	C ₆ H ₆	21.40
C ₂ H ₄	32.73	C ₆ H ₁₀	1.23
C ₂ H ₆	31.35	C ₆ H ₁₂	15.64
C ₃ H ₄	0.49	C ₆ H ₁₄	8.71
C ₃ H ₆	14.99	C ₇ H ₈	11.42
C ₃ H ₈	37.79	C ₇ H ₁₄	0.98
C ₄ H ₈	78.68	C ₇ H ₁₆	1.96
C ₄ H ₁₀	58.39	C ₈ H ₈	39.47
C ₅ H ₈	1.22	C ₈ HCl ₂	5.52
C ₅ H ₁₀	37.96	H ₂	0.99
C ₅ H ₁₂	24.77	HCl	175.92
Polyvinyl Chloride	14.56		
Polystyrene	298.52		
Polyethylene	88.17	Steam Required	(1500°K) 1045.30

TABLE VIII

Reactor Geometry for a Waste Plastic/H ₂ O Decomposition					
Reactant	Temp.	Per Cent Con- verted	Radius (cm)	Length (cm)	Volume (cm ³)
Polyvinyl Chloride	700°K	85%	30	24	6.79×10 ⁴
Polystyrene	823°K	55%	20	555	6.98×10 ⁵
Polyethylene ADP = 822	700°K	75%	30	375	1.06×10 ⁶
Mixture of the Above (½ each by weight)	823°K	85%	20	550	6.91×10 ⁵

The steps in one embodiment of the method of the instant invention can be easily followed by reference to FIG. 3. The polyvinyl chloride waste is fed into a semi-continuous stainless steel reactor 24 of a type shown in FIG. 1. Nitrogen, which is used as an inert heat carrier, is preheated to 1,230°C. in a direct fired heater using oil/gas combination burners. The hot nitrogen stream is fed to the reactor 24 where thermal degradation of the polyvinyl chloride is accomplished at a constant temperature of 450°C. The overall system is exothermic, with the heat carried by the nitrogen being used to elevate the temperature of the polyvinyl chloride feed. After leaving the reactor, the gaseous reaction products are sent to the scrubbing system which is capable of removing 99 percent of the hydrogen chloride from the reactor effluent. The scrubbing system includes graphite humidifying tower 26 and primary falling film absorber 28 where the organic phase is removed. From the primary falling film absorber 28, the effluent goes to secondary falling film absorber 30 from which 18° to 20° Baume acid is removed, with a portion of the product going to tertiary falling film absorber 32. The material from the tertiary falling film absorber 32 is cycled back to the secondary falling film absorber 30 to be withdrawn as the product acid of 18° to 20° Baume. If desired, an additional stripper system can be used to produce anhydrous hydrogen chloride. This system would include falling film stripper 34, water condenser 36, brine condenser 38, and entrainment separator 40. Bottoms cooler acid can be drawn from falling film stripper 34 at 42 and 21 percent stripper stored in suitable means such as a tank 44 which supplies make-up liquor to tertiary falling film absorber 32.

In the method for thermal degradation of scrap polystyrene, a series of steps as outlined in FIG. 4 is employed. The polystyrene is fed into stainless steel reactor 46 which is of the type shown in FIG. 1. Nitrogen is used as the inert carrier gas and is fed into the reactor at about 1,230°C. so as to provide a degradation temperature of about 600°C. The effluent from reactor 46 passes to heat exchanger 48 where the gaseous reaction products are cooled to about 250°C. by heat exchange with the nitrogen recycle from the refrigeration step. From the heat exchanger 48 the gaseous reaction products are sent to secondary heat exchanger 50 where they are further cooled with water to about 50°C. Refrigeration is used to cool the stream to about 20°C. in refrigerator 52, removing all but 0.6 percent of the styrene monomer from the gaseous nitrogen. The stream then goes to phase separator 54 and an inhibitor is added to the liquid monomer before it is pumped to the

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product storage tank 56. The nitrogen leaving the refrigerator 52 via the phase separator 54 is recycled to the direct fired heater 58, cooling the effluent reactor gases on the way. In the direct fired heater step, make-up nitrogen is added to the recycled nitrogen stream, now at 460°C., and heated up to 1,230°C. using oil/gas combination burners.

When degrading mixed waste plastics, according to the instant invention, the plastics are charged to a semi-continuous stainless steel reactor 60 in FIG. 5 which also is of the type shown in FIG. 1. Nitrogen, again used as an inert heat carrier, is preheated to 1,230°C. in a direct fired heater 62, using oil/gas combination burners. Degradation of the waste plastics mixture is accomplished at a constant temperature in the reactor 60 of 600°C.

After leaving the reactor, the gaseous decomposition products are cooled by heat exchange with incoming nitrogen being sent to the direct fired heater for pre-heating in heat exchanger 64. The stream temperature is then lowered to 90°C. with a water spray quench at 66 which removes the hydrogen chloride and water from the stream. The condensed hydrogen chloride/water stream is sent through a phase separator 68 for recovery of heavy hydrocarbons and then on to a hydrogen chloride distillation column 70 through preheater 72.

The gaseous stream leaving the quench 66 is cooled to 50°C. with a cold water heat exchanger 74, sent to a phase separator 76 to remove organics other than styrene, and then refrigerated to 20°C. by refrigerator 78, which removes all but 0.6 percent of the styrene monomer from the gas stream. After passing through phase separator 80, the condensed styrene stream is further purified in a vacuum finishing column 82, treated with an inhibitor, and sent to storage.

When using steam instead of nitrogen as the inert carrier gas, low pressure steam is sent through the direct fired heater and heated to 1,230°C. prior to being sent to the reactor. Basically, the same method steps are used for the recovery of the degradation products.

In another aspect of the present invention, the mixed plastic wastes are thermally degraded in the presence of an oxidizing atmosphere, the preferred such atmosphere being air. In order to prevent the formation of "hot spots" in a combustion reactor, the design of the same was made as indicated in FIG. 2. The reactor, generally indicated by the numeral 84, has a waste plastics inlet 86 and an air inlet 88. The oxidation products are drawn off at 90. The reactor system is adiabatic with air entering at ambient temperature. The product distribution, reactor exit temperature, and air input was calculated for systems of polyvinyl chloride, polyethylene, polystyrene, and a mixture of equal parts by weight of the three plastics. The results of the determination are shown in Table IX.

TABLE IX

Waste Plastics/Air Adiabatic Reactor*				
Products (Grams)	Polyvinyl Chloride	Polyethylene	Poly-styrene	Mixture (Equal parts by weight of the three)
CO ₂	1.41	3.06	3.19	2.69
CO	traces	0.06	0.08	<0.01

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H ₂ O	0.30	1.27	0.66	0.77
N ₂	12.00	13.19	11.74	12.85
NO	traces	0.06	0.06	0.05
O ₂	2.12	0.34	0.34	1.01
HCl	0.55	—	—	0.18
Cl ₂	0.04	—	—	traces
Others	traces	0.02	0.02	0.01
Temperature out of Reactor	1200°K	2130°K	2200°K	1870°K
Weight of Air Input	15.40	16.99	15.10	16.55

*All data Based on 1 Gram of Plastic

The result of the combustion according to this aspect of the present invention is to completely combust the organic material with the subsequent harnessing of the heat energy produced. The hydrogen chloride is recovered following the method shown in FIG. 3, the only difference being that the reactor is of an adiabatic type shown in FIG. 2 rather than the semi-continuous reactor of FIG. 1. The need for a hot nitrogen or other inert carrier gas is, of course, not necessary.

Having now described in illustrative and preferred embodiments of the present invention in sufficient detail to permit a complete understanding of the various aspects of the invention, it should be apparent to those reading this specification that the objects set forth at the outset hereof have been successfully achieved.

What is claimed is:

1. A method of disposing of waste plastic without polluting the environment, said waste plastic being a mixture of polyvinyl chloride, polystyrene and polyethylene, said method comprising passing said plastic to a reactor, contacting said plastic in said reactor in a counter-current flow with an inert carrier gas, said gas entering said reactor at a temperature sufficient to heat said plastic to at least the decomposition temperature thereof, heating said plastic to a temperature of about 600°C. by said gas to thereby produce reaction products comprising hydrogen chloride, monomeric styrene, and mixed hydrocarbons, and recovering said decomposition products.

2. A method as defined in claim 1, wherein said inert carrier gas enters said reactor at about 1,230° C.

3. A method as defined in claim 1, wherein said gas is selected from the group consisting of nitrogen and steam.

4. A method as defined in claim 1, further comprising the steps of recovering said hydrogen chloride acid by scrubbing the same from the reactor effluent and carrier gas, and burning said hydrocarbons for the utilization of the heat produced thereby.

5. A method as defined in claim 1, further comprising the steps of cooling the reactor effluent to a temperature below the boiling point of styrene and separating the resulting liquid styrene from the inert carrier gas.

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