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Evaluation of the Impact of RCRA Amendments on Waste-to-Energy Activities by Using a System Simulation Computer Code

by

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INTRODUCTION

The primary methodology that has been, and that continues to be, used for disposal of municipal solid waste is the use of land fills; ~80-85% of the municipal solid waste (MSW) produced in the country currently is land filled (EPA 1991). The two other disposal alternatives used are recycling and incineration. The increasing use of the latter alternatives is being driven by social and political pressures for enhanced environmental protection and energy utilization (efficiency). The recycling option is attractive in certain cases. Waste-to-energy technology (WTE) which incinerates MSW to produce electricity and/or steam is attractive in other cases since it reduces landfill volume, reduces the consumption of fossil and other fuels, and produces a revenue stream from the sale of the electricity or steam. The gaseous effluents from landfills can also be used to fuel power plants. Several such plants are currently operating in the U.S. This study was undertaken to explore the effects that mandated increased recycling could have on MSW-WTE plants and on collection and utilization of methane emission from landfills.

Since 1988 the number of plants being planned decreased by ~60% and at least 121 WTE plants that were to have been built were abandoned (Berenyi and Gould 1991). One of the most critical factors impacting economic viability of WTE plants is the need to have essentially a guaranteed waste stream within specified ranges of throughput and heating value. A relatively stable input is critical to the design and efficient economic operation of the WTE plants. While the design of the WTE plants are generally quite robust, and they can accommodate significant variations in heating value and throughput, limits exist within which the plants must operate to maintain economic viability. Deviations from the design range will impact revenues generated from tipping fees and the sale of the electricity (or steam); also unit operating and maintenance costs can be impacted.

Recycling and material separation programs can have a substantial impact on the throughput and heating value of MSW collected and thus impact WTE plant economics; the magnitude of the impact will depend upon a number of factors such as what materials and what fraction are separated and recycled, the design of the WTE plant itself (its operating window); the contractual arrangements relative to maintaining throughput (ability to adjust catchment area), limitations on adjusting tipping fees, etc. Depending upon the impact that these factors have, the WTE plant option can become economically unattractive, vis-a-vis straight landfilling, which as indicated is the most attractive disposal option. This scenario, however, can be substantially altered if proposed new regulations on landfills are implemented that will require elimination of the discharge of landfill gases (methane) directly to the atmosphere. This would require landfill operators to install gas collection and disposal systems, such as flaring and WTE plants. Mandated increased recycling and landfill gaseous effluent control - could alter substantially the economics and competitive position of the MSW-WTE industry.

The objectives of this study are: (1) to simulate typical WTE plants fired with a national average waste stream, (2) to evaluate the parametric effects of waste component recycling on the performance of the typical WTE plants, and (3) to assess the impact of RCRA recycling amendments on the performance of the typical WTE plants and on the potential methane generation of typical landfills. The relevant technical issues, technical approach, results and conclusions are presented in the following sections.

TECHNICAL ISSUES

There are a number of issues which bear on the potential impact of increased recycling on both the municipal waste combustor and landfill disposal options. They relate to the impact that recycling can have on the heating value and throughput of the waste stream and hence on the operating characteristics and economic viability of the WTE plants as well as the economics of landfill gas production and utilization. For example, if mandated recycling is increased, the MSW stream generated within a specific catchment area would decrease in proportion to the amount of material recovered. This could produce an immediate impact on the operation and economic viability of an existing WTE plant. A reduction in tipping fees and salable electricity produced would occur unless the catchment area can be expanded commensurate with the reduction in throughput and change in heating value. Likewise, less biodegradable material in the landfill will discourage the installation of energy recovery system for utilization of landfill gas as a fuel.

MSW Incinerators

The operation of WTE plants as other conventional furnaces must occur within an operating parameter window. The operating window is set by fuel characteristics, combustion-environmental constraints, material (corrosion) limitations, fouling and slagging, individual component performance limitations, etc.

The composition of the MSW stream has changed over time in response to changing consumer products and consumption. This has produced corresponding changes in heating values. The composition and heating value of the waste also varies significantly with area and the season in response to variation in production, consumption, and utilization of specific MSW components such as garden waste, corrugated cardboard, newsprint, etc. (Ege and Brown 1990) The net result is that the manufacturers of WTE plants have strived to provide the widest possible range in the throughput and heating value of the waste stream that can be accommodated in boilers of fixed heating surfaces. Operating and/or design temperature limits of boiler components must be adhered to in order to achieve efficient, reliable operation. By design, the incinerators generally operate with a high excess air (or low stoichiometric ratio) to achieve complete combustion. However, the ratio is generally constrained in a range to produce combustion temperatures between 1000-1100°C (EPRI 1992). The temperature is high enough to destroy the dioxin precursors and low enough to prevent excessive NOx formation.

Metal and gas temperatures also must be constrained with certain limits in the furnace to preclude excessive fouling and corrosion as well as to maintain proper steam conditions. The operating experience of WTE plant to date in conjunction with laboratory studies have served to delineate both the causes and solutions to the boiler tube failure problems that plagued the industry early on (EPRI 1992). The chemical reactions involved in the corrosive attack on tubes have been identified and shown to be sensitive to the chlorine and sulfur content of the MSW fuel. The short term corrosion rates of carbon steel have been shown to be a function of the chlorine content and temperature via probe exposures in an incinerator (Kraine 1987). The corrosion rate increases with increasing temperature, up to 600°C and refuse chlorine content up to 1%.

These temperatures are sensitive to the combustor volumetric heat release rate (which is a function of the heating value and composition) and gas velocities. There is a limiting range of volumetric heat release that can be accommodated due to the need to balance sensible and latent heat and because of changing heat transfer coefficients as the feed rate is varied.

The net result is that there exists an operating envelope for each WTE plant which is based on its design and the expected range of values of throughput and waste heating value. The operating envelope is schematically illustrated in Figure 1. The boundaries of the envelope are set by the design of the plant itself. The upper boundary (DE segment) represents the heat transfer capability for the fixed area plant design. The lower boundary (AB segment) represents the heat release range (turn down ratio) that can be accommodated. The left boundary (FA segment) represents the waste feeder system turn down ratio. These turn down ratios are consistent with the combustion and heat transfer limitations calculations. The right boundary (CD segment) represents the upper limit of the feeder system. The slanted lines (BC and EF segments) in this envelope represent different heating value of the fuel that can be accommodated. Thus, for example, if the heating value is substantially reduced the throughput must be increased and combustion stoichiometry adjusted to maintain the temperature condition. Plant turn down ratio, combustor volumetric heat release, and throughput are functions of the waste heating value and plant design. In general, relatively large changes in waste heating value can be accommodated, 80-120% of a reference heating value, assuming that the corresponding MSW flow adjustment can be developed. A typical range of heating value can be accommodated is between 8.8 and 15 MJ/kg.

MSW Landfills

Landfill gas, mainly consisting of methane and carbon dioxide, is produced by the biodegradation of refuse in the landfill under anaerobic conditions. Landfill gas generation rate is a function of the following factors: composition of refuse, moisture content of refuse, age of refuse, temperature of the landfill, pH and alkalinity of the landfill, and quantity and quality of nutrients.

For a typical landfill, the gas generation rate peaks within six years after initial waste placement and declines steadily afterwards. Refuse composition directly affects the rate of landfill gas generation. The higher the percentage of biodegradable material, e.g., food and garden wastes, paper, textiles, and wood, the higher the landfill gas generation rate. Certain compounds potentially present in the waste may be toxic to any bacteria active in the landfill and can upset the activity of methanogenic bacteria, resulting in a decreased gas generation rate. Examples of such substances are toxic organic solvents like carbon tetrachloride, chloroform and common salts of sodium, potassium, magnesium, calcium, ammonium, and sulfide at high concentrations. The mandated recycling reduces the refuse acceptance rate and extends the lifetime of landfills. The recycling changes refuse composition, therefore, it affects the rate of landfill gas generation. Recycling of paper, a biodegradable materiel, reduces landfill gas generation. However, if paper is recycled along with glass and plastics (non-biodegradable material), the impact on landfill gas generation may become small.

TECHNICAL APPROACH

The following analytical methodology was used to evaluate potential impact of the RCRA recycle amendments on MSW-WTE plants and on the collection and utilization of methane emitted from landfills. Initially, municipal waste composition, property, and heating value data were obtained from the literature to bracket the expected variations and to define a generic average waste stream composition for WTE plants. A general system simulation computer code was used to simulate a generic WTE plant and predict the performance of the plant. The generic WTE plant was operated in an operating window which reflected realistic turndown ratios on the feeder system and volumetric release rates in the combustor. The plant simulation was then used to conduct "what if" and parametric/sensitivity type studies related to the proposed changes in recycling rates. Results of plant simulation studies were then compared with the operating window to assess potential impact of the RCRA recycle amendments on the operation of an average WTE plant. The impact on landfill methane generation was assessed using an empirical first-order Ahrrenius-type formula and Buswell method that expressed a methane generation capacity in terms of waste element compositions.

The system simulation computer code SALT developed at ANL (Geyer and Berry 1985a,b) was used for the MSW WTE and landfill simulations. The SALT code has been used to evaluate the performance of several power plants (Chang etc. 1988, 1989). The SALT code is a systems-analysis and process-simulation computer code for steady-state and dynamic systems. Based on a preprocessor concept, it uses a language translator to allow the user great flexibility in specifying a systems-analysis problem. The precompiled component submodels, generic flow types, and several thermodynamic and transport property routines that are included in the code were readily configured into a WTE plant simulation. Some component submodels in the SALT code including air and water flow characterization, heat exchangers, steam turbine, steam drum, pump, and stack were directly used for this simulation. Three new component submodels were developed for waste flow characterization, landfill gas production, and WTE combustor and incorporated into the SALT code for the simulation of a generic WTE power plant model. One submodel calculates the heating value as a function of elemental composition for a given waste stream by specifying the mass fractions of all waste components. The submodel was validated by comparing the predictions with the published data. The second submodel calculates landfill gas production as a function of waste composition. The third submodel calculates the stoichiometric ratio of an air/waste mixture, combustion temperature, and flue gas properties in a WTE combustor.

Waste Flow Characterization

Municipal solid waste is either a mixture or a single-item stream of household, commercial, and/or institutional discards; the waste stream includes items such as paper, plastics, glass, wood, yard wastes, leather, rubber, metals, and other combustible and noncombustible materials. Waste compositions and properties vary from location to location and seasonably. EPA (1990a) defined a national average waste stream consisting of eleven components: paper, glass, plastics, rubber, leather, textiles, wood, food, yard wastes, metals, and dirt as shown in Table I. In the table, the component heating value is the higher heating value of a waste component and the component heat content is the percentage heat release contribution by a single component in the complete combustion of the waste. The heating values of the eleven waste components were used to determine the higher heating value of a waste stream as shown in Eq.(1).

$$HHV = \sum_i X_i HHV_i \qquad (1)$$

where X_i is mass fraction of a waste component i,
HHV_i is component heating value listed in Table I, and
i represents a waste component listed in Table I.

Waste components consist of six elements, i.e., carbon, hydrogen, oxygen, nitrogen, sulfur, and ash. Elemental compositions of the eleven waste components are listed in Table II (Corbitt 1990; Wilson 1977). The component element compositions were used to determine waste stream elemental composition as shown in Eq.(2).

$$Y_j = \sum_i X_i Y_{i,j} \qquad (2)$$

where Y_j is waste element composition (in mass percentage),
$Y_{i,j}$ is element compositions of a waste component listed in Table II, and
element j represents carbon, hydrogen, oxygen, nitrogen, sulfur, or ash.

Waste heating value and element compositions were used in the waste combustor submodel to determine the stoichiometric ratio of an air/waste mixture, combustion temperature, and flue gas properties. In a typical waste combustor, the flue gas temperature is about 1100°C. At this temperature, the flue gas consists of gaseous species such as CO_2, H_2O, N_2, O_2, SO_2, NO, and OH. The species concentrations of the flue gas can be determined in an equilibrium state calculation by minimizing the free energies of the species. A thermodynamic property library of the SALT code contains free energy data for a variety of gas species including all the flue gas species. In the combustion calculations a general thermodynamics properties routine is repeatedly called to determine the thermodynamic states of the flue gas at various conditions.

Landfill Methane Generation Submodel

Methane generation rates of MSW landfill sites, are generally expressed by an empirical first order Ahrrenius type formula Eq.(3) (EPA 1991).

$$Q_m = L_o R\{\exp(-kc) - \exp(-kt)\} \qquad (3)$$

where Q_m is methane generation rate at time t; L_o is potential methane generation capacity of the refuse; R is average annual refuse acceptance rate during active life; k is methane generation rate constant; c is the time since landfill closure; and t is time since the initial refuse placement. Rate constant k and generation capacity L_o vary from site to site depending on various factors.

Potential methane generation capacity can be theoretically predicted with a Buswell model that expresses a generation capacity in terms of waste element compositions. The Buswell model assumes that methane is generated in a complete reaction of waste $C_aH_bO_cNS_e$ and water H_2O, in which waste and water are the reactants and methane, carbon dioxide, ammonia, and H_2S are the products. By balancing the element mass, the potential methane generation capacity should be (a/2+b/8-c/4-3/8-e/4) kmol of methane per one kmol of waste. The molecular weight of the waste equals (12a+b+16c+14+32e) kg/kmol

Simulation of a Baseline WTE Plant

Currently, a variety of WTE plants are in operation with widely varying operating characteristics. It was necessary, therefore, to define a typical or average WTE plant as a baseline plant. A review of the operating WTE plant characteristics (EPA 1990b) indicates the average WTE plant has a waste throughput of ~510 ton/day (tpd). The trend, however, in plants coming into operation is to higher throughput. Thus a plant of 650 tpd was assumed to be typical of those operating today. The boiler steam pressure and temperature vary widely, e.g., $2<P<170$ atm, and $100<T<570$°C (Berenyi and Gould 1991). Fifty percent of the facilities operated at $P>34$ atm and $T>260$°C. In view of the variations in the operating characteristics of WTE plants, a Bristol resource recovery facility (Barrett 1992) was selected as the baseline plant.

The Bristol facility is a medium size, 650 tpd mass-burn plant that generates 16 MW electricity. The plant normally fires refuses around the clock, 24 hrs/day, 7 days/week. The boiler operates at 65 atm at the drum and 59 atm and 444°C at superheater outlet. The boiler has a rating of 18 kg/s steam when firing refuse with 90 percent excess air. The baseline WTE plant is schematically illustrated in Figure 2. In the combustor WTE_1, the waste from INW_1 is burned with the air from IN_A1 and slag and flue gas are produced. Slag is rejected from the combustor. The high temperature flue gas flows through a boiler HX_BL, a superheater HX_SH, and an economizer HX_EC where it transfers heat to a high pressure water/steam flow. The steam generated in the boiler is used to generate electricity in a simple steam turbine ST_1 (no steam extraction for reheat). The simulation was made under the following assumptions: (1) the overall heat transfer coefficients of the boiler, the superheater, and the economizer were set at 11 W/m^2K and (2) the boiler recirculating water flow rate was set at 40 kg/s. The heat transfer coefficient value was calculated from typical pipe geometries/flue gas velocities encountered in the components. While there was some variation (2-3%) in the computed value for each component, the one value was specified for sake of simplicity. The water flow rate value was back-calculated from the limited data available on the baseline plant as given in (Barrett 1992).

The computer simulation was validated by inputting a waste stream composition with the reported (design) heating value for the Bristol plant and computing all plant parameters; these were then compared with the data in reference (Barrett 1992). The waste stream component composition was the average composition specified in Table I. Key computed performance values are compared with reported values for the Bristol plant in Table III. As indicated a good comparison was achieved. Other computed values of the baseline plant are listed in Fig.2. Combustion temperature is 1083°C. At this temperature, the equilibrium NO concentration in the flue gas is 370 ppm. The flue gas temperatures at the exit of boiler, superheater, and stack are 464, 312, and 190°C, respectively. The log mean temperature differences of the boiler, the superheater, and the economizer are 477, 27, and 48°C, respectively. The tube surface temperatures of the boiler, the superheater, and the economizer are 299, 361, and 203°C, respectively. At the stack, the flue gas contains 8.9% CO_2, 12.5% H_2O, 69.8% N_2, 8.8% O_2, and 190 ppm SO_2. These values are consistent with the operating parameters ranges described in previous section.

RESULTS AND DISCUSSIONS

The potential impact of the proposed mandated recycling rates was assessed by utilizing the waste stream characterization models and WTE plant simulation to determine (1) whether the waste fuel (of a new composition) that would result could be successfully burned within the operating envelope of a generic WTE plant and (2) whether the plant parameters are within operating ranges that are considered to be consistent with good practices and design values. Specifically, the models and computer simulation were exercised to: (1) generate an operating envelopc for the generic baseline plant to provide a basis for assessing the impact of proposed RCRA amendments; (2) compute the expected charges in heating value and potential changes in throughputs that would result from the proposed amendments; (3) conduct analysis of mandated recycling on various plant operation operating scenarios; and (4) compute changes in critical plant operating parameters, e.g. flame temperature, metal surface temperatures which could be compared with normal practice. The specific recycling rates used in the study were derived in the following manner.

Proposed RCRA recycling amendments (US House and Senate 1991) focus on the recycling of three major components in municipal solid waste: paper, plastics, and glass. The waste paper stream is further divided into various categories: newspaper (18%), corrugated paper (29%), mixed paper grades (25%), and high grade deinking (28%) (EPA 1990a,b). The proposed recycling rates for the four waste paper categories are 52% for newspaper, 66% for corrugated paper products, 20% for mixed paper grades, and 50% for high grade deinking paper, respectively. By summing recycling rates over all waste paper categories, an overall paper recycling rate 45% is obtained. Waste plastics has 39% of bottles and containers (EPA 1990a,b), for which the proposed recycling rate is 25%. Therefore, the overall plastics recycling rate becomes 10%. Waste glass includes 91% of bottles (Wang and Pereira 1980), for which the proposed recycling rate is 65%. The overall glass recycling rate becomes 60%. In summary, the RCRA recycling rates are 45% of paper, 10% of plastics, and 60% of glass.

WTE Plant Operating Envelope

The operating envelope (a stoker capability diagram) is generally used to indicate limits of a WTE plant. For the baseline WTE plant, a stoker capability diagram was constructed by assuming 75%

and 125% of nominal waste throughput design point as upper and lower limits for the stoker. The stoker capability diagram generated for the baseline plant is shown in Figure 1. The diagram relates the waste throughput (ton per day) to the stoker heat input (MW) for waste having higher heating values from 10 to 15 MJ/kg. Line segment AD represents states of firing 12.6 MJ/kg waste (the national average value) at various throughputs. Point O is the reference state for the baseline plant throughput rate of 650 tpd, point A represents the 75% turndown state (490 tpd throughput) and point D represents the state for a 810 tpd throughput (125% of the baseline value). The boundaries of the envelope stem from a typical combustor design. The right and left boundaries of the envelope (line segments FA and CD) represent the mass limits of the grate. Top and bottom limits (line segments DE and AB) represent the boiler operation limits (set by the turn down ratio waste was assumed to be 20%). The upper left and lower right limits (line segments EF and BC) represent the heating value limits. In this simulation plant, the grate limits are 810 and 490 tpd, the heat input limits are 108 and 64 MW, and the heating value limits are 15 and 10 MJ/kg. If an operational condition falls outside the envelope, it represents poor and probably unacceptable plant performance. It should be noted that the turndown ratio for the stoker and boiler operation were set following a review of several operating envelopes of existing plants and from discussions with plant designers. These ratios vary with plant design; the assumed values are, however, believed to be typical of a large fraction of the existing plants.

Impact on Waste Stream HHV and Throughput

By recycling 45% of paper, 10% of plastics, and 60% of glass in a waste stream to a WTE plant in accordance with the proposed RCRA amendments, the amount of waste burnt in the plant (waste feed rate) would be reduced by 20% if the amount of waste collected for the plant (catchment area) remains the same. Such a reduction in throughput is near the lower limit of stoker feed rate capability and hence plant operational capability.

The INW submodel was used to calculate the HHV and element compositions of the baseline waste stream. The baseline waste HHV is 12.64 MJ/kg and the element compositions are 27% moisture, 16.3% ash, 29% carbon, 3.7% hydrogen, 0.9% nitrogen, 22.9% oxygen, and 0.2% sulfur which are within the ranges of the ultimate analyses of typical average waste streams (Corbitt 1990; Wilson 1977). The higher heating value of the baseline waste 12.48 MJ/kg is about 45% of the coal heating value 28 MJ/kg. The HHV of the waste stream that would result after imposition of the recycling rate, however, is reduced only by ~4%, from 12.48 to 12.05 MJ/kg. The reason for the limited change is that the loss in heating value from removal of paper is offset by the proportionately higher percentage of plastic that occurs in the waste stream per unit weight; the plastic has a component heating value of almost twice that of the paper. This is readily apparent from the data given in Table I. Paper and plastics' heating values (16.7 and 32.6 MJ/kg) are higher than that of the average waste stream (12.48 MJ/kg). Recycling of them would lower the waste HHV. On the other hand, glass contains a good portion of the inert material and has a negligible component heating value (0.14 MJ/kg) and, therefore, tends to raise the HHV if it is recycled.

Impact on WTE Plant Operations

A parametric study was initially conducted to study the effects of individual waste stream component recycling on the WTE plant performance. The assumptions for these calculations are basically the same as discussed above in the baseline calculation. The surface areas of the boiler, superheater, and economizer were kept constant and the waste collection rate was kept at 650 ton/day; excess air at 90%. The waste stream composition was varied by adjusting each of the waste stream components that are to be recycled individually, in accordance with proposed RCRA amendments, while holding the other stream component concentrations constant.

For convenience of discussion, the baseline calculation is referred as case 0; the cases studied include 45% paper recycle, case P1; 10% plastics recycle, case P2; 60% glass recycle, case P3; and 90% paper recycle, case P4. Table V provides a comparative summary of the cases studied.

By maintaining a fixed waste collection rate, recycling reduces the waste throughput and heat input to the WTE plant. Paper and plastics recycling causes the waste heating value and combustion temperature to decrease, but glass recycling produces a reverse trend. The sets of waste throughput and heat input values for cases P1, P2, and P3 are (533 tpd, 65.7 MW), (645 tpd, 84.5 MW), and (623 tpd, 86.3 MW), respectively. These values fall within the envelope of the stoker capability diagram indicating that WTE plant operation should remain viable. Because of the amount of paper (40%) in waste, paper recycling has more significant impact on the WTE plant operation. As an example, if paper recycling were increased beyond the proposed ~45% rate, to 90%, a strong negative effect on plant performance is clearly seen. The waste throughput and heat input values decrease to 416 tpd, 45.2 MW, respectively; these values are outside the stoker capability envelope, thus precluding viable plant operation. In addition, the combustor temperature is below the desired minimum level of 982°C.

Three scenarios were analyzed to assess the impacts of the proposed RCRA amendments on the performance of the baseline WTE plant. In these scenarios the waste stream input to the WTE plant is of the component composition defined in Table I; the proposed RCRA recycle rates (45% paper, 10% plastics, and 60% glass) is then applied to the collected refuse. In scenario 1 (or case S1), the WTE combustor maintains the baseline plant stoichiometric ratio (~0.526); in scenario 2 (or case S2) the WTE combustor maintains combustion temperature at the level found in the baseline plant by adjusting stoichiometric (about 1083°K); in scenario 3 (or case S3); waste collection rate of the WTE plant is increased (assuming the catchment area can be enlarged) to maintain the same throughput and combustion temperature as in the baseline plant. Results from the analysis of scenarios S1, S2, and S3 with the computer simulations are summarized in Figures 3, 4, and 5, respectively; Table V presents a comparative summary of the pertinent results of the three scenarios and the baseline case.

The proposed RCRA recycling rates have a significant effect on waste throughput and heat input. The recycling of paper, plastics and glass, according to the proposed rates, decreases waste throughput by 23% from 650 to 500 tpd and heat input by 26% from 86.3 to 63.9 MW, if the waste collection rate (catchment area) remains the same. For scenarios S1 and S2, the set of waste throughput and heat input values are the same (500 tpd, 63.9 MW), and are on the margin of the stoker capability diagram. If more of the paper waste component is recycled than proposed, the throughput/heat input values would be outside the stoker capability envelope and the performance of WTE plants would likely be seriously impacted. However, if collection rate (catchment area) can be increased, the situation would be improved. For scenario S3, the set of waste throughput and heat input values is (650 tpd, 83.0 MW), which is in the middle of the stoker capability envelope; normal plant operation could be maintained. It appears that it will be possible to maintain the desired combustion temperature range in the WTE plant if the proposed amendments are adopted. The power output, however, will decrease dramatically (approximately 26%) unless the catchment area is increased to maintain the design throughput. While an economic impact study is beyond the scope of this study, it seems clear that under the no enlargement of the catchment area scenario there would likely be a substantive negative impact on overall plant economics. The economic impact would be further exacerbated through a loss of tipping fees, with a reduced throughput. If the catchment areas for the WTE plant can be increased to maintain the plant design throughput (after recycling) the plant economics could actually improve through an increase in tipping fee revenues, assuming operating costs per unit of throughput do not increase significantly.

From a national perspective, the proposed RCRA amendments would reduce a significant amount of potential waste energy generation by WTE plants. National municipal waste generation rate is estimated (Barrett etc. 1992) as 150 million tons per year with a average heating value 10.5 MW/kg. This waste represents a significant source of energy equivalent to 45,000 MW(t) on a continuous basis. Assuming all the waste is converted to electric power and average plant efficiency is 22%, municipal waste represents the equivalence of 10,000 MW(e) of electrical power on a continuous basis. The RCRA amendments would reduce 26% of the total heat input to WTE plants. Therefore, potential waste energy generation by WTE plants would be reduced by 26,000 MW(e).

Impact on Landfill Methane Generation Rates

The proposed RCRA recycle rate would have a significant effect on the landfill refuse acceptance rate. By recycling 45% of the paper, 10% of the plastics, and 60% of the glass in the typical waste stream, the refuse acceptance rate is reduced by 23% which is identical to the throughput reduction of WTE plants, as indicated in the previous section.

The impact on the potential methane generation rate was developed with the Busswell model. The waste element compositions were first computed for the average (baseline) waste stream and for the waste stream which would result from the application of the proposed recycle rates; the compositions are shown in Table VI.

From the above compositions, the chemical formulas of the baseline waste and RCRA recycle waste can be derived as $C_{36.5}H_{56.4}O_{19.9}NS_{0.087}$ and $C_{31.5}H_{48}O_{16}NS_{0.074}$, respectively. The potential methane generation capacities for the baseline and the RCRA recycle cases were calculated to be 316 and 332 m^3/Mg waste, respectively. The impact on the potential methane generation rate is, therefore, relatively minor. RCRA recycle causes the potential generation rate to increase by 5%. The actual landfill generation methane rate, however, is proportional to the product of both methane generation capacity and refuse acceptance rate. According to the 1986 EPA survey, there are an estimated 6034 active municipal landfills in the United State receiving about 209 million megagrams of waste annually. If refuse collection rate (or catchment area) remains the same, the waste received in the landfills would decrease from 209 to 164 million megagrams annually, a 20% reduction, and the potential landfill methane generation rate would decrease from 66 to 54 x 10^9 m^3 annually, 16% reduction, as a result of the proposed RCRA recycle rates.

CONCLUSION

The proposed RCRA recycling amendments would reduce the throughput of an average waste stream through a typical WTE plant by 23% and reduce its heating value by 4%. The new average waste stream that would result generally should be able to be burned in existing plants since the new combination of flow rate and heating value is expected to fall within the operating envelope of the vast majority of existing plants. Thus, a major impact on WTE plants energy output resulting from inability to utilize new waste streams should not occur. The overall heat releases and hence energy produced, however, will be substantially reduced, by approximately 26%. As a nation, potential waste energy generation by WTE plants was estimated as 10,000 MW(e) and the RCRA amendments would reduced the potential waste energy generation by 2,600 MW(e). However, if the recycling rates increase further, the study showed that WTE plants may operate outside the operating envelope. This conclusion is based on the assumption that the catchment area for the typical plant remains constant and, thus the quantity of waste produced is not increased. This assumption will not hold for all plants; therefore, the energy impact on each WTE plant will differ.

From a national perspective, however, the total quantity of waste fed to WTE plants would decrease by the 23%, and the heating values reduced by 4%, if the amendments are adopted (the whole U.S. is considered the catchment area). Some WTE plants would undoubtedly close down due to the development of unfavorable economics, thus causing a diversion of the waste stream to landfills or to other larger WTE plants. The overall impact on the WTE industry, however, cannot be developed from such a limited study, since the economics of each WTE plants is subject to many technical, social, and political factors.

The impact of the proposed RCRA amendments on the methane generation rate is relatively small. The waste component recycling increases potential methane generation rate of landfills by 4%. If refuse collection rate (or catchment area) remains the same, the contribution of the altered waste stream to the overall landfill generation rate would decrease by ~20% (at the time methane generation begins in the refuse life cycle) as a result of the proposed RCRA recycle rates.

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TABLES:

Table I Compositions and Properties of the Baseline Waste Stream

Component	Mass Fraction (%)	Component Heating Value (MJ/kg)	Component Heat Content (%)
Paper	34.2	16.7	45.8
Plastics	9.1	32.6	23.8
Glass	7.1	0.14	0.1
Yard Wastes	19.9	6.51	10.4
Metals	8.4	0.70	0.5
Food	8.4	4.65	3.1
Wood	4.2	18.6	6.3
Dirt	3.3	6.98	1.8
Textiles	2.5	17.4	3.5
Leather	1.5	17.4	2.1
Rubber	1.4	23.3	2.6
Total	100.0	12.48	100.0

Table II Elemental Composition of Waste Components

Component	C	H	O	N	S	Ash
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Plastics	60.0	7.2	22.8	-	-	10.0
Glass	1.0	0	1.0	0	0	98.0
Food	48.0	6.4	37.6	2.6	0.4	5.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard Waste	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Dirt	26.3	3.0	2.0	0.5	0.2	68.0
Metal	-	-	-	-	-	100.0

Table III Comparison of Operating Parameters of Baseline Calculation and Bristol Facility

Case	Baseline	Bristol
Waste throughput (tpd)	650	650
Electricity Produced (MW)	16.5	16
Steam rate (kg/s)	18.6	18
Boiler pressure (atm)	60	59-65
Superheater steam temp (C)	444	444
Excess air (%)	90	90
Excess oxygen (%)	8.8	8.5-9.5
Overall plant efficiency (%)	19.1	~18

Table IV Comparison of WTE performance for various waste component recycling

Case	Baseline	P1	P2	P3	P4
Waste HHV	12.48	11.72	12.30	13.03	10.61
Waste throughput (after recycling each component (tpd)	650	533	645	623	416
Heat Input (MW)	86.3	65.7	84.5	86.3	45.2
Electricity Produced (MW)	16.5	11.7	16.0	16.7	7.3
Steam rate (kg/s)	18.6	14.4	18.2	18.8	9.7
Combustion temp. (C)	1083	1011	1070	1091	902
Potential NO conc. (ppm)	370	240	350	390	110
Boiler tube temp (C)	299	320	299	302	322
Superheater tube temp (C)	361	297	352	364	281
Economizer tube temp (C)	203	198	200	206	203
Slag rejection (kg/s)	1.11	1.06	1.11	0.91	1.00
Flue gas flow rate (kg/s)	52.9	43.2	52.5	52.8	33.1
Flue gas compositions (%)					
CO_2	8.92	8.78	8.89	8.93	8.64
H_2O	12.5	12.3	12.4	12.3	12.1
N_2	69.8	70.1	69.8	70.0	70.4
O_2	8.78	8.85	8.82	8.80	8.87

Table V Comparison of WTE performance for various RCRA scenarios

Case	0	S1	S2	S3
Waste coll. rate (tpd)	650	650	650	844
Waste feed rate after recycling (tpd)	650	500	500	650
Waste HHV (MJ/kg)	12.48	12.05	12.05	12.05
Waste throughput (tpd)	650	500	500	650
Heat input (MW)	86.3	63.9	63.9	83.0
Combustion temp. (C)	1083	1014	1083	1083
Excess air (%)	90	90	73	73
Electricity (MW)	16.5	11.5	11.6	15.6
Steam rate (kg/s)	18.6	14.1	14.6	18.0
Boiler tube temp (C)	299	324	310	311
Potential NO conc. (ppm)	370	240	350	350
Slag rejection (kg/s)	1.11	0.85	0.85	1.10
Flue gas flow rate (kg/s)	52.9	42.2	38.9	50.5
Flue gas compositions (%)				
CO_2	8.92	8.84	9.59	9.59
H_2O	12.5	12.1	13.2	13.2
N_2	69.8	70.2	69.4	69.4
O_2	8.78	8.82	7.79	7.79

Table VI Waste Elemental Composition for the Baseline and RCRA Recycling Cases

Element	Baseline case	RCRA recycle
Carbon	52.8	54.1
Hydrogen	6.8	6.9
Nitrogen	1.7	2.0
Oxygen	38.4	36.7
Sulfur	0.3	0.3

Figures:

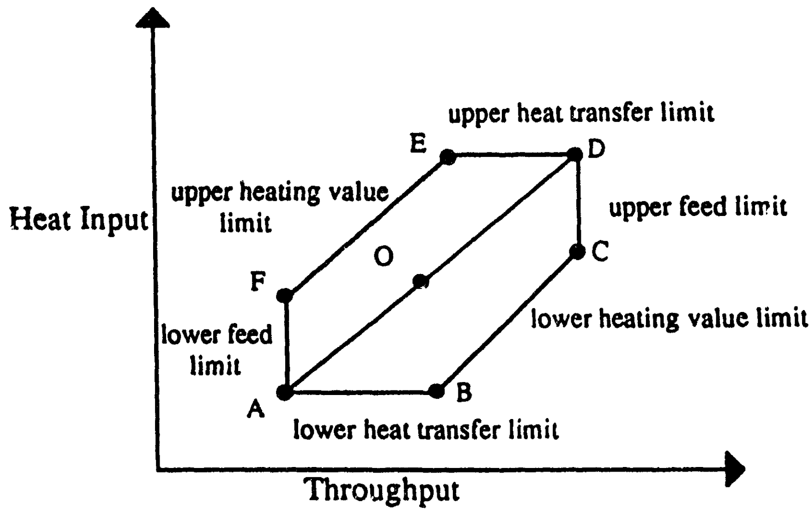

Figure 1 Operating Envelope of A WTE Plant

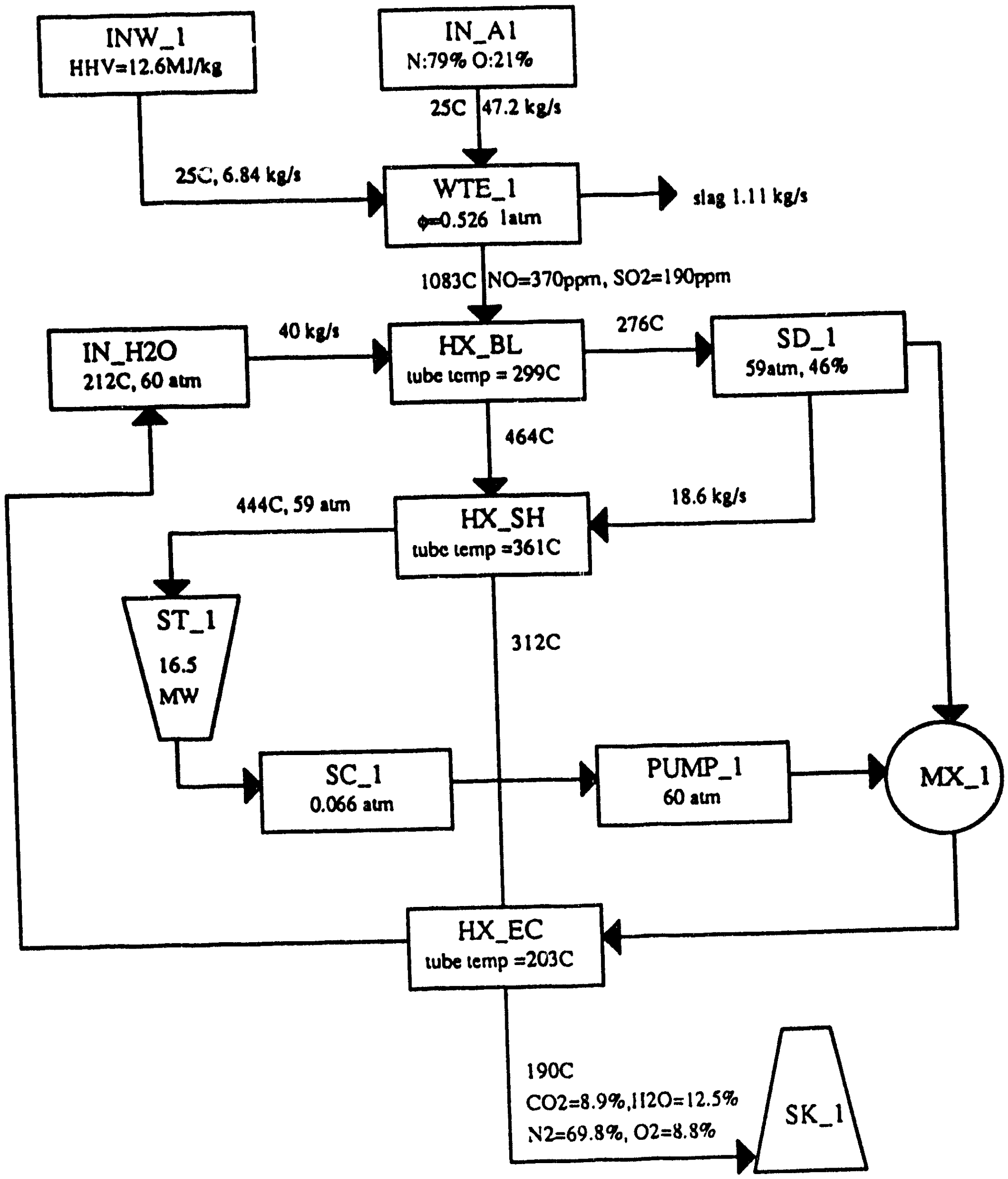

Figure 2 Simulation Results of the Baseline WTE Plant

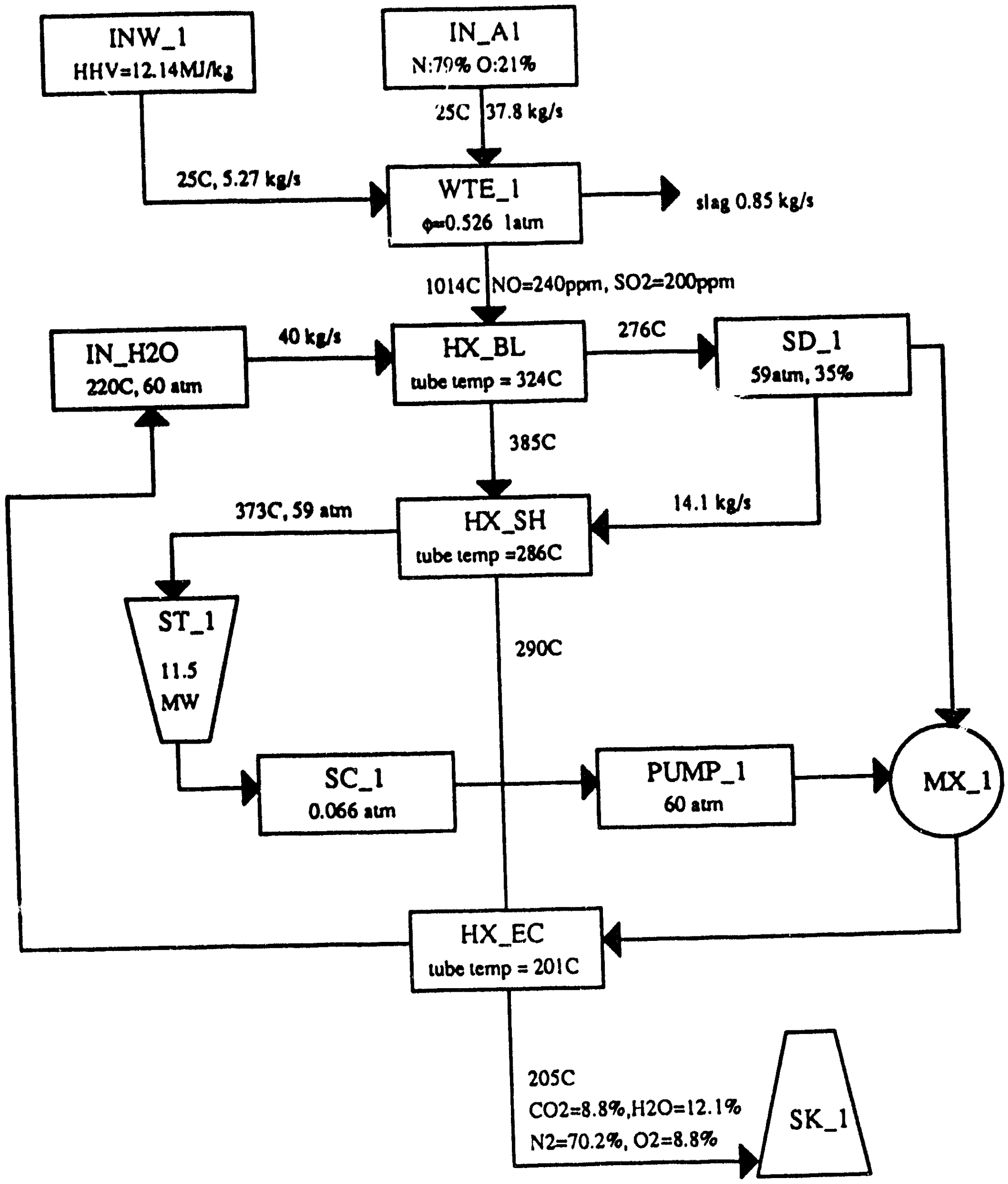

Figure 3 Simulation Results of RCRA Scenario 1

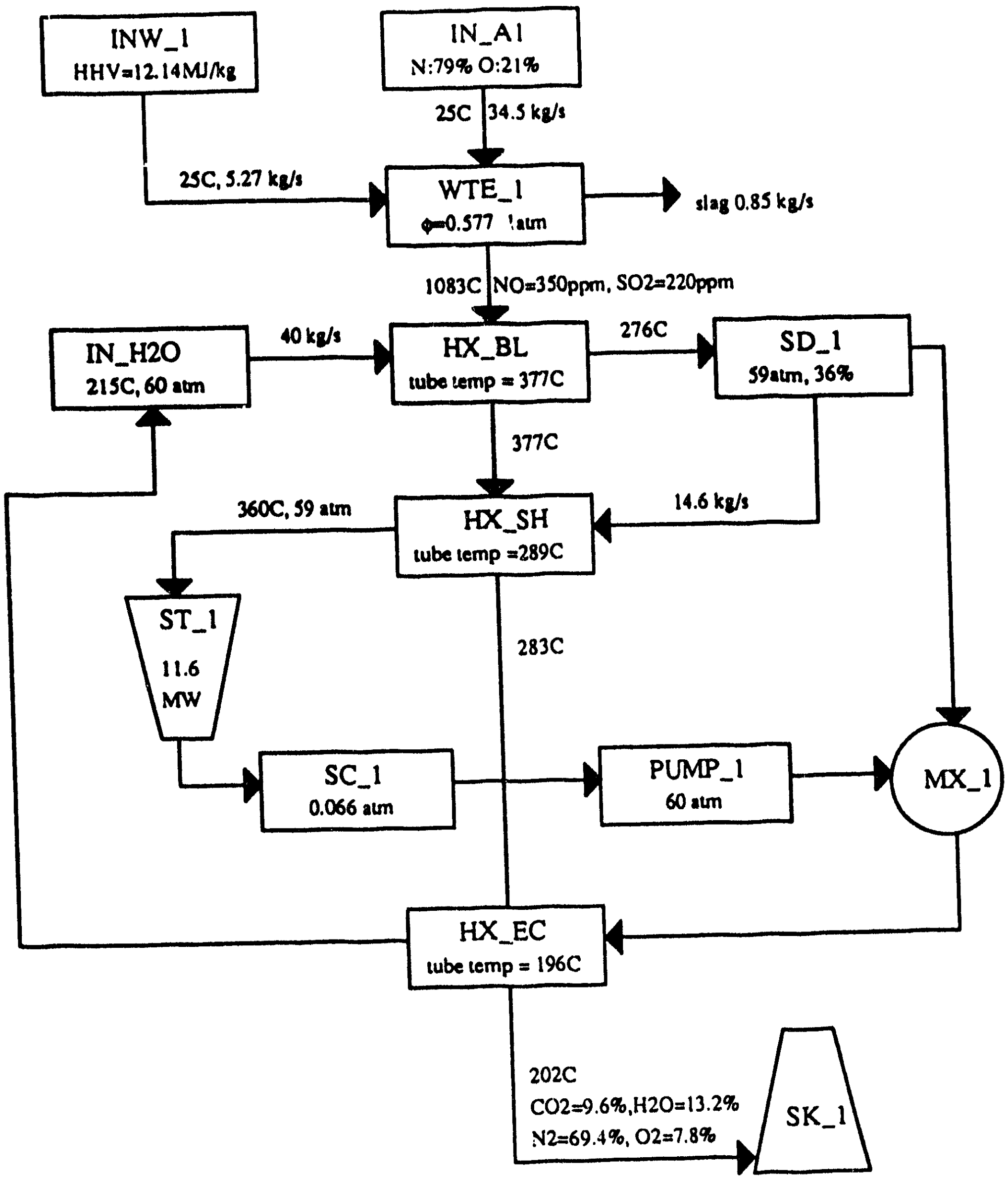

Figure 4 Simulation Results of RCRA Scenario 2

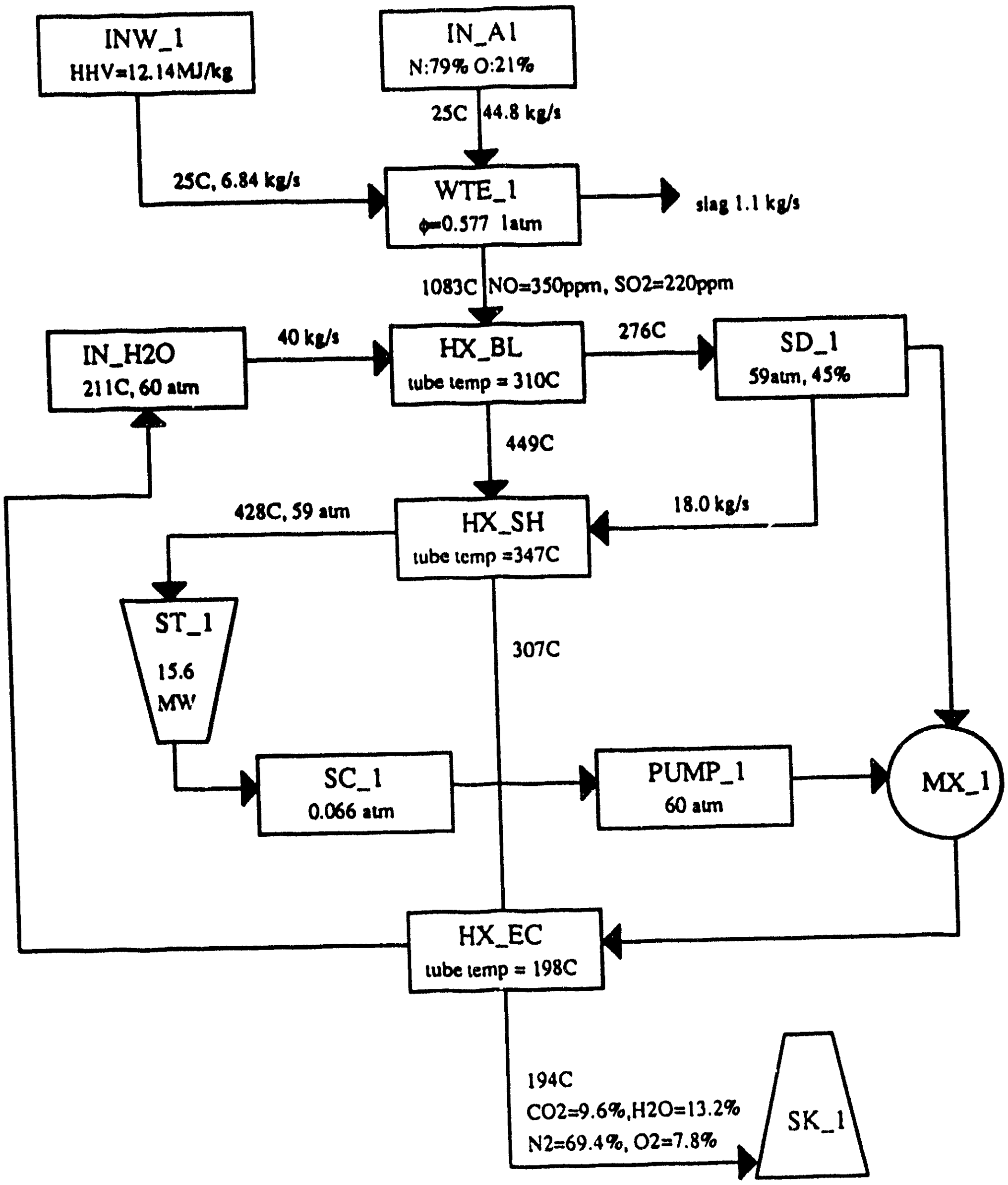

Figure 5 Simulation Results of RCRA Scenario 3

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