

CHAPTER - II

LITERATURE REVIEW

Production of solid waste and its disposal is an age old phenomenon which has undergone various modifications by utilising modern technological aspects. The disposal of waste was not a severe problem in olden days as the cities were small and scantily populated. Conventional methods of disposal of solid waste like landfill and composting were widely used. As a part of development of nations, industrialization and thus the concentration of population in urban areas increased and the methods of disposal of solid waste by landfill and composting also underwent lot of modifications involving technological aspects. Also pollution problem and hygienic requirement of the population dictated to look for other methods of disposal of solid waste. Thus incineration, biogas production and pyrolysis techniques gained importance. Due to increased utilization of fossil fuels as raw materials and as an energy source, the reserves of fossil fuels are depleted and it necessiated to search for new source of raw material and energy. In this context the recycling of the solid waste as a viable alternative to fossil fuels is gaining ground.

Although a large amount of research is going on in this field, it is only recently that the technological advancements became the basis of new disposal techniques. These new techniques necessiated the systematic study of solid waste with respect to its origin, its composition and sampling.

A survey of Madras city solid waste done by Sastry et al.¹ has shown that the daily production of solid waste is 0.545 kg/person. The waste obtained by high income residential areas contained larger fraction of leaves, paper and plastics than in the refuse obtained in slum areas.

Trinklein, Barbara² have adopted the statistical method of analysis for the solid waste for the San Diego Energy Recovery Facility. It has been shown that the higher heating value of waste derived from commercial source is 13000 kJ·kg⁻¹ and that obtained from residential source is 10,200 kJ·kg⁻¹. The higher values have been attributed to low percentage of moisture content and non-combustibles.

Patil et al.³ have studied the composition of solid waste from Puna city, which revealed high amount of organic matter and high paper content. The average calorific value of waste was 7,100 kJ kg⁻¹ and the density was 250-465 kg m⁻³. The C to N ratio was ideal for composting.

Ghosh et al.⁴ have conducted a study of the solid waste obtained in Calcutta city which has shown that fruit and vegetable form 20%, leaves, grass straw etc. form 21% and dust, ash and cinder form 57% by weight of solid waste.

Another study of solid waste produced in Calcutta city by CPHERI⁵ during the year 1970 has shown that fruits and vegetables form 14%, rags 2%, glass, porcelain pieces and bones 4%, metal and tin 4% and dust, ash and cinder form 69% with miscellaneous 7%.

Beg et al.⁶ have analysed the solid waste produced in Karachi city and have shown that the paper content was 3.6%, glass 2.5%, rags 7.1%, plastics 2.1, fines 18.2%, moisture 43.5% and combustible matter 52.0%.

Yutaka et al.⁷ in their study of solid waste have recommended the stratified sampling as a better method than quartering, random sampling and cluster sampling for the solid waste.

2.1 Landfill and Composting

Although the new techniques of disposal of solid waste like incineration and pyrolysis are widely adopted the conventional techniques of landfilling and composting may be used if otherwise unusable land is available and if the cities are small. The major disadvantage of these methods is the leachate produced and the longer time required for sterilization of waste.

Kenneth⁸ has discussed the disposal of solid waste with respect to recovery of energy, recyclables and compost. According to the studies three acres of land is required for continuous composting of solid waste produced by 1,000 households. The landfill composting anaerobic digesters will produce 769 m³ of methane per day which is roughly equivalent to the domestic cooking demand of the neighbourhood. Source separation, recycling, controlled landfilling and composting are combined to provide continuous biogas and soil amendment production.

Jourden⁹ has studied the landfilling. The study has revealed that the comminution and moistening the refuse and recirculation of leachate alongwith aeration improves the biodegradation of solid waste. It resulted in rapid degradation, relatively clean leachate and safe operation.

Horvath¹⁰ in his studies has shown that waste dump pollutants leach out by rain and ground water. He has proposed that, to prevent the pollution, the disposal site must be chosen above the ground water level, the zone between the bottom of the dump and ground water level should be extensively unsaturated and the zone should have good filter ability, absorption, chemisorption and ion exchange properties and should be distant from gravel strata.

Yamada, et al.¹¹ in their study of landfill leachate have revealed that the annual leachate volume calculated on rainfall, out-flow evaporation and permeation was approximately 430 L-m^3 . The level of Cl^- in the leachate was 3,000-4,000 ppm for 2 years and decreased to 300 ppm in 5 years. The BOD was $< 10,000$ ppm for several months and decreased to 1,000 ppm in 1 year and to 100 ppm in 3 years showing that the BOD removal reached $> 99\%$. The COD was 700-500 ppm in 2 years and dropped to 10-50 ppm in 4 years.

Bull et al.¹² have analysed the landfill leachate under laboratory conditions. Under conditions of average BOD loading (600 g m^{-3}) and at 20°C the laboratory results indicated that $> 95\%$ of the sol. BOD and essentially all the Fe was removed and that 90% of the N was converted to free NH_3 .

Canpos¹³ in his studies of landfill leachate has suggested the treatment of waste with CaO , distribution of leachate from lower part of the deposit over the treated surface, addition of a layer of municipal waste and compaction to prevent the contamination of leachate. This process has to be repeated and heap should be covered with aggregate and oil, it is reported.

Varma¹⁴ in his studies of Moyer Landfill Site has revealed that more than $22.7 \times 10^3 \text{ m}^3$ of highly contaminated leachate was produced per year and he has suggested that old landfill sites must be geologically evaluated and carefully monitored to prevent further environmental pollution.

Duell et al.¹⁵ have cautioned that trees should not be planted without a gas barrier in closed landfill area where vegetation cannot be established due to the landfill gases coming to the surface. They have concluded that good grass growth in such areas does not guarantee the survival of trees, and the foul odour and dark appearance of the deeper soil can be taken as indicator of anaerobic soils that will not support plant growth.

It has been reported¹⁶ that the landfill gas produced at UK's largest landfill site at Stone, near Dartford has been efficiently recovered and used. The landfill gas is collected in wells sunk to an average depth of 25 m. It is then compressed and dried before being piped underground to cement works.

A similar attempt to recover the landfill gas from Merseyside Landfill Site is also reported.¹⁷ It is providing 1,00,00,000 therms (1 Therm = $1054 \times 10^5 \text{ kJ}$) per annum of high quality methane gas. The source was expected to last from 5-10 years providing energy less costlier than conventional natural gas.

Similar to the landfill method of disposal of solid waste, composting is also an old method characterized by biodegradation of the organic components of the solid waste over a prolonged period.

Wolfgang¹⁸ has shown that the degradation rate of organic substances in compost at 50°C reaches 59.4% in 8 weeks; the rate decreases to 48.2 and 40.1% respectively as the reaction temperature decreases to 30°C or increases to 70°C. The mesophilic bacterial count increases by > 10 at 30°C in 2 weeks but decreases significantly at > 50°C. It is observed that a similar trend was there for mesophilic actinomycetes and fungus counts.

Chuang et al.¹⁹ have discussed the composting of municipal refuse in Taiwan. Their studies have revealed that the kitchen residue and moisture content of Taipei & Kaohsiung refuse are 25 and 56% respectively, compared to 10-25% for typical USA municipal refuse. This high organic content and proper moisture content is suitable for composting of solid waste produced in Taiwan, they concluded.

Takeuchi et al.²⁰ have described a composting method which consists of pretreatment, fermentation and refining of solid waste. The waste freed from Fe, batteries, glass etc. is subjected to size reduction and added to a multiple padding fermentor with intermittent stirring and continuous aeration.

Ciprini²¹ has explained a composting method in which the refuse is shredded in rotating drum and water is added to a suitable level for aerobic fermentation. Discards of drum are thrown into collection pit for incineration. Metals, glass and ceramic fragments are separated from refuse in an air classifier, mineral salts and waste water sludge mixed and allowed for aerobic fermentation of 8-12 weeks.

Kuno²² has studied the physical conditions and relations for an aerobic development of the microbial process in a naturally aerated

compost windrow. The height of compost windrow has to be adjusted in first week for the maximum possible airflow necessary for sufficient O₂ supply and after a week the air demand is reduced and additional layers can be built up as pore volume and air permeability increase with decay, it is concluded.

Golueke et al.²³ have explained the usage of light fraction of refuse as bulking agent in composting of dewatered sewage sludge. The sludge and the lights must be thoroughly mixed and the porosity must be maintained throughout the subsequent turning or aeration, they said.

Tabasaran²⁴ has discussed the composting of refuse after removal of non-degradable materials and mixing it with sewage sludges which are made into briquettes, stacked in decaying hall for 3 weeks for not phase rotting at 70°C. Water is added to accelerate the biodegradation > 50°C. Mature compost was obtained by rough crushing of the briquettes and storage in open air for 3 months.

Wolfgang et al.²⁵ have shown that briquettes made up of sewage sludge and treated dry waste with water content of optimal 45% when composted, the temperature rises to 60-70°C and helps in killing the pathogens. The nitrogen losses caused by NH₃ outgoing are maximum 25%.

De Haan²⁶ has shown that the concentration of pollutants including COD, N and metals in the drainage water from matured sewage sludges and refuse compost in the first year are 20-100 times those of normal soils, in the 6th year it is 1-5 times. Mixing the predried sludge or compost with soil resulted in a decrease in pollutant

concentrations in drainage water. A sandy soil treated with liquid sludges in 7.5 - 22.5 ton dry matter per hectare per year resulted in increased concentrations of N, Ca, S, Mn and Zn as compared to untreated soils.

2.2 Production of Refuse Derived Fuel

The production of Refuse Derived Fuel (RDF) from the domestic waste is a technique which gives a fuel of considerable calorific value which can be used as an alternative to the conventional fuels such as fuel oil and coal. It is a resource recovery technique and intermediary. All the domestic waste is of no use in the production of RDF, but only the combustible fraction of the refuse is useful. The problems associated with the use of RDF is similar to that of incineration, because the burning of RDF is essentially incineration. The combustible components of domestic refuse are separated mechanically using different techniques from non-combustible portion and made into pellets or briquettes for ease of handling. Where combustible fractions are more, the technique is economically feasible and saves the conventional fuels.

Ramon²⁷ has explained the method of manufacturing of RDF. In this method wastes are milled, soil, ash, sand and part of vegetable particles are removed alongwith metals and glass. The organic material is milled to < 50 mm, CaCO₃ is added to neutralize Cl from PVC wastes; and the mixture is compressed to cylinders and heated to 60°C and cooled to form solid fuel having moisture content of 8-12%, density of 600 kg m⁻³ and calorific value of 12,500 - 13,300 kJ kg⁻¹.

Braker et al.²⁸ have explained a pilot plant to manufacture fuel from municipal solid waste with 5 metric tons-hr⁻¹ capacity. The produced fuel is dust like and storable. An extension of technology for treating the municipal solid waste individually according to individual conditions with possibility to produce coarse-grained, briquetted and dusty fuels is also explained. 1 metric ton of municipal solid waste gives 300 kg of fuel with a calorific value 18 GJ / ton.

Hug²⁹ has explained an experimental operation to obtain RDF. The yield and composition of the fuel pellets depended on the process temperature, heating curve and the composition of the raw pellets. The fuel pellets were suitable for storage with no decomposition or odour emission.

Howard³⁰ has explained a method to produce the RDF from solid waste in which refuse was crushed, passed over a double vibrating screen and the coarse material was fed to a 2nd crusher to give particles of size < 2.5 cm. The material was passed to a magnetic unit for metal removal and to an air classifier from which the lighter components were fed to a paddle mixer for blending with powdered lignosulfonate. The dry mixture was compressed into pellets, pyrolyzed at > 350°C quenched and packed to give a stable fuel with heating value 17,500 kJ - kg⁻¹.

A manufacturing method described by MUT Maschinen and Transportanlagen³¹ involves storage, pulverizing, sorting to separate Fe portion, and hard substance, sieving and rotting of the wastes. Thus

fuel containing < 3 and 3-13 mm particles was prepared from refuse whose lower heating was $5,800 \text{ kJ} \cdot \text{kg}^{-1}$. The chemical composition of the fuel was C 18, H 2.3, O 14, H_2O 40, ash 23, S 0.38 and Cl 0.11%.

Haq et al.³² have shown that each metric^{ton} of refuse can be converted into 0.025 mV of electricity. It also eliminates the sulphur pollution problem. The potential for saving oil and gas by retrofitting existing boiler with burners that uses RDF is shown as technologically possible.

A plant has been designed by the Warren Spring Laboratory of the Department of Trade and Industry³³ at Doncaster, to produce RDF. The calorific value of $20,000 \text{ kJ} \cdot \text{kg}^{-1}$, ash content 12.2%, fixed carbon 11.3%, volatile matter 57%, sulphur content 0.3% and chlorine 0.9% have been reported for the RDF produced.

Carrera et al.³⁴ have explained the development of a process by integrating the production of RDF from municipal solid waste presently operating in Rome East MSW recycling plant which can allow the introduction of industrial and commercial waste considered suitable for the production of solid fuel for industrial uses.

Bagstam³⁵ has explained the experiments with storage tests of RDF at two different sorting plants in Sweden. The tests have been performed in order to find an acceptable way of handling and storing of RDF during summer period. Different qualities of RDF were studied like fluff RDF of different origin, RDF in bales and RDF pellets.

Lorber³⁶ in his study has compared the emissions from the incineration of RDF and incineration of total waste. Based on the lower calorific value the contamination of RDF with heavy metals and

sulphur is significantly decreased compared to unprocessed total waste. This is not true for Cl which is enriched in total waste as well as

- RDF. Incineration of RDF and total waste leads to mobilization and formation of environmental pollutants.

Jakobson³⁷ have explained the pelletizing of selected solid waste material. The pellets produced on a die roller press were combusted in boiler and combustion test programme comprised of specific combustion analysis of pellets, analyses of pellets composition, full scale combustion tests, selected analyses on stack gas emission, selected analyses on fly ash and slagg.

2.3 Biogas

This is an intermediary step in the disposal of solid waste. Only the biologically degradable components of municipal solid waste are useful in biogas technique. It is extensively used for the digestion of sewage sludge and night soil rather than municipal solid waste. The amount of water or liquid concentration must be high, nearly 50-60% of the biomass. This biomass undergoes biochemical degradation over a relatively long period of 4-8 weeks under anaerobic condition to produce methane rich biogas. The sludge or treated biomass can later be used as manure.

Diaz et al.³⁸ have studied the anaerobic digestion of the organic fraction of municipal refuse in different sized digesters. The refuse used as feed was enriched by the addition of < 100% sewage sludge of the total volatile solids. It is observed that no nutrient addition is essential, and at low organic loading rates (1.12 g vol

solid/L-day) and long duration times (30 days) the total gas production was independent of refuse loading.

Studies conducted by Rajabapaiah et al.³⁹ have shown that conventional biogas plants are isothermal, probably imperfectly mixed, fed, batch reactors operating at mean ambient temperature. Their studies have revealed that the daily gas yield was much less (27%) than rated capacity with 60% CH₄, 40% CO₂ and 0.06% H₂S by volume.

A newly developed technique by De Baere et al.⁴⁰ involved a solid state fermentation for the stabilization of organic fraction of solid household refuse. The process consists of an intensive anaerobic fermentation at 30-35% total solids and 35-55°, followed by a post digestion. Biogas and humus like end products are obtained. Gas production rates of 6-18 m³ m⁻³ day⁻¹ were obtained at a retention time of 12-18 days under thermophilic conditions. The gas yield per ton of raw organic fraction amounted to 180 m³ of biogas with a CH₄ content of 55%.

Deshpande et al.⁴¹ have studied the biogas production by anaerobic digestion of night soil. A biogas productivity of 0.507 m³ kg⁻¹ volatile solids was attained when the minimum total solid concentration of substrate (night soil) in the digester was 3%.

Mamoru⁴² has explained the mechanization of sewage water along with the night soil. The waste water is first biologically treated with a cultivated sludge containing *Lactobacillus* and *Bacillus*. The biological effluent is concentrated, a portion is used for methanization bacterial cultivation and the cultivated portion is mixed with

the rest of the concentrated portion for methanization at $> 50^{\circ}\text{C}$. Thus biogas produced from methanization of night soil at 65°C was $72 \text{ m}^3 \text{ day}^{-1}$ from 10 tons of night soil/day (10 h). The calorific value of the biogas was $29,000 \text{ kJ m}^{-3}$.

Masahiko et al.⁴³ have described the biogas production from garbage and sewage sludge. The sludge and garbage are mixed to make a slurry, then treated with lime to adjust pH at 9-10, and subjected to heat treatment for 3 h at 60°C . Then liquified fermentation is conducted in weak acidic condition and gasified fermentation at pH 7-8 by anaerobic bacterial. This technique reduces the time required for biogas production to 8 days against 15 days required in conventional systems.

Agency of Industrial Science and Technology⁴⁴ have devised a technique in which the organic waste is ground and treated with $\text{Ca}(\text{OH})_2$ solution and microorganisms to generate methane.

Tatsuo⁴⁵ has explained the production of digestion gas and digestion liquor from the manure and domestic wastes by aerobic and anaerobic conditions (lagooning). The effluent from lagooning is charged into the ground or used as fertilizer. The digestion sludge is used for soil conditioning.

2.4 Incineration

This method of disposal of solid waste can be considered as intermediary step which produces the residue and flue gases. The residue has to be ultimately disposed off as landfill or put to use as binder in road making or as building material. This technique is

marked by the evolution of noxious gases which cause the air pollution, although heat can be recovered by incineration of solid waste.

A technique developed by Kubota Ltd.⁴⁶ consisted of drying the waste by flue gas, where a portion of N compounds are converted to NH_3 . Then the waste gas from drying is discharged through a flue gas stack containing catalyst for NO_x removal.

In a technique developed by Mitsubishi Heavy Industries Ltd., Japan,⁴⁷ the refuse was crushed to > 300, 20-300, 1-20, and 1 mm size, Fe and Al were recovered from 1-20 and 20-300 mm fractions, then the metal free refuse was mixed with clay and pelletized to 1 cm size and incinerated at 1,000 - 1,100°C.

Yet in another technique developed by Takuma Co Ltd., Japan,⁴⁸ waste solids are incinerated in a shaft furnace and the combustion gas is heat exchanged, scrubbed, and then used as fuel substitute. The resulting fuel gas is also used to preheat the air for incineration at 750 - 1,000°C.

Kaketa et al.⁴⁹ have discussed the incineration of combustible municipal refuse mixed with silica, glass to obtain incineration residue as clinker.

Hirokatru et al.⁵⁰ have shown that in incineration ash there was little correlation of metals because of diversity in composition. A small amount of Cd, Zn, Cu and As were found in ash of solid wastes containing no non-combustibles. Cd and As concentrations were high in collected flue dust. Cd, Mn, Hg concentrations were high in the spent scrubbing solution. The ash was tested for leaching and confirmed the landfill leachate standards.

Saburo⁵¹ has revealed Zn contained in the incineration flue gas as shown by the electrostatic precipitator ash extracts. About 25 kg of salts were obtained from flue gas scrubber waste water for each ton of refuse incinerated. After heavy metal removal electrolytically, these salts can be used in caustic soda production.

Toussaint⁵² has recommended the use of incineration residues containing glass and ceramic fragments 30-70, fine ashes 20-60, non-ferrous metals 1-3, and combustibles matter 1-4% with particle size 0-120 mm, density 2.34 - 2.86, bulk density 0.76 - 1.2 as embankment fill material and pavement base courses without binder.

Ijsselkring⁵³ has explained the use of incineration residue as building material. The building material contains slags from the incineration of domestic refuse 75-95, binder 5-25, foaming agent 0.01-1, and water proofing agent 0.01-1% by dry weight. The materials are useful as foundations for roads.

Knorr⁵⁴ has discussed the use of incineration residue in road construction or in dams as packing material. Solid residues from dry or semidry waste gas scrubbing have no use and must be disposed off by landfilling, he concluded.

Pedersen⁵⁵ has revealed that the solubility of metals and metal oxides in the incineration residue was extremely low. Leached amount of metals from a full scale disposal site suggested that the environmental output of the trace metals was negligible. The concentrations of Cd^{2+} , Na^+ , SO_4^{2-} and Cl^- in leachate were of the same magnitude as in sea water. Bulk precipitation of atomic Pb, Cd, Cu, Zn, Fe

and Mn on a disposal site for incineration waste was a greater source of pollutants than leachate from the site.

Kubota Ltd. Japan,⁵⁶ has described the method to remove the pollutant from waste gas from the incineration of refuse, containing NH_3 3.52, H_2S 0.052, Me_3N 0.02, Me_2S 1.28, MeSH 0.04, SO_x 182 and HCl 39.5 ppm by pressuring the waste gas in a solution to dissolve or suspend the pollutant, followed by decreasing the pressure to evaporate the gas.

A similar method was described by Ishikawajima Harima Heavy Industries Co. Ltd.,⁵⁷ to remove the pollutants in incineration flue gases by using H_2SO_4 solution and a NaClO solution for scrubbing.

A study conducted by Gounon et al.⁵⁸ of incineration flue gases originated in incineration plants in Paris, France, has shown that HCl in flue gas was $1,000 \text{ mg m}^{-3}$. The heavy metal emission is 4 or 500 mg m^{-3} .

Tojo et al.⁵⁹ in their study have shown that NO concentration in the gas evolved from incineration of waste showed an exponential increase as the temperature at incinerator outlet ranged from 600-1,000°C. Two zones in the incinerator 1,100-1,200 and 800-1,000°C are the major sites where thermal NO_x is formed and Fuel NO_x is converted.

2.5 PYROLYSIS

The pyrolysis technique is characterized by total avoidance of pollutant emissions. It is a modified technique of incineration, in which the material is subjected to thermal treatment, either in presence of restricted amount of air or total absence of air. Due

to this modification the products that obtained differ widely in their chemical composition compared with the incineration products. Although the incineration technique provides heat energy by combustion of combustible matter present in the solid waste the pollutant emissions make it less suitable for treating the solid waste. In pyrolysis, most of gas produced is combustible and does not pose any pollution problem. The organic condensate which is a chief source of many organic compounds like cresols and phenols, is also one of the major products of pyrolysis, which is not recoverable in incineration and is finally is converted to low molecular weight gases.

Shikota et al.⁶⁰ have demonstrated pyrolysis of solid waste in a plant which satisfactorily operated for 104 hrs. The yield of pyrolysis gas was 200-300 kg (240-350 m³)/ton of refuse. The calorific value of gas was 16 MJ m⁻³. They have observed that the char obtained can be disposed off without any pollution problem.

A Japan company JGC Corporation Trukishima Kikai Company Ltd⁶¹ manufactured the fuel gas from waste solids by pyrolyzing at 700-900°C, wet scrubbing, hydrogenating, desalting and desulfurizing and optionally steam reforming or CO₂-CO converting and separating steam and residual CO₂ from the resulting gas. Thus the refuse gave a fuel gas containing CH₄ 83.6, H 10.8, CO 0.7, and N 4.9 % by volume.

Another method of pyrolysis of solid waste designed by Bobcok-Krauss-Maffei Industrie analgen GmbH,⁶² consisted of carbonization of waste solids at low temperature without air, in a rotary kiln, then the gas from the kiln is decomposed in a high temperature (1200°C) reactor for 0.5-4 s, and gaseous product is cooled at 200-500°C/s.

The gaseous product was scrubbed and contained H 25, N 56, CO 12, CO₂ S, and hydrocarbons 2%. The gas had the energy value 5040 kJ m⁻³.

Knight⁶³ has revealed that pyrolysis of pine bark, saw dust, municipal refuse in vertical gravity fed, packed bed reactor gave charcoal with volatile contents 3-25%, and heating value 27860-31350 kJ kg⁻¹ oil with heating value 21150-24650 kJ kg⁻¹ and flue gases with heating value 7403 kJ m⁻³.

Nowak⁶⁴ has explained the Kiener Pyrolysis Process which is suitable for processing domestic, commercial and industrial refuse and sewage sludge. This process consists of refuse volatilization in an air free atmosphere and cracking of the produced gases.

Hitachi Plant Engineering and Construction Co. Ltd.⁶⁵ has devised a technique to prevent the fouling of pyrolysis equipment by tar. The tar containing pyrolysis gas is fed to a catalytic reactor to gasify the tar and contacted with a molybdenum sulfate catalyst at 800-900°C. The tar was completely converted to CO, H and CO₂.

Zeman et al.⁶⁶ studied the thermal decomposition of domestic refuse including paper, wood and plant and animal wastes. The decomposition occurred in the same temperature region as the pyrolysis of organic components i.e., 160-400°C with the pyrolysis maximum at 327-364°C. For the pyrolysis of mixtures containing large amount of polyethylene, the temperature range is 400-500°C with pyrolysis maximum at 475°C.

Rito, et al.⁶⁷ studied the pyrolysis of waste in a rotating combustion chamber heated by a furnace unit. The energy rich combus-

tible gas produced is removed and mixed with air/O₂, in the gas mixing unit which was used as fuel source to furnace unit. Byproducts such as cresotars are also produced.

A study conducted by Mudge et al.⁶⁸ was regarding the conversion of materials consisting of wood waste, cornstalks, straw, and mixtures of plastics, rubber tyres with cellulosic wastes yielded low calorific value gas with a heating value of average 6292 kJ m⁻³.

Walter⁶⁹ has studied the pyrolysis of cellulosic solid waste and biomass to produce the unsaturated hydrocarbons for conversion to gasoline. The studies revealed that the necessary condition for polymerization of hydrocarbons to gasoline is similar to that used in petroleum industry.

A system devised by Asakawa Kiyoshi et al.⁷⁰ for the pyrolysis of solid waste consisted of five steps, pretreatment process, pyrolysis process, gas washing process, waste water treatment process, and pyrolysis of the residue from the treatment process. The gas that produced per ton of refuse was 280-350 m³ and its calorific value was about 17,150 kJ m⁻³. The composition of the gas was H 45.3, CO 10.3, CO₂ 24.8, CH₄ 14.9 and C₂H₄ 4.7% by volume.

A plant for high temperature and high pressure conversion of solid waste to fuel gas, fuel oil and carbaneous residue devised by Rossi⁷¹ consisted of material handling mechanisms, a gasifier-liquefier reactor, operating at < 350°C and < 3.5 kg cm⁻² pressure, a condensing system and a gas holder. A charge of 70:30 domestic-industrial waste gave 20% gas (heating value 15,060 kJ m⁻³) and 20% oil (heating value 42,530 kJ kg⁻¹) and the remainder carbaneous material (heating value 9,625 kJ kg⁻¹).

8208

A

~~A~~
A

Graboski's⁷² studies have revealed that high temperature steam pyrolysis of municipal solid waste and biomass at short residence times produces olefin (C_2H_4 , C_3H_6 , C_4H_8) as well as large amounts of CO and H. He has also discussed the potential options like olefin recovery by cryogenic separation, hydration of olefins to alcohols either through the catalytic or H_2SO_4 routes, and polymerization of C_2H_4 to gasoline both catalytically and homogeneously along with economics.

Partial oxidation studies of municipal solid waste of average particle size 0.42 mm in a continuous reactor at 973–1123°K, conducted by Bharadwaj et al.⁷³ have shown that a gas is produced consisting of H, CH_4 , CO and CO_2 . In some runs unreacted oxygen was also present in the off gases. The heating value of product gas varied from 14.1 to 20.0 MJ m^{-3} and the energy production efficiency was 34–50%. At a constant oxygen-feed mass ratio, thermal efficiency increased with temperature. The highest energy production efficiency was obtained at 1123 K and oxygen to feed ratio of 0.17 $kJ\ kg^{-1}$ dry feed.

Agency of Industrial Science and Technology⁷⁴ conducted a study of pyrolysis of municipal refuse with a moisture content of 35% in a fluidized bed pyrolysis furnace. The resulting char was pulverized and fed to the oxygen rich zone at the lower part of the furnace as a fuel aid. Char production was ~10% and its calorific value 23,000 $kJ\ kg^{-1}$. The resulting gas was condensed to recover a fuel oil at 15% of refuse weight and of calorific value 28,000 $kJ\ kg^{-1}$. The calorific value of noncondensable gas was 3,350 $kJ\ m^{-3}$.

Funk et al.⁷⁵ studied the gasification of shredded household and industrial waste. The shredded waste is screened to remove glass, ceramics and other inerts, and fed through locks to the top of a shaft furnace with revolving grates where it is gasified by oxygen and steam at 1300 K. The product fuel gas is discharged overhead from the reactor and is cooled to ambient temperature, thus condensing tar, light oils, and steam. The tars and oils are recycled to the reactor. The product gas contains H₂ 25-35, CO 13-40, CO₂ 18-40 and CH₄ 5-10% by volume. It has a heating value of 7500-9500 kJ m⁻³ and yield is 700-1100 m³ ton⁻¹ of waste.

Diebold et al.⁷⁶ have studied and shown that gasoline is produced from the olefin containing gases formed when solid wastes are pyrolyzed with steam at ~ 750°C with a short residence time. Char, steam and tars are removed from the pyrolysis gases and the gases are compressed to 450 Psia for purification and then compressed to 750 Psia and fed to a conventional polymerization reactor to give the hydrocarbon product with 90% of mols boiling in the gasoline range. The preliminary economic analysis indicated that the process is competitive with petroleum derived gasoline.

A study conducted by Zielinski et al.⁷⁷ have revealed that the ash obtained from incineration of municipal wastes in an electric furnace at 1173°K was having absolute moisture content of 1.1, H 3.5, C 40.3, O+N+S 5.3 and mineral substances 49.8%. The ash has a high content of volatile substances and weak sorption capacity.

Feldmann et al.⁷⁸ have discussed a two stage process for conversion of biomass type of materials or municipal solid wastes into

fuel gas with a calorific value 12955-14806 kJ m⁻³. The first stage was a hydrogasification or CH₄ production stage where the volatile products are converted in the presence of a H rich gasifier gas into a CH₄ rich product gas and a char containing residual C. The residual C was completely converted in a separate stage to CO/H rich gas by steam-oxygen gasification.

The manufacture of storable liquid fuels from biomass have been explained by Kuester James.⁷⁹ The method involves charging of feed stock to a thermal gasification system at 500-1000° and < 5 Psig where it is decomposed to a gas rich in CO, H, and C₂H₄. This gas is then reacted in a catalytic step to produce a primary aliphatic hydrocarbons phase and a secondary alcohol water phase.

Yukitaka⁸⁰ has explained the conversion of municipal refuse to electrical energy by ; gasifying the material, mixing the gas formed with H and O, burning the mixed gas, spraying water on the flame (1000°C) to generate steam and feeding the steam to a turbine to generate electricity. Thus, from 10 kg municipal refuse, 20 kW can be continuously generated for 5 h.

Pyrolysis at 450-500°C of solid waste performed by Furue et al.⁸¹ has yielded plastic oil of heating value 30,540 kJ kg⁻¹ and cellulosic oil with heating value 5860 kJ kg⁻¹. The other byproduct obtained was char of 12550-20900 kJ kg⁻¹.

A similar pyrolysis conducted by Agra⁸² produced charcoal and flammable gas. The yield was 27 % charcoal and 3% tar, based on dry waste.

Makeikina et al.⁸³ have studied the composition of the pyrolysis tar obtained from pyrolysis of household waste. The phenols extracted from solid waste pyrolysis tar have low molecular mass and high oxygen concentration indicating that they contain dihydroxy derivatives of benzene and do not contain alkyl substituted phenols, with long chains. The pyrolytic fraction between 180-240 and 240-280 contained methoxyphenols. The 180-240 fraction also contained o-cresol, m-cresol, np-cresol, xylenols and phenol.

Pyrolysis process devised by Ebara Mfg. Co. Ltd., Japan,⁸⁴ consisted of a heat carrier (sand) circulated between combustion tower and a pyrolyzer. The pyrolysis gas is passed through two cyclones, a heat exchanger and a cooling tower. The drainage collected at the bottom of cooling tower is separated into water and oil and the oil is used as fuel to heat the carrier and to control the pyrolysis temperature.

Collin⁸⁵ has shown that the pyrolysis of household waste, plastic scrap, discarded tyres at 700°C gave hydrocarbons containing mainly aromatic components such as C_6H_6 and C_6H_9 homologs, PnMe, condensed ring aromatic hydrocarbons including naphthalene, methyl naphthalene, acenpthene, phenanthrene and anthracene, thermoplastic resins and highly aromatized oils.

Saito et al.⁸⁶ condensed the acidic water from pyrolysis of municipal cellulose containing refuse and neutralized to extract oils economically. The condensed water contained 5.8% oil, which was extracted at pH 7 at 45% yield.

Studies conducted by Ishii et al.⁸⁷ have shown that the composition of waste was paper 56.9 , garbage 1.7 , non combustible 4.2, plastic 21.9, textiles 9.9, wood etc. 2.5, grass etc. 2.2 and other 0.7%. The pyrolysis of this waste at 650°C in a two bed pyrolysis system yielded the gas containing H₂ 22.9, N₂ 3.2, CO 17.1, CO₂ 24.8, CH₄ 16.3% and remaining unsaturated hydrocarbons with a calorific value 22,100 kJ m⁻³.

Molle et al.⁸⁸ have device a carbonizer to pyrolysis the solid waste, in which the pyrolysis gas is recirculated into carbonizer unit so that no tar or carbonaceous char is produced and all the combustible matter is effectively used.

REFERENCES

1. C.R.Sastry and B.V.S.Gurunadha Rao : Conserv Recycl, 7, 249 (1984).
2. Trinklein, Barbara J. : Proc.Natl. Waste Process Conf. 365 (1982).
3. A.D.Patil, B.Z.Alone, and A.D.Bhide : Curr. Polut.Res India, 189, 186 (1985).
4. G.Ghosh; A.K.Adhya and I.Radhakrishnan: Journal of Institute of Engineers (India), 44, 59 (1964).
5. Central Public Health Engineering Research Institute: Nagpur: CPHERI (1970).
6. Beg,M Arshad Ali, Mahmood S. Naeem and Naeem Sitwat: Pak J Sci Ind Res, 28, 157 (1985).
7. Terashima,Yutaka; Urabe,Shinro and Yoshikawa, Katsuhiko: "Conserv Recycle" 7, 295 (1984).
8. Smith, Kenneth D. : "Biogas Alcohol Fuels Prod Proc Semin 1979 " 121 (1980).
9. Jourden, Bernd : Muell Abfall, 12, 178 (1980).
10. Horvath, Zsolt : Hidrol Kozl, 65, 85 (1985).
11. Yamada, Koichi; Inoue, Zensuke; Honda Atsuhiko : Yosui to Haisui, 20, 1301 (1978).
12. P.S.Bull; J.V.Evans; R.M.Wechsler and K.J.Cleland : Public Aspirations Realities Water Resource Mange, 7,309(1977)
13. Canpos Alvatraz, Jose : Span ES, 539807 (1985).
14. M.Madan Verma : Proc.Pa.Acad.Sci., 59, 67 (1985).

15. Duell, Robert W.; Leona, Ida A.; Flower, Franklin B.: Pollut Eng, 18, 38 (1986).
16. Energy World, 22 (Oct. 1986).
17. Energy Management, 8, 20 (1986).
18. Von Rheinbaben, Wolfgang: Muell Abfall, 11, 25 (1979).
19. C.Y.Chuang; K.S.Fan; S.Y.Yuan: Biocycle 27, 52 (1985).
20. R.Takeuchi; Y.Hirayama; K.Ito: Recycling, 2, 1070 (1979).
21. Ciprini, Antonia : Congr.Pro.Recycling World Congr., 2nd II/7/173 (1979).
22. Schebdat, Kuno : Recycling, 2, 1062 (1979).
23. C.G.Golueke; D.Lafrenz; B.Chaser; L.F.Diaz: Compost Sci/land util, 21, 42 (1980).
24. O.Tabasaran : Recycling, 2, 1076 (1979).
25. Baader, Wolfgang; Schuchardt, Frank: Muell abfall, 11, 205 (1979).
26. S.De Haan : Land Wirtsch Forseh, 33 166 (1980).
27. Martinez Hueso, Ramon : Span ES (1982).
28. G.P.Bracker; H.W. Sonnensehein: Congr-Proc. Recycling World Congr., 3, 1/4/1 (1980).
29. Hug, Franz O.: Recycle Congr. Energy Mater Residues Waste, 194 (1982).
30. Howard, Fredrick George : Brit, 1555, 574 (C1 C10 B 53/00), (1979).
31. MUT Maschinen und Transportanlagen GmbH:A ustrian AT, 371, 497 (C1 CIOLS/46) , (1983).
32. Mahamood Ul Haq S and others : Energy World 6, (1987).
33. Energy Management Focus, 3, (1985).

34. P. Carrera and S.Dunin : "Sorting of Household Waste and Thermal Treatment of Waste": Elsevier Applied Science Publishers, 178, (1985).
35. G.Bagstam : "Sorting of Household Waste and Thermal Treatment of Waste": Elsevier Applied Science Publishers, 194 (1985).
36. K.E.Lorber: "Sorting of Household Waste and Thermal Treatment of Waste" : Elsevier Applied Science Publishers, 208 (1985).
37. J.Bjorn Jakobsen: Sorting of Household Waste and Thermal Treatment of Waste : Elsevier Applied Science Publishers, 225 (1985).
38. Diaz,L.F.; Savage G.M.; Trezek G.J.; Golueke C.G.: Proc. Natl. Waste Process Conf., 9, 403 (1980).
39. P.Rajabapaiah; K.V.Ramanayya; S.R.Mohan; N.Amulya kumar Reddy: Proc. Indian Acad. Sci., 2, 357 (1979).
40. L.De Baere; P.Van Meenen; S.Deboosere; W.Verstraete; Resource Conserv", 14, 295 (1987).
41. C.V.Deshpande; S.Shanta; A.M.Deshkar; S.R.Wate; M.V.Srinivasan Indian Journal of Environmental Health, 28, 273 (1986).
42. Uchimizu, Mamoru: Jpn. Kokai Tokkyo Koho JP 59, 177, 197 [84, 177, 197] (C1 C02 F3/28) (1983).
43. Ishida, Masahiko; Haga, Ruoichi; Gejo, Tetsuo; Ishizuku, Toshiaki : Hitachi Hyoron, 66, 153 (1984).
44. Agency of Industrial Sciences and Technology: Jpn Kokai Tokkyo Koho, 80,59,899, (C1 C02 F11/04) (1980).
45. Hamajima, Tatsuo : Jpn Kokai Tokkyo Koho JP, 61,133,200 [86,133,200] (1986).

46. Kubota Ltd.: Jpn Tokkyo Koho JP, 59,17,322 [84,17,322],
(C1 F23G5/00) (1976).
47. Mitsubishi Heavy Industries Ltd.: Jpn Kokai Tokkyo Koho JP
81, 124, 481 (C1 B09,B 3/00) (1981).
48. Takuma Co. Ltd., Jpn. Tokkyo Koho JP 60,09,074
[85, 09, 074] (C1 C10 J3/20) (1975).
49. Kaketa, Kenji; Fukiharu, Minco: Jpn. Kokai Tokkye Koho Jp.
61, 22, 116 [86,22,116] (1986).
50. Yamamoto, Hirokatru; Ichikawa, Snogo, Ohnishi Noboru; Hata,
Hiroshi, Shimizu Mitsuro: 'Okayama-Ken Kenkyo Hoken Senta
Nempo' 3, 152 (1979).
51. Hayashi, Saburo : Recycling, 1, 563 (1979).
52. A. Toussaint : Collog Int Util Sous. Prod. Dechets Genie
cir (CR), 2, 437 (1978).
53. B.V.Ijsselkring : 'Neth AppL NL' 86,00,085, (C1 C04 B18/10)
(1987).
54. W.Khorr : Stuttg - Ber, Abfallwirtsch, 20, 319 (1985).
55. Pedersen, Swend Dige : Nordforsk, Miljoevavdssekr, 2,349(1977)
56. Kubota Ltd.: Jpn Kokai Tokkyo Koho, 80, 88, 825
(C1 B 01 D 53/14) (1980).
57. Ishikawajima-Farima. Heavy Industries Co. Ltd.: Jpn Kokai
Tokkyo Koho, 80, 54, 020 (C1 B 01 D 53/34) (1980).
58. J. Gounon; A.Milhan : Waste Manage Res, 4, 95 (1986).
59. Tojo, Todayo; Sakai, Hiroshi : Kotai Haibutsu. 23, 48 (1977).
60. Shikota, Nabuo; Wakabayashi, Mitsuo: 'Recycling', 1,
634 (1979).

61. JGC Corp Trukishima Kikai Co. Ltd.: Jpn Kokai Tokkyo Koho Jp.
82, 30, 794 (C1 C10 K3/00) (1982).
62. Babcock Krauss : Maffoi Industrieanlagen G.m.b.H : Jpn Kokai Tokkyo Koho 80, 165, 180 (C1 B 09 B 3/00) (1980).
63. J.A.Knight : Prog. Biomass Convers, 1, 87 (1979).
64. F. Nowak : Proc. Natl. Waste Process Conf., 8, 29 (1978).
65. Hitachi Plant Engg and Costn. Co. Ltd.: Jpn Kokai Tokkyo Koho
81, 38, 385 (C1 C10 B53/00) (1981).
66. Zeman, Alfred : Becker, Holmut; Woerle, Rudolf; Fichtel,
Konrad : Muell Abfall 11, 82, 88 (1979).
67. Rito, William Michael Fio; Kidd, Ralph: Gen offen 2,848,485
(C1 C10 B53/00) (1979).
68. L.K.Mudge; C.A. Kohrman : Prepr-Pap, Natl Meet. Am-Chem. Soc.
Div Environ - Chem, 18, 313 (1978).
69. Libevick, Walter,W. Jr.: Symp Pap : Energy Biomass Wastes,
4, 747 (1980).
70. Asakawa, Kiyoshi; Wakabayashi, Mitsuo : 'Hitachi Hyoron'
61, 125 (1979).
71. Rossi, Andrea : Fr Demande FR 2, 452, 329 (C1 B09 B3/00)(1980)
72. Graboski, Michael S.: Proc. Bio.Energy '80, World Congre.
Expo., 211 (1980).
- 73 K.Anil Bharadwaj; Deepak Kunzru : Resource Conservation,
10, 221 (1983).
74. Agency of Industrial Sciences and Technology: Jpn. Tokkyo Koho
JP, 58, 29, 997 [83, 29, 997] (1983).

75. Funk, Harald; Hummelsiep, Horst: Acs symp ser, 130, 485 (1980).
76. J.P. Diebold; C.D. Smith: Biosources Dig., 1, 218 (1979).
77. Zielinski, Jerzy; Przywarska, Renatu : Recycling, 1, 707 (1979)
78. H.F. Fldmann; J. Adlerstein: Propr. Pap, Natl-Meet, Am Chem Soc Div. Environ Chem., 18, 421 (1978).
79. L. James Kuester : Prepr Div. Pet Chem. Am Chem Soc. 79, 24, 456 (1979).
80. Odagiri, Yukitaka: Jpn Kokai Tokkyo Koho 81, 22, 387 (C1 C10 J3/02) (1981).
81. T. Furue; K. Shimada; Y. Nishimoto; K. Tamada; T. Yoshioka: Reg J Energy, Heat Mass Transfer, 5, 123 (1983).
82. Agra, Ida Bagus; Soehendro, Bambang : Reg J Energy Heat Mass Transfer, 5, 141 (1983).
83. V.V. Kaeikkina; N.A. Titova; U.G. Zavyalov; L.K. Vagina: Khim Trerd Topl (Moscow), 2, 140 (1982).
84. Ebara Mfg Co. Ltd., : Jpn Tokkyo Koho Jp. 60, 23, 719 [85, 23, 719] (C1 C 10 B 53/00) (1985).
85. Collin, Gerd : Chem. Rundsch, 32, (1979).
86. Saito, Yukio; Shimado, Kazusnige; Konuvo, Takotoshi; Haga, Tetsuro; Nokita, Shunsuke : Jpn Tokkyo Koho (1979).
87. Y. Isnii; N. Ishii; K. Kondo : "Sorting of Household Waste and Thermal Treatment of Waste" Elsevier Applied Science Publishers : 403 (1985).
88. J.F. Molle, "Sorting of Household Waste and Thermal Treatment of Waste" : Elsevier Applied Science Publishers, 265 (1985).

...