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General characteristics of waste management: A review

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Abstract

The amount of waste has been steadily increasing due to the increasing human population and urbanization. Waste materials are generated from manufacturing processes, industries and municipal solid wastes (MSW). The increasing awareness about the environment has tremendously contributed to the concerns related with disposal of the generated wastes. This paper presents a detailed review about waste and waste management options, and research published on the effect of waste materials on environment.

Keywords: Waste management; Waste to energy; Disposal methods
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1. Introduction

Waste management is one of the major environmental concerns in the world. Human activities and changes in lifestyles and consumption patterns have resulted in an increase in solid waste generation rates. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each. A typical waste management system comprises collection, transportation, pre-treatment, processing, and final abatement of residues. Various types of waste can be collected separately. Early researcher mentioned as the waste management is one of the public infrastructures that are based on a specific type of physical infrastructure to provide the goods or services, and in this respect it resembles the electricity, natural gas, and water sector [1].

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial, producers. Management for non-hazardous residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator. When recycling began to be recognized as essential for both environmental and resource management reasons, recycling rates for household wastes in most developed countries in the 1980s were in the low single figures by percent. Modern western waste management systems have rebuilt recycling rates over the last 20 years [2]. Modern waste management systems, which many developing country cities aspire to, are all characterized by high recycling rates of clean, source separated materials.

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Most technologies for waste management are mature and have been successfully implemented for decades in many countries. In Turkey, Solid Waste Control Regulation came into force in order to manage solid waste in 1991. The regulation has been continuously updated. Considering the Directive of Waste Frame EEC and the other directives of the European Union as part of the requirements of the integration process into the EU, the Department has started the preparations for the Regulation of Waste Frame and the draft of the Regulation has been presented for consideration. Finally, the waste management is conducted according to the Turkish Solid Waste Management that was adopted in 2008 [3]. In the Regulation, the procedures about the classification of the wastes, collection, transportation, and temporary storage of the wastes within the institutions and the transportation of them to the final disposal area were explained. In the last part of the Regulation, the method of the disposal of the wastes was mentioned.

A waste management concept including the following goals:

1. Reduction of total amount of waste by reduction and recycling of refuse.
2. Recycling and re-introduction of suitable groups of substances into production cycles as secondary raw material or energy carrier.
3. Re-introduction of biological waste into the natural cycle.
4. Best-possible reduction of residual waste quantities, which are to be disposed on "suitable" landfills.
5. Flexible concept concerning fluctuations in waste quantities and the composition of domestic waste. New developments in the field of waste management must be included into the system [4].

Large quantities of this waste cannot be eliminated. However, the environmental impact can be reduced by making more sustainable use of this waste. This is known as the "Waste Hierarchy" [5]. The waste hierarchy refers to the "3 Rs" reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimization. The hierarchy of disposal options, which categorizes environmental impacts into six levels, from low to high; namely, reduce, reuse, recycle, compost, incinerate and landfill [6]. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.

Waste collection methods vary widely between different countries and regions. Domestic waste collection services are often provided by local government authorities, or by private industry. Some areas, especially those in less developed countries, do not have a formal waste-collection system.

2. Waste management methods

Classification and assignment of different waste materials to classes cannot be easily achieved by conventional parameters. Some new techniques have been proposed and developed by researchers. Nowadays not all the wastes are classified under the same classical category, requiring the same procedure of elimination. Especially in the industries in which the types of wastes are so varied it is very difficult and impractical to set up and operate a different management system for different types of wastes [7]. Thus has emerged the necessity of a, management system which would eliminate all types of wastes. Table 1 has presented a selection of promising waste treatment processes.

2.1. Disposal methods

An integrated approach is required in an attempt to manage such large quantities of a diverse, contaminated mixture of wastes in an energy efficient and environmentally benign manner. This would require examining critically various steps in the life of the wastes such as the raw materials for their manufacture, the manufacturing processes, design and fabrication of the finished products, possible reuse of those items, and the proper disposal of the wastes, in totality. Such an integrated waste management concept comprises: (i) source reduction; (ii) reuse; (iii) recycling; (iv) landfill and gas-to energy (v) waste-to energy conversion.

Table 1. Selected waste treatment processes

Waste stream		Waste disposal methods
Combustible wastes		Roaster incineration Fluid bed incineration Pyrolysis-incineration Pyrolysis-gasification Separation-composting-incineration (Wet and dry) separation-digesting-incineration Separation-digesting-pyrolysis Separation-digesting-gasification Separation-digesting-incineration in a cement plant Selective separation-incineration
Non-combustible wastes		Landfill
Partially combustible waste streams	Wood	Pyrolysis and co-incineration in a coal power plant Pyrolysis and co-incineration in a powdered coal power plant Incineration in a fluid bed furnace Gasification
	Plastics	Gasification Feedstock Recycling
	Organic wastes	Composting Anaerobic Digestion

2.1.1. Landfill

A landfill is not a normal environmental condition, though, nor is it intended to be. Instead, a landfill is more like a tightly sealed storage container. A landfill is designed to inhibit degradation to protect the environment from harmful contamination. Deprived of air and water, even organic wastes like paper and grass clippings degrade very slowly in a landfill. Municipal Solid Waste Landfills (MSWLs) are places where heterogeneous mixtures of municipal and industrial wastes are disposed. Mechanical properties of MSW such as strength and compressibility depend on composition of waste, mechanical properties of components of the material deposited, water content and decomposition [8].

Disposing of waste in a landfill involves burying waste to dispose of it, and this remains a common practice in most countries. Landfills were often established in disused quarries, mining voids or borrow pits. A properly-designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly-designed or poorly-managed landfills can create a number of adverse environmental impacts

such as wind-blown litter, attraction of vermin (especially, noxious little animals or insects, collectively, as squirrels, rats, mice, flies, lice, bugs, etc), and generation of liquid leachate.

Landfill leachates contain a large number of compounds, some of which can be expected to create a threat to health and nature if released into the natural environment. For this purpose, Öman and Junestedt [9], have been studied screened samples from 12 Swedish municipal landfill sites for 400 parameters and compounds which expected to be present in landfill leachate. More than 90 organic and metal organic compounds and 50 inorganic elements were detected, some of which seem to have not been detected before. Compounds detected include halogenated aliphatic compounds, benzene and alkylated benzenes, phenol and alkylated phenols, ethoxylates, polycyclic aromatic compounds, phthalic esters, chlorinated benzenes, chlorinated phenols, PCB, chlorinated dioxins and chlorinated furans, bromated flame-retardants, pesticides, organic tin, methyl mercury and heavy metals. According to Öman and Junestedt [9], the presence of this large number of hazardous compounds in landfill leachates should have a significant impact on future landfill risk assessments and the development of leachate treatment methods.

Today's landfills are very different from the open dumps of the past. For one thing, new landfills are situated where clay deposits and other land features act as natural buffers between the landfills and the surrounding environment. Second, the bottom and sides of modern landfills are lined with layers of clay or plastic to keep the liquid waste, called leachate, from escaping into the soil. Deposited waste is normally compacted to increase its density and stability, and covered to prevent attracting vermin (Fig. 1).

Another common by product of landfills is gases. Landfill gas is a renewable energy source. Methane (CH_4) and carbon dioxide (CO_2) are major gases, forming from the anaerobic degradation of degradable domestic solid wastes. Landfill gases generally contain 45-60% CH_4 and 40-60% CO_2 [10]. These gases can create odor problems, kill surface vegetation, and is a greenhouse gas (GHG). Some of these compounds may cause corrosion or other damage to engines if they are not removed from the gas before utilization.

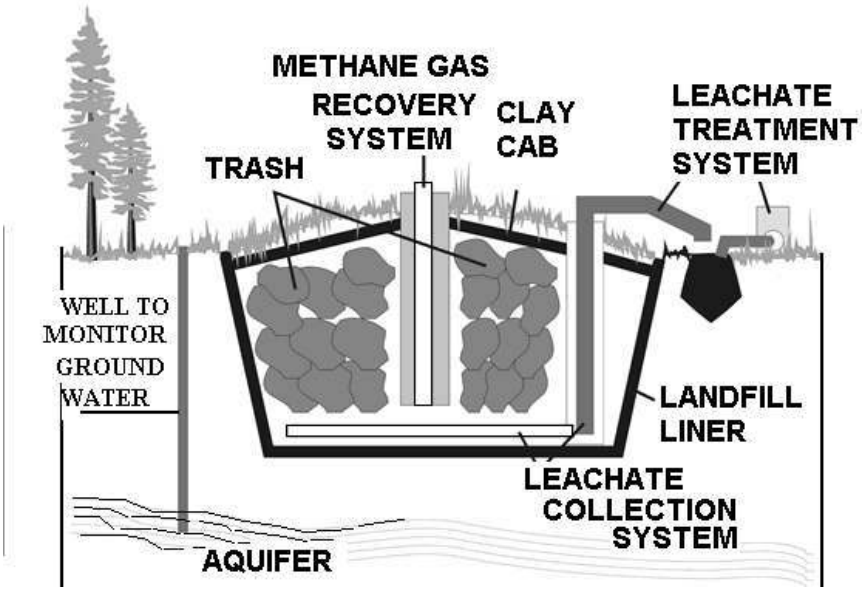


Fig.1. Modern landfill [13].

Landfills are an important source of atmospheric CH_4 due to methanogenic activity under anaerobic conditions [11]. Landfill CH_4 recovery and optimized wastewater treatment can directly reduce GHG emissions. So far, studies and applications on upgrading landfill gas are relatively few, while the upgrading of biogases from sewage and biowaste digesters is rapidly increasing in some countries. For example, in Reykjavik (Iceland), landfill gas upgrading was started in 2000 with water scrubber technology [12]. In 2003, East Kentucky Power Cooperative began recovering methane gas from three landfills. The utility uses the landfill gas to generate 8.8 MW of electricity, enough power 7500-8000 homes [13].

According to Magrinho et al., [14], landfilling is the last choice method in the hierarchy of waste management. However, even with sanitary landfilling being the most common method of solid waste management, there was no landfill gas energy recovery.

With the scarcity of space for landfilling and due to its ever increasing cost, waste utilization has become an attractive alternative to disposal.

3. Biorenewable gaseous fuels

Liquid (bioethanol and biodiesel) and gaseous (biogas and biohydrogen) biofuels have become more attractive recently because of its environmental benefits. In recent years, many studies have investigated the economic and environmental impacts of the biofuels, especially bioethanol and biodiesel [15-21]. Liquid biofuels are important because they replace petroleum fuels. There are many benefits for the environment, economy and consumers in using biofuels. Biofuels production costs can vary widely by feedstock, conversion process, scale of production and region. Biofuels production costs can vary widely by feedstock, conversion process, scale of production and region. On an energy basis, ethanol is currently more expensive to produce than gasoline in all regions considered [22-29].

Biogas can be obtained from several sources. It is obtained from decomposing organic material. Contents of domestic solid waste are given in Table 2. Biogas is composed by methane (CH_4), carbon dioxide (CO_2), air, ammonia, carbon monoxide, hydrogen, sulfur gases, nitrogen and oxygen. Among its components, methane is the most important one, particularly for the combustion process in vehicle engines [30]. A typical analysis of raw landfill gas is given in Table 3. CH_4 and CO_2 make up around 90% of the gas volume produced. The main constituents of landfill gas are methane and carbon dioxide, both of which are major contributors to global warming. Because of the widely varying nature of the contents of landfill sites the constituents of landfill gases vary widely.

Landfill leachate treatment has received significant attention in recent years, especially in municipal areas [31]. The generation of municipal solid wastes (MSW) has increased in parallel to rapid industrialization. Approximately 16% of all discarded MSW is incinerated [32]; the remainder is disposed of in landfills. Effective management of these wastes has become a major social and environmental concern [33]. Disposal of MSW in sanitary landfills is usually associated with soil, surface water and groundwater contamination when the landfill is not properly constructed. The flow rate and composition of leachate vary from site to site, seasonally at each site and depending on the age of the landfill. Young leachate normally contains high amounts of volatile fatty acids [34]. MSW statistics and management practices including waste recovery and recycling initiatives have been evaluated [35]. The organic MSW was chemically and biologically characterized, in order to study its behaviour during anaerobic digestion, and its pH, biogas production, alkalinity, and volatile fatty acid production was determined by Plaza et al. [36]. Anaerobic digestion of the organic food fraction of MSW, on its own or co-digested with primary sewage sludge, produces high

quality biogas, suitable as renewable energy [37]. The processing of MSW (e.i. landfill, incineration, aerobic composting) secures many advantages and limitations [38]. The greenhouse gas emissions can be reduced by the uncontrolled releasing of methane from improperly disposed organic waste in a large landfill [39].

Table 2. Contents of domestic solid waste (wt% of total)

Component	Lower limit	Upper limit
Paper waste	33.2	50.7
Food waste	18.3	21.2
Plastic matter	7.8	11.2
Metal	7.3	10.5
Glass	8.6	10.2
Textile	2.0	2.8
Wood	1.8	2.9
Leather and rubber	0.6	1.0
Miscellaneous	1.2	1.8

Source: Demirbas, 2006b.

Table 3. Typical analysis of raw landfill gas

Component	Chemical formula	Content
Methane	CH_4	40-60 (% by vol.)
Carbon dioxide	CO_2	20-40 (% by vol.)
Nitrogen	N_2	2-20 (% by vol.)
Oxygen	O_2	<1 (% by vol.)
Heavier hydrocarbons	C_nH_{2n+2}	<1 (% by vol.)
Hydrogen sulfide	H_2S	40-100 ppm
Complex organics	-	1000-2000 ppm

Source: Demirbas, 2006b.

Decomposition in landfills occurs in a series of stages, each of which is characterized by the increase or decrease of specific bacterial populations and the formation and utilization of certain metabolic products. The first stage of decomposition, which usually lasts less than a week, is characterized by the removal of oxygen from the waste by aerobic bacteria [40]. In the second stage, which has been termed the anaerobic acid stage, a diverse population of hydrolytic and fermentative bacteria hydrolyzes polymers, such as cellulose, hemicellulose, proteins, and lipids, into soluble sugars, amino acids, long-chain carboxylic acids, and glycerol [41]. Fig. 2 shows the behavior of biogas production with time, in terms of the biogas components. Fig. 2 indicates that the economic exploitation of CH_4 is worthwhile after one year from the start of the landfill operation. The main components of landfill gas are by-products of the decomposition of organic material, usually in the form of domestic waste, by the action of naturally occurring bacteria under anaerobic conditions.

Methods developed for treatment of landfill leachates can be classified as physical, chemical and biological which are usually used in combinations in order to improve the treatment efficiency. Biological treatment methods used for the leachate treatment can be

classified as aerobic, anaerobic and anoxic processes which are widely used for the removal of biodegradable compounds [42]. Biological treatment of landfill leachate usually results in low nutrient removals because of high chemical oxygen demand (COD), high ammonium-N content and the presence of toxic compounds such as heavy metals [31]. Landfill leachate obtained from the solid waste landfill area contained high COD and ammonium ions which resulted in low COD and ammonium removals by direct biological treatment [42]. Several anaerobic and aerobic treatment systems have been studied in landfill leachate [43]. Leachates contain non-biodegradable substrates which are not removed by biological treatment alone and an increase of leachate input may cause reduction in substrate removal [44]. Raw landfill leachate was subjected to pre-treatment by coagulation-flocculation and air stripping of ammonia before biological treatment [45]. In order to improve biological treatability of the leachate, coagulation-flocculation and air stripping of ammonia were used as pre-treatment [45]. Natural zeolite and bentonite can be utilized as a novel landfill liner material [46].

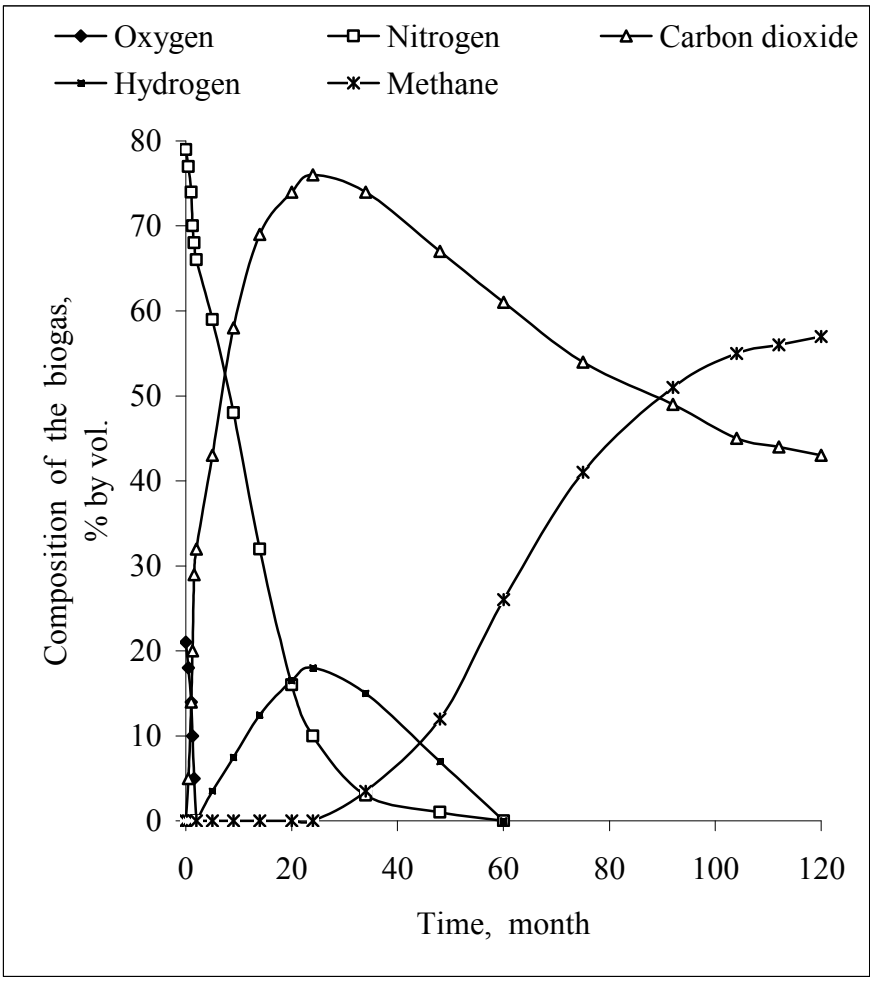


Fig. 2. Production of biogas components with time in landfill.

3. 1. Biogas technology

Anaerobic digestion (AD) is the conversion of organic material directly to a gas, termed biogas, a mixture of mainly methane and carbon dioxide with small quantities of other gases such as hydrogen sulfide. Methane is the major component of the biogas used in many homes for cooking and heating. The biogas has a chemical composition close to that of natural gas, the biodigester, or a biogas plant, is a physical structure used to provide an anaerobic condition which stimulates various chemical and microbiological reactions resulting in the decomposition of input slurries and the production of biogas—mainly methane [15].

Biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, other processes, or for the manufacturing of chemicals. Before landfilling, treatment or stabilization of biodegradable materials can be accomplished by a combination of anaerobic digestion followed by aerobic composting.

The same types of anaerobic bacteria that produced natural gas also produce methane today. Anaerobic bacteria are some of the oldest forms of life on earth. They evolved before the photosynthesis of green plants released large quantities of oxygen into the atmosphere. Anaerobic bacteria break down or digest organic material in the absence of oxygen and produce biogas as a waste product.

The first methane digester plant was built at a leper colony in Bombay, India, in 1859 [47]. Most of the biogas plants utilize animal dung or sewage. Schematic of biogas plant utilizing cow dung is illustrated in Fig. 3 [15]. Anaerobic digestion is a commercially proven technology and is widely used for treating high moisture content organic wastes including +80%–90% moisture. Biogas can be used directly in spark ignition gas engines (SIGEs) and gas turbines. Used as a fuel in SIGE to produce electricity only, the overall conversion efficiency from biomass to electricity is about 10%–16% [48].

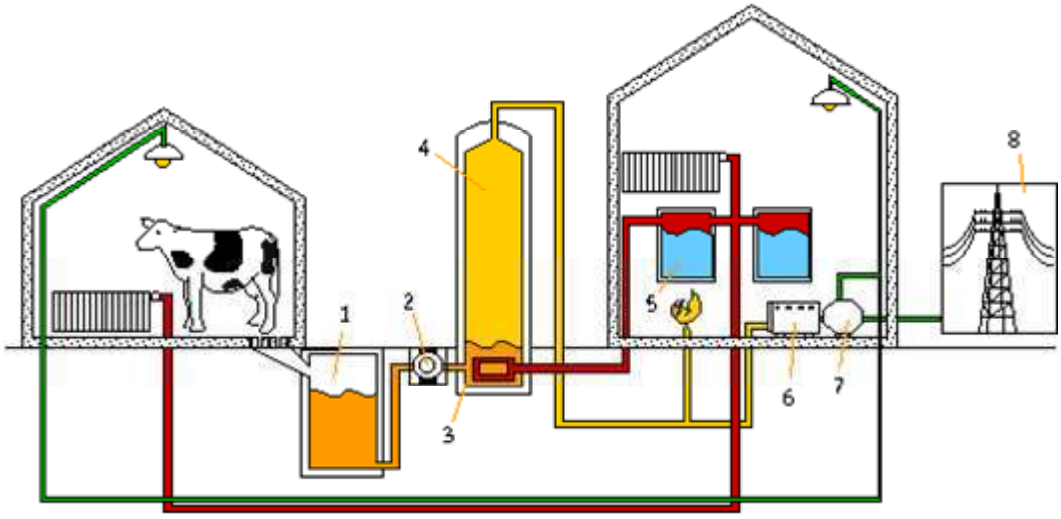


Fig. 3. Schematic of biogas plant utilizing cow dung: 1. Compost storage, 2. Pump, 3. Internal heater, 4. Digester, 5. Combustor, 6-8. Power generator.

3. 1. 1. Aerobic conversion processes

Aerobic conversion includes most commercial composting and activated sludge wastewater treatment processes. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Nutritional considerations are also important to the proper functioning of aerobic processes. Aerobic processes operate at much higher reaction rates than anaerobic processes and produce more cell mass, but generally do not produce useful fuel gases. Aerobic decomposition can occur from as low as near freezing to about 344 K.

Respiration refers to those biochemical processes in which organisms oxidize organic matter and extract the stored chemical energy needed for growth and reproduction. Respiration patterns may be subdivided into two major groups, based on the nature of the ultimate election acceptor. Although alternative pathways exist for the oxidation of various organic substrates, it is convenient to consider only the degradation of glucose. The breakdown of glucose is via the Embden-Meyerof-Parnas glycolytic pathway which yields 2 moles each of pyruvate, ATP, and reduced nicotinamide adenine dinucleotide (NAD) per mole of glucose.

Under aerobic conditions, the pyruvate is oxidized to CO_2 and H_2O via the tricarboxylic acid or Krebs cycle and the electron transport system. The net yield for glycolysis followed by complete oxidation is 38 moles ATP per mole glucose, although there is evidence that the yield for bacteria is 16 moles ATP per mole glucose [49]. Thus, 673 kcal are liberated per mole glucose, much of which is stored as ATP.

3. 1. 2. Anaerobic conversion processes

Anaerobic digestion (AD) is a bacterial fermentation process that is sometimes employed in wastewater treatment for sludge degradation and stabilization. This is also the principal process occurring in the decomposition of food wastes and other biomass in landfills. The AD operates without free oxygen and results in a fuel gas called biogas, containing mostly CH_4 and CO_2 but frequently carrying other substances such as moisture, hydrogen sulfide (H_2S), and particulate matter that are generally removed prior to use of the biogas. The AD is a biochemical process for converting biogenic solid waste into a stable, humus-like product. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Aerobic conversion includes composting and activated sludge wastewater treatment processes. Composting produces useful materials, such as mulch, soil additives and amendments, and fertilizers.

Digestion is a term usually applied to anaerobic mixed bacterial culture systems employed in many wastewater treatment facilities for sludge degradation and stabilization. Anaerobic digestion is also becoming more widely used in on-farm animal manure management systems, and is the principal process occurring in landfills that creates landfill gas (LFG). Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas containing mostly methane (CH_4) and carbon dioxide (CO_2), but frequently carrying impurities such as moisture, hydrogen sulfide (H_2S), and particulate matter.

The AD is known to occur over a wide temperature range from 10 to 71 ºC. Anaerobic digestion requires attention to the nutritional needs and the maintenance of reasonable temperatures for the facultative and methanogenic bacteria degrading the waste substrates. The carbon/nitrogen (C/N) ratio of the feedstock is especially important. Biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial

heaters, other processes, and the manufacturing of chemicals. Anaerobic digestion is also being explored as a route for direct conversion to hydrogen.

Cellulose and hemicelluloses can be hydrolyzed to simple sugars and amino acids that are consumed and transformed by the fermentive bacteria. The lignin is refractory to hydrolysis and generally exits the process undigested. In fact, lignin may be the most recalcitrant naturally produced organic chemical. Lignin polymers are cross-linked carbohydrate structures with molecular weights on the order of 10,000 atomic mass units. As such, lignin can bind with or encapsulate some cellulose making that cellulose unavailable to hydrolysis and digestion. Lignin degradation (or delignification of lignocellulosics) in nature is due principally to aerobic filamentous fungi that decompose the lignin in order to gain access to the cellulose and hemicelluloses.

For anaerobic systems, methane gas is an important product. Depending on the type and nature of the biological components, different yields can be obtained for different biodegradable wastes. For pure cellulose, for example, the biogas product is 50 % methane and 50 % carbon dioxide. Mixed waste feedstocks yield biogas with methane concentrations of 40-60 % (by volume). Fats and oils can yield biogas with 70 % methane content.

Anaerobic digestion functions over a wide temperature range from the so-called psychrophilic temperature near 283 K to extreme thermophilic temperatures above 344 K. The temperature of the reaction has a very strong influence on the anaerobic activity, but there are two optimal temperature ranges in which microbial activity and biogas production rate are highest, the socalled mesophilic and thermophilic ranges. The mesophilic regime is associated with temperatures of about 308 K, the thermophilic regime of about 328 K. Operation at thermophilic temperature allows for shorter retention time and a higher biogas production rate, however, maintaining the high temperature generally requires an outside heat source because anaerobic bacteria do not generate sufficient heat. Aerobic composting can achieve relatively high temperatures (up to 344 K) without heat addition because reaction rates for aerobic systems are much higher than those for anaerobic systems. If heat is not conducted away from the hot center of a compost pile, then thermochemical reactions can initiate which can lead to spontaneous combustion if sufficient oxygen reaches the hot areas. Managed compost operations use aeration to provide oxygen to the bacteria but also to transport heat out of the pile. The anaerobic digestion of lignocellulosic waste occurs in a three-step process often termed hydrolysis, acetogenesis, and methanogenesis, as shown schematically in Figure ES-5. The molecular structure of the biodegradable portion of the waste that contains proteins and carbohydrates is first broken down through hydrolysis. The lipids are converted to volatile fatty acids and amino acids. Carbohydrates and proteins are hydrolyzed to sugars and amino acids. In acetogenesis, acid forming bacteria use these by-products to generate intermediary products such as propionate and butyrate. Further microbial action results in the degradation of these intermediary products into hydrogen and acetate. Methanogenic bacteria consume the hydrogen and acetate to produce methane and carbon dioxide.

Under anaerobic conditions, various pathways exist for pyruvate metabolism which serve to reoxidize the reduced hydrogen carriers formed during glycolysis. The ultimate acceptor builds up as a waste product in the culture medium. The end products of the pathways are: (1) CO_2, ATP, and acetate; (2) CO_2 and ethanol; (3) H_2 and CO_2; (4) CO_2 and 2,3-butylene glycol; (5) CO_2, H_2, acetone, ATP, and butanol; (6) succinate; and (7) lactate. The pathway that occurs depends on the microorganism cultivated and the culture.

3. 1. 3. Biogas processing

A methane digester system, commonly referred to as an AD is a device that promotes the decomposition of manure or digestion of the organics in manure to simple organics and gaseous biogas products. There are three types of continuous digesters: vertical tank systems, horizontal tank or plug-flow systems, and multiple tank systems. Proper design, operation, and maintenance of continuous digesters produce a steady and predictable supply of usable biogas.

Biogas, a clean and renewable form of energy could very well substitute (especially in the rural sector) for conventional sources of energy (fossil fuels, oil, etc.) which are causing ecological–environmental problems and at the same time depleting at a faster rate. Biogas is a modern form of bioenergy that is derived from the anaerobic digestion of organic matter, such as manure, sewage sludge, municipal solid waste, biodegradable waste and agricultural slurry under anaerobic conditions.

Anaerobic digestion of organic compounds is a complex process, involving several different types of microorganisms. This is the natural breakdown of organic matter, such as biomass, by bacterial populations in the absence of air into biogas, i.e., a mixture of methane (40-75% v/v) and carbon dioxide. The end products of anaerobic digestion are biogas and digestate, a moist solid which is normally dewatered to produce a liquid stream and a drier solid. During anaerobic digestion, typically 30-60% of the input solids are converted to biogas; byproducts consist of undigested fibre and various water-soluble substances.

The anaerobic digestion process occurs in the following four basic steps: (1) hydrolysis, (2) acidogenesis, (3) acetogenesis, and (4) methanogenesis. A simplified model of anaerobic digestion process, showing the main steps, is shown in Fig. 4 [50].

3. 2. Incineration

Incineration is a disposal method that involves combustion of waste material. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam, and ash. As stated by Yang et al. [51] a solid waste incinerator is a type of facility which is designed, built, and operated at specified design conditions. A typical incinerator processes wastes that have been collected as input material, and achieves its goal, i.e., treatment of waste material and as secondary benefit recovers heat energy from the combustion process.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants. Solid waste incineration generates solid residues, such as bottom ash and air pollution control residues. Besides a high content of inorganic compounds, incineration residues also contain abundant carbon compounds deriving from incomplete combustion, unburned organic matter and carbon compounds formed during the incineration process [52]. In addition, the incineration of fossil carbon results in minor emissions of CO_2.

Incineration is common in countries such as Japan where land is scarcer, as these facilities generally do not require as much area as landfills. In Japan, where open space is very limited for construction of waste management infrastructure, very high rates of both recycling and incineration are practiced and are expected to continue into the future.

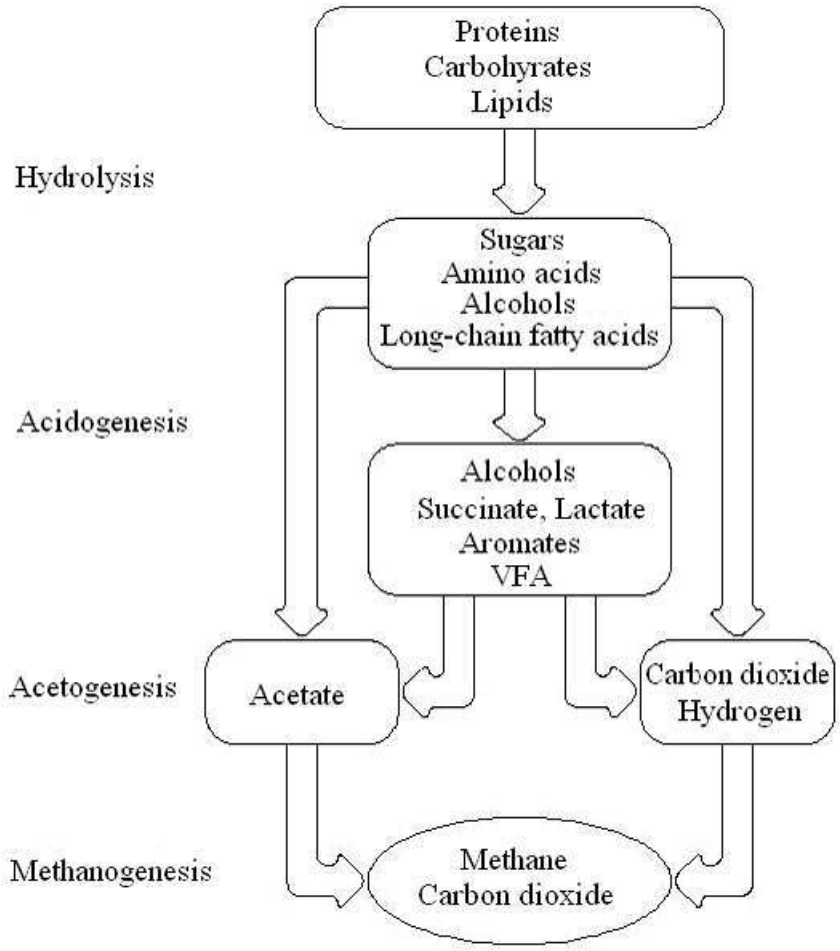


Fig. 4. A simplified conversion processes in anaerobic digestion.

Waste-to-energy (WTE) or energy-from-waste (EFW) is broad terms for facilities that burn waste in a furnace or boiler to generate heat, steam and/or electricity. Combustion in an incinerator is not always perfect and there have been concerns about micro-pollutants in gaseous emissions from incinerator stacks. Particular concern has focused on some very persistent organics such as Dioxins which may be created within the incinerator and which may have serious environmental consequences in the area immediately around the incinerator. Gullet et al. [53] have reported the discovery of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) from waste combustion sources and the increased under-standing of the toxic effects of these chemicals have prompted extensive study over the last 10 or so years on how these trace compounds are formed in combustion systems.

Incineration for waste to energy (WTE) has been widely implemented in many European countries for decades. In 2002, EU WTE plants generated 41 million GJ of electrical energy and 110 million GJ of thermal energy. Incineration and industrial co-combustion for WTE provide significant renewable energy benefits and fossil fuel offsets. Currently, over 130 million tonnes of waste per year are incinerated at over 600 plants [54]. Thermal processes with advanced emission controls are proven technology but more costly than controlled landfilling with landfill gas recovery; however, thermal processes may become more viable as energy prices increase.

Because landfills produce CH_4 for decades, incineration, composting and other strategies that reduce land filled waste are complementary mitigation measures to landfill gas recovery in the short- to medium-term [55].

4. Conclusion

Educating personnel will also improve the efficiency of the waste management system and minimize its possible health and environmental risks. While the growth in production and marketing during this process makes excessive use of natural resources inevitable, wastes produced due to increasing trend of consumption has reached to threatening levels due to their quantity and hazardous contents. On this account, in parallel with the environmental consciousness rising all over the world, the protection of environment has become one of the major priority policies of countries and waste management has taken a major field among the environmental protection policies of all countries.

The promotion of a high quality waste management system not only enhances social, economic and environmental efficiency, and promotes sustainable development, but can also help resolve the dual crisis of resource shortages and environmental deterioration [56]. Poor management of waste may result in serious environmental problems such as an unpleasant odor and the risk of explosion in landfill areas, as well as groundwater contamination because of leachate percolation [57]. Unsuitable waste management practices also result in the loss of resources and energy, which could be recycled and produced from a large part of the solid waste. Solid waste knowledge is hard won and too easily lost [58].

Today world is facing three critical problems: (1) high fuel prices, (2) climatic changes, (3) air pollution [59]. Renewable energy is a promising alternative solution because it is clean and environmentally safe [60]. Waste and recycling management plans should be developed for any construction project prior to the start of work in order to sustain environmental, economic, and social development principles.

References

[1] Dijkema GPJ, Reuter MA, Verhoef EV. A new paradigm for waste management. Waste Manage 2000;20:633-638.
[2] Wilson DC, Araba AO, Chinwah K, Cheeseman CR. Building recycling rates through the informal sector. Waste Manage doi:10.1016/j.wasman.2008.06.016 (in press)
[3] RTMEF, Republic of Turkey Ministry of Environment and Forestry. Regulations of fundamental waste control. Official Gazette No. 2008/26927, Ankara, Turkey.
[4] AEVG, Waste management concept of the city of Graz. www.aevg, 2008.
[5] Batayneh M, Marie I, Asi I. Use of selected waste materials in concrete mixes. Waste Manage 2007;27:1870–1876.
[6] Siddique R, Khatib J, Kaur I. Use of recycled plastic in concrete: A review. Waste Manage 2008;28:1835–1852.
[7] Buyukbektas F, Varinca KB. The notion of integrated waste management and the regulation of waste frame in the process of integration into EU. http://cevre.club.fatih.edu.tr/webyeni/.
[8] Edincliler A, Baykal G, Erdik M, Mowrtage W. Modeling of behavior of solid waste landfills during earthquake. Sixth National Conference on Earthquake Engineering 16-20 October 2007, Istanbul, Turkey
[9] Oman CB, Junestedt C. Chemical characterization of landfill leachates – 400 parameters and compounds. Waste Manage 2008;28:1876–1891.
[10] Ozcan HK, Borat M, Bayat C. Katı Atık Depo Sahası Gazları ve Çevresel Etkileri. II. Congress of Engineering Science Young Researchers. İstanbul, 2005 (in Turkish).

[11] Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson A. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2001.
[12] Rasi S, Lantela J, Veijanen A, Rintala J. Landfill gas upgrading with countercurrent water wash. Waste Manage 2008;28:1528–1534.
[13] EIA. Energy Information Administration. http://www.eia.doe.gov, accessed 11.25.2008.

[14] Magrinho A, Didelet F, Semiao F. Country report. Municipal solid waste disposal in Portugal. Waste Manage 2006;26: 1477–1489.
[15] Balat M. Progress in biogas production processes. Energy Educ Sci Technol 2008;22:15-36.
[16] Balat M. Possible methods for hydrogen production. Energy Sources Part A 2009;31:39-50.
[17] Balat M. Hydrogen in fueled systems and the significance of hydrogen in vehicular transportation**.** Energy Sources Part B 2007;2:49–61.
[18] Demirbas A. Biohydrogen generation from organic wastes. Energy Sources Part A 2008;30:475-482.
[19] Demirbas B. Biofuels for internal combustion engines. Energy Edu Sci Technol Part A 2009;22:117-132.
[20] Demirbas T. Overview of bioethanol from biorenewable feedstocks: technology, economics, policy and impacts. Energy Edu Sci Technol Part A 2009;22:163-177.
[21] Balat M. New biofuel production technologies. Energy Edu Sci Technol Part A 2009;22:147-161.
[22] Demirbas A. Economic and environmental impacts of the liquid biofuels. Energy Educ Sci Technol 2008;22:37-58.
[23] Demirbas A. Recent progress in biorenewable feedstocks. Energy Educ Sci Technol 2008;22:69-95.
[24] Demirbas C. The global climate challenge: Recent trends in CO_2 emissions from fuel combustion. Energy Edu Sci Technol Part A 2009;22:179-193.
[25] Hacisaligoglu S. Ethanol–gasoline and ethanol–diesel fuel blends. Energy Edu Sci Technol Part A 2009;22:133-146.
[26] Demirbas MF. Pyrolysis of vegetable oils and animal fats for the production of renewable fuels. Energy Edu Sci Technol 2008;22:59-67.
[27] Demirbas A. New liquid biofuels from vegetable oils via catalytic pyrolysis. Energy Edu Sci Technol 2008;21:1-59.
[28] Demirbas A. Bio-fuels from agricultural residues. Energy Sources Part A 2008;30:101–109.
[29] Demirbas K, Demirbas A. Technical assessment of different biorenewable wastes into energy solutions by briquetting. Energy Edu Sci Technol Part A 2009;22:97-106.
[30] Kuwahara, N., M. D. Berni, and S. V. Bajay. 1999. Energy supply from municipal wastes: The potential of biogas-fuelled buses in Brazıl. Renewable Energy 16:1000-1003.
[31] Uygur, Kargi F. 2004. Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor. J Environ Mgmt 71: 9–14.
[32] EPA. Characterization of potential of municipal solid waste (MSW) components. Municipal Solid Waste in the United States: 1992 Update. EPA/530-R-94-042, NTS #PB 95-147690. Solid Waste and Emergency Response (5305), Washington. D.C.: U.S. Environmental Protection Agency (EPA), 1994.
[33] Erses AS, Onay TT. In situ heavy metal attenuation in landfills under methanogenic conditions. J Hazard Mat B 2003;99:159–175.
[34] Timur H, Ozturk I. Anaerobic sequencing batch reactor treatment of landfill leachate. Wat Res 1999;33:3225-3230.
[35] Metin E, Erozturk A, Neyim C. Solid waste management practices and review of recovery and recycling operations in Turkey. Waste Manage 2003;23:425–432.
[36] Plaza G, Robredo P, Pacheco O, Toledo AS. Anaerobic treatment of municipal solid waste. Water Sci Technol 1996;33:169-175.
[37] Kiely G, Tayfur G, Dolan C, Tanji K. Physical and mathematical modelling of anaerobic

digestion of organıc wastes. Water Res 1997;31:534-540.
[38] Braber K. Anaerobic digestion of municipal solid waste: A modern waste disposal option on the verge of breakthrough. Biomass Bioenergy 1995;9:365-376.
[39] Al-Dabbas MAF. Reduction of methane emissions and utilization of municipal waste for energy in Amman. Renewable Energy 1998;14:427-434.
[40] Augenstein D, Pacey J. Landfill methane models. Proceedings from the Technical Sessions of SWANA's 29th Annual International Solid Waste Exposition, SWANA, Silver Spring, MD, 1991.
[41] Micales JA, Skog KE. The Decomposition of forest products in landfills. Int Biodeterior Biodegr 1997;39:145-158.
[42] Kargi F, Pamukoglu MY. Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation. Biores Technol 2004;94:285–291.
[43] Ozturk I, Altinbas M,. Koyuncu I, Arikan O, Gomec-Yangin C. Advanced physico-chemical treatment experiences on young municipal landfill leachates. Waste Manage 2003;23:441– 446.
[44] Cecen F, Erdincler A, Kilic E. Effect of powdered activated carbon addition on sludge dewaterability and substrate removal in landfill leachate treatment. Advances Environ Res 2003;7:707–713.
[45] Kargi , PamukoglY. Repeated fed-batch biological treatment of pre-treated landfill leachate by powdered activated carbon addition. Enzyme Microbial Technol 2004;34:422–428.
[46] Kayabali K. Engineering aspects of a novel landfill liner material: bentonite-amended natural zeolite. Engin Geology 1997;46:105-114.
[47] Meynell, P.-J. Methane: Planning a Digester. New York: Schocken Books, 1976.
[48] Demirbas A. Biogas potential of manure and straw mixtures. Energy Sources Part A 2006;28:71-78.
[49] Aiba S, Humphrey AE, Milis NF. Biochemical Engineering, 2d ed., Academic, New York, 1973.
[50] Asplund S. The Biogas Production Plant at Umea Dairy Evaluation of Design and Start up. Degree thesis, Linköpings University, Linköping, Sweden, October 5, 2005.
[51] Yang W, Nam H, Choi S. Improvement of operating conditions in waste incinerators using engineering tools Waste Management 2007;27:604–613.
[52] Ecke H, Svensson M, Mobility of organic carbon from incineration residues Waste Management 2008;28:1301–1309.
[53] Gullett BK, Dunn JE, Bae SK, Raghunathan K. Effects of combustion parameters on polychlorinated dibenzodioxin and dibenzofuran homologue profiles from municipal waste and coal co-combustion. Waste Management 1998;18: 473- 483.
[54] Themelis N. An overview of the global waste-to-energy industry. Waste Manage World 2003;40-47.
[55] Bogner J, Ahmed MA, Diaz C, Faaij A, Gao Q, Hashimoto S, Mareckova K, Pipatti R, Zhang T. Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Uni. Press, Cambridge, 2007.
[56] Damghani AM, Savarypour G, Zand E, Deihimfard R. Country Report. Municipal solid waste management in Tehran: Current practices, opportunities and challenges. Waste Manage 2008;28:929–934.
[57] Mor S, Ravindra K, Visscher A, Dahiya RP, Chandra A. Municipal solid waste characterization and its assessment for potential methane generation: A case study. Sci Total Environ 2006;371:1–10.
[58] Milke M. The world's great solid waste management libraries. Editorial. Waste Manage 2008;28: 937–938.
[59] Demirbas A. Energy concept and energy education. Energy Educ Sci Technol Part B 2009;1:85-101.
[60] Kurnaz MA, Calik M. A thematic review of 'energy' teaching studies: focuses, needs, methods, general knowledge claims and implications. Energy Educ Sci Technol Part B 2009;1:1-26.
[61] Demirbas A. Future Energy Sources: Part I. Future Energy Source 2009;1:1-95

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General characteristics of waste management: A review

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Abstract

The amount of waste has been steadily increasing due to the increasing human population and urbanization. Waste materials are generated from manufacturing processes, industries and municipal solid wastes (MSW). The increasing awareness about the environment has tremendously contributed to the concerns related with disposal of the generated wastes. This paper presents a detailed review about waste and waste management options, and research published on the effect of waste materials on environment.

Keywords: Waste management; Waste to energy; Disposal methods
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1. Introduction

Waste management is one of the major environmental concerns in the world. Human activities and changes in lifestyles and consumption patterns have resulted in an increase in solid waste generation rates. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each. A typical waste management system comprises collection, transportation, pre-treatment, processing, and final abatement of residues. Various types of waste can be collected separately. Early researcher mentioned as the waste management is one of the public infrastructures that are based on a specific type of physical infrastructure to provide the goods or services, and in this respect it resembles the electricity, natural gas, and water sector [1].

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial, producers. Management for non-hazardous residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator. When recycling began to be recognized as essential for both environmental and resource management reasons, recycling rates for household wastes in most developed countries in the 1980s were in the low single figures by percent. Modern western waste management systems have rebuilt recycling rates over the last 20 years [2]. Modern waste management systems, which many developing country cities aspire to, are all characterized by high recycling rates of clean, source separated materials.

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Most technologies for waste management are mature and have been successfully implemented for decades in many countries. In Turkey, Solid Waste Control Regulation came into force in order to manage solid waste in 1991. The regulation has been continuously updated. Considering the Directive of Waste Frame EEC and the other directives of the European Union as part of the requirements of the integration process into the EU, the Department has started the preparations for the Regulation of Waste Frame and the draft of the Regulation has been presented for consideration. Finally, the waste management is conducted according to the Turkish Solid Waste Management that was adopted in 2008 [3]. In the Regulation, the procedures about the classification of the wastes, collection, transportation, and temporary storage of the wastes within the institutions and the transportation of them to the final disposal area were explained. In the last part of the Regulation, the method of the disposal of the wastes was mentioned.

A waste management concept including the following goals:

1. Reduction of total amount of waste by reduction and recycling of refuse.
2. Recycling and re-introduction of suitable groups of substances into production cycles as secondary raw material or energy carrier.
3. Re-introduction of biological waste into the natural cycle.
4. Best-possible reduction of residual waste quantities, which are to be disposed on "suitable" landfills.
5. Flexible concept concerning fluctuations in waste quantities and the composition of domestic waste. New developments in the field of waste management must be included into the system [4].

Large quantities of this waste cannot be eliminated. However, the environmental impact can be reduced by making more sustainable use of this waste. This is known as the "Waste Hierarchy" [5]. The waste hierarchy refers to the "3 Rs" reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimization. The hierarchy of disposal options, which categorizes environmental impacts into six levels, from low to high; namely, reduce, reuse, recycle, compost, incinerate and landfill [6]. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.

Waste collection methods vary widely between different countries and regions. Domestic waste collection services are often provided by local government authorities, or by private industry. Some areas, especially those in less developed countries, do not have a formal waste-collection system.

2. Waste management methods

Classification and assignment of different waste materials to classes cannot be easily achieved by conventional parameters. Some new techniques have been proposed and developed by researchers. Nowadays not all the wastes are classified under the same classical category, requiring the same procedure of elimination. Especially in the industries in which the types of wastes are so varied it is very difficult and impractical to set up and operate a different management system for different types of wastes [7]. Thus has emerged the necessity of a, management system which would eliminate all types of wastes. Table 1 has presented a selection of promising waste treatment processes.

2.1. Disposal methods

An integrated approach is required in an attempt to manage such large quantities of a diverse, contaminated mixture of wastes in an energy efficient and environmentally benign manner. This would require examining critically various steps in the life of the wastes such as the raw materials for their manufacture, the manufacturing processes, design and fabrication of the finished products, possible reuse of those items, and the proper disposal of the wastes, in totality. Such an integrated waste management concept comprises: (i) source reduction; (ii) reuse; (iii) recycling; (iv) landfill and gas-to energy (v) waste-to energy conversion.

Table 1. Selected waste treatment processes

Waste stream		Waste disposal methods
Combustible wastes		Roaster incineration Fluid bed incineration Pyrolysis-incineration Pyrolysis-gasification Separation-composting-incineration (Wet and dry) separation-digesting-incineration Separation-digesting-pyrolysis Separation-digesting-gasification Separation-digesting-incineration in a cement plant Selective separation-incineration
Non-combustible wastes		Landfill
Partially combustible waste streams	Wood	Pyrolysis and co-incineration in a coal power plant Pyrolysis and co-incineration in a powdered coal power plant Incineration in a fluid bed furnace Gasification
	Plastics	Gasification Feedstock Recycling
	Organic wastes	Composting Anaerobic Digestion

2.1.1. Landfill

A landfill is not a normal environmental condition, though, nor is it intended to be. Instead, a landfill is more like a tightly sealed storage container. A landfill is designed to inhibit degradation to protect the environment from harmful contamination. Deprived of air and water, even organic wastes like paper and grass clippings degrade very slowly in a landfill. Municipal Solid Waste Landfills (MSWLs) are places where heterogeneous mixtures of municipal and industrial wastes are disposed. Mechanical properties of MSW such as strength and compressibility depend on composition of waste, mechanical properties of components of the material deposited, water content and decomposition [8].

Disposing of waste in a landfill involves burying waste to dispose of it, and this remains a common practice in most countries. Landfills were often established in disused quarries, mining voids or borrow pits. A properly-designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly-designed or poorly-managed landfills can create a number of adverse environmental impacts

such as wind-blown litter, attraction of vermin (especially, noxious little animals or insects, collectively, as squirrels, rats, mice, flies, lice, bugs, etc), and generation of liquid leachate.

Landfill leachates contain a large number of compounds, some of which can be expected to create a threat to health and nature if released into the natural environment. For this purpose, Öman and Junestedt [9], have been studied screened samples from 12 Swedish municipal landfill sites for 400 parameters and compounds which expected to be present in landfill leachate. More than 90 organic and metal organic compounds and 50 inorganic elements were detected, some of which seem to have not been detected before. Compounds detected include halogenated aliphatic compounds, benzene and alkylated benzenes, phenol and alkylated phenols, ethoxylates, polycyclic aromatic compounds, phthalic esters, chlorinated benzenes, chlorinated phenols, PCB, chlorinated dioxins and chlorinated furans, bromated flame-retardants, pesticides, organic tin, methyl mercury and heavy metals. According to Öman and Junestedt [9], the presence of this large number of hazardous compounds in landfill leachates should have a significant impact on future landfill risk assessments and the development of leachate treatment methods.

Today's landfills are very different from the open dumps of the past. For one thing, new landfills are situated where clay deposits and other land features act as natural buffers between the landfills and the surrounding environment. Second, the bottom and sides of modern landfills are lined with layers of clay or plastic to keep the liquid waste, called leachate, from escaping into the soil. Deposited waste is normally compacted to increase its density and stability, and covered to prevent attracting vermin (Fig. 1).

Another common by product of landfills is gases. Landfill gas is a renewable energy source. Methane (CH_4) and carbon dioxide (CO_2) are major gases, forming from the anaerobic degradation of degradable domestic solid wastes. Landfill gases generally contain 45-60% CH_4 and 40-60% CO_2 [10]. These gases can create odor problems, kill surface vegetation, and is a greenhouse gas (GHG). Some of these compounds may cause corrosion or other damage to engines if they are not removed from the gas before utilization.

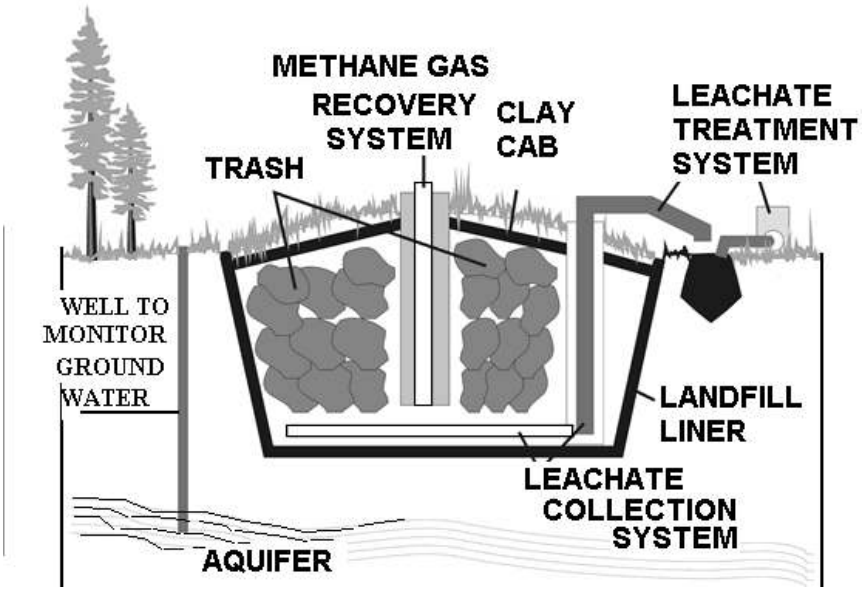


Fig.1. Modern landfill [13].

Landfills are an important source of atmospheric CH_4 due to methanogenic activity under anaerobic conditions [11]. Landfill CH_4 recovery and optimized wastewater treatment can directly reduce GHG emissions. So far, studies and applications on upgrading landfill gas are relatively few, while the upgrading of biogases from sewage and biowaste digesters is rapidly increasing in some countries. For example, in Reykjavik (Iceland), landfill gas upgrading was started in 2000 with water scrubber technology [12]. In 2003, East Kentucky Power Cooperative began recovering methane gas from three landfills. The utility uses the landfill gas to generate 8.8 MW of electricity, enough power 7500-8000 homes [13].

According to Magrinho et al., [14], landfilling is the last choice method in the hierarchy of waste management. However, even with sanitary landfilling being the most common method of solid waste management, there was no landfill gas energy recovery.

With the scarcity of space for landfilling and due to its ever increasing cost, waste utilization has become an attractive alternative to disposal.

3. Biorenewable gaseous fuels

Liquid (bioethanol and biodiesel) and gaseous (biogas and biohydrogen) biofuels have become more attractive recently because of its environmental benefits. In recent years, many studies have investigated the economic and environmental impacts of the biofuels, especially bioethanol and biodiesel [15-21]. Liquid biofuels are important because they replace petroleum fuels. There are many benefits for the environment, economy and consumers in using biofuels. Biofuels production costs can vary widely by feedstock, conversion process, scale of production and region. Biofuels production costs can vary widely by feedstock, conversion process, scale of production and region. On an energy basis, ethanol is currently more expensive to produce than gasoline in all regions considered [22-29].

Biogas can be obtained from several sources. It is obtained from decomposing organic material. Contents of domestic solid waste are given in Table 2. Biogas is composed by methane (CH_4), carbon dioxide (CO_2), air, ammonia, carbon monoxide, hydrogen, sulfur gases, nitrogen and oxygen. Among its components, methane is the most important one, particularly for the combustion process in vehicle engines [30]. A typical analysis of raw landfill gas is given in Table 3. CH_4 and CO_2 make up around 90% of the gas volume produced. The main constituents of landfill gas are methane and carbon dioxide, both of which are major contributors to global warming. Because of the widely varying nature of the contents of landfill sites the constituents of landfill gases vary widely.

Landfill leachate treatment has received significant attention in recent years, especially in municipal areas [31]. The generation of municipal solid wastes (MSW) has increased in parallel to rapid industrialization. Approximately 16% of all discarded MSW is incinerated [32]; the remainder is disposed of in landfills. Effective management of these wastes has become a major social and environmental concern [33]. Disposal of MSW in sanitary landfills is usually associated with soil, surface water and groundwater contamination when the landfill is not properly constructed. The flow rate and composition of leachate vary from site to site, seasonally at each site and depending on the age of the landfill. Young leachate normally contains high amounts of volatile fatty acids [34]. MSW statistics and management practices including waste recovery and recycling initiatives have been evaluated [35]. The organic MSW was chemically and biologically characterized, in order to study its behaviour during anaerobic digestion, and its pH, biogas production, alkalinity, and volatile fatty acid production was determined by Plaza et al. [36]. Anaerobic digestion of the organic food fraction of MSW, on its own or co-digested with primary sewage sludge, produces high

quality biogas, suitable as renewable energy [37]. The processing of MSW (e.i. landfill, incineration, aerobic composting) secures many advantages and limitations [38]. The greenhouse gas emissions can be reduced by the uncontrolled releasing of methane from improperly disposed organic waste in a large landfill [39].

Table 2. Contents of domestic solid waste (wt% of total)

Component	Lower limit	Upper limit
Paper waste	33.2	50.7
Food waste	18.3	21.2
Plastic matter	7.8	11.2
Metal	7.3	10.5
Glass	8.6	10.2
Textile	2.0	2.8
Wood	1.8	2.9
Leather and rubber	0.6	1.0
Miscellaneous	1.2	1.8

Source: Demirbas, 2006b.

Table 3. Typical analysis of raw landfill gas

Component	Chemical formula	Content
Methane	CH_4	40-60 (% by vol.)
Carbon dioxide	CO_2	20-40 (% by vol.)
Nitrogen	N_2	2-20 (% by vol.)
Oxygen	O_2	<1 (% by vol.)
Heavier hydrocarbons	C_nH_{2n+2}	<1 (% by vol.)
Hydrogen sulfide	H_2S	40-100 ppm
Complex organics	-	1000-2000 ppm

Source: Demirbas, 2006b.

Decomposition in landfills occurs in a series of stages, each of which is characterized by the increase or decrease of specific bacterial populations and the formation and utilization of certain metabolic products. The first stage of decomposition, which usually lasts less than a week, is characterized by the removal of oxygen from the waste by aerobic bacteria [40]. In the second stage, which has been termed the anaerobic acid stage, a diverse population of hydrolytic and fermentative bacteria hydrolyzes polymers, such as cellulose, hemicellulose, proteins, and lipids, into soluble sugars, amino acids, long-chain carboxylic acids, and glycerol [41]. Fig. 2 shows the behavior of biogas production with time, in terms of the biogas components. Fig. 2 indicates that the economic exploitation of CH_4 is worthwhile after one year from the start of the landfill operation. The main components of landfill gas are by-products of the decomposition of organic material, usually in the form of domestic waste, by the action of naturally occurring bacteria under anaerobic conditions.

Methods developed for treatment of landfill leachates can be classified as physical, chemical and biological which are usually used in combinations in order to improve the treatment efficiency. Biological treatment methods used for the leachate treatment can be

classified as aerobic, anaerobic and anoxic processes which are widely used for the removal of biodegradable compounds [42]. Biological treatment of landfill leachate usually results in low nutrient removals because of high chemical oxygen demand (COD), high ammonium-N content and the presence of toxic compounds such as heavy metals [31]. Landfill leachate obtained from the solid waste landfill area contained high COD and ammonium ions which resulted in low COD and ammonium removals by direct biological treatment [42]. Several anaerobic and aerobic treatment systems have been studied in landfill leachate [43]. Leachates contain non-biodegradable substrates which are not removed by biological treatment alone and an increase of leachate input may cause reduction in substrate removal [44]. Raw landfill leachate was subjected to pre-treatment by coagulation-flocculation and air stripping of ammonia before biological treatment [45]. In order to improve biological treatability of the leachate, coagulation-flocculation and air stripping of ammonia were used as pre-treatment [45]. Natural zeolite and bentonite can be utilized as a novel landfill liner material [46].

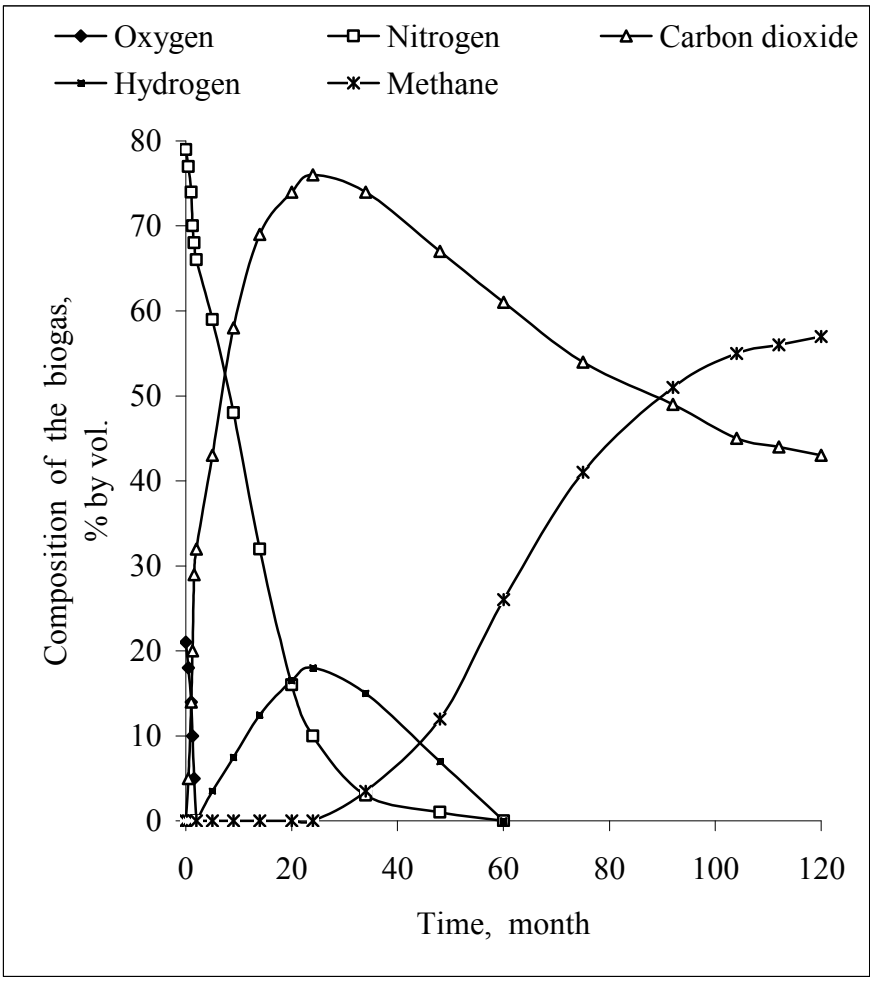


Fig. 2. Production of biogas components with time in landfill.

3. 1. Biogas technology

Anaerobic digestion (AD) is the conversion of organic material directly to a gas, termed biogas, a mixture of mainly methane and carbon dioxide with small quantities of other gases such as hydrogen sulfide. Methane is the major component of the biogas used in many homes for cooking and heating. The biogas has a chemical composition close to that of natural gas, the biodigester, or a biogas plant, is a physical structure used to provide an anaerobic condition which stimulates various chemical and microbiological reactions resulting in the decomposition of input slurries and the production of biogas—mainly methane [15].

Biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial heaters, other processes, or for the manufacturing of chemicals. Before landfilling, treatment or stabilization of biodegradable materials can be accomplished by a combination of anaerobic digestion followed by aerobic composting.

The same types of anaerobic bacteria that produced natural gas also produce methane today. Anaerobic bacteria are some of the oldest forms of life on earth. They evolved before the photosynthesis of green plants released large quantities of oxygen into the atmosphere. Anaerobic bacteria break down or digest organic material in the absence of oxygen and produce biogas as a waste product.

The first methane digester plant was built at a leper colony in Bombay, India, in 1859 [47]. Most of the biogas plants utilize animal dung or sewage. Schematic of biogas plant utilizing cow dung is illustrated in Fig. 3 [15]. Anaerobic digestion is a commercially proven technology and is widely used for treating high moisture content organic wastes including +80%–90% moisture. Biogas can be used directly in spark ignition gas engines (SIGEs) and gas turbines. Used as a fuel in SIGE to produce electricity only, the overall conversion efficiency from biomass to electricity is about 10%–16% [48].

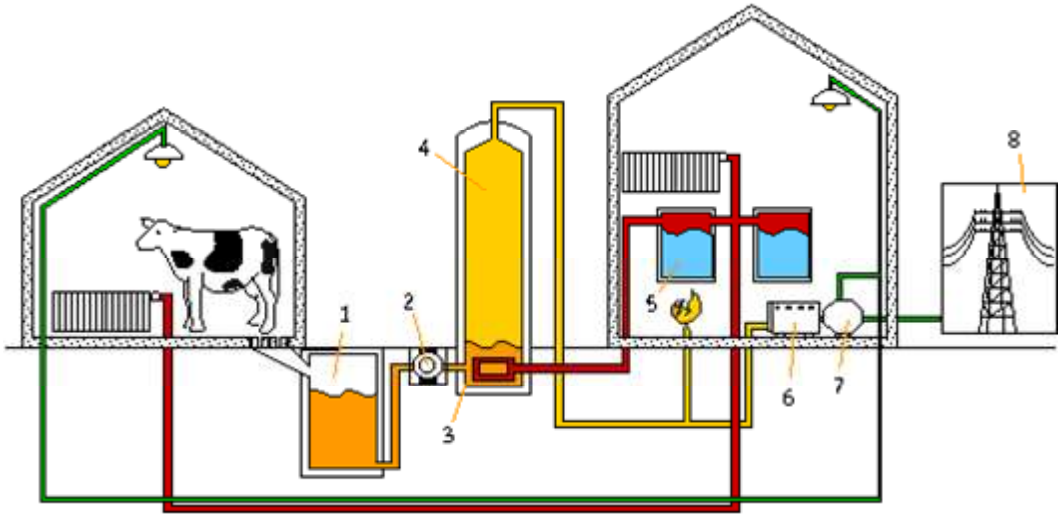


Fig. 3. Schematic of biogas plant utilizing cow dung: 1. Compost storage, 2. Pump, 3. Internal heater, 4. Digester, 5. Combustor, 6-8. Power generator.

3. 1. 1. Aerobic conversion processes

Aerobic conversion includes most commercial composting and activated sludge wastewater treatment processes. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Nutritional considerations are also important to the proper functioning of aerobic processes. Aerobic processes operate at much higher reaction rates than anaerobic processes and produce more cell mass, but generally do not produce useful fuel gases. Aerobic decomposition can occur from as low as near freezing to about 344 K.

Respiration refers to those biochemical processes in which organisms oxidize organic matter and extract the stored chemical energy needed for growth and reproduction. Respiration patterns may be subdivided into two major groups, based on the nature of the ultimate election acceptor. Although alternative pathways exist for the oxidation of various organic substrates, it is convenient to consider only the degradation of glucose. The breakdown of glucose is via the Embden-Meyerof-Parnas glycolytic pathway which yields 2 moles each of pyruvate, ATP, and reduced nicotinamide adenine dinucleotide (NAD) per mole of glucose.

Under aerobic conditions, the pyruvate is oxidized to CO_2 and H_2O via the tricarboxylic acid or Krebs cycle and the electron transport system. The net yield for glycolysis followed by complete oxidation is 38 moles ATP per mole glucose, although there is evidence that the yield for bacteria is 16 moles ATP per mole glucose [49]. Thus, 673 kcal are liberated per mole glucose, much of which is stored as ATP.

3. 1. 2. Anaerobic conversion processes

Anaerobic digestion (AD) is a bacterial fermentation process that is sometimes employed in wastewater treatment for sludge degradation and stabilization. This is also the principal process occurring in the decomposition of food wastes and other biomass in landfills. The AD operates without free oxygen and results in a fuel gas called biogas, containing mostly CH_4 and CO_2 but frequently carrying other substances such as moisture, hydrogen sulfide (H_2S), and particulate matter that are generally removed prior to use of the biogas. The AD is a biochemical process for converting biogenic solid waste into a stable, humus-like product. Aerobic conversion uses air or oxygen to support the metabolism of the aerobic microorganisms degrading the substrate. Aerobic conversion includes composting and activated sludge wastewater treatment processes. Composting produces useful materials, such as mulch, soil additives and amendments, and fertilizers.

Digestion is a term usually applied to anaerobic mixed bacterial culture systems employed in many wastewater treatment facilities for sludge degradation and stabilization. Anaerobic digestion is also becoming more widely used in on-farm animal manure management systems, and is the principal process occurring in landfills that creates landfill gas (LFG). Anaerobic digestion operates without free oxygen and results in a fuel gas called biogas containing mostly methane (CH_4) and carbon dioxide (CO_2), but frequently carrying impurities such as moisture, hydrogen sulfide (H_2S), and particulate matter.

The AD is known to occur over a wide temperature range from 10 to 71 ºC. Anaerobic digestion requires attention to the nutritional needs and the maintenance of reasonable temperatures for the facultative and methanogenic bacteria degrading the waste substrates. The carbon/nitrogen (C/N) ratio of the feedstock is especially important. Biogas can be used after appropriate gas cleanup as a fuel for engines, gas turbines, fuel cells, boilers, industrial

heaters, other processes, and the manufacturing of chemicals. Anaerobic digestion is also being explored as a route for direct conversion to hydrogen.

Cellulose and hemicelluloses can be hydrolyzed to simple sugars and amino acids that are consumed and transformed by the fermentive bacteria. The lignin is refractory to hydrolysis and generally exits the process undigested. In fact, lignin may be the most recalcitrant naturally produced organic chemical. Lignin polymers are cross-linked carbohydrate structures with molecular weights on the order of 10,000 atomic mass units. As such, lignin can bind with or encapsulate some cellulose making that cellulose unavailable to hydrolysis and digestion. Lignin degradation (or delignification of lignocellulosics) in nature is due principally to aerobic filamentous fungi that decompose the lignin in order to gain access to the cellulose and hemicelluloses.

For anaerobic systems, methane gas is an important product. Depending on the type and nature of the biological components, different yields can be obtained for different biodegradable wastes. For pure cellulose, for example, the biogas product is 50 % methane and 50 % carbon dioxide. Mixed waste feedstocks yield biogas with methane concentrations of 40-60 % (by volume). Fats and oils can yield biogas with 70 % methane content.

Anaerobic digestion functions over a wide temperature range from the so-called psychrophilic temperature near 283 K to extreme thermophilic temperatures above 344 K. The temperature of the reaction has a very strong influence on the anaerobic activity, but there are two optimal temperature ranges in which microbial activity and biogas production rate are highest, the socalled mesophilic and thermophilic ranges. The mesophilic regime is associated with temperatures of about 308 K, the thermophilic regime of about 328 K. Operation at thermophilic temperature allows for shorter retention time and a higher biogas production rate, however, maintaining the high temperature generally requires an outside heat source because anaerobic bacteria do not generate sufficient heat. Aerobic composting can achieve relatively high temperatures (up to 344 K) without heat addition because reaction rates for aerobic systems are much higher than those for anaerobic systems. If heat is not conducted away from the hot center of a compost pile, then thermochemical reactions can initiate which can lead to spontaneous combustion if sufficient oxygen reaches the hot areas. Managed compost operations use aeration to provide oxygen to the bacteria but also to transport heat out of the pile. The anaerobic digestion of lignocellulosic waste occurs in a three-step process often termed hydrolysis, acetogenesis, and methanogenesis, as shown schematically in Figure ES-5. The molecular structure of the biodegradable portion of the waste that contains proteins and carbohydrates is first broken down through hydrolysis. The lipids are converted to volatile fatty acids and amino acids. Carbohydrates and proteins are hydrolyzed to sugars and amino acids. In acetogenesis, acid forming bacteria use these by-products to generate intermediary products such as propionate and butyrate. Further microbial action results in the degradation of these intermediary products into hydrogen and acetate. Methanogenic bacteria consume the hydrogen and acetate to produce methane and carbon dioxide.

Under anaerobic conditions, various pathways exist for pyruvate metabolism which serve to reoxidize the reduced hydrogen carriers formed during glycolysis. The ultimate acceptor builds up as a waste product in the culture medium. The end products of the pathways are: (1) CO_2, ATP, and acetate; (2) CO_2 and ethanol; (3) H_2 and CO_2; (4) CO_2 and 2,3-butylene glycol; (5) CO_2, H_2, acetone, ATP, and butanol; (6) succinate; and (7) lactate. The pathway that occurs depends on the microorganism cultivated and the culture.

3. 1. 3. Biogas processing

A methane digester system, commonly referred to as an AD is a device that promotes the decomposition of manure or digestion of the organics in manure to simple organics and gaseous biogas products. There are three types of continuous digesters: vertical tank systems, horizontal tank or plug-flow systems, and multiple tank systems. Proper design, operation, and maintenance of continuous digesters produce a steady and predictable supply of usable biogas.

Biogas, a clean and renewable form of energy could very well substitute (especially in the rural sector) for conventional sources of energy (fossil fuels, oil, etc.) which are causing ecological–environmental problems and at the same time depleting at a faster rate. Biogas is a modern form of bioenergy that is derived from the anaerobic digestion of organic matter, such as manure, sewage sludge, municipal solid waste, biodegradable waste and agricultural slurry under anaerobic conditions.

Anaerobic digestion of organic compounds is a complex process, involving several different types of microorganisms. This is the natural breakdown of organic matter, such as biomass, by bacterial populations in the absence of air into biogas, i.e., a mixture of methane (40-75% v/v) and carbon dioxide. The end products of anaerobic digestion are biogas and digestate, a moist solid which is normally dewatered to produce a liquid stream and a drier solid. During anaerobic digestion, typically 30-60% of the input solids are converted to biogas; byproducts consist of undigested fibre and various water-soluble substances.

The anaerobic digestion process occurs in the following four basic steps: (1) hydrolysis, (2) acidogenesis, (3) acetogenesis, and (4) methanogenesis. A simplified model of anaerobic digestion process, showing the main steps, is shown in Fig. 4 [50].

3. 2. Incineration

Incineration is a disposal method that involves combustion of waste material. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam, and ash. As stated by Yang et al. [51] a solid waste incinerator is a type of facility which is designed, built, and operated at specified design conditions. A typical incinerator processes wastes that have been collected as input material, and achieves its goal, i.e., treatment of waste material and as secondary benefit recovers heat energy from the combustion process.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants. Solid waste incineration generates solid residues, such as bottom ash and air pollution control residues. Besides a high content of inorganic compounds, incineration residues also contain abundant carbon compounds deriving from incomplete combustion, unburned organic matter and carbon compounds formed during the incineration process [52]. In addition, the incineration of fossil carbon results in minor emissions of CO_2.

Incineration is common in countries such as Japan where land is scarcer, as these facilities generally do not require as much area as landfills. In Japan, where open space is very limited for construction of waste management infrastructure, very high rates of both recycling and incineration are practiced and are expected to continue into the future.

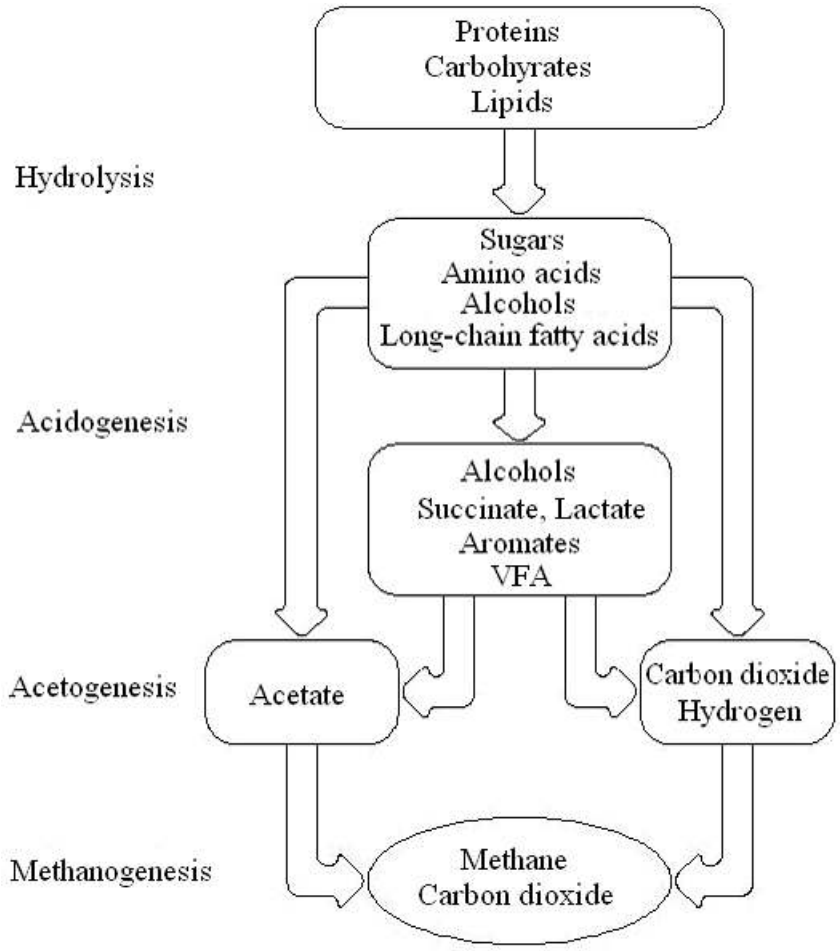


Fig. 4. A simplified conversion processes in anaerobic digestion.

Waste-to-energy (WTE) or energy-from-waste (EFW) is broad terms for facilities that burn waste in a furnace or boiler to generate heat, steam and/or electricity. Combustion in an incinerator is not always perfect and there have been concerns about micro-pollutants in gaseous emissions from incinerator stacks. Particular concern has focused on some very persistent organics such as Dioxins which may be created within the incinerator and which may have serious environmental consequences in the area immediately around the incinerator. Gullet et al. [53] have reported the discovery of polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) from waste combustion sources and the increased under-standing of the toxic effects of these chemicals have prompted extensive study over the last 10 or so years on how these trace compounds are formed in combustion systems.

Incineration for waste to energy (WTE) has been widely implemented in many European countries for decades. In 2002, EU WTE plants generated 41 million GJ of electrical energy and 110 million GJ of thermal energy. Incineration and industrial co-combustion for WTE provide significant renewable energy benefits and fossil fuel offsets. Currently, over 130 million tonnes of waste per year are incinerated at over 600 plants [54]. Thermal processes with advanced emission controls are proven technology but more costly than controlled landfilling with landfill gas recovery; however, thermal processes may become more viable as energy prices increase.

Because landfills produce CH_4 for decades, incineration, composting and other strategies that reduce land filled waste are complementary mitigation measures to landfill gas recovery in the short- to medium-term [55].

4. Conclusion

Educating personnel will also improve the efficiency of the waste management system and minimize its possible health and environmental risks. While the growth in production and marketing during this process makes excessive use of natural resources inevitable, wastes produced due to increasing trend of consumption has reached to threatening levels due to their quantity and hazardous contents. On this account, in parallel with the environmental consciousness rising all over the world, the protection of environment has become one of the major priority policies of countries and waste management has taken a major field among the environmental protection policies of all countries.

The promotion of a high quality waste management system not only enhances social, economic and environmental efficiency, and promotes sustainable development, but can also help resolve the dual crisis of resource shortages and environmental deterioration [56]. Poor management of waste may result in serious environmental problems such as an unpleasant odor and the risk of explosion in landfill areas, as well as groundwater contamination because of leachate percolation [57]. Unsuitable waste management practices also result in the loss of resources and energy, which could be recycled and produced from a large part of the solid waste. Solid waste knowledge is hard won and too easily lost [58].

Today world is facing three critical problems: (1) high fuel prices, (2) climatic changes, (3) air pollution [59]. Renewable energy is a promising alternative solution because it is clean and environmentally safe [60]. Waste and recycling management plans should be developed for any construction project prior to the start of work in order to sustain environmental, economic, and social development principles.

References

[1] Dijkema GPJ, Reuter MA, Verhoef EV. A new paradigm for waste management. Waste Manage 2000;20:633-638.
[2] Wilson DC, Araba AO, Chinwah K, Cheeseman CR. Building recycling rates through the informal sector. Waste Manage doi:10.1016/j.wasman.2008.06.016 (in press)
[3] RTMEF, Republic of Turkey Ministry of Environment and Forestry. Regulations of fundamental waste control. Official Gazette No. 2008/26927, Ankara, Turkey.
[4] AEVG, Waste management concept of the city of Graz. www.aevg, 2008.
[5] Batayneh M, Marie I, Asi I. Use of selected waste materials in concrete mixes. Waste Manage 2007;27:1870–1876.
[6] Siddique R, Khatib J, Kaur I. Use of recycled plastic in concrete: A review. Waste Manage 2008;28:1835–1852.
[7] Buyukbektas F, Varinca KB. The notion of integrated waste management and the regulation of waste frame in the process of integration into EU. http://cevre.club.fatih.edu.tr/webyeni/.
[8] Edincliler A, Baykal G, Erdik M, Mowrtage W. Modeling of behavior of solid waste landfills during earthquake. Sixth National Conference on Earthquake Engineering 16-20 October 2007, Istanbul, Turkey
[9] Oman CB, Junestedt C. Chemical characterization of landfill leachates – 400 parameters and compounds. Waste Manage 2008;28:1876–1891.
[10] Ozcan HK, Borat M, Bayat C. Katı Atık Depo Sahası Gazları ve Çevresel Etkileri. II. Congress of Engineering Science Young Researchers. İstanbul, 2005 (in Turkish).

[11] Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson A. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2001.
[12] Rasi S, Lantela J, Veijanen A, Rintala J. Landfill gas upgrading with countercurrent water wash. Waste Manage 2008;28:1528–1534.
[13] EIA. Energy Information Administration. http://www.eia.doe.gov, accessed 11.25.2008.
[14] Magrinho A, Didelet F, Semiao F. Country report. Municipal solid waste disposal in Portugal. Waste Manage 2006;26: 1477–1489.
[15] Balat M. Progress in biogas production processes. Energy Educ Sci Technol 2008;22:15-36.
[16] Balat M. Possible methods for hydrogen production. Energy Sources Part A 2009;31:39-50.
[17] Balat M. Hydrogen in fueled systems and the significance of hydrogen in vehicular transportation**.** Energy Sources Part B 2007;2:49–61.
[18] Demirbas A. Biohydrogen generation from organic wastes. Energy Sources Part A 2008;30:475-482.
[19] Demirbas B. Biofuels for internal combustion engines. Energy Edu Sci Technol Part A 2009;22:117-132.
[20] Demirbas T. Overview of bioethanol from biorenewable feedstocks: technology, economics, policy and impacts. Energy Edu Sci Technol Part A 2009;22:163-177.
[21] Balat M. New biofuel production technologies. Energy Edu Sci Technol Part A 2009;22:147-161.
[22] Demirbas A. Economic and environmental impacts of the liquid biofuels. Energy Educ Sci Technol 2008;22:37-58.
[23] Demirbas A. Recent progress in biorenewable feedstocks. Energy Educ Sci Technol 2008;22:69-95.
[24] Demirbas C. The global climate challenge: Recent trends in CO_2 emissions from fuel combustion. Energy Edu Sci Technol Part A 2009;22:179-193.
[25] Hacisaligoglu S. Ethanol–gasoline and ethanol–diesel fuel blends. Energy Edu Sci Technol Part A 2009;22:133-146.
[26] Demirbas MF. Pyrolysis of vegetable oils and animal fats for the production of renewable fuels. Energy Edu Sci Technol 2008;22:59-67.
[27] Demirbas A. New liquid biofuels from vegetable oils via catalytic pyrolysis. Energy Edu Sci Technol 2008;21:1-59.
[28] Demirbas A. Bio-fuels from agricultural residues. Energy Sources Part A 2008;30:101–109.
[29] Demirbas K, Demirbas A. Technical assessment of different biorenewable wastes into energy solutions by briquetting. Energy Edu Sci Technol Part A 2009;22:97-106.
[30] Kuwahara, N., M. D. Berni, and S. V. Bajay. 1999. Energy supply from municipal wastes: The potential of biogas-fuelled buses in Brazıl. Renewable Energy 16:1000-1003.
[31] Uygur, Kargi F. 2004. Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor. J Environ Mgmt 71: 9–14.
[32] EPA. Characterization of potential of municipal solid waste (MSW) components. Municipal Solid Waste in the United States: 1992 Update. EPA/530-R-94-042, NTS #PB 95-147690. Solid Waste and Emergency Response (5305), Washington. D.C.: U.S. Environmental Protection Agency (EPA), 1994.
[33] Erses AS, Onay TT. In situ heavy metal attenuation in landfills under methanogenic conditions. J Hazard Mat B 2003;99:159–175.
[34] Timur H, Ozturk I. Anaerobic sequencing batch reactor treatment of landfill leachate. Wat Res 1999;33:3225-3230.
[35] Metin E, Erozturk A, Neyim C. Solid waste management practices and review of recovery and recycling operations in Turkey. Waste Manage 2003;23:425–432.
[36] Plaza G, Robredo P, Pacheco O, Toledo AS. Anaerobic treatment of municipal solid waste. Water Sci Technol 1996;33:169-175.
[37] Kiely G, Tayfur G, Dolan C, Tanji K. Physical and mathematical modelling of anaerobic digestion of organıc wastes. Water Res 1997;31:534-540.

[38] Braber K. Anaerobic digestion of municipal solid waste: A modern waste disposal option on the verge of breakthrough. Biomass Bioenergy 1995;9:365-376.
[39] Al-Dabbas MAF. Reduction of methane emissions and utilization of municipal waste for energy in Amman. Renewable Energy 1998;14:427-434.
[40] Augenstein D, Pacey J. Landfill methane models. Proceedings from the Technical Sessions of SWANA's 29th Annual International Solid Waste Exposition, SWANA, Silver Spring, MD, 1991.
[41] Micales JA, Skog KE. The Decomposition of forest products in landfills. Int Biodeterior Biodegr 1997;39:145-158.
[42] Kargi F, Pamukoglu MY. Adsorbent supplemented biological treatment of pre-treated landfill leachate by fed-batch operation. Biores Technol 2004;94:285–291.
[43] Ozturk I, Altinbas M,. Koyuncu I, Arikan O, Gomec-Yangin C. Advanced physico-chemical treatment experiences on young municipal landfill leachates. Waste Manage 2003;23:441– 446.
[44] Cecen F, Erdincler A, Kilic E. Effect of powdered activated carbon addition on sludge dewaterability and substrate removal in landfill leachate treatment. Advances Environ Res 2003;7:707–713.
[45] Kargi , PamukoglY. Repeated fed-batch biological treatment of pre-treated landfill leachate by powdered activated carbon addition. Enzyme Microbial Technol 2004;34:422–428.
[46] Kayabali K. Engineering aspects of a novel landfill liner material: bentonite-amended natural zeolite. Engin Geology 1997;46:105-114.
[47] Meynell, P.-J. Methane: Planning a Digester. New York: Schocken Books, 1976.
[48] Demirbas A. Biogas potential of manure and straw mixtures. Energy Sources Part A 2006;28:71-78.
[49] Aiba S, Humphrey AE, Milis NF. Biochemical Engineering, 2d ed., Academic, New York, 1973.
[50] Asplund S. The Biogas Production Plant at Umea Dairy Evaluation of Design and Start up. Degree thesis, Linköpings University, Linköping, Sweden, October 5, 2005.
[51] Yang W, Nam H, Choi S. Improvement of operating conditions in waste incinerators using engineering tools Waste Management 2007;27:604–613.
[52] Ecke H, Svensson M, Mobility of organic carbon from incineration residues Waste Management 2008;28:1301–1309.
[53] Gullett BK, Dunn JE, Bae SK, Raghunathan K. Effects of combustion parameters on polychlorinated dibenzodioxin and dibenzofuran homologue profiles from municipal waste and coal co-combustion. Waste Management 1998;18: 473- 483.
[54] Themelis N. An overview of the global waste-to-energy industry. Waste Manage World 2003;40-47.
[55] Bogner J, Ahmed MA, Diaz C, Faaij A, Gao Q, Hashimoto S, Mareckova K, Pipatti R, Zhang T. Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Uni. Press, Cambridge, 2007.
[56] Damghani AM, Savarypour G, Zand E, Deihimfard R. Country Report. Municipal solid waste management in Tehran: Current practices, opportunities and challenges. Waste Manage 2008;28:929–934.
[57] Mor S, Ravindra K, Visscher A, Dahiya RP, Chandra A. Municipal solid waste characterization and its assessment for potential methane generation: A case study. Sci Total Environ 2006;371:1–10.
[58] Milke M. The world's great solid waste management libraries. Editorial. Waste Manage 2008;28: 937–938.
[59] Demirbas A. Energy concept and energy education. Energy Educ Sci Technol Part B 2009;1:85-101.
[60] Kurnaz MA, Calik M. A thematic review of 'energy' teaching studies: focuses, needs, methods, general knowledge claims and implications. Energy Educ Sci Technol Part B 2009;1:1-26.
[61] Demirbas A. Future Energy Sources: Part I. Future Energy Source 2009;1:1-95