

WASTE MANAGEMENT – CURRENT TRENDS

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ABSTRACT. Solid industrial and municipal waste, besides an environmental problem, can also be a source of a number of valuable ingredients, in relation to which they have to be analysed in two aspects: as a sustainable development problem and as alternative raw materials. The solution of problems in solid industrial and municipal waste processing is of particular importance due to the gradual natural mineral resources depletion and the need of the full use of all waste types as useful products. In a number of countries, such as the USA, Japan, Germany, UK, Sweden, etc., most of the tasks related to the solid industrial and household waste processing have been successfully solved. This paper presents and analyses the most promising technologies for waste recovery or re-use. Numerous good practices for their implementation are known worldwide.

Keywords: solid industrial and household waste, technologies, recycling

СЪВРЕМЕННИ ТЕНДЕНЦИИ В УПРАВЛЕНИЕТО НА ОТПАДЪЦИ

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РЕЗЮМЕ. Твърдите промишлени и битови отпадъци, освен екологичен проблем, могат да бъдат и източник на редица ценни съставки, във връзка с което те трябва да се анализират в два аспекта: като проблем на устойчивото развитие и като алтернативни суровини. Решението на проблемите при преработката на твърдите промишлени и битови отпадъци придобива особена значимост, поради постепенното изтощаване на природните минерални суровини и необходимостта от пълноценното използване на всички видове отпадъци, като полезни продукти. В редица държави, като САЩ, Япония, Германия, Великобритания, Швеция и др., успешно са решени повечето задачи, свързани с преработката на твърдите промишлени и битови отпадъци. Настоящата разработка представя и анализира най-обещаващите технологии за оползотворяване на отпадъци или тяхната повторна употреба. В световен мащаб са известни множество добри практики за тяхното прилагане.

Ключови думи: твърди промишлени и битови отпадъци, технологии, рециклиране.

Introduction

Urban density is rapidly increasing in line with an expanding global population. The importance of creating a sustainable legacy is now widely recognized throughout the world at every level of society – from those responsible for designing the developments of tomorrow to those who will ultimately inhabit them. Waste management has never before been such a crucial factor in achieving this legacy and is now an essential component of any long-term sustainability strategy.

Currently, world cities generate about 1.3 billion tonnes of solid waste per year. This volume is expected to increase to 2.2 billion tonnes by 2025. Waste generation rates will more than double over the next twenty years in lower income countries (Hoornweg, Bhada-Tata, 2012).

Solid wastes arise from unusable residue in raw materials, leftovers, rejects and scrap from process operations, used or scrap packaging materials and even saleable products themselves when they are finally discarded (Tchobanoglous et al., 1993).

According to the Pan-American Health Organization (2005) solid or semi-solid waste generated in population centers including domestic and commercial wastes, as well as those originated by the small-scale industries and institutions (including hospitals and clinics); market street sweeping, and from public cleansing.

Solid waste management includes control of generation, storage, collection, transport or transfer, processing and disposal of solid waste materials in a way that best addresses the range of public health, conservation, economics, aesthetic, engineering and other environmental considerations (LeBlanc, 2017).

The selection of treatment technology and disposal of solid waste vary from one country to another and depends on the types of waste, composition, infrastructure, land availability, labour, economic aspects, recycling strategy, public awareness, calorific value of waste, energy availability and demand, and environmental impact (Agamuthu, 2001; Samah et al., 2005). The ecological merits of resource conservation and recycling became an area of growing interest.

New technologies are continuously developing in the urban infrastructure and improving the environment. Yet the principal of waste management has remained unchanged since the 19th century.

The last two decades have brought a new challenge for waste management: the growing vagaries of global secondary materials markets.

Rogoff (2014) reports that over the past several decades, the variety of technologies, and their ability to recover more of the incoming waste stream than ever before, has been a significant improvement in recycling management. This trend has enabled recycling coordinators to help implement programmes with the objective of increasing the diversion of potentially recyclable materials from landfills and waste-to-energy facilities. Better designs of materials recovery facilities and the addition of specialized equipment are improved recovery of fiber, plastics, and metals, thereby improving the overall economics and reducing the residues for plant operators (Rogoff, 2014).

This paper provides a summary of the priorities technologies for solid waste processing. A large number of research papers are reported in solid waste recycling area. The main focus of this paper is to survey the state of the art techniques for solid waste management.

Waste management

Waste treatment and disposal methods

Waste treatment and disposal methods are selected and used, based on the form, composition, and quantity of waste materials (LeBlanc, 2017). Table 1 briefly summarizes and presents the major methods.

Table 1. *Waste treatment and disposal methods (adapted from LeBlanc, 2017)*

Methods	Waste treatment process	In brief
Thermal waste treatment (refers to the processes that use heat to treat waste materials)	Incineration	One of the most common waste treatments. Involves the combustion of waste material in the presence of oxygen. Used as a means of recovering energy for electricity or heating. <i>Advantages:</i> quickly reduces waste volume, lessens transportation costs and decreases harmful greenhouse gas emissions.
	Gasification and pyrolysis	Two similar methods, both of which decompose organic waste materials by exposing waste to low amounts of oxygen and very high temperature.

Dumps and landfills	Open burning	Environmentally harmful.
	Sanitary landfills	The most commonly used waste disposal solution.
	Controlled dumps	More or less the same as sanitary landfills.
Bioreactor landfills	Bioreactor landfills	The result of recent technological research. These landfills use superior microbiological processes to speed up waste decomposition.
	Composting	Frequently used waste disposal or treatment method, which is the controlled aerobic decomposition of organic waste materials by the action of small invertebrates and microorganisms. The most common techniques include <i>static pile composting, vermin-composting, windrow composting and in-vessel composting.</i>
Biological waste treatment	Anaerobic digestion	Also uses biological processes to decompose organic materials, however, uses an oxygen and bacteria-free environment to decompose the waste material where composting must have air to enable the growth of microbes.

Waste technologies

Saleem et al. (2016) reviewed latest technologies of waste management from storage, collection, recycling, processing, energy recovery and final disposal. The following Table 2 summarizes information based on Saleem et al. (2016) research.

Table 2. *Waste management technologies*

Management system	Technology
Collection and transport	Underground collection system
	Web based on geographic information system technology
	Waste bin monitoring technology using Global System of Mobile
	Compact garbage collection trucks
Segregation and sorting	Multi-compartment bins
	Optical sorting
	Automatic Bottle Sorting

	System
	Automated Sorting
	Mechanical Biological Treatment (MBT)
Recycling	Deinking Technology for paper recycling
	Biodegradable and degradable plastic
	Cullet remanufacturing
Processing	Autoclaving
	Fluffing
	Melting technology
	Incineration
	Vermicomposting
Energy recovery	Thermal Conversion: <i>Plasma Gasification and plasma pyrolysis; Refuse Derived Fuel (RDF); Fluidized Bed Technology.</i>
	Bio-conversion: Dry Anaerobic Composting
Disposal	Sanitary Landfill
	Bioreactor Technology
	Landfill gas recovery technologies (<i>Microturbine and Fuel cell Technologies</i>)

Serious environmental degradation occurs due to open, uncontrolled and poorly managed waste dumping in many cities of developing countries. Municipal solid waste sustainable management can reduce the short and long term environmental and human health hazards. The proper implementation of latest technologies in the sector of MSW management can play a very important role in providing pollution free and sustainable environment (Saleem et al., 2016).

Waste-to-energy (WTE) technologies

Seltenrich (2016) observes that three thermal waste-to-energy (WTE) technologies seek to turn municipal solid waste from a burden to an asset. Adherents of these technologies (gasification, plasma gasification, and pyrolysis) they produce fewer toxic emissions and virtually eliminate landfilling. Today, 70 mass-burn plants in 21 states consume about 13% of the USA waste, down from a peak of 14.5% in 1990. Cumulatively they offer roughly 2.5 gigawatts of power in return, less than a tenth of what the U.S. solar industry produces (EPA, 2014, 2015).

Waste gasification technology is recognized as an alternative thermal treatment technology. Gasification, plasma gasification, and pyrolysis involve the super-heating of a feedstock - be it municipal solid waste, coal, or agricultural residues - in an oxygen-controlled environment to avoid combustion. The primary differences among them relate to heat source, oxygen level, and temperature, from as low as about 300°C for pyrolysis to as high as 11 000°C for plasma gasification. In these low-oxygen environments the production of dioxins and furans from waste can be significantly reduced

compared with incineration, with emissions potentially falling even below detection limits (Stringfellow, 2014).

Conversion technologies are further distinguished from conventional solid waste incineration by the production of synthesis gas composed mainly of hydrogen and carbon monoxide, a product of the thermal reactions that take place during the processes. The synthesis gas can then be burned in a boiler system to generate electricity. It can also be processed into fuel for an efficient, low-emissions natural gas generator or refined into other valuable products.

Incinerators produce significant amounts of a waste called bottom ash, of which about 40% must be landfilled. The remaining 60% can be further treated to separate metals, which are sold, from inert materials, which are often used as road base. The newer technologies, by contrast, offer immediate recovery of metals and inert slags, with smaller volumes of landfill. This explains why conversion technologies have caught on in regions where landfill space is extremely tight or available at a premium (Arena, 2015; Arena, Gregorio, 2013; Seltenrich, 2016)

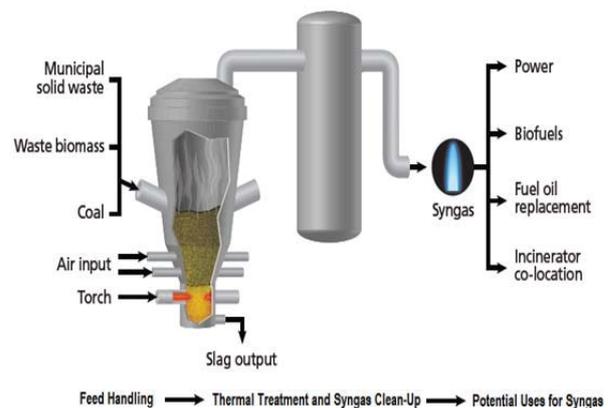


Fig. 1. Technologies work scheme (Stringfellow, 2014)

Municipal solid waste (MSW) is a mix of all kinds of materials: not just combustible carbon-based materials but also glass, metals, and more. Proponents of a decades-old philosophy called "zero waste" contend that at least 80% of the typical MSW stream can be recycled or composted (e.g. through anaerobic digestion), and that reuse and waste prevention can reduce the remaining portion - if not all the way to zero (Stringfellow, 2014).

Waste sorting innovations

Gundupalli, Hait and Thakur (2017) reviewed recent advances in physical processes, sensors, and actuators used as well as control and autonomy related issues in the area of automated sorting and recycling of source-separated municipality solid waste.

The authors (Gundupalli et al., 2017) observed that most of the research advances in the area of automated waste sorting systems have taken place in developed countries. In developed countries, source segregation of waste into recyclables is very common. Therefore, most of the automated

waste sorting systems have been designed and are suitable only for the automated sorting of source-segregated waste. In contrast to this, source segregation is usually not implemented in developing countries due to very limited door-to-door collection and lack of motivation. As a result, the collected waste is in mixed form and is later dumped in landfill sites. After this, waste sorting is performed manually and exposes involved workers to toxic and pathogenic work environment. Therefore, a need exists to facilitate the workers involved in mixed waste sorting with automated tools to improve safety and efficiency (Paulraj et al., 2016; Takemura et al., 2006).

Plastic solid waste (PSW) recycling

Years of research, study and testing have resulted in a number of treatment, recycling and recovery methods for PSW that can be economically and environmentally viable (Howard, 2002).

PSW treatment and recycling processes could be allocated to four major categories (Mastellone, 1999): re-extrusion (primary), mechanical (secondary), chemical (tertiary) and energy recovery (quaternary). Each method provides a unique set of advantages that make it particularly beneficial for specific locations, applications or requirements. Mechanical recycling (i.e. secondary or material recycling) involves physical treatment, whilst chemical recycling and treatment (i.e. tertiary encompassing feedstock recycling) produces feedstock chemicals for the chemical industry. Energy recovery involves complete or partial oxidation of the material (Troitsch, 1990), producing heat, power and/or gaseous fuels, oils and chars besides by-products that must be disposed of, such as ash (Al-Salem et al., 2009).

Integrated solid waste management (ISWM)

LeBlanc (2016) published a comprehensive review on ISWM. An efficient ISWM system considers how to reduce, reuse, recycle, and manage waste to protect human health and the natural environment. ISWM is based on the hierarchy of waste management: reduce, reuse, and recycle. ISWM represents a contemporary and systematic approach to solid waste management. The functional elements of ISWM include source reduction, recycling and composting, waste transportation and landfilling (LeBlanc, 2016).

Actually, Bulgaria is also putting its waste management system up to best practice standards. The European Investment Bank has helped the capital city of Sofia successfully develop an integrated waste management system that turns waste into a resource. Today, about 60% of the waste in Sofia is composted, recycled or energetically recovered. By diverting the biodegradable materials away from landfills, these facilities help to limit greenhouse gas emissions that contribute to climate change. In addition, the waste management system also re-injects valuable materials back into the economy; thus contributing to the circular economy, saving energy, and avoiding the production of greenhouse gases.

The key components of the Sofia Municipality ISWM are landfill for non-hazardous waste "Sadinata", mechanical and biological treatment plant for Refuse Derived Fuel (RDF) production, placed also on "Sadinata" landfill, "Han Bogrov" installation for biological treatment and installation for anaerobic digestion of biowaste, part of the installation for biological treatment "Han Bogrov".

The treatment process incorporates state of the art technologies making the mechanical and biological treatment plant (MBT) one of the most modern MSW facilities in Europe. MSW are received and treated through process lines which are fully automated and optimized according to the special characteristics of the input waste and are designed for residue minimization and product maximization.

The products are recyclable materials, high quality Refused Derived Fuel (RDF) and non-standard compost (CLO) while residue is material suitable for sanitary landfilling.

The construction and operation of the MBT Facilities is in full compliance with the European legislation regarding waste management and environmental regulations. The technical solution applied achieves minimization of the residues that needs to be diverted to landfill, production of useful by-products, avoidance of hazardous residuals, minimization of CO₂ emissions and positive carbon footprint.

Urban waste management underground solutions

Kaliampakos and Benardos (2013) note that the utilization of subsurface space is nowadays a key issue towards attaining an environmental friendly and sustainable development, especially in urban areas. Thus, activities or infrastructures that are difficult, impossible, environmentally undesirable or even less profitable to be installed above ground can be relocated underground releasing valuable surface space for other uses and enhancing urban living conditions. Hence, the management of waste through underground developed infrastructure can be looked as an important evolution which would allow for the efficient and cost-effective tackling of one of the more pressing needs of modern society.

Rising waste volumes, increased hygienic and amenity demands as well as environmental considerations impose additional requirements to the waste management system that traditional management schemes are either unable to meet or come across with increased operating cost figures. The utilization of the subsurface space can provide the setting for the development of infrastructure which is capable of addressing in a more efficient manner the limitations of existing waste management schemes (Kaliampakos, Benardos, 2013).

Automated vacuum (pneumatic) waste collection systems (AVAC) provide an integrated framework for the tackling of the waste handling problem. Table 3 presented the major advantages and disadvantages of the underground AVAC system.

Table 3.
Underground AVAC system advantages and disadvantages (Kaliampakos, Benardos, 2013)

<i>Advantages</i>	<i>Disadvantages</i>
Minimized operation cost and long term savings	Heavy construction operations needed requiring high investment costs
Ability to collect apparently all waste streams	Cannot collect large items, bulky wastes, WEEE and has difficulties with glass wastes
Flexible system with the ability to easily adopts to changes	After installation the flexibility of the system is reduced
Minimized usage of garbage collection trucks in urban areas	Truck transportation is not eliminated
Minimized noise, aesthetic pollution and odour problems	Risk of problems related to pipe blockages
Release of surface space for community needs or development	Public willingness and training to proper disposal required
Enhanced safety for collection workers (hygiene, accidents, etc.)	Experienced workforce is required

Table 4 provides some examples of cities that utilize underground waste collection systems.

Table 4.
Cities that utilize underground AVAC systems

<i>Country/City</i>	<i>Comments</i>
Roosevelt Island (NY, USA)	AVAC was commissioned in 1975 and since then it has handled 10 tons of waste on a daily basis from the island's 16 apartment complexes.
Disney World (FL, USA)	Was put into operation in the early 1970's and was the first underground waste collection scheme ever employed in the United States. The systems operate on a 24 hour basis and transport the waste from all points around the park to a central location where they are processed and recycled.
Wembley city (Great Britain)	The automated waste collection system has been operating there since 2008, handling 160 tons of waste per week.
Yas Island (UAE)	Consisting of 43 inlet points, installed around walkways or in buildings and a total of 5.3 km of pipes with a handling waste capacity of about 40 tons per day.
Abu Dhabi (UAE)	The installation of the AVAC is expected to be operational by the end of 2017.
Barcelona (Spain)	The first automated underground vacuum collection system was developed in the Olympic city (Villa Olimpica) in 1992, as part of the city's renovation for the 1992 Olympic Games.
Leon (Spain)	The system handles two waste types organic waste and paper / cardboard.

Romainville (France)	The system consists of 179 inlet points and of 4.1 km of transport pipes placed 2 m below ground level.
Hammarby Sjöstad (Sweden)	One of the results of the vacuum system is that the traffic with heavy waste collection vehicles has been reduced by 60%. At the same time, residents benefit from reduced waste collection fees.
Porimao – Algarve (Portugal)	An underground collection point was introduced to the town's waste management system in 2010.
Mecca - Masjid al-Haram (Saudi Arabia)	The largest facility of its kind in the world, with a capacity of 600 tons per day, or 4,500 m ³ of waste.

According to an increasing number of experts the automated vacuum (pneumatic) waste collection systems (AVAC) provide an integrated framework for the tackling of the waste handling problem.

Conclusions

The development of many new industries has led to a sharp increase of the waste products quantities with varied origin. The proper management of these waste products by applying suitable processing technology is appropriate in terms of effective economic development. A necessary condition for achieving sustainable development and minimize environmental pollution is the technological efficiency of processing technology. The problems of economic development and environmental protection are inextricably connected, and the current and future generations life quality depends on their resolution. To protect the public health and the environment from potentially harmful effects of waste is a primary objective of waste management.

The disposal methods such as landfilling were insufficient to the waste problems tackle. The modern municipal solid waste processing plants are complexes of technologies and installations for the separation, disposal, recycling and waste conversion into target products. In order to increase the plants' efficiency and reduce the impact on human health and the environment, it is necessary to achieve the most complete raw materials processing and to use proven systems of waste stream treatment.

The analysis of key trends that may determine waste management future indicated that in recent years, rapid development has shown waste-to-energy technologies with energy recovery and the waste products processing in alternative fuels replacing natural gas, oil and coal.

Our survey demonstrated that the main waste management and recycling trends are as follows:

- Energy production from waste is the biggest trend.
- Some of the new ways through which wastes are being transformed into energy with no harm to the environment are incineration, gasification and anaerobic digestion. Newly designed incinerator

models are being used to trap methane from decomposing waste and turning it into renewable energy.

- Carrying out prior planning to reduce the amount of waste generated per activity. A lot of waste comes from using more than the required amounts of raw materials.
- Waste sorting technological advancements, where machines can separate the different recyclable materials at recycling plants.

There is no doubt that the waste management and recycling requires global efforts. The easier method of waste management is to reduce waste materials creation.

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