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OVERVIEW OF THE UTILIZATION AND DISPOSAL OF WASTE FROM MARITIME SHIPPING AND EXAMINATION OF POSSIBLE SOLUTIONS

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Abstract: Towards the middle of the XXI. century, environmental protection is becoming more and more of a focus in the world. According to not only environmentalists but also many politicians, economists, and even historians, the biggest threat to the world is environmental pollution and climate change caused by global warming. Accordingly, the development of environmentally friendly technologies, which does not only apply to the automotive industry, is also in full swing in the transport industry. Much attention is paid to reducing the environmental burden of shipping as well. This is all the more justified since nowadays, the most common ship fuel, the so-called heavy oil, contains 3500 times more sulfur than conventional diesel fuel. Accordingly, there are now floating hotels operating around the world that use LNG as a green fuel. In this article, we try to collect the literature strongly related to the topic in order to develop detailed technology in our further work.

Keywords: shipboard waste, waste utilization, MARPOL convention, Rankine-Clausius cycle, heat treatment technologies

1. Introduction

1.1. Concepts of waste and its utilization

Defining waste involves many difficulties. On the one hand, waste is a set of substances that are created during many human activities, so their physical and chemical properties can be different. And on the other hand, waste management is one of the youngest areas of environmental protection, so its legal background is constantly changing [1]. The nature of waste is not directly an environmental concept but rather an economic and legal formulation [2]. As a result, in practice, there are definitions that need to be explained or supplemented. Certain terms are not clear, so their redefinition is inevitable in future legislation. In addition, several definitions are known in international practice that accurately interpret each type of waste, so their introduction in Hungary is becoming more and more urgent. This subsection provides a brief overview of the world and interpretation of the basic concepts of waste management.

We use several definitions to define waste. In a more general sense, "waste is a substance, product, residue, object, isolated pollutant, contaminated area, which cannot be used or sold directly by their owner, and which must be treated separately" [1].

According to this formulation, waste is a completely unnecessary set of materials for the owner which cannot be utilized. Since most waste contains recoverable components, it is justified to modify this definition. The official concept of waste is much simpler than this. CLXXXV of 2012 on waste. (Section 2, paragraph (1), point 23) waste is defined as "any substance or object that the owner throws away, intends to throw away or must throw away". This wording is very simplistic, but it also includes materials and objects that are not considered waste under any circumstances. In international practice, components suitable for energy production are called RDF (Refuse-Derived Fuel) or SRF (Solid Recovered Fuels), i.e. waste-derived fuel or alternative fuel [3], [4], [5].

1.2. Integrated waste management pyramid

The waste pyramid establishes a hierarchical ranking in terms of waste management (Figure 1.).

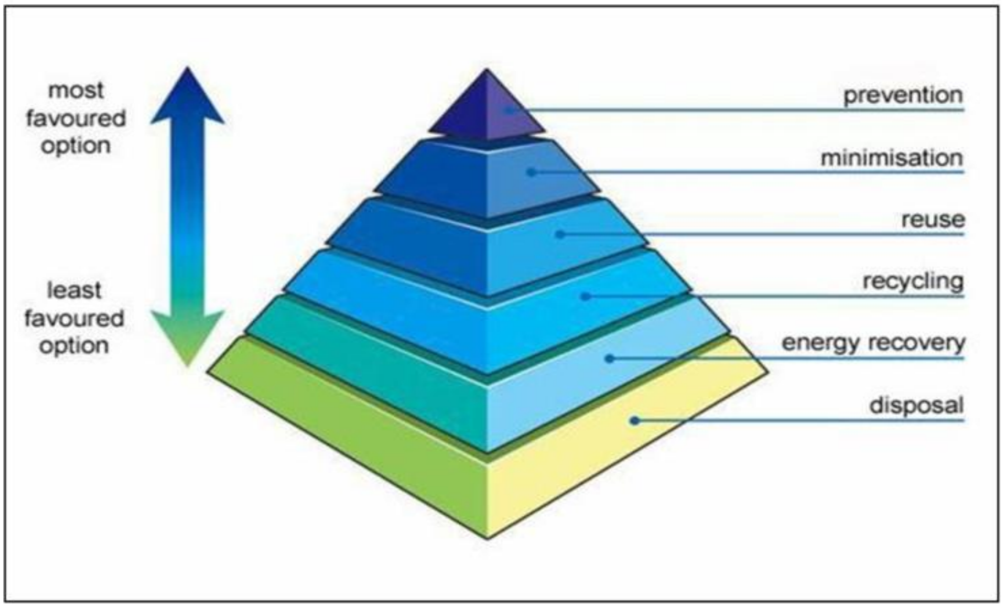

Figure 1. Integrated waste management pyramid

From an environmental protection point of view, prevention is the most important thing because if no waste is generated, then we don't have to think about further treatment. Nowadays, it is difficult to imagine a production or consumption process that produces or uses products without generating waste. Consequently, the principle of minimization should be applied, which aims to formulate the maximum possible recycling of waste and by-products generated during the production process [3]. During production, auxiliary streams are used to maximize the incorporation of raw materials into the final product, thereby ensuring that waste generation is minimized.

2. Materials and methods

2.1. The MARPOL convention

The purpose of the MARPOL 1973/1978 Convention (International Convention for the Prevention of Pollution from Ships) is to protect the marine environment and prevent pollution caused by ships at sea. The convention, which is mandatory for all seagoing vessels over 500 GT participating in international trade, covers the management of the following potential hazards and sources of pollution:

- Annex I: Regulations for the prevention of oil spills
- Annex II: Provisions for the prevention of contamination caused by bulk liquid toxic substances
- Annex III: Regulations for the prevention of pollution caused by packaged hazardous materials transported by sea
- Annex IV: Regulations for the prevention of pollution caused by wastewater generated on ships
- Annex V: Regulations for the prevention of pollution caused by household and other waste on ships
- Annex VI: Air pollution caused by ships

Especially highlighting Annex IV., as it is the most important in relation to our work.

Wastewater:

a) drainage and other waste from any type of toilet, urinal and toilet sink;
b) drainage from the medical rooms (pharmacy, patient bay, etc.) on the wash basins in such rooms,
c) removal from places containing live animals;
d) other wastewater if it is mixed with the above drains.

2.2. Energetic utilization of waste

Utilization for energetic purposes in the narrower sense means the production of electricity and heat; in addition, it is advisable to list the production of mechanical energy as a viable energy type because biofuels are increasingly important in addition to power plant energy consumption. Thermal waste management technologies are used to utilize waste for energy purposes. In international practice, the term energy from waste (WtE) is widespread and includes all processes that enable the recovery of the amount of energy in waste in the form of useful heat and/or electricity [6], [7].

Depending on their composition, we use different types and temperatures of waste treatment (Figure 2.). Processes that also take place at normal atmospheric temperatures are classified as traditional technologies. The most well-known traditional technology is fermentation, which results in the biological degradation of devices. The final product in the form of gas is biogas, which can be used to replace natural gas. Many technologies can be used to separate carbon dioxide from biogas and other energy-neutral gases; after removing these gases, we get so-called biomethane of the same quality as natural gas. Biomethane can be introduced into the natural gas network if it complies with MSZ 1648:2000.

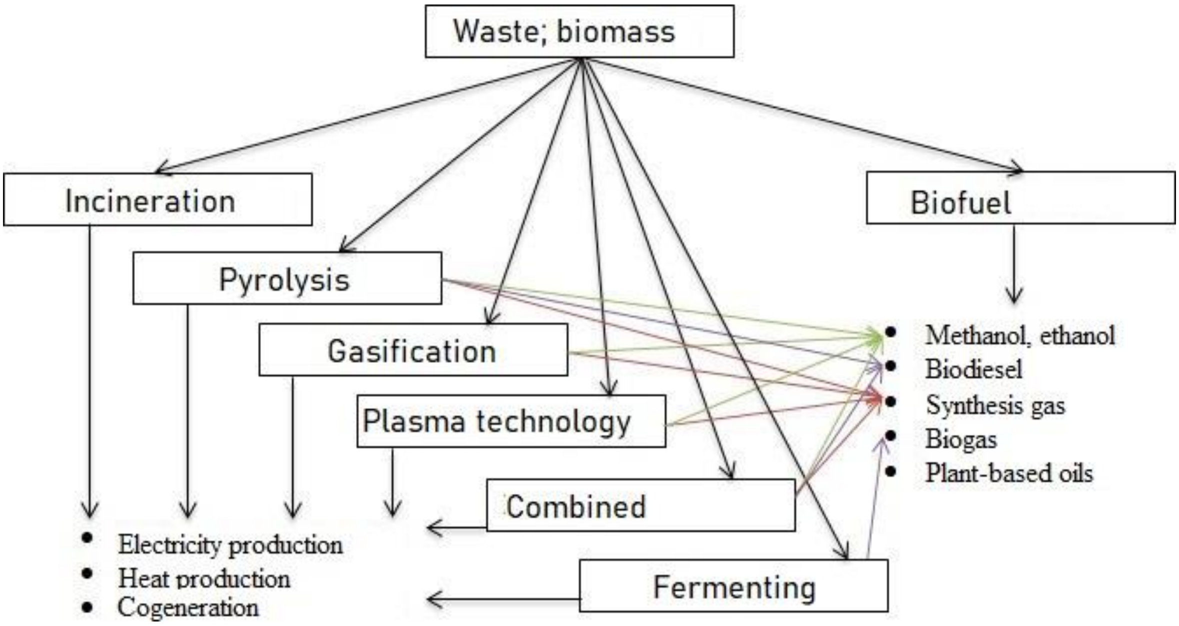

Figure 2. Possibilities of using waste for energy purposes

Thermal technologies can be divided into two main groups. The first group is represented by basic technologies. The most well-known technology is traditional incineration, where the calorific value of the waste is extracted simply by incineration and used in the form of heat and/or electricity. During combustion, non-combustible flue gas and ash are formed in the solid phase, and their release into the environment leads to the deterioration of air quality.

New technologies such as pyrolysis, gasification and plasma technology, as well as their combinations, make it possible to produce a gaseous energy carrier (wood gas) from solid biomass. In addition to the gas phase, pyrolysis still produces combustible carbon dioxide-rich pyrocoke and pyrrole oil, which can be used for power generation or further gasification in coal and oil power plants. During gasification, the solid final product is the slag and ash produced during combustion. Among the new thermal technologies, plasma technology should be prioritized because the solid phase here is vitreous slag (glass slag), a product that is completely indifferent to the environment, particularly suitable for construction use. Keeping all of this in mind, plasma technology achieves the complete disposal of waste while recovering energy, but it requires electricity for its operation, which reduces the energy efficiency of the technology [8], [9].

In addition to traditional incineration, alternative technologies produce useful products that can be used with favourable efficiency in the energy, chemical and construction industries, among others. Nevertheless, more than 95% of thermal waste treatment plants today use traditional incineration technology [8]. The biggest electrical disadvantage of this technology is the low electrical efficiency. During the implementation of the Rankine-Clausius cycle (Figure 3.), the available net electrical efficiency is usually between 19 - 27% [10].

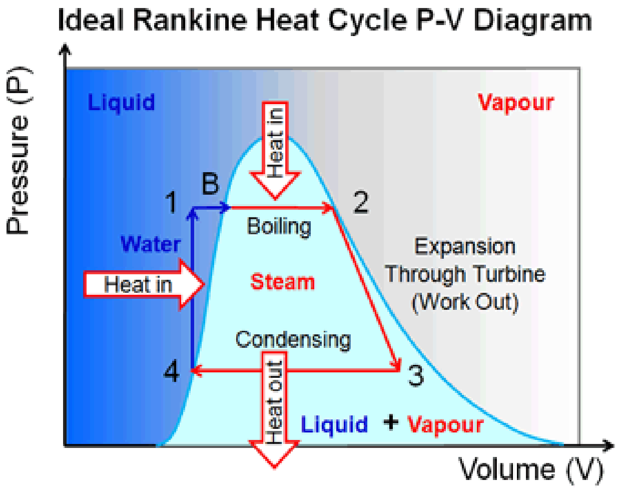

Figure 3. Rankine-Clausius cycle

On the other hand, new thermal technologies represent the first step in converting waste into high-energy synthesis gas, which can operate in a diesel cycle, gas engine or gas turbine with a net electrical efficiency of up to 35% [11], [12]. With this solution, the specific electricity production can even be doubled,

2.3. Composition of shipboard waste

EMSA assists the European Commission in the work of the possible revision of Directive 2000/59/EC [13] on port reception facilities for ship-generated waste and cargo residues, also known as the PRF Directive. One issue raised is the amount and management of ship-generated waste (SGW) on board ships. The relevant literature is out of date and does not reflect new developments in waste treatment and management. Better information on the volume of waste generated during voyages, waste management practices on board ships, and waste discharged at ports would help regulators, ports and waste managers plan for waste reception and transport.

2.3.1. Oily bilge water

A bilge is a mixture of liquids that collect in the bilge of a ship. It comprises a mixture of fresh water, seawater, oil, mud, chemicals and various other fluids that lead to the water house. Seawater and freshwater can enter the deck water well from the engine room or engine room due to deck drains, piping leaks, and pump and valve gland leaks.

Bilge water is produced by condensation, seepage and cleaning. As a general rule, bilge water contains oil from the engine room; hence the term "oily bilge". Fluid entering the bilge system, including bilge wells, bilge lines, tank top or bilge holding tanks, is classified as oily bilge water [14], [15], [16], [17], [18]. All boats have oily bilges, although recreational boats have a minimal amount.

Although there are many technologies for separating water and oil, such as absorption/adsorption, biological treatment, coagulation/flocculation, flotation and membranes, the most commonly used technology for ship inspections is oil-water density differences is based on. This type of treatment can reduce the amount of bilge water by 65-85%.

MARPOL mandated that all ships over 400 gross tons (GT) must be fitted with equipment to limit the release of oil into the oceans to 15 ppm when a ship is underway. They must also have an oil content monitor (OCM) and a bottom alarm to determine if the treated bottom water meets the emission requirements.

2.3.2. Oily residue (sludge)

Oil residue (sludge) is waste from the cleaning of fuel or lubricating oil, or oil collected in oil water

separators, oil filter equipment or drip trays, and waste from hydraulic and lubricating oils [19].
Sludge is usually collected in a sludge tank, waste fuel tank, waste oil tank, or lube oil or fuel oil drain tank. It can then be transferred directly from the tank to a port receiving facility.

The amount of sludge from lubricating oil depends on the type of lubricating oil and the consumption of lubricating oil. It is usually several orders of magnitude less than the oil residues in the fuel. Thanks to the automatic lubrication system, usage can be reduced by 70% [20], [21].

Oil sludge is the residual waste from fuel consumption. Treatment of oily sludge can be achieved by evaporation and/or incineration. Most of the sludge is stored and disposed on PRF without treatment.

The generation of oily sludge water depends on many factors, including the type and amount of fuel. Ships produce 0.01 - 0.03 m^3 of sludge. Evaporation can reduce the amount of sludge by up to 75% while burning the remaining sludge by 99% or more.

2.3.3. Oil tank washing

Cargo tanks in oil tankers must be cleaned before new cargo incompatible with the previous cargo is loaded or before dry docking. Tank cleaning can be done by spraying with crude oil (crude oil wash or COW), seawater or fresh water and cleaning agents. The former does not produce waste because the remains are converted into useful cargo.

Regulation 34 of MARPOL Annex 1 allows controlled unloading if the ship is en route, not in a special area and more than 50 nautical miles from the coast. The water fraction has a maximum volume of 30 litres per nautical mile. If the vessel has an Oil Discharge Monitoring and Control System (ODMCS) and a slop tank, no additional requirements are required for discharges at sea. [22], [23], [24], [25]. Unlike the discharge of bottom water to the sea, no ppm limits are required for the disposal of sedimented slopes, and therefore, oil water separators are not usually used. The total amount of oil discharged into the sea shall not exceed 1/30,000 of the total amount of the cargo, the remainder of which is intended for tankers built/delivered after 31 January 1979.

2.3.4. Sewage

Sewage is any form of drainage and other waste from toilets and urinals; water drainage from medical rooms (office, patient room, etc.) through the sinks, bathtubs and drains located in such rooms; drainage from spaces containing live animals; or other wastewaters, if mixed with the channels defined above [26], [27]. This is commonly referred to as "black water". It does not include greywater, which is the drain from dishwashers, showers, laundry, bathtubs and sinks [28].

MARPOL IV prohibits the discharge of sewage into the sea unless the ship has an approved sewage treatment plant or the ship discharges the shredded and disinfected sewage more than three nautical miles offshore using an approved system nearest land. Unshredded or disinfected sewage may be discharged more than 12 nautical miles from the nearest land.

The size of the tank should take into account the capacity to hold all the sewage, the operation of the vessel, the number of persons on board and other relevant factors. The storage tank must have means of visually indicating its contents.

The storage tank can also be used to collect grey water and/or galley water. However, grey water is not always piped to the tank and is sometimes stored in separate storage tanks. Grey water can sometimes be discharged directly into the sea or must be mixed with the wastewater to be treated. It can also be recycled into the toilet flushing system.

About a quarter of cruise ships have installed an advanced wastewater treatment system (AWTS), which mixes and cleans grey and black water and produces a bioresidue or sewage sludge that must be preserved for discharge ashore [29]. It is common on cruise ships to have a separate tank for galley water, which is emptied in accordance with food waste regulations. It is common for cruise ships to chop, mix and disinfect the water before it is released into the sea.

The main factors of the amount of wastewater are:

- number of crew and passengers;
- type of toilets: flush toilets produce a larger amount of wastewater than vacuum toilets;
- the length of the trip;
- the type of treatment: the presence of a sewage treatment plant or a shredding and disinfection system ensures different amounts of waste.

The amount of wastewater produced in the sewage depends on the size of the ship and the technology used [30].

2.3.5. Plastic

Plastic waste can be generated in all types of containers and often originates from domestic provisions and supplies used for shipboard operations.

Plastic waste typically includes sheets, packaging, bottles, cans, synthetic ropes, synthetic fishing nets, plastic trash bags, and empty chemical cans.

Plastics on board can be handled in two ways: they are stored separately (compacted or otherwise) and transported to the PRF, or they can be incinerated, and the ash treated as incinerator ash. Incineration is restricted by MARPOL VI. Regulation 16 prohibits the burning of polyvinyl chloride (PVC) on board ships, except in shipboard incinerators for which an IMO-type approval certificate has been issued in accordance with MEPC.244 [31], [32]. Burning plastics with PCBs is always prohibited.

According to the literature, each person produces 1 kg of solid waste per day, and other sources give an estimate of 3 kg/day for staff members [33]. Maintenance-related solid waste is 11 kg/ship-day for all ships [34].

These estimates are not specific to plastic waste but are on the order of 0.06 - 0.2 m^3 per person per day and 0.7 per day [35].

2.3.6. Food waste

Food waste is generated on all kinds of dishes in the kitchen and/or restaurant. The IMO defines this as any spoiled or intact food material and, including fruit, vegetables, dairy products, poultry, meat products, and food scraps generated on board. However, onboard large ships (cargo and cruise ships), sometimes a distinction is made between soft organic food waste (shells, leftovers, etc.) and hard organic (bone) and packaging (even though the packaging is not food waste according to Annex V of MARPOL). This separation is not based on regulation but comes from practical management on board ships.

Organic food waste can be discharged directly into the sea 12 km from the nearest land or shredded and then discharged into the sea 3 km from the nearest land (12 km in special areas).

Ships that generate a lot of food waste (e.g. cruise ships or work ships) should sometimes be dried to reduce odours and reduce the risk of rotting [36].

Solid organic waste, waste from plates and packages, is collected in bags and bins and disposed of in port reception facilities [37], [38]. In some cases, this is delivered to the household waste category instead of food waste. Regarding the treatment of food waste, we found no difference between cruise ships and normal cargo ships. The exception is that cruise ships usually have galley waste tanks that are emptied under the same regulations as food waste and/or greywater.

2.3.7. Household waste

Household waste is any waste that originates from the domestic spaces on board the vessel and is not food waste, cooking oil or plastic. The IMO defines this as “all other waste generated in the accommodation spaces on board a ship, not covered by another Annex. Household waste does not include greywater. "Household waste is therefore typically paper, cardboard, fluorescent tubes, synthetic material, foil, metal cans, lids, glass, chamber packaging waste and so on. Domestic waste is generated on board by crew and passenger accommodation and is generated on all types of ships. Waste minimization measures are mostly found on cruise ships to reduce the amount generated inland. [39], [40]

2.3.8. Cooking oil

Cooking oil waste is produced on board during food preparation and is produced in most types of ships. In most cases, cooking oil is collected and delivered to the PRF. In some cases, they are burned. On some ships, it was customary to mix cooking oil with sludge and treat it as sludge. However, MEPC 68 decided that this was inconsistent with MARPOL Annex V [32].

Large cruises have a separate tank for storing large-capacity (up to 1000 m3) cooking oil. The used oil is sold in the port, and e.g. biofuel production.

2.3.9. Operational waste

Many different types of waste are classified as 'operational waste'.

Most ships include engine room waste such as oily rags and batteries in this category, but it can also include other waste from ship operations such as old ropes, glassware, wood, washing machines, debris, refrigerators, aerosols, ladders, fireworks and flares, chemical residues, asbestos and paint. Therefore, some of these wastes must be classified as hazardous materials. Some ships also report cargo handling waste in this category, such as wooden pallets, storage materials and rubber gloves.

On other ships, the category is used for other household waste, such as fluorescent lamps, torn work clothes, etc. [19], [41].

2.3.10. Cargo residue

MARPOL Annex V defines cargo residues as “remains of all cargo not covered by other Annexes of the Convention which remain on board or in a hold after loading or unloading, including loading or unloading excess or spillage, whether wet or dry or in washing water, but does not include cargo dust left on deck after sweeping or dust on the outer surface of the ship" [41].

Cargo residues can remain in the corner of the hold or in other places that are not accessible during unloading and are highly dependent on the efficiency and methods of unloading the cargo.

2.3.11. Ozone-depleting substances

MARPOL VI. Its annex defines ozone-depleting substances as controlled substances listed in Annex A, B, C or E of the then-current Montreal Protocol on Substances that Deplete the Ozone Layer, as defined in Article 1(4) of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. The application or interpretation of Annex.

Examples include Halon 1211, Halon 1301, Halon 2402, CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115 [19], [41].

Substances that deplete the ozone layer are used on board ships in air conditioning or refrigeration equipment. They can also be placed in mobile devices (refrigerators, mobile air conditioners).

Equipment containing ozone-depleting substances produces ozone-depleting substances during renovation, but this is likely to be removed by repair companies.

2.3.12. Other uncommon waste streams

Dirty ballast water

Ballast water is carried in ships' ballast tanks to improve stability, balance and equipment. If oil tanks are used to transport ballast water, the water is contaminated with oil and is classified as waste in MARPOL Annex I [26].

It is very rare to produce oily ballast water on board. A likely waste from onboard ballast water operations is when sediment in the ballast water tank needs to be removed during a port state control tank integrity assessment or when the ship needs to treat its ballast water and is unable to do so. Both of these circumstances are very rare, and in such circumstances, the ports are likely to put the ship in touch with specialist waste management contractors.

Animal carcasses

Animal carcasses are the remains of deceased livestock. The discharge of animal carcasses is allowed only outside special areas, as far as possible from the nearest land and on the road. So, the possibility of disposal of animal carcasses is to release them into the sea or transport them to the PRF. If the vessel has adequate storage space on board, a limited amount of carcasses can be stored for a short time before unloading. In case of health and safety threats, it is recommended to release it into the sea, but more than 12 km from the nearest land. Before release into the sea, animal carcasses must be dismembered/shredded or treated to facilitate the sinking or dispersal of the carcasses [41].

Fishing equipment

Fishing equipment waste is generated when fishing equipment wears out and tears beyond repair. It only occurs on fishing boats.

2.4. Heat treatment technologies

Heat treatment technologies are operations that are suitable for transforming waste awaiting disposal into a product or energy with more favourable properties from certain points of view. The main end products of the applied processes are gaseous and solid materials [9].

Heat treatment technologies are usually compared based on their typical reaction conditions. One of the most important reaction conditions is the applied temperature, which provides preliminary information on the impact of the technology on the environment and the costs of the investment. The higher temperature requires the use of special materials, metal alloys and technical ceramics, which leads to a significant increase in costs. The most decisive factors in investment costs are operating temperature and pressure.

The second and most important reaction condition is the excess air factor. This characteristic partly shows the chemical composition and specific quantity of the emitted gas product. In the case of perfect combustion, we must expect a significant air surplus (a surplus of air greater than one), which directly increases the amount of flue gas emitted (containing more air) and indirectly - through the flue gas cleaning system - the investment and operating costs.

The third reaction condition is the operating pressure, which determines the relationship between the reactions. It plays an important role in the chemical composition of the resulting gas product and is a determining factor in investment costs.

The fourth reaction condition involves the type of auxiliary currents. The auxiliary flows can be divided into two groups; on the one hand, we distinguish material flows and on the other energy flows. The auxiliary gas used affects the composition, handling, and physical and chemical properties of the final products obtained.

2.4.1. Basic technologies

Table 1. Typical reaction conditions of thermal treatment technologies

Proceedings	Temperature [°C]	Excess air factor	Operating pressure [bar]	Auxiliary currents
Pyrolysis	300−600(1,600)	$\lambda = 0$ endothermic	$p \leq 1$ bar $p \geq 1$ bar	- nitrogen
Pyrolytic-gassing	800−1,000°C	$0 < \lambda < 0.5$	$p \geq 1$ bar	air, water vapour
Traditional firing	850−1,200°C	$\lambda \geq 1$ $1.1 \leq \lambda \leq 2.5$ exothermic	$p \geq 1$ bar	air, natural gas supplementary heating
Gasification	600−1,600	$\lambda < 1$ $0.5 \leq \lambda \leq 0.8$ is partial oxidation	$1 \leq p \leq 20$ bar	air, water vapour, CO_2 and O_2 mixture, a combination of these
Plasma technology	2,000−6,000	$\lambda = 0.5$ endothermic	$1 \leq p \leq 20$ bar	air, water vapour, CO_2 and O_2 mixture, a combination of these
Reference: Natural gas-powered gas engine torus power plant	600−1,200	$\lambda = 1.8$ exothermic	$p = 1$ bar	air

The basic technologies are all thermal treatment technologies, during which the waste undergoes chemical changes that cause the decomposition of individual components and the evaporation of volatile compounds. The basic technologies differ in their characteristic reaction conditions. In a basic technology, the characteristic chemical reactions are decisive, but different processes can also take place, which influence the composition of the resulting gas product. If the chemical reactions characteristic of different technologies take place to a similar degree within a device, then we are talking about a single-step or process-integrated combined heat treatment technology.

Tables 1. and 2. show the typical reaction conditions of the basic technologies, as well as the final products produced and the type of power plants used. The names of the residues generated after energy production are also indicated in the tables [8], [9], [10], [42], [43], [44].

Table 2. Products of thermal treatment technologies and the used power machines

Proceedings	Emerging product before power machine	Power machine	Eastern end product after power plant
Pyrolysis	pyrogas, pyro oil, pyrocoke	gas engine, gas turbine, diesel engine, steam boiler-steam turbine	flue gas (<5 % combustible), slag, ashes, cinders
Pyrolytic gasification	pyrogas, less pyrocoke and oil		
Traditional firing	fuel, waste [1]	steam boiler steam turbine	
Gasification	synthesis gas, slag, ashes, cinders	gas turbine, gas engine	flue gas (<5 % combustible)
Plasma technology	synthesis gas, glass slag slag	gas turbine, gas engine	
Reference: Natural gas-powered gas engine power plant	natural gas [2]	gas turbine, gas engine	flue gas (<3% CH4 content)

Notes:
[1] is not the product of the technology, but the raw material entering the technology, which is the same for all technologies
[2]at the reference power plant, the fuel is natural gas instead of waste

Traditional combustion

Conventional incineration is a technology that allows simple burning of the amount of energy contained in waste and fuel [45]. During the combustion process, we can utilize the so-called reaction heat released as a result of the chemical reactions taking place, which corresponds to the calorific value of the waste. Combustible materials in the waste are sufficient under appropriate conditions [42]. Waste incineration is a heat-generating, i.e. exothermic, process where the amount of oxygen required for perfect combustion can be provided with a sufficiently high air surplus. During incineration, the organic components of the waste react with the oxygen in the air to form gases and water vapor and leave the flue gas as flue gas [46].

Incombustible inorganic materials, such as ash, slag, and fly ash, usually remain in a solid state [47]. Due to the diversity of waste, different types, chemical compositions and states of materials must be burned, which makes the burning process complex. A number of conditions must be met to achieve perfect oxidation. 29/2014 on the technical requirements, operating conditions and technological emission limit values of waste incineration. FM regulation provides. The decree stipulates strict conditions for the placement of waste incinerators. The regulation covers the temperature and residence time of the flue gas leaving the combustion equipment. In order to satisfy the conditions, the flue gas is led to an afterburner, where the remaining combustible material is burned, so the combustion is completed. The required temperature in the afterburner is usually 850 °C, or in the case of hazardous waste, the temperature 1100 °C can only be reached with the help of a supporting burner. The large amount of secondary air introduced into the chamber mixes with the flue gas in a turbulent flow, resulting in significant heat loss, which is why a heat supply is needed. In order to achieve mixing and burnout, the residence time is a minimum of 2 seconds. For the perfect, soot-free combustion of hydrocarbons and plastics, the residence time of 2 seconds is usually short [42], [43.].

Pyrolysis

Pyrolysis is a process based on the thermal decomposition of organic matter, which takes place with the complete exclusion of oxygen. The treatment of organic waste includes transformation by chemical decomposition under the influence of heat, usually under pressure, usually under pressure [6], [7], [48], [49]. During the treatment, a gaseous energy carrier is released, which is called pyrolysis gas or pyrogas. Pyrogas is a gas mixture rich mainly in carbon monoxide, hydrogen and methane, the heating value of which can be close to that of natural gas. It may also contain energetically inert components, especially carbon dioxide and water vapour [10], [50], [51], [52]. Utilization of gas products in power plants are primarily advisable in a gas turbine or gas-fired systems, which makes it suitable for replacing natural gas-fired power plants [31], [51].

In the solid phase, pyrolysis coke, or coke for short, remains, in which the carbon content of the given waste is enriched [9], [53], [54]. The energy produced in this way can be used to replace coal in ironworks, cement production and coal-fired power plants. In the case of waste contaminated with heavy and light metals, the metals usually remain in the solid phase, so the pyrocoke must be further treated in order to recover it [55]. Pyrolysis, like traditional burning, is one of the heat treatment processes, but we are basically talking about two different processes. Combustion requires three basic things: combustible material, oxidizing material, and heat. In contrast, pyrolysis requires only combustible material and heat [56.]. Pyrolysis is an umbrella term that includes several technologies. The main purpose of a very low temperature (<300 °C) process such as torrefaction is to remove volatile compounds from the fuel and reduce moisture content, thereby increasing the energy density of the remaining solid product.

Gasification

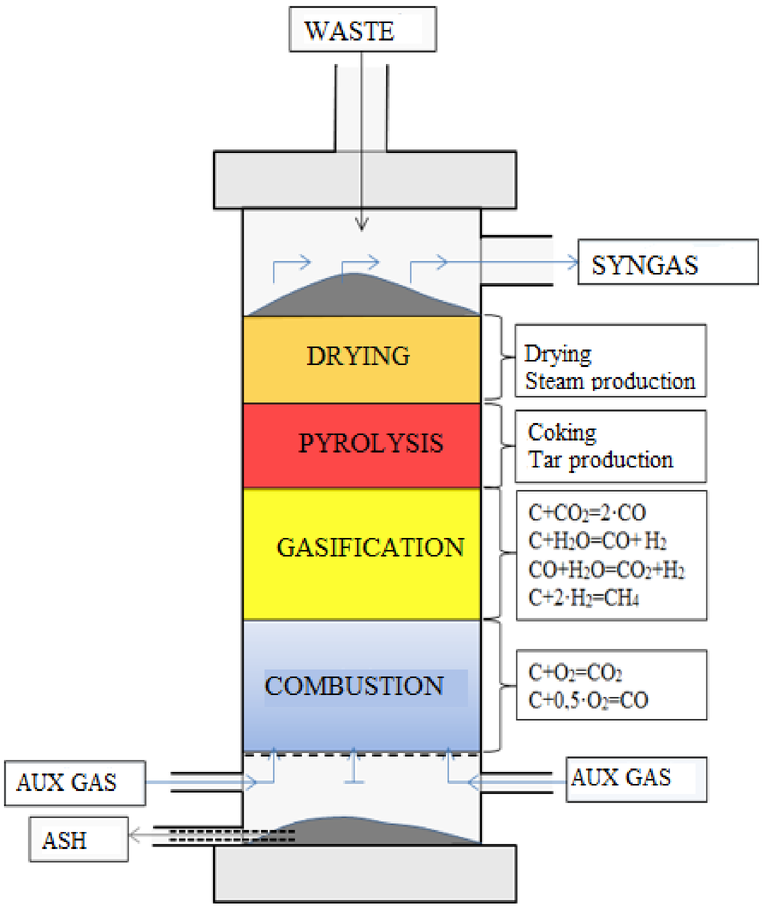

Figure 4. The principle structure of the zones formed in an upper outflow gasification reactor

Gasification is one of the oldest processes for converting solid fossil and renewable energy sources into combustible syngas and liquid fuels. Gasification was first used by Thomas Shirley to produce hydrogen in 1659. The first patent was filed by Robert Gardner in 1788, marking the beginning of the spread of gasification. Gasification is a process based on the rapid thermal decomposition of materials by partial oxidation, which thus requires less oxygen than the theoretical amount of oxygen required for perfect combustion [46]. During the partial oxidation of the organic compounds in the raw material, synthesis gas is released, which can be used either as a raw material, in chemical syntheses or as a fuel [55], [51.]. Due to the sensitivity of the process, it is important that the characteristics of the fed waste (size, moisture content, consistency) remain within certain predetermined limits [43]. The effect of sensitivity is typically manifested in energy and environmental efficiency.

In addition to waste management, the main goal of the process is the highest gas emission, which is accompanied by the achievement of optimal energy efficiency. The synthesis gas produced during gasification is a gas mixture rich in hydrogen and carbon monoxide, which, depending on the gasification medium, may also contain other energetically neutral components. Gasification is not an independent technology, as both pyrolysis and the combustion zone are formed in the reactor designed for this purpose. However, the name is correct because the reactions taking place in the case of thermodynamic equilibrium result in a self-sustaining process, except for radiation losses [6]. The relative location of the zones and the flow direction affect the chemical composition and temperature of the resulting synthesis gas [7], [57]. Figures 4. and 5. illustrate the basic structure of the reactor in two versions [7], [58], [59].

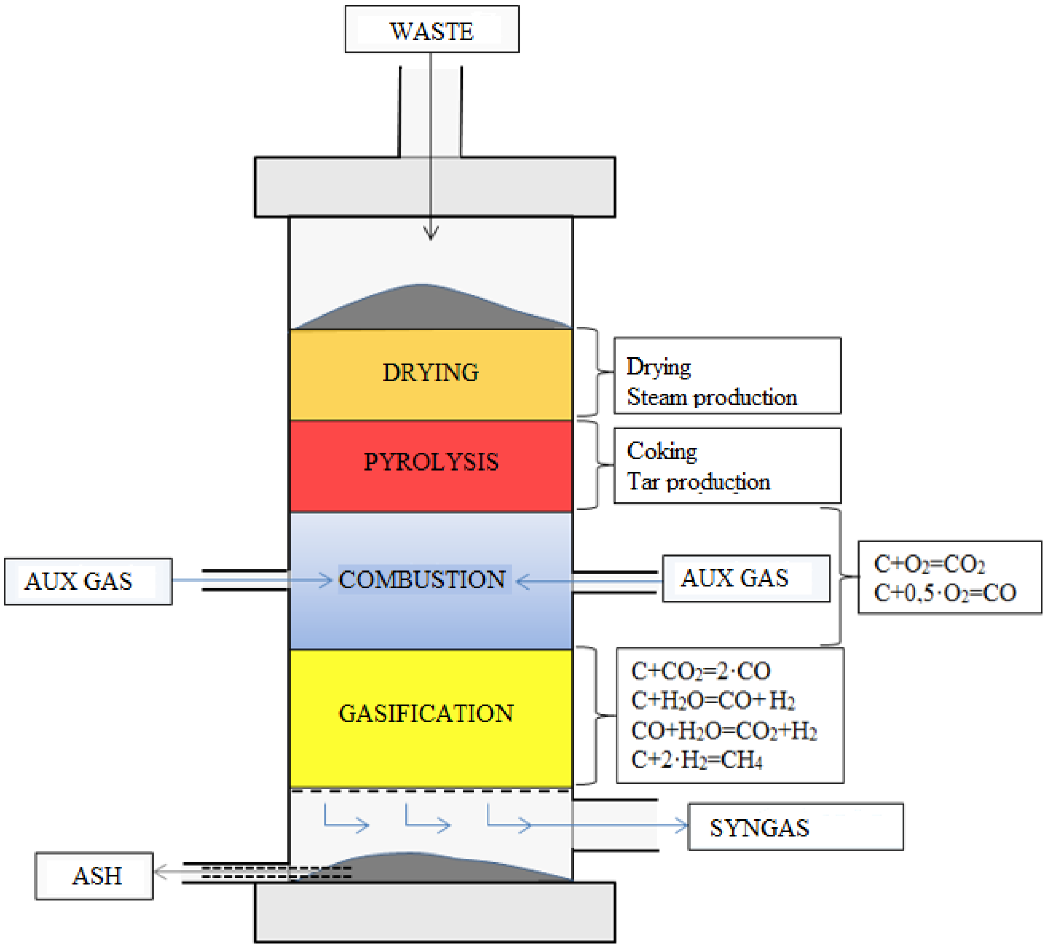

Figure 5. The principle structure of the zones formed in a bottom outflow gasification reactor

Plasma technology

To understand how plasma technology works, it is helpful to first define the concept of plasma. Plasma is an ionized gas formed by a high-current electric arc between electrodes in an inert gas stream. During the process, the charged electrons leaving the cathode excite the atoms and particles in the arc. The excitation causes a light phenomenon called an electric arc. Due to the large flowing currents, the materials enter the plasma state, which can be considered the fourth state [60], due to the high temperature of the arc space. In the case of plasma technologies, the core temperature would normally be between 3000 and 5000°C, but up to 30,000°C could be achieved [60], [61].

The temperature of 5000°C is also a significant problem, as it requires expensive technical ceramics and metal alloys [45]. At this temperature, waste components, such as toxic substances, break down into their components. Above 5000°C, chemicals and toxic gases (dioxins and furans) completely decompose. Substances harmful to the environment are produced only in small quantities or not at all [62]. Although this is a common commercial technology, the process is extremely complex and expensive and requires the involvement of a skilled operator [42], [57]. Figure 6. illustrates the structure and operation of the plasma reactor through the material flows. The reactor provides overcurrent and countercurrent operation.

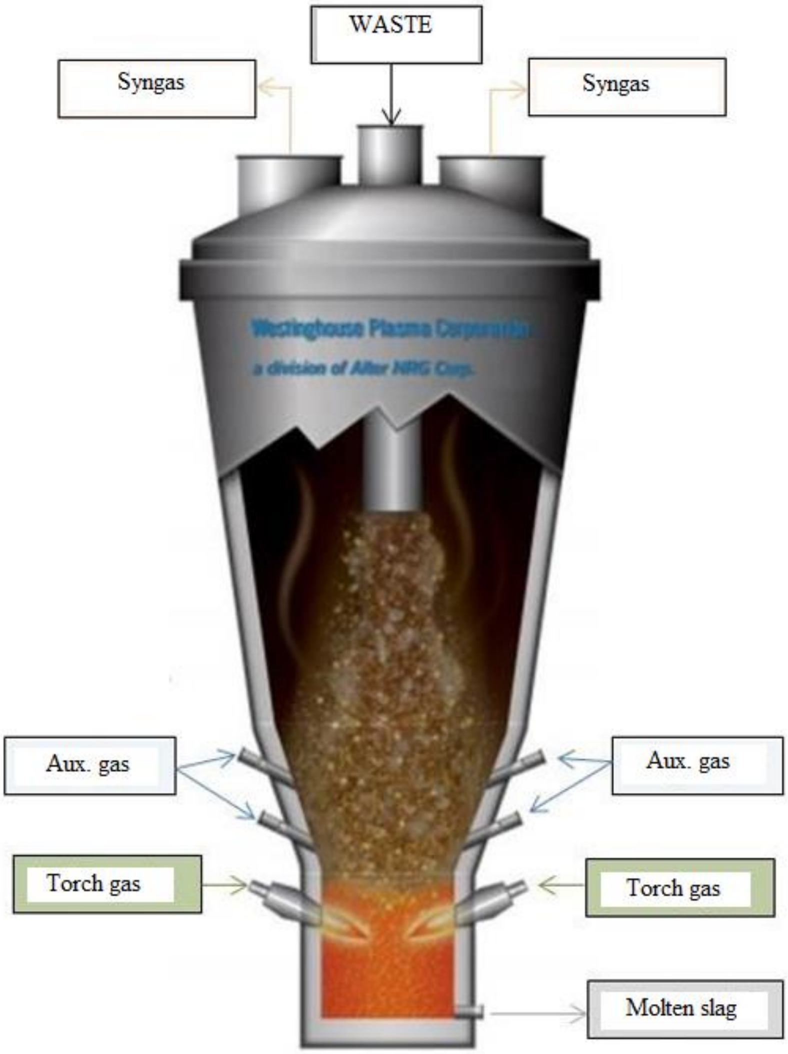

Figure 6. Construction and material flows of a plasma reactor

The operating pressure affects the nature of the reactions taking place and, through this, the composition and calorific value of the synthesis gas produced [31].

1. Disadvantages of plasma technology [9], [10], [62], [63], [64], [65]:
   - In plasma-based processes with lower temperatures (below 2000 ° C), gas purification is more complex and complicated.
   - The most heavily polluted washing water produced during the application of the technology must

also be treated in a complex manner.
- Compared to combustion, there is a greater possibility of the formation of imperfect combustion products that are difficult to decompose.

2. Environmental advantages of plasma technology [9], [10], [62], [63], [64], [65]:
   - It does not require pre-sorting of the waste, so regardless of its composition, it can be sent mixed.
   - Inorganic wastes partially decompose, partially melt and vitrify.
   - Organic materials are completely decomposed.
   - Halogens are chemically bound to the resulting glass and do not dissolve from it.
   - The strong ultraviolet radiation emitted by the plasma accelerates the decomposition of chlorine-containing organic compounds.
   - The ultraviolet radiation generated in the plasma space gets "stuck" in the plasma arc, thereby causing additional excitation, which increases with increasing temperature.
3. Technical and economic advantages of plasma technology [9], [10], [62], [63], [64], [65]:
   - Due to the high temperature, plasma technology can be effectively used to break down all types of waste (dangerous, toxic, deadly).
   - The process takes place in a completely closed space, so no harmful substances enter the environment.
   - The by-products of the process are harmless and can be used as raw materials in the metallurgical and construction industries.
   - The reduction in the amount of waste is 300:1 compared to conventional incineration, where this ratio is only 5:1 (for solid waste) due to the large amount of ash.
   - The maximum daily capacity of plasma technology is up to 500 tons/day.
   - Machines using plasma technology are computer-controlled, silent, and can be stationary or mobile.
   - During the application of plasma technology, impurities entering the slag, such as mercury, cadmium, sulfur, various dioxins and heavy metals, can be significantly reduced by using special washing water, dry washers and filters.

Combined technologies

Combined heat treatment technologies are alternative solutions created by combining basic technologies. The purpose of these technologies is to eliminate the disadvantages of the underlying technologies and combine their advantages. The most common reasons are to reduce investment and operating costs, increase energy efficiency and improve environmental performance.

3. Conclusion

In the study, we summarized the possibilities for the utilization and destruction of waste. In the first part, we studied the utilization and grouping of waste. We examined the legal background and regulations of waste management and disposal, as well as land and settlement regulations (Hungarian and international), as well as maritime and shipping regulations. Afterwards, we studied the disposal of waste and the composition of the waste generated on the ship.

The technology we have designed reduces the moisture content of very mixed waste below 15 m/m%, after which we obtain a material that is easy to handle and suitable for further utilization(s). The utilization, destruction and use of this material can be decided after various chemical analyses. Recyclability and environmental protection are the primary considerations, taking into account the quantities generated on ships. According to our plans, with the technology, we can reduce the amount of hazardous substances produced and increase the recyclability of waste. The project (2019-1.1.1-PIACI-KFI-2019-00320) aimed at the development of a product and technology that complies with current shipping regulations and offers a new and efficient solution for the treatment and disposal of wet waste generated on board ships.

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References

[1] **Barótfi** I., (2000) Környezettechnika, Mezőgazda Kiadó, Budapest, 2000: p. 981.
[2] **Kun-Szabó T**. (1999) A Környezetvédelem minőségmenedzsmentje. (The Quality Management of Environmental Care) Műszaki Könyvkiadó, Magyar Minőség Társaság, Budapest p. 396. ISBN 9789631630480
[3] **Antonio C. Caputo, Pacifico M. Pelagagge** (2002) RDF production plants: I Design and costs. Applied Thermal Engineering 22. pp. 423−437. 2002, https://doi.org/10.1016/S1359-4311(01)00100-4
[4] **Fellner J., Rechberger H**. (2009) Abundance of 14C in biomass fractions of wastes and solid recovered fuels. Waste Management 29. pp. 1495−1503. 2009, https://doi.org/10.1016/j.wasman.2008.11.023
[5] **Basu P**. (2013) Biomass gasification, pyrolysis and torrefaction, Practical design and theory, Second edition, Elsevire, San Diego, 2013. p. 529.
[6] **Szuhi A**. (2009) Új termikus technológiák és hagyományos hulladékégetők. Környezetvédelmi és Vízügyi Minisztérium (New thermal technologies and traditional waste incinerators) 2009. p. 36.
[7] **Red T. B., Das A**. (1988) Handbook of biomass downdraft gasifier engine systems, Solar Energy Research Institute, Colorado, 1988. p. 140.
[8] **Szuhi A**. (2013) Az új termikus technológiák környezeti hatásai (pirolízis, elgázosítás és plazma technológia). Humusz Szövetség és Vidékfejlesztési Minisztérium 2013. p. 14.
[9] **Hornyák M., Bánhidy J., Kovacs E., Kovacs L., Varga P**. (2008) Útmutató az elérhető legjobb technika meghatározásához a hulladékégetők engedélyezése során, Környezetvédelmi és Vízügyi Minisztérium, Budapest 2008. p. 386.
[10] **Büki G**. (2007) Kapcsolt energiatermelés. Műegyetemi Kiadó, Budapest 2007. p. 420.
[11] **Gróf Gy., Könczöl S**. (2008) Gázmotoros kapcsolt hő- és villamosenergia-termelés. Háttértanulmány az üzemeltetési ajánlás kidolgozásához 2008. (Gas engine combined heat and electricity production. Background study for the development of the operating recommendation)
[12] **Committee on Shipborne Wastes**; Marine Board; Commission on Engineering and Technical Systems: National Research Council, 1995. Clean ships clean ports clean oceans: Controlling garbage and plastic wastes at sea. Washington DC: National Academy Press.
[13] **MEPC, 2006**. Resolution MEPC.157(55) Adopted on 13 October 2006: Recommendation on Standards for the Rate of Discharge of Untreated Sewage from Ships, London: The Marine Environment Protection Committee.
[14] **MEPC, 2007**. Prevention of Air Pollution from Ships: Washwater Discharge Criteria for Exhaust Gas-SOx Cleaning Systems, MEPC 56/INF5, London: IMO, Marine Environmental Protection Committee (MEPC)
[15] **MEPC, 2011a**. ANNEX 12: Resolution MEPC.200(62), Adopted on 15 July 2011: Amendments to the annex of the protocol of 1978 relating to the international convention for the prevention of pollution from ships, 1973.
[16] **MEPC 62/24**, London: The Marine Environment Protection Committee (MEPC). MEPC, 2011. ANNEX 12: Resolution MEPC.200(62), Adopted on 15 July 2011: Amendments to the annex of the protocol of 1978 relating to the international convention for the prevention of pollution from ships, 1973. MEPC 62/24, London: The Marine Environment Protection Committee (MEPC).
[17] **MEPC, 2011**. Resolution MEPC 201(62) adopted on 15 July 2011: Amendments to the Annex of the Protocol of 1978 relating to the International Convention for the prevention of pollution from ships, 1973 (Revised MARPOL Annex V), London: International Maritime Organization (IMO).
[18] **IMO, 2006d**. Marpol Consolidation 2006: Annex VI Regulations for the Prevention of Air Pollution from Ships. http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_VI/r12.htm.
[19] **NEA**; PM Group, 2009. Annex 2: Ship Generated Waste Analysis, Zoetermeer: NEA.
[20] **Netherlands Maritime Technology**, 2016. Sustainable Maritime Solutions: Waste. http://sustainable-maritime-solutions.nl/waste/
[21] **HELCOM, 2013**. HELCOM interim guidance on technical and operational aspects of delivery of sewage by passenger ships to port reception facilities: 2013 HELCOM Ministerial Declaration, Helsinki: HELCOM, Baltic Marine Environment Protection Commission.
[22] **HELCOM, 2015**. Baltic Sea Sewage Port Reception Facilities: *HELCOM Overview 2014, Revised*

Second Edition, Helsinki: HELCOM, Baltic Marine Environment Protection Commission.

[23] **HPTI, 2007**. Study on Ships producing reduced quantities of ships generated waste: present situation and future opportunities to encourage the development of cleaner ships, Lissabon: European Maritime Safety Agency (EMSA), Unit D – Implementation EU maritime legislation.

[24] **MEPC, 2016**. ANNEX 9 (Adopted on 22 April 2016): Amendments to the Annex of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto Amendments to MARPOL Annex IV, Resolution MEPC. 274(69), London: The Marine Environment Protection Committee (MEPC).

[25] **IMO, 1983**. Annex I- Regulations for the Prevention of Pollution by Oil: Chapter 4, Part B, Regulations 33: Crude oil washing requirements, London: IMO.

[26] **IMO, 2006a**. Marpol Consolidation 2006: Annex I- Regulations for the Prevention of Pollution by Oil. [Online]http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_I/index.htm

[27] **MEPC, 2012**. Annex 24: Resolution MEPC.219(63) : Guidelines for the Implementation of MARPOL Annex V.
www.imo.org/en/OurWork/environment/pollutionprevention/garbage/documents/219(63).pdf.

[28] **Handson tv/e, 2004**. Fishing for Litter – Denmark. [Online] http://handson.tve.org/series-5/green-current/fishing-litter-denmark/.

[29] **MEPC, 2015**. Report of the Marine Environment Protection Committee on its sixty-eighth Session, MEPC 68/21, London: International Maritime Organization (IMO), Marine Environment Protection Committee (MEPC).

[30] **Mountouris A., Voutsas E., Tassios D**. (2006) Solid waste plasma gasification: equilibrium model development and exergy analysis. Energy Conversion and Management. Vol. 47. 2006. pp. 1723−1737.

[31] **MEPC, 2014**. Resolution MEPC.244(66) Adopted on 4 April 2014: The 2014 Standard specification for shipboard incinerators, London: The Marine Environment Protection Committee (MEPC).

[32] **ASCI, 2000**. Alaska Cruise Ship Initiative Part I Final Report: Activities and Workproducts up to June 1, 2000, sl: Alaska Cruise Ship Initiative (ASCI).

[33] **Mohammed J., Torres R., Obenshain E**. (1998) Waste Reduction at Sea: Pollution prevention Strategies on Miami-Based Cruise Lines, Ann Arbor: National Pollution Prevention Center for Higher Education, University of Michigan.

[34] **Brandstoftafel scheepvaart**, 2014. Visie Duurzame Brandstoffenmix: Dealrapport Brandstoftafel scheepvaart, sl: Brandstoftafel scheepvaart

[35] **TEN ECOPORT**, 2014. Common Action Plan for ship-generated waste Ports of Bari and Durres, sl: Transnational Enhancement of ECOPORT8 network (TEN ECOPORT)

[36] **MMPA, 2012**. Ship-generated waste management plan at the maritime port of Dudinka. Dudinka: Murmansk Maritime Port Administration (MMPA), Dudinskiy Branch.

[37] **Environmental Board**, 2015. Ship-generated waste and cargo residues reception and handling plan, Tallinn: Environmental Board of Port of Tallinn

[38] **IMO, 2006b**. Marpol Consolidation 2006: Annex IV- Regulations for the Prevention of Pollution by Sewage from Ships.
http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_IV/index.htm.

[39] **IMO, 2006c**. Marpol Consolidation 2006: Annex V- Regulations for the Prevention of Pollution by Garbage from
Ships.http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_V/index.htm

[40] **IMO, 2008**. 2008 Revised Guidelines for Systems for handling Oily Wastes in Machinery spaces of Ships incorporating Guidance Notes for an Integrated Bilge Water Treatment System (IBTS), MEPC.1/Circ.642, London: International Maritime Organization (IMO).

[41] **Csőke B**. (2011) Hulladékgazdálkodás (Waste management), Pannon Egyetem – Környezetmérnöki Intézet, 2. javított kiadás, 2nd revised edition, Veszprém, 2011. p. 699.

[42] **Örvös M**. (2011) Disposal with thermal processes. Educational aid BME, 2011. p. 31IMO, 2006d. Marpol Consolidation 2006: Annex VI Regulations for the Prevention of Air Pollution from Ships. http://www.marpoltraining.com/MMSKOREAN/MARPOL/Annex_VI/r12.htm

[43] **Mannheim V**. (2010) Thermal treatment of organic chemical industrial waste with plasma technology. Energy management. Budapest, 2010. 51st year. No. 3 p. 21−23.

[44] **Murphy JD, Mckeogh E**.: Technical, economic and environmental analysis of energy production from municipal solid waste. Renewable Energy 29. pp. 1043−1057. 2004.
[45] **Woodhead Publishing**, Philadelphia, USA, 2013. p. 234.
[46] **Young G. C**. (2010) Municipal solid waste to energy conversion processes: Economic, technical, and renewable comparisons. John Wiley & Sons, Inc., New Jersey. 2010 p. 398
[47] **V. Madár, A. Betovics, L. Tóth**: Production and Production-Increasing Factors of Biochar, Hungarian Agricultural Engineering No 42/2023 14-25.
[48] **Korzenszky P.; Lányi K.; Simándi P.**, (2015) Test Results of a Pyrolysis Pilot Plant in Hungary Hungarian Agricultural Engineering 2015: 28 pp. 48-52, 5 p.
[49] **Lányi K., Molnar E., Vanó I., Korzenszky P.** (2014) Looking Behind The Process of Pyrolysis in Waste Management: Questions on The Composition and Quality of End-Product and Their Answers by Meas of Analytical Chemistry, Hungarian Agricultural Engineering 26 pp. 25-28, 4 p.
[50] **Virág S, Montvajszki M, Korzenszky P.** (2015) Thermal waste treatment procedures, 295 p. Szarvas, 2015. Project TÁMOP-4.2.2.A-11/1/KONV-2012-0015: Basic research and development at the Pyrolysis Technology Center of Szent István University.
[51] **Korzenszky P., Simándi, P.** (2015) Results of a thermolysis pilot plant in Hungary, In: Futó, Zoltán (ed.) The latest development possibilities of waste management, Szarvas, Hungary: Szent István University Faculty of Economics, Agriculture and Health 126 p. pp. 22-30, 9 p.m.
[52] **Korzenszky P., Puskás J., Mozsgai, K., Lányi K., Mák Z.,** (2014) Innovation possibilities of a thermolysis plant to be established in Hungary, In: Marianne, Bell (ed.) 20th International Symposium on Analytical & Applied Pyrolysis: Birmingham Pyro2014, Paper: B143.
[53] **Bártfai Z., Korzenszky P., Szalkai I.** (2019) Preprocess Variations of Plastic Waste Recycling, In: Magó L., Kurják Z. (ed.) SYNERGY - Engineering, Agriculture and Green Industry Innovation: ABSTRACTS of the VI. International Conference of CIGR Hungarian National Committee and the Szent István University, Faculty of Mechanical Engineering and the XXXIX. R&D Conference of Hungarian Academy of Sciences, Committee of Agricultural and Biosystems Engineering, Gödöllő, Hungary, 4 – 6 November 2019. Gödöllő, Hungary: Szent István University Faculty of Mechanical Engineering 96 pp 36, 1 p.
[54] **Hill T., Dowen S**. (2010) Pyrolysis and gasification. Briefing (Draft 2), UK Without Incineration Network (UK WIN), 2010. pp. 1-9.
[55] **Helsen L., Bosmans A**. (2010) Waste-to-Energy through thermochemical processes: matching waste with process. Proceedings of the International Academic Symposium on Enhanced Landfill Mining, Houthalen-Helchtern, Belgium, pp. 133−180. 2010.
[56] **Huang H., Tang L**. (2007) Treatment of organic waste using thermal plasma pyrolysis technology. Energy Conversion and Management 48. pp. 1331−1337. 2007
[57] **Rajvanshi K. A**. (1986) Biomass gasification. Alternative Energy in Agriculture. Vol. 2. No. 4. 1986. pp. 83−102
[58] **Schuster G., Löffer G., Weigel K., Hobfauer H**. (2001) Biomass steam gasification – an extensive parametric modeling study. Bioresource Technology. Vol. 77. 2001. pp. 71−79,
[59] **Lee S., Speight J. G., Loyalka S. K**. (2015) Handbook of alternative fuel technologies. Taylor & Francis, 2015. p. 686.
[60] **Klinghoffer N. B., Castaldi M. J**. (2013) Waste to energy conversion technology, Woodhead Publishing, pp. 3-14., https://doi.org/10.1533/9780857096364.1.3.
[61] **Mountouris A., Voutsas E., Tassios D**. (2008) Plasma gasification of sewage sludge: Process development and energy optimization. Energy Conversion and Management 2008 49. pp. 2264−2271.
[62] **Szépvölgyi J**. (2000) Transformation of substances in high-temperature plasmas. Instrumentation and Measurement Technology Bulletins. 2000 (vol. 36) No. 65 p. 4
[63] **Morly C**. (2005) Method for calculating equilibrium compositions at specified temperature. Gaseq, the chemical equilibrium program for windows 2005 p. 6. www.gaseq.co.uk
[64] **Corti A., Lombardi L**. (2004) Biomass integrated gasification combined cycle with reduced CO2 emission: Performance analysis and life cycle assessment (LCA). Energy, Vol. 29. 2004. pp. 2109−2124.