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ENERGY EFFICIENCY ANALYSIS OF THE BASIC AND THE COMBINED THERMIC TREATMENT PROCESSES

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Abstract: The current paper presents the energy efficiency analysis of the Basic and Combined Thermic Treatment Processes. The calculation method of energy efficiency of Waste to Energy Technology is defined by the R 1 formula. This formula shall be applied according to the reference document on Best Available Techniques for waste incineration (2008/98/EC). It is also characterized by the energy conversion efficiency, the change of energy, and electricity intensity indicators.
Keywords: Basic and Combined Thermic Treatment Processes, Waste to Energy, Energy Conversion Efficiency, Energy Generation, Change of Energy Intensity

1. INTRODUCTION

Nowadays the Waste Management is a popular topic worldwide. The eco-friendly treatment of the Municipal Solid Waste (MSW) and the Industrial Solid Waste (ISW) is the centrally theme among the experts, too. Is recycling or thermic treatment with energy generation the real solution of the treatment of the continuously reproducing wastes? This question is frequently asked for years. According to the scientists the recycling is the correct solution, but there are many preconditions. For example the selective waste collection, which is not solved in case of some countries? In these counties the best solution is the thermic treatment processes primarily with energy generation. We can efficiently generate energy out of waste with Combined Heat and Power (CHP) technologies. For this task a gas engine set or a gas turbine is the most popular method.

2. BASIC AND COMBINED THERMIC TREATMENT PROCESSES

The Thermic Treatment Processes (TTP) can be classified into two categories: the Basic Thermic Treatment Processes (BTTP); and the Combined Thermic Treatment Processes (CTTP) (Table 1). The basic technologies which are the most common in these processes are the conventional incineration, the pyrolysis, the gasification, and the plasma technology. The difference between the new technologies and the traditional incineration processes is that using modern techniques chemical energy is recovered from the waste. The derived chemical products may be used as feedstock for other processes or as secondary fuel in some cases. The waste is converted into secondary energy source (a combustible liquid, gas or solid fuel), while it is utilised in a steam turbine, gas turbine or in a gas engine in order to produce heat and/or electricity. The calorific value of the synthesis gas is lower than the same property of the natural gas.

Table 1. Thermic Treatment Processes categories

<table>
<tr><th colspan="3">Thermic Treatment Processes</th></tr>
<tr><th rowspan="2">Basic</th><th colspan="2">Combined</th></tr>
<tr><th>Process Integration (One Step)</th><th>Technology Integration (Two Step)</th></tr>
<tr><td>Conventional Incineration
Pyrolysis
Gasification
Plasma technology</td><td>Pyrolysis and Conventional Incineration
Gasification and Conventional Incineration
Plasma-gasification</td><td>First Technology: Pyrolysis
Second Technology: Plasma technology or Gasification or Conventional Incineration</td></tr>
</table>

Typically, the residual components of the waste are incinerated producing electricity at an efficiency of about 20% and thermal product of about 55%. Applying gasification the efficiency of the electricity production is nearly 34%; this would suggest that gasification of the residual components of waste is more advantageous than incineration. Market for thermal product does not exist. Gasification produces more electricity than incineration, requires smaller gate fee than incineration and when thermal product is not utilised generates less greenhouse gas per kWh than incineration. The previously mentioned technology is, however, not proven at commercial scale but primarily better electrical output compared with incineration. On the other hand in large-scale systems combined cycle gas turbines or gas engines are used, which increase this value, but reduce the temperature of the residual heat in the steam. Thus thermal energy production is significantly lower than that produced by incineration. Gasification is primarily concerned with electricity production [1].

Table 2. The technologies and the data of the tested

Tested technology	T [°C]	Oxidation factor	Atmosphere	Product	Engine
Pyrolysis	500 1200	λ = 0 endothermic	-	pyrolysis- gas, coke and oil	gas engine, steam turbine
Pyrolysis and Conventional Incineration (One Step)	500-850	λ = 0 - 1.5	- air	pyrolysis- gas, coke and oil, End Product: flue gas (<5% burnable), slag and ash	steam turbine
Pyrolysis and Conventional Incineration (Two Step)	500 850	λ = 0 λ = 1.5	- air	pyrolysis- gas, coke and oil; flue gas (<5% burnable), slag and ash	gas engine, steam turbine
Gasification and Conventional Incineration (One Step)	650-850	λ = 0.5 λ = 1.5	air	synthesis gas, End Product: flue gas (<5% burnable), slag and ash	steam turbine
Pyrolysis and Plasma technology (Two Step)	500 3000	λ = 0 λ = 0.5	- steam	pyrolysis- gas, coke and oil; synthesis gas, vitreous slag	gas engine
Conventional Incineration	1150	λ = 1.5 exothermic	natural gas additional firing, air	flue gas (<5% burnable), slag and ash	steam turbine
Gasification	1200	λ = 0.55 partial oxidation	case 1: air case 2: steam	synthesis gas, slag and ash	gas engine
Plasma pyrolysis (One Step)	2000	λ = 0 endothermic	-	pyrolysis- gas, coke and oil	gas engine, steam turbine
Plasma-gasification (One Step)	2000	λ = 0.5 partial oxidation	case 1: air case 2: steam	synthesis gas, vitreous slag	gas engine
Plasma technology	3000	λ = 0.5 partial oxidation	case 1: air case 2: steam	synthesis gas, vitreous slag	gas engine
Natural- and Biogas in cogeneration	650	λ = 1.8 exothermic	air	flue gas (<3% CH_4 content)	gas engine

The plasma-gasification process has been demonstrated in many of the most recent studies as one of the most effective and environmentally friendly methods for waste treatment, and energy utilization. Plasma-gasification is an advanced technology, and environmentally friendly process, disposing solid wastes and converting them into commercially usable products. It is a non-incineration thermic process that uses extremely high temperatures in an oxygen starved environment in order to decompose the input waste material into very simple molecules. The main product of this process is a gas, known as synthesis gas, which can be used, among others, in the production of energy and as an inert vitreous by product material, known as slag. Furthermore, it consistently exhibits much lower environmental levels for both air emissions and slag leachate toxicity than competing technologies like incineration. Plasma- gasification uses an external energy source, thus resulting combustion of the waste material in low ranges. As a result, most of the carbon is converted into fuel gas. Plasma-gasification is the closest technology available for pure gasification; it is a "true gasification". Because of the high temperatures involved, all the tars, char and dioxins are broken down. The ending product gas from the reactor is cleaner, and besides there is no ash at the bottom of the reactor. Plasma-gasification is an environmentally sound process which has a great potential to convert an organic-content material into electricity which is more efficient than conventional combustion, for instance gasification or pyrolysis systems. This technology is examined here for the treatment of waste with a view of producing the highest possible amount of electrical energy. A particularized and a well-documented energy analysis is even more necessary for those cases where a subsystem of an integrated plasma-gasification process is characterized as a high energy consumer [2]. Plasma-gasification produces electricity at an efficiency of about 32%.

Thermic plasma-pyrolysis can be described as reaction of a carbonaceous solid with limited amount of oxygen at high temperature which produces gas and solid products. In the highly reactive plasma zone, there is a large fraction of electrons, ions and excited molecules together with the high energy radiation. When carbonaceous particles are injected into the plasma, they are heated rapidly by the plasma; and the volatile matter is released and cracked giving rise to hydrogen and light hydrocarbons such as methane and acetylene. Water/steam could be effectively used as an additional material to promote the production of syngas (H_2 and CO) production. High temperature combined with the high heating rate of the plasma results in the destruction of organic waste, giving rise to a gas and a solid residue with varied properties depending on the feed characteristics and operating conditions. Plasma-pyrolysis methods have previously been used in the production of carbon black and coal gasification [3]. The effectiveness of the electricity production of the plasma-pyrolysis is about 32%.

3. ENERGY EFFICIENCY INDICATORS OF THE TESTED TECHNOLOGY

Energy efficiency now has an important place in the public policy agenda of the most developed countries. The importance of energy efficiency as a policy objective is linked to commercial, industrial competitiveness and energy security benefits, as well as increasingly to environmental benefits, such as reducing CO_2 emissions [4]. Energy conversion efficiency is not defined uniquely, but instead it depends on the usefulness of the output parameters. All or part of the heat which is produced from the combustion of the fuel may become a rejected waste heat if, for example, work is the desired output from the thermodynamic cycle. The energy converter is an example of an energy transformation. Generally, the efficiency of the energy conversion is a dimensionless number between 0 and 1.0, or 0 to 100 %. Efficiencies may not exceed 100%. Talking about the efficiency of heat engines and power stations a convention should be stated such as HHV (High Heating Value) if gross output (at the generator terminals) or LCV (Low Heating Value), whether net output (at the power station fence) is being considered. These two types are separated but both must be stated. In contrast to the energy efficiency, the energy generation has a unit. The net energy generation shows the value of waste which can be produced from useful energy. Accordingly, the unit of the net energy is similar to the net calorific value of waste, but these two types of energies are distinguished. The rate of this energy is influenced mainly by the used auxiliary gas (atmosphere), and by the oxidation factor, and secondly by the net energy efficiency.

The calculation method of the energy efficiency of Waste to Energy Technology is defined by the R 1 formula. This formula shall be applied according to the reference document on Best Available Techniques for waste incineration (2008/98/EC).

R 1 formula for determining the energy efficiency (the waste used principally as a fuel or as other means to generate energy) [5]:

$$\eta_n = \frac{E_p - (E_f + E_i)}{0.97 \cdot (E_w + E_f)} \qquad (1)$$

in which: E_p: the annually produced energy as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 and heat produced for commercial uses multiplied by 1.1 (GJ/year), E_f: the annually input energy to the system from fuels contributing to the production of steam (GJ/year), E_w: the annually contained energy in the treated waste which is calculated using the net calorific value of the waste (GJ/year), E_i: the annually imported energy excluding E_w and E_f (GJ/year) and 0.97 is a factor accounting for energy losses due to the bottom ash and radiation.

The criterion includes incineration facilities dedicated to the processing of municipal solid waste only where their energy efficiency is equal to or above:

» 0.60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009,

» 0.65 for installations permitted after 31 December 2008.

It is also characterized by the energy efficiency, the change of energy, and electricity intensity indicators. The change of the energy intensity shows that the technology can be much more useful in producing energy than conventional incineration. If the rate is positive, we can produce more, otherwise, we can produce less energy per kg waste. Similarly, the change of electricity indicates the change of the quantity of the electricity produced [6]. The results are shown in Figure 1-4 and Table 3-4.

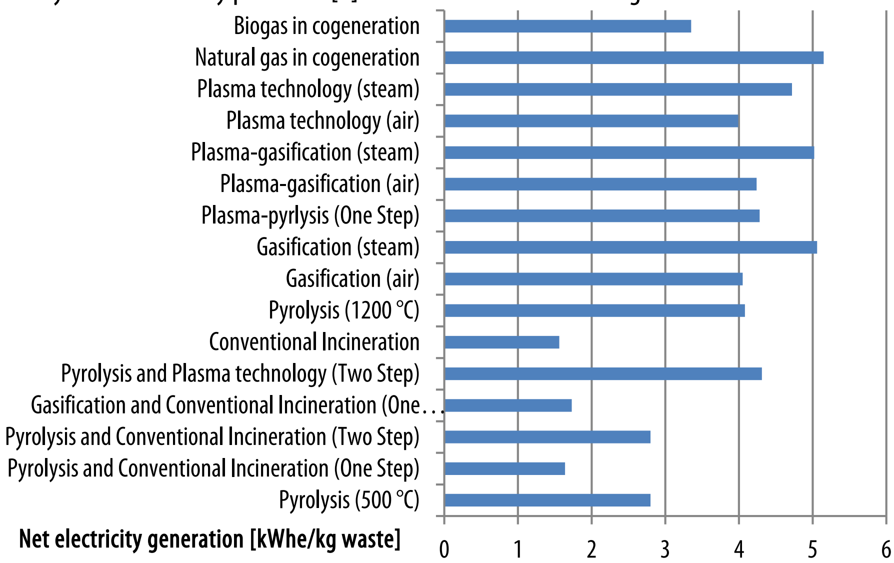

Figure 1. Net electricity generation

According to the results it can be said that the most significant figures were achieved by the gasification technologies in steam atmosphere. The gasification shows the best net energy efficiency (83.68%). With constant net electric efficiency (34.96%), net electricity generation is 5.06 kWh_e/kg_{waste} in steam atmosphere, and it is only 4.05 kWh_e/kg_{waste} in air atmosphere. The net energy efficiency of the pyrolysis and the gasification is below that of the natural gas. The most unfavourable net energy efficiency is observed by the plasma technology (73.05%) [7].

Table 3. Electricity and thermal energy efficiency

Tested Technology	Electricity		Thermal energy	
	$e_{n\,e}$ [kWh_e/kg_{waste}]	$\eta_{n\,e}$ [%]	$e_{n\,th}$ [kWh_{th}/kg_{waste}]	$\eta_{n\,th}$ [%]
Pyrolysis (500 °C)	2.80	27.60	5.63	55.50
Pyrolysis and Conventional Incineration (One Step)	1.64	15.71	6.87	65.77
Pyrolysis and Conventional Incineration (Two Step)	2.80	27.60	5.63	55.50
Gasification and Conventional Incineration (One Step)	1.73	16.56	6.89	65.89
Pyrolysis and Plasma technology (Two Step)	4.31	30.63	6.42	45.55
Conventional Incineration	1.56	14.93	6.81	65.17
Pyrolysis (1200 °C)	4.08	34.12	5.83	48.72
Gasification (air)	4.05	34.96	5.64	48.72
Gasification (steam)	5.06	34.96	7.04	48.72
Plasma-pyrolysis (One Step)	4.28	31.38	6.24	45.68
Plasma-gasification (air)	4.24	31.78	6.05	45.33
Plasma-gasification (steam)	5.02	31.78	7.17	45.33
Plasma technology (air)	3.99	28.31	6.30	44.74
Plasma technology (steam)	4.72	28.31	7.47	44.74
Natural gas in cogeneration	5.15*	36.80	6.26**	44.70
Biogas in cogeneration	3.35	33.71	4.39	44.16

Comments: *measure: $kWh_e/kg_{natural\ gas}$; **measure: $kWh_{th}/kg_{natural\ gas}$, in which: $e_{n\,e}$: net electricity generation, $e_{n\,th}$: net thermal energy generation, $\eta_{n\,e}$: net electric efficiency, $\eta_{n\,th}$: net thermal efficiency;

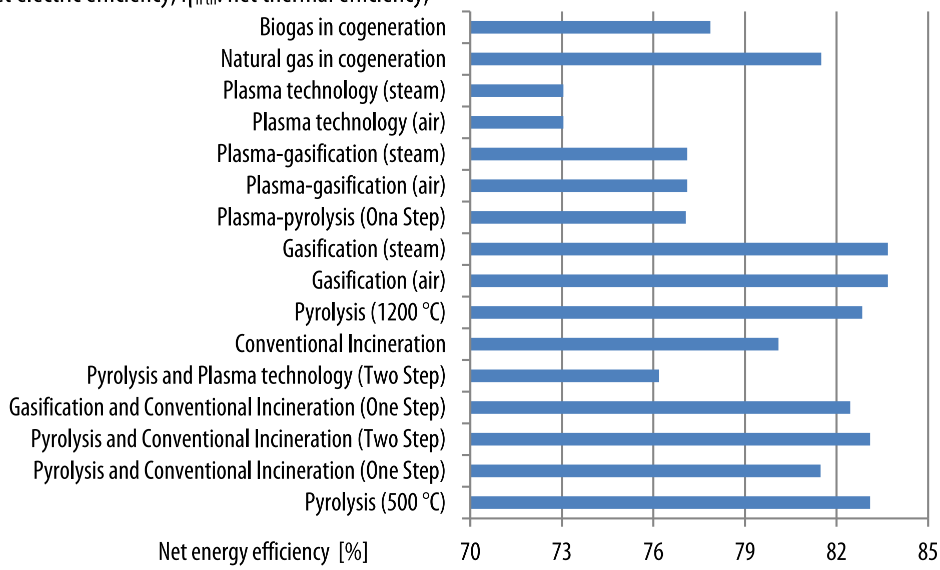

Figure 2. Net energy efficiency

Table 4. Energy parameters of the thermic treatment process

Tested Technology	e_n [kWh/kg_{waste}]	η_n [%]	$\Delta\ e_{n\,\%}$ [%]	$\Delta\ e_{n\,e\,\%}$ [%]
Pyrolysis (500 °C)	8.44	83.10	0.84	79.49
Pyrolysis and Conventional Incineration (One Step)	8.51	81.48	1.67	5.13
Pyrolysis and Conventional Incineration (Two Step)	8.43	83.10	0.72	79.49
Gasification and Conventional Incineration (One Step)	8.62	82.45	2.99	10.90
Pyrolysis and Plasma technology (Two Step)	10.73	76.18	28.20	176.55
Conventional Incineration	8.37	80.10	-	-
Pyrolysis (1200 °C)	9.91	82.84	18.40	161.65
Gasification (air)	9.69	83.68	15.77	159.51
Gasification (steam)	12.10	83.68	44.56	224.05
Plasma-pyrolysis (One Step)	10.52	77.06	25.69	174.36
Plasma-gasification (air)	10.29	77.11	22.94	171.85
Plasma-gasification (steam)	12.19	77.11	45.64	222.05
Plasma technology (air)	10.29	73.05	22.92	155.63
Plasma technology (steam)	12.19	73.05	45.64	202.83
Natural gas in cogeneration	11.41*	81.50	-	-
Biogas in cogeneration	7.74	77.87	-7.53	114.74

Comments: *measure: $kWh/kg_{natural\ gas}$, in which: e_n: net energy generation (proportional net caloric value of synthesis gas), η_n: net energy efficiency, $\Delta\ e_{n\,\%}$: change of energy intensity, $\Delta\ e_{n\,e\,\%}$: change of electricity intensity

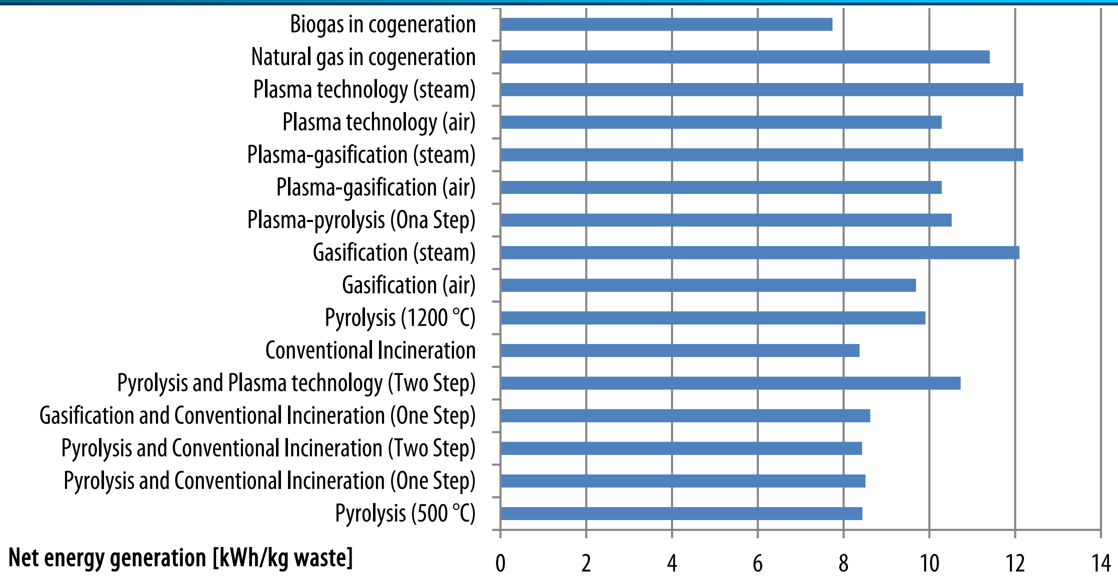

Figure 3. Net energy generation

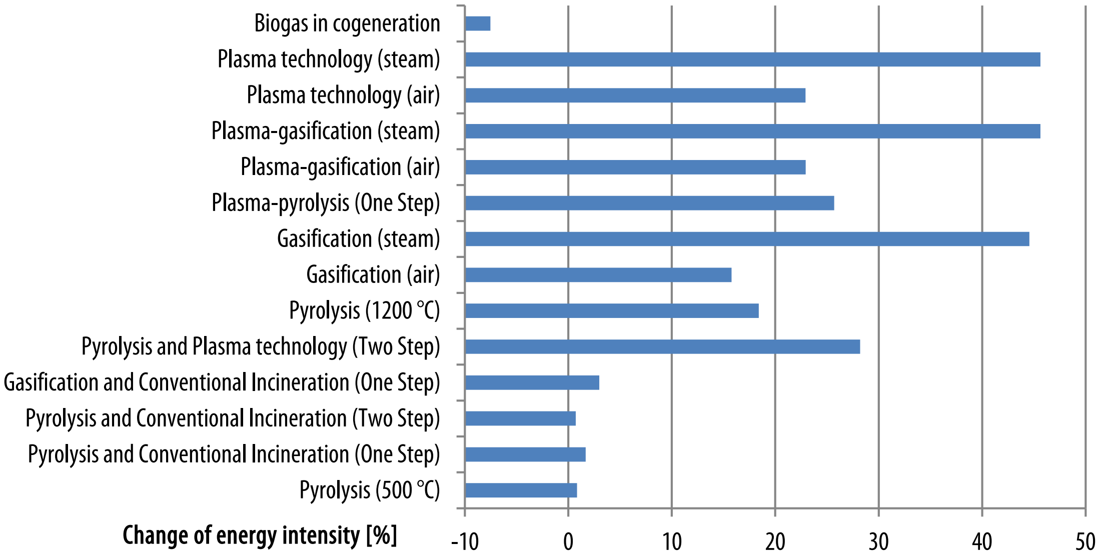

Figure 4. Change of energy intensity

4. CONCLUSION

The technology with the smallest net electric and energy efficiency is the plasma technology. In order to be able to raise the net efficiency the process has combined with gasification in one-step (plasma- gasification). Using this modification the net energy efficiency and the energy generation have increased. My goal for the future is to develop this technology further and to find, analyse and design new technologies. The most significant figure in the change of the energy intensity was achieved by the plasma technology with steam, and by the plasma-gasification with steam (45.64%). The most unfavourable rate is observed by the biogas in cogeneration (-7.53%). The best rate of the change of the electricity intensity was achieved by the gasification with steam (224.05%). I would like to analyse these technologies with Life Cycle Assessment, and with Lice Cycle Coast Assessment.

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