Safety Based Comparison Of Incineration And Gasification Technologies For Electrical Energy Production By Municipal Solid Waste In Bulgaria

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***Abstract*— This paper objective is to present the advantages and disadvantages of operating municipal solid waste (MSW) plants for the production of electricity in Bulgaria. The two most commonly used technologies are compared – direct combustion in a steam cycle combustion plant and thermal gasification with subsequent combustion of syngas in a gas turbine and secondary steam cycle generation. Tertiary organic cycle generation has not been considered since its energy benefits are too low. The focus is on the safety and environmental risks of both technologies. The specific risks and dangerous factors in the different technological processes from the preparation of the raw material to the cleaning of the final products of combustion are defined. In order to minimize the risks, especially in the case of gasification, technical and organizational measures have been formulated.**

Keywords — MSW, combustion, gasification, electricity production, explosion, fire, poisoning, human health, ecology, Bulgaria.

I. Introduction

The problem of municipal solid waste (MSW) in urban areas, affordable waste from agriculture and forestry, and the desire to implement cost-effective and environmentally friendly renewable energy sources (RES) for electricity generation are key drivers for experimental research and development of biomass and MSW gasification technologies in economically developed countries. This paper extends the scope of the topic on the safety of biomass for energy use in Bulgaria, discussed in [5] with a view to expanding the technological, economic and environmental potential of technologies by covering the vast amount of MSW available in Bulgaria. Regulatory requirements for environmental protection (EP) limiting the disposal of MSW and the available opportunities for subsidizing modern processing technologies are an additional impetus, despite serious problems in the construction and operation of such commercial installations, and the reported numerous operational accidents [1]. The continued sustainable increase in the price of fossil fuels and carbon emissions cannot also be overlooked as an economic factor. The problem of MSW disposal is particularly acute in Bulgaria, experience in the operation of incineration plants is scarce, and there is virtually no experience with gasification installation.

II. Comparison of Direct Combustion and Thermal Gasification as Technologies for MSW Treatment Processing

The oldest and most widespread technology of MSW treatment is direct incineration in incinerators at temperatures above 1000^{0}C in high oxygen environment, often in conjunction with mineral fuels - natural gas, fuel oil or coal (co-incineration).

The electricity generation from MSW is based on the classic steam cycle (Rankin cycle), Fig. 1 with electrical efficiency up to just over 30%, [2] or co-generation cycle.

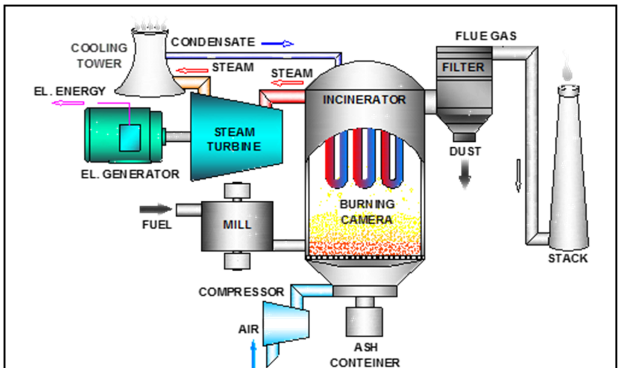

Fig. 1

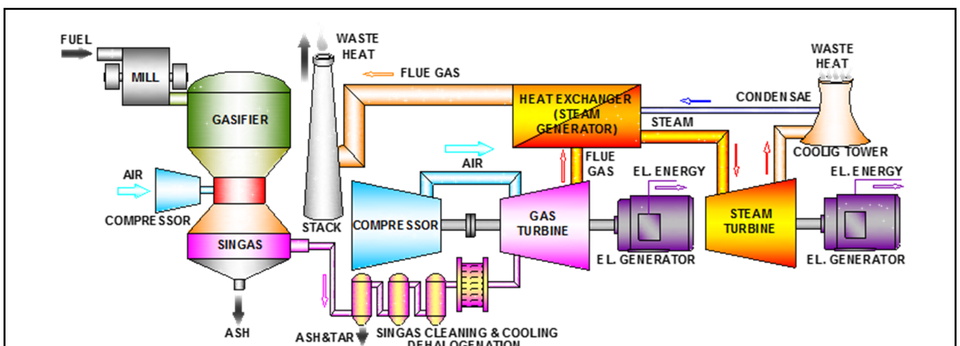

Fig. 2

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Thermal gasification of MSW is a newer technology, but it also has a long history. It has been popularized in recent decades as "Advanced Conversion Technology" (ACT), although the sector has qualified as a dangerous industry, with real risks to the health and life of operating personnel, nearby populations and negative impacts on the environment [1].

The MSW gasification and utilization of the byproduct – synthetic gas (syngas) for electricity production by the Integrated Gasification Combined Cycle (IGCC) technology, Fig. 2, enables to achieve much higher electrical efficiency - up to about 50 %, [2].

Therefore, nowadays it is much more promising, but in view of the production, processing, transportation and storage of syngas, which is poisonous and explosive, supposed significantly higher risks to safety and the environment.

Technological problems in the operation of commercial installations for thermal gasification of MSW are explained by the physical and chemical heterogeneity of the raw material and the deviations in the modes of operation of the installations. The quantity and the ratio of ingredients in the mixture of byproducts, leading to potential risks of explosions and leakage of toxic substances [3]. In thermal gasification, MSW is heated in a gasifier in an oxygen deficient environment to decompose to a complex mixture, Table 1, [1], [2], [3].

TABLE I. MSW DECOMPOSITION MIXTURE

	MSW decomposition ingredients			
Ingre-dients	***Gases (70-80% by weight)***	***Corrosive gases***	***Ash and soot***	***Tar***
	CO_2, CO, H_2, CH_4	HCl, HF, H_2S, etc.	Hg, Pb, Cd, As, dioxins, furans	Heavy C_XH_Y

Gasifying reactors are complex facilities divided into zones with different thermodynamic conditions for optimal running on the desired chemical reactions and providing the transfer of the required heat and mass during the technological cycle, Fig. 3, [1], [2], [3].

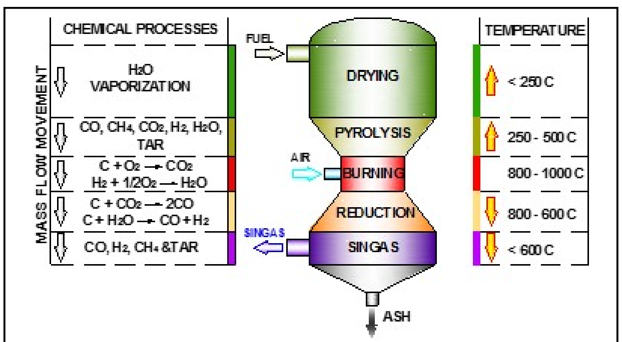

Fig. 3

There are different designs of gasifiers, but the byproducts of their operation are similar. Minor changes in temperature, humidity and oxygen content in the reactor greatly affect chemical processes, stability of reactions and the ratio of byproducts, which implies a sophisticated system for precise automatic control and a reliable system for real time monitoring of work, environments and facilities. Prior to supplying the synthesis gas to the combustion system (gas turbine), it is necessary to cool and clean the harmful components (acid gases, dust, tar) in the gas cleaning installations.

From the point of view of human safety, direct combustion and thermal gasification cause different dangers, and those of gasification are much more serious, Table. 2, [1], [3].

The fuel preparation and fuel supply of the two technologies are similar, as well as the risks [1]. The difference is in the byproducts and their potential risks.

TABLE II. SYMPTOMS OF CARBON MONOXIDE POISONING, DEPENDING ON ITS CONTENT IN THE AIR, PPM [4]

Technological process	**Potentially dangerous factors**					
	Fire	Dust expl osion	Gas expl osion	Gas poiso ning	Tar product ion	burn
Fuel preparation						
Fuel supply						
Direct combustion						
Flue gas cleaning						
Gasification						
Purification of syngas						
Transport and storage of syngas						

A. Direct combustion

After cleaning the flue gas, water, carbon dioxide and minimal amounts of heavy metal dust are released. In order to minimize investment and to bypass the emission standards, flue gas cleaning is not always a priority in Bulgaria and the emitted in the environment final products may contain much more acid oxides (HCl, HF, NO_X, SO_2) and heavy metals as dust and aerosols.

B. Gasification

The byproducts after the gasifier are tars in the form of vapors and aerosols, acid gases, dust and soot in significant quantities. However, the advantage of the technology is that the compromises with the cleaning of the syngas are technologically unacceptable because of the subsequent inevitable damage to the gas turbine and the permanent shutdown of the plant with severe financial consequences. This eliminates the possibility of savings from investments and plants operation, and minimizes the emission of harmful emissions through the flue gases in normal operating mode due to compelling economic losses.
The harmful emissions of SO_2 and NO_X are result of most combustion systems processing technologies, and are not the subject of this study.

III. TOXIC SUBSTANCES OF THE TWO TECHNOLOGIES AND THEIR IMPACT

Due to high burning temperatures (above 1000^{o}C) and high oxygen content in the incineration process, organic toxins have been decomposed to harmless substances. It is quite different in gasification.

A. Dioxins

Dioxins are generated only by gasification. They are among the most powerful known toxins, Table 2. They are heavy and accumulate close to the source – in the territory of the installation and in the nearby settlements, causing mainly chronic poisoning with manifestation of specific symptoms in the personnel and the population in the area.

TABLE III. DIOXIN TOXISITY COMPARISON WITH OTHER POISONS

	toxic substance	lethal dose for 50% of the population, mg
	**dioxin**	**0,02**
	potassium cyanide	5
	arsenic trioxide	14
	sodium nitrite	180
	benzene	500
	insecticides	1000

B. Carbon monoxide

Carbon monoxide (CO) is released by gasification. It is the main constituent of synthetic gas, has no color or odor, it is heavier than air and has the ability to accumulate in closed and unventilated spaces. Its physiological action is hemotoxic – it permanently binds hemoglobin in the erythrocytes, blocking the transfer of oxygen to body tissues. Causes rapid death in high concentration and a number of physiological symptoms in lower, Table 3, which primarily concerns operating personnel.

TABLE IV. SYMPTOMS OF CARBON MONOXIDE POISONING, DEPENDING ON ITS CONTENT IN THE AIR, PPM [4]

CO, ppm	Symptoms
10	No symptoms
70	Breathing in intense physical exertion, heaviness in the front of the head, dilation of superficial blood vessels
120	Shortness of breath with moderate exertion, variable headache with throbbing in the temples
220	Persistent headache, irritability, fatigue, diminished judgment and response
350 – 520	Headache, disorientation, seizure with loss of consciousness during physical exertion
800 – 1220	Loss of consciousness, muscle convulsions, respiratory failure, death on prolonged exposure
1950	Fast death

Recent studies conducted in the US, Pennsylvania [4] showed that exposure to acute CO results an autoimmune response that causes long-term brain damage. On the other hand, the same source mentioned that hundreds of thousands of people need active hospital treatment each year after carbon monoxide exposure. In the US alone, there are over 40,000 cases, which indicates that CO poisoning is a widespread, difficult to treat, socially significant physiological and psychiatric illness. It is suggested that the chronic effects of lower doses may have similar effects, but no authoritative publications have been found.

C. Hydrogen sulphide and methane

Hydrogen sulphide (H_2S) and methane (CH_4) are released during preparation of the fuel fueling, both during direct combustion and gasification. Hydrogen sulphide is a toxic suffocating gas, but due to its low concentration, it leads to a sensation of deterioration of the air quality in the area and discomfort rather than a physiological effect – it has a strong unpleasant odor. Methane is less toxic to humans but about 25 times more powerful greenhouse gas compared to carbon dioxide, causes the effects of global warming and has a negative environmental effect.

D. Halo – hydrogens

Halo-hydrogens (HCl, HF) are released in much greater quantities by the conversion of biomass and MSW compared to mineral fuels, during both direct combustion and gasification. They are chemically highly active, poisonous and acidic gases, but rarely appear as physiological poisons. Their main effect is the corrosion of the equipment and causing acid rain with a negative impact on the environment, if not neutralized.

E. Dust and aerosols – particulate matters (PM)

Dust and aerosols are released during both direct combustion and gasification, and contain heavy metals compounds. They are also deposited near installations, causing chronic poisoning with manifestation of chronic diseases in operating personnel and the population in nearby settlements [1]. Despite the cleaning facilities, certain amounts of these substances are released into the environment and, in the event of an accident, the doses are shocking.

IV. FIRE AND EXPLOSION HAZARDS OF THE FUEL AND BYPRODUCTS

A. Fuel storage and fuel supply risks

With the accumulation of MSW in a thick layer (storage), the processes of spontaneous anaerobic decomposition leads to heating and the release of explosive gases, mainly methane and small amounts of hydrogen. Open storage of MSW can hardly lead to methane or hydrogen explosion, but due to spontaneous heating, self-ignition can be induced, resulting in difficult-to-extinguish fires at storage sites, gassing sites and nearby settlements [1]. The risk is the same with burning and gasification. Taking in account, that Bulgarian workers are not among the most disciplined, the human mistake could not be neglected as reason for accidents, especially the cigarette smoking.

B. Combustion processes and processing of syngas

When burned directly in normal operating mode, no combustible or explosive gases are released after the combustion system, due to their complete decomposition at temperatures above 1000 ° C in an oxygen-rich environment and no possibility of explosion or fire exist.

During the lifetime of commercial gasification installations from the 1930s to the present days, numerous cases of seemingly unreasonable fires and explosions in industrialized countries of Europe, America and Asia, involving human casualties, temporary and permanent damage to people, which has led to a ban on the operation of problematic facilities by the authorities [1].

Syngas contains major combustible constituents: hydrogen, carbon monoxide and methane (H_2, CO and CH_4), as well as various amounts of higher hydrocarbons (tar), soot and ash. Tar is deposited on all surfaces of the technological tract after the gasifier, due to their wide range of condensation temperatures, followed by the ash sticking, increasing the risk of fires.

Hydrogen, methane and carbon monoxide are explosive gases with low lower flammability limits of the gas-air mixture, which implies a high risk of explosion if relatively small quantities leak out, especially in closed spaces.

Gasifiers are generally not airtight containers, although some manufacturers claim to work as such [1]. They usually maintain under-pressure and, rarely, over-pressure, which implies air (oxygen) leakage into the facilities or gas leakage into the atmosphere.
Existing a risk of mixing explosive gases with oxygen in the facilities generating, transporting and storing syngas. That may cause a local ignition of the resulting explosive mixture inside the facilities, resulting in a disruption of their integrity and leakage of large quantities of gas into the atmosphere, which is a prerequisite for a large-scale accident with a powerful explosion, human damage and environmental pollution.
Various scenarios are possible for explosions to occur, caused mainly by alternating load mode, non-homogeneous fuel, interruption of the fuel flow, and especially when shutting down and starting installations [1].
Volatile soot is suspended by air, and can also create a flammable dust-air suspension, but much less likely [3].

C. Equipment corrosion and erosion

Combustion and gasification of MSW and biomass is associated with much more intensive corrosion and erosion of facilities than of fossil fuels due to the higher content of halogen compounds (HCl, HF), abrasive metal oxides in ash and a large amount of tar.
Corrosion and erosion run the risk of rapid mechanical deterioration of the equipment, including stainless steel, and potential damage to their integrity. Syngas leakage into the atmosphere or air leakage into the facilities carries the risk of explosion and fire. The use of black steel and aluminum elements in the facilities is forbidden. There is no risk of explosion and fire in direct combustion in normal operating mode.

D. Tar and ash accumulation during gasification

The accumulation of tar and the adhesion of ash on it to the contact surfaces of the heat exchangers in the flue tract after the gasifier leads to an increase in the syngas temperature and creates a risk of self-ignition, fire or explosion in gas purifying equipment, especially in bag filters [1], [2]. In incineration, these risks do not exist.

V. Environmental impact in Bulgaria

As mentioned, gas purification facilities are not perfect despite their high efficiency. Failures are not excluded. In case of significant content of harmful substances in syngas or flue gas, their leakage into the environment cannot be excluded. In the event of an accident, the leakage can be shocking. With both technologies considered, contamination with heavy metals, acidic and odor gases is possible. In Bulgaria, this kind of risks are higher, for above mentioned reasons.
By cleaning the syngas or flue gases using wet technologies, wastewater with a high content of toxic hydrocarbons, dioxins and heavy metals is generated, which, if improperly treated, carries a risk of water and soil contamination.

VI. Risk reduction measures in Bulgaria

The design and implementation of MSW fuel systems is a complex and responsible undertaking. The lack of experience in Bulgaria requires the selection of reputable manufacturers and suppliers with a comprehensive approach, years of experience and numerous successful implementations of solid waste utilization excellent references.
The experience gained from operating gasification systems around the world [1] shows that automated remote control systems (SCADA), systems for continuous monitoring of processes and the gas composition of the atmosphere at the site, the qualifications of operational and maintenance personnel are crucial for the accident prevention in such technologies. There could not be allowed compromises in the automation, monitoring and signaling systems for the construction of processing plants in Bulgaria, for financial reasons.
Accurate adherence to technological instructions, maintenance of sustainable operating modes, accurate planning and execution of periodic inspections and repairs are no less important in preventing explosions, fires, negative impacts on people and the environment. In Bulgaria, this is only achievable through precise selection, quality training and proper remuneration of the operational and repair personnel servicing the facilities, including the hiring of foreign experts, regardless of financial considerations. Institutions with unquestionable authority should carry out training and assessment of staff knowledge and skills. Safety and reliability must be of the highest priority.
The operation of gasification installations together with the generating machines (gas turbines) is accompanied by high noise levels, which necessitates effective technical measures to limit it, especially in the vicinity of settlements.
Risk assessment of gasification installations is a complex task. The process equipment must be divided into functional units, taking into account technology, operating mode, heterogeneity and dispersion of the raw material, the potential for leakage of explosive gases or oxygen leakage in the technological facilities, and incidental factors such as earthquakes, floods and lightning. The large number of influencing factors implies a comprehensive approach to risk assessment.
In order to stabilize technological processes in the gasification of MSW and biomass, co-gasification - with fossil fuel with constant chemical and physical properties is applied. Co-gasification is a formally unattractive for classification of fuel as nonrenewable with the relevant economic negatives.
Location of MSW treatment facilities in urban areas of Bulgaria have to be chosen taking into account:

- responsible consideration of the potential dangers to the life and health of the local population;
- the availability of suitable terrain for the site of the installation and a landfill or installation for the treatment of hazardous waste;
- availability of logistical infrastructure;
- the potential expansion of settlements;
- geological and climatic characteristics of the area – relief, direction and speed of winds, temperature inversions, etc., to avoid potential negative impact on surrounding settlements and natural sites.

Co-gasification of MSW can be a potentially more promising technology for MSW processing in Bulgaria, because it provides high electrical efficiency of the generating capacities, stable, predictable and relatively safer operation of the gasification installations with the available raw material waste or biomass with logistic options for the delivery of the fossil supplement.

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