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Waste to Energy and Syngas

Enrique Posada and Gilmar Saenz

Abstract

Getting energy from waste is one of the best alternatives for sustainable handling of waste. Mass burning is generally the preferred option. Usually, this applies to large facilities where more than 500 tons of waste per day are treated. Syngas production from waste has also been tried with mixed success. This chapter reviews the situation in this field and proposes an alternative based on co-combustion with coal as a possible route, applied preferably to treat municipal solid waste (MSW) and biosolids from small- or medium-sized municipalities, producing less than 200 tons of waste per day, with the aim of generating electric energy. For this, a theoretical model is proposed and applied to a specific case.

Keywords: waste to energy, municipal solid waste, design, modeling, syngas composition, technologies, experience, electric energy, coal, co-combustion

1. Introduction

This chapter deals with the possibilities of making use of municipal solid waste (MSW) in combined gasification systems with coal to help solving two situations. One is the need for a more sustainable use of highly available coal resources and the other is the need for a more sustainable handling of domestic solid wastes, which are not properly disposed. When these two combine, as is the case for a country like Colombia, there are real spaces for the use of waste to energy technologies.

Coal is an abundant resource in many places of the world. Unfortunately, the combustion of coal has been clearly associated with the generation of CO_2 and global warming, which has caused a tendency to gradually abandon coal as an energy resource, preferring natural gas and renewable energy. This is a worrying situation for a country like Colombia, which possess very large coal deposits. Currently, this country is exporting large amounts of coal and this contributes largely to the generation of income. In this sense, it is important to find applications for coal, both in chemical process and more sustainable energy systems and also develop ways for CO_2 recovery and conversion that allow for the continuous use of coal.

The waste problem is very important in developing countries like Colombia [1]. With 49 million people in 2017 and its population mostly concentrated in the Andean highlands and along the Caribbean coast, it has 31 cities of more than 200,000 habitants and 65 with more than 100,000; being one of most urbanized countries in the region, its urban population is estimated at 76%. Informality and poverty are big problems, and these come associated with informal waste recycling practices. With a medium generation of 0.54 kg/hab./day, the estimated daily generation is around 26,000 tons. Colombia is a model in the region in the recycling of paper and cardboard, with a recovery of 57%. This has to do with the existence of industrial

plants able to use these materials in their process, which has favored a well-organized recycling scheme. Currently in the country, the recycling rate of waste such as paper, cardboard, glass, metals, and plastics is 17%, and by 2019, the goal will be to achieve a recycling target of 20% as a result of the implementation of regulatory instruments in the public cleaning services and the tariff frameworks, processes that the national government advances. The rest of the waste goes to waste dumps or sanitary landfills as there are not any thermal treatment facilities in the country. Very few of the landfills facilities have water lixiviate treating plants or methane burning systems. Space is becoming an issue and there are growing concerns and limitations about the growth of the landfill system areas in the coming years. In other cases, environmental concerns are becoming more and more important [2–5].

Waste to energy systems are very important for the sustainable disposition of municipal waste as has been consistently shown in developed countries. This has to do with available technology. In general, in developing countries, there is lack of companies that can manufacture equipment for thermal treatment systems capable of handling hundred or thousand tons per day of mixed waste, burning them in a controlled way, generating electricity, and controlling the air pollution problems related to this. This means that local responsible waste-handling entities will tend to look for solutions with external providers and this means usually very high initial investments. As shown in the case of China and India, this can be changed, creating competitive sectors in the WtE technology, able to confront their own situations and to export technology and equipment.

Engineering and design are very important components of the necessary technology for the development of WtE (waste to energy) systems in a country. Implementing these systems requires detailed studies and planning activities and it is advisable to do the projects considering all the engineering stages. There is always the temptation and the idea that the projects can be accelerated and put into place based on the experience and support of suppliers and makers, by means of EPC developments. The idea being that in such a way, the engineering stages can be simplified or even avoided. This normally is a much costlier and rigid solution and does not contribute to developing local technology and desired prosperity. In the solution of the problems, there is ample space to develop a region, as compared to relying only on externally provided solutions.

One of the most important stages is the development of conceptual studies and engineering based as much as possible on local expertise, duly backed, of course with external experience and support. The authors are part of an international working group known as WTERT supported by Earth Institute at Columbia University [6]. The Waste to Energy Research and Technology Council (WTERT) brings together engineers, scientists, and managers from universities and industries worldwide and the authors belong to the Colombian chapter, which is supported by ACIEM (Engineering Colombian Association). WTERT tries to identify and advance the best available waste to energy technologies for the recovery of energy or fuels from municipal solid wastes and other industrial, agricultural, and forestry residues. The authors are also project engineers at HATCH, an international engineering company, and have experience in waste to energy systems for industrial applications.

As part of their work, they participated in a project aimed at using gasification systems based on the co-combustion of coal with biosolids coming from a municipal water treatment system [7–9]. This chapter considers using this technology for waste to energy systems applied to municipal solid waste (MSW). It reviews the situation in this field. This, in order to explore the basis for an alternative based on co-combustion with coal for generating syngas in small- or medium-sized municipalities, produces less than 200 tons of waste per day. It develops a theoretical

model applied to the specific case of municipal waste similar to the one generated at the city of Medellin, where the authors work, co-gasified with available local coal.

Gasification processes involve the reaction of carbonaceous feedstock with an oxygen-containing reagent, usually oxygen, air, steam, or carbon dioxide, generally at temperatures in excess of 800°C. It involves the partial oxidation of a substance which implies that oxygen is added but the amounts are not sufficient to allow the fuel to be completely oxidized and full combustion to occur [10]. The main product is syngas, which is a mixture of gases including CO and H_2, which can be used to produce fuels and chemicals, or be burned to generate heat or electricity. Some by-products are ash and tars depending on the technology used.

The basics of the gasification process can be found in many publications and books. MSW gasification has been an object of many studies also and the process details and specificities have been compiled and documented. Zafar [10] shows the qualitative basics, advantages, and disadvantages, as well as classifications depending on the technology, feedstock, and reactors, focused on municipal solid waste. Arena [11] presents a deeper treatment of the gasification technology, the chemistry, reactor and technology description and comparison, and environmental aspects. In his thesis, Klein [12] also analyzes these aspects in depth and also considers investment and operative costs with data of operating plants at that time.

In terms of co-gasification, specific studies have been carried out showing the technical feasibility of the technique, and quantifying the improvements depending on the co-gasification agent.

Koukouzas et al. analyzed co-gasification of MSW with coal. They evaluated the techno-economic feasibility, of a 30-MW (e) co-gasification power plant based on integrated gasification combined cycle (IGCC) technology, using lignite and refuse-derived fuel (RDF), in the region of Western Macedonia, Greece. The preliminary cost estimation indicated that this plant was not profitable, due to high specific capital investment and in spite of the lower fuel supply cost. The estimated cost of electricity was not competitive, compared to the dominating prices for the Greek electricity market [13].

Hu et al. studied a three-stage system for co-gasification of MSW with high-alkali coal char. Tar content was controlled to as low as 11.3 mg/Nm^3 and HCl to 17.6 mg/Nm^3. Lower heating value attains 12.2 MJ/Nm^3, meeting the intake-gas conditions for internal combustion engines. They concluded that high-quality syngas can be produced at a steady yield rate of 1.57 Nm^3/kg from three-stage gasifier, due to dichlorination and catalytic tar cracking action of high-alkali coal char at a low cost [14].

Co-gasification of MSW with switchgrass cuttings, by means of a small commercial-scale downdraft gasifier (100 kg/h), indicates that co-gasification of up to 40% MSW performed satisfactorily. The heating values of syngas were 6.2, 6.5, and 6.7 MJ/Nm^3 for co-gasification ratios of 0, 20, and 40%, respectively; in the same cases, the cold and hot gas efficiencies were 60.1, 51.1, and 60.0% and 65.0, 55.2, and 64.4% [15]. Eghtedaei et al. also analyzed co-gasification with biomass and found an improvement in the H_2 concentration [16].

The co-gasification with the bottom ash has been studied, finding improvements in the final ash quality and the gas emissions without important changes in the operability and syngas quality [17].

These few examples show that in principle, not only MSW gasification, but also co-gasification are feasible at different scales, including commercial scale. Many companies or institutes have developed their own process routes with particularities to be more efficient or suitable for the feedstock. In addition to the studies reviewed, some other successful cases could be considered.

Enerkem has effectively developed its own process to obtain methanol and ethanol from MSW through gasification and has an operating plant in Alberta,

Canada [18]. Mitsubishi Heavy Industries has a medium-sized plant in Kushiro, Japan, which has been operating since 2006, processing 240 T/day of MSW (2 units × 120 T/day), producing 4.6 MW of electricity. Their technology includes an ash melting system that improves the ash quality and controls the dioxin emissions [19]. Currently, Fulcrum-Bioenergy is preparing the construction of a MSW gasification facility in Nevada (USA) to produce 10 million gallons a year of biofuels [20]. Aries Clean Energy has different facilities already working in the USA. In Sanford, Florida, they installed a fluidized bed gasification plant for 30 T/day biosolids from a sewage treatment plant [21]. In Lebanon, Tennessee, a downdraft reactor gasifies 64 T/day of biomass to produce heat that is used with organic Rankine cycles (ORCs) [22]. The same technology was used in Covington, Tennessee, with a reactor of 12 T/day mixture of wood residues and sludge moving a 235-kW ORC [23]. In Boral Bricks, Alabama, 12 modular downdraft systems were used to process residual wood to produce syngas to be burned in brick furnaces [24].

Tanigaki et al. have reviewed the operation of two plants in Japan. They reported more than 46 gasification facilities working nowadays in Japan but focused on the two more recent ones, one processes MSW with higher operating hours and lower consumables in Japan. The other one is focused on its waste flexibility, processing not only MSW but also IBA, rejects from recycling center, and sewage sludge. They show the reliability of these plants as well as their effectiveness on the MSW treatment, energy efficiency, and accomplishing environmental requirements [25].

There are many gasification facilities in the world. A good review of them can be found in the Worldwide Syngas database of the Global Syngas Technology Council [26]; here, the facilities can be located and filtered by feedstock, product, and technology among others. In the following studies, in addition to very good technological reviews of the MSW thermal treatment, especially on gasification, there are sets and lists of plants, facilities around the world with their capacities and owners.

- Thermal municipal solid waste gasification [27].

- Thermal processing of waste [28].

- Municipal solid waste (MSW) to liquid fuels synthesis, volume 1: Availability of feedstock and technology [29].

- Feasibility study on solid waste to energy: Technological aspects [30].

- Gasification of non-recycled plastics from municipal solid waste in the United States: Thermal municipal solid waste gasification [31].

- Thermal plasma gasification of municipal solid waste (MSW) [32].

There can be found good examples of feasible and working projects for MSW treatment; however, it is important to note that these projects have specific and contextual difficulties. Hakan Rylander, an experienced actor in WtE, is a bit skeptical about gasification of MSW, mostly because of the heterogeneity of the feedstock, and because the energy balance sometimes has turned out to be negative [33]. Also, Tangri and Wilson [34], make an interesting risk analysis of the gasification and pyrolysis of MSW. They conclude that "the potential returns on waste gasification are smaller and more uncertain, and the risks much higher, than proponents claim," "Technical and economic challenges for gasification projects include failing to meet projected energy generation, revenue generation, and emission targets. Gasification plants also have historically sought public subsidies to be profitable." At the end of

the document, there is a list of ten notable cases of plants and facilities around the world that have stopped operations.

There is no general rule to assure success of a MSW gasification or co-gasification facility; it depends on the technology used, the nature and variability of the feedstock, and strongly on the local cost and price structure. Where landfilling is still cheap and permitted, WtE tends to be not an economically feasible option. But where waste disposal is becoming more regulated and costly, a WtE plant of this kind is a great option to reduce the amount of material disposed and its inertness while having a benefit, that could be the obtention of energy or of value-added chemicals.

2. Modeling of municipal solid waste and coal co-combustion to generate syngas

This section develops a theoretical model applied to the specific case of municipal waste. The basic information for this is the composition of the MSW and of the coal to be used, plus their heat powers. **Tables 1** and **2** show the data used. These tables have been prepared by authors based on several studies made during their work with coal boilers and power plants at Colombia. Two cases are considered for the waste. In the first one, waste as currently generated, the average quality of the MSW is considered in the city of Medellin, which is quite rich in organic materials and, so, very high in water content. In the second case, previously separated waste is

Water content	% wet basis	7.20
Carbon	% dry basis	68.77
Hydrogen	% dry basis	4.55
Nitrogen	% dry basis	1.27
Oxygen	% dry basis	12.08
Sulfur	% dry basis	0.45
Ashes	% dry basis	12.87
High heat value (dry basis)	KJ/kg	25,911
Lower heat value (wet basis)	KJ/kg	23,155

Table 1.
Coal properties considered [35].

Case		As generated	Separated
Water content	% wet basis	45.58	24.93
Carbon	% dry basis	42.70	38.50
Hydrogen	% dry basis	5.93	5.35
Oxygen	% dry basis	37.95	34.22
Ashes	% dry basis	13.42	21.93
High heat value (dry basis)	KJ/kg	16,244	14,647
Lower heat value (wet basis)	KJ/kg	8,129	10,111

Table 2.
MSW properties considered [35].

considered, removing 75% of organic material, 50% of paper, 20% of plastics, 55% of glass, 60% of cardboard, and 50% of metals of the generated waste. This would amount to 45% of the initial as generated MSW.

Gasification is modeled considering three combinations for co-gasification, identified by the mass ratio of coal to MSW: 0, 0.25, and 0.50. Saturated steam was supplied at 4 bar relative pressure (ambient pressure 1 bar) with steam-to-MSW mass ratios between 0.0 and 1.0 and heated air (120°C) was supplied with air-to-MSW rates between 1.70 and 5.0. **Figure 1** schematizes the basic model used.

The following chemical reactions were considered for the equilibrium calculations in the simulations. No methane generation was considered. Sulfur was controlled by the addition of calcium carbonate at a mass ratio of 0.0163 to coal.
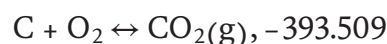
$$C + CO_2 \leftrightarrow 2CO \tag{1}$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \tag{2}$$

$$H_2 + 1/2O_2 \leftrightarrow H_2O \tag{3}$$

$$C + H_2O \leftrightarrow CO + H_2 \tag{4}$$

$$C + 1/2O_2 \leftrightarrow CO \tag{5}$$

$$CO + 1/2O_2 \leftrightarrow CO_2 \tag{6}$$

$$C + O_2 \leftrightarrow CO_2 \tag{7}$$
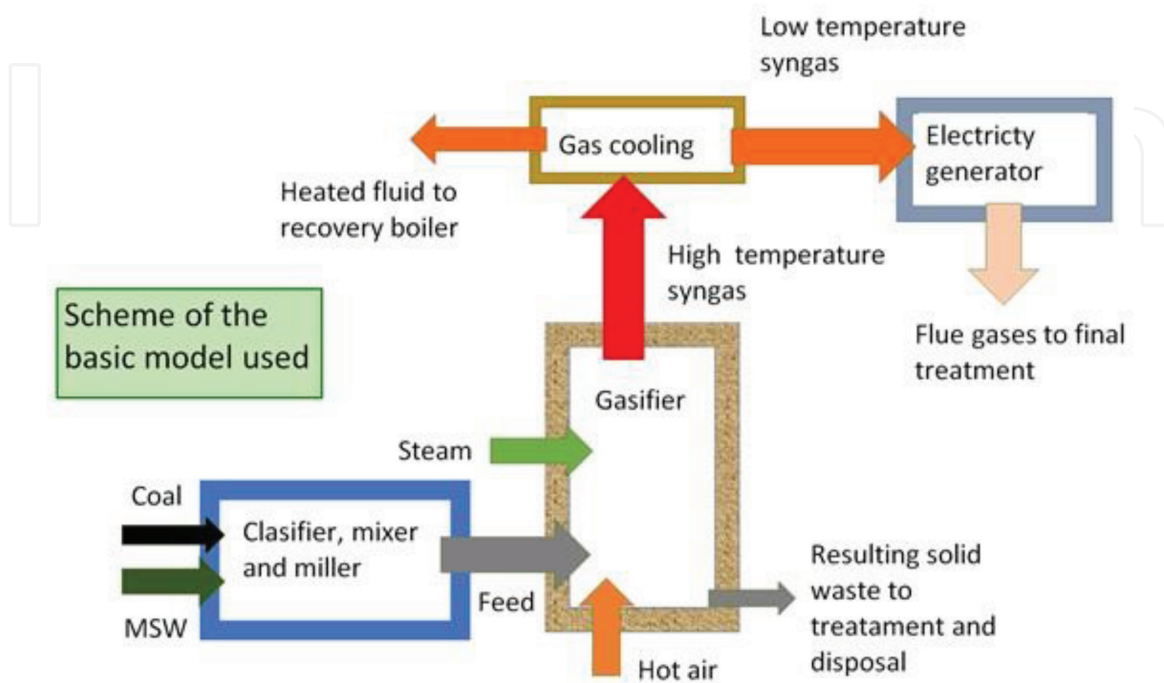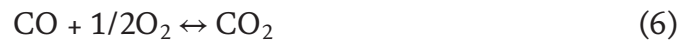
Figure 1.
Scheme of the basic model used.

An iterative model calculation was developed using the solver routine of MS excel in which the concentrations of syngas were iterated with temperature until the expected convergence was found with species mass balance, energy balance, and chemical equilibrium.

Iterations were performed as follows:

- Final syngas temperature is assumed.

- Volumetric fractions of CO_2, CO, H_2, and H_2O in syngas are assumed.

- Fraction of C converted as per reactions (1), (4), and (5) are assumed.

- Fraction of O_2 converted as per reaction (3) and forming CO are assumed.

- Fraction of CO converted as per reaction (2) is assumed.

- With the partial fractions of syngas, equilibria constants for reactions (1) to (7) are found.

- With syngas temperatures, equilibria constants for reactions (1) to (7) are also found.

- A convergence limit was established for the comparison of these two equilibria constants. This was set as less than 15% maximum error for each reaction.

- Mass balance was checked for each species with a convergence limit of less than 5%.

- Energy balance was performed comparing energy formation based on reactions (1) to(7), outgoing syngas enthalpy, incoming vapor and air enthalpy and heat losses (sensible heat, wall and ashes loses). A convergence limit of 5% was established.

Energy formations (kJ/kmol) used were as follows for syngas forming reactions.

$$C + 2H_2 \leftrightarrow CH_4(g), -74.520$$

$$H_2 + 1/2O_2 \leftrightarrow H_2O(g), -241.818$$

$$C + 1/2O_2 \leftrightarrow CO(g), -110.525$$

$$C + O_2 \leftrightarrow CO_2(g), -393.509$$

Enthalpy of syngas was calculated based on syngas composition and specific heat values for each component, depending on temperature, using the expressions of the form: $Cp/R = A + B\cdot T + C\cdot T2 + D\cdot T - 2$; T (K) where A–D are constants for each gas component and R is the universal gas constant.

Figures 2–12 show the results of the iterations for all major resulting variables. Comments are included for them.

Syngas temperatures tend to increase with higher coal-to-MSW ratios. For each ratio, there is a characteristic curve which indicates higher temperatures for

lower air-to-MSW ratios and lower temperatures for higher steam-to-MSW ratios. Temperatures tend to be higher for the case of the separated MSW. **Figure 1** indicates the real working ranges for the simulations. With no coal use, the only range of air-to-MSW ratios that gave convergence in the simulations was in the neighborhood of
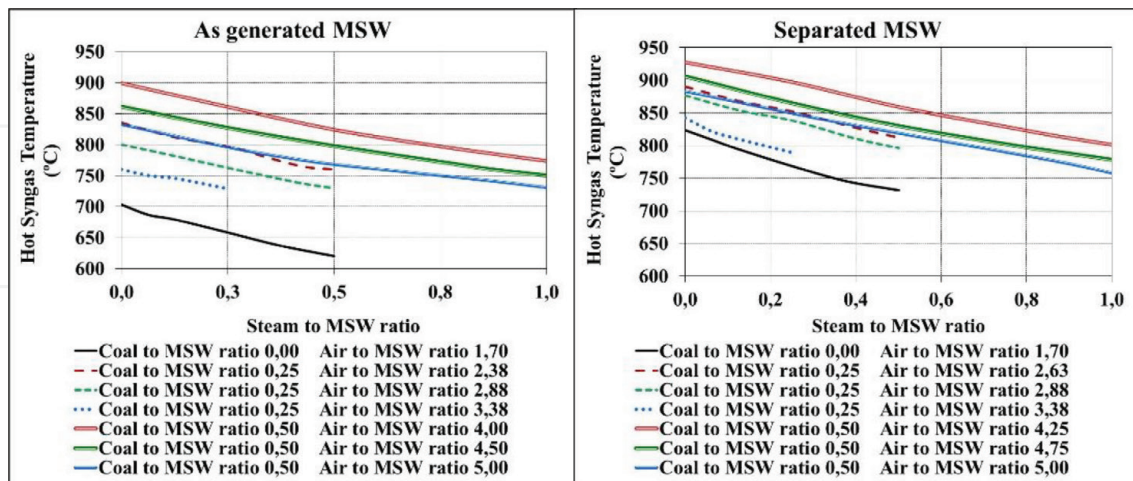

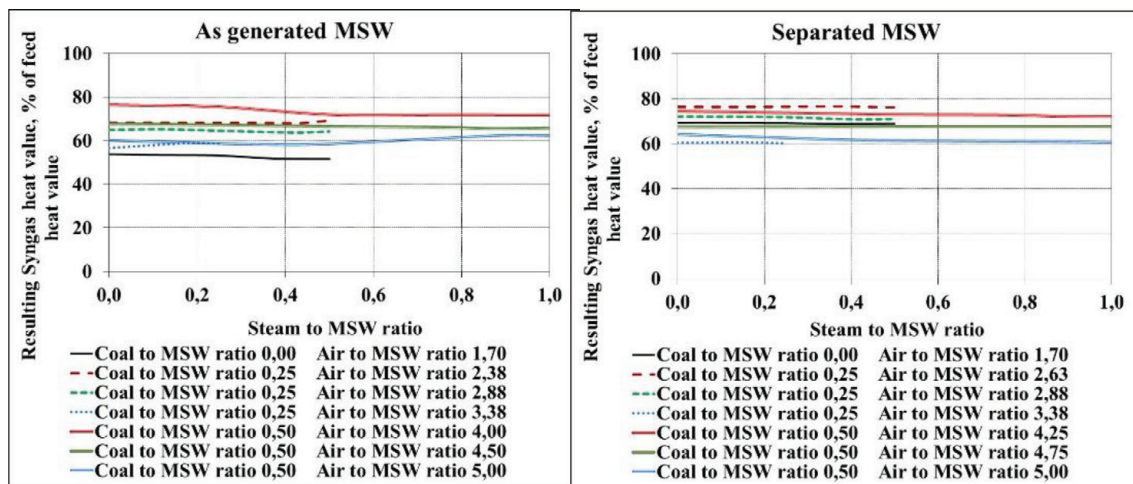**Figure 2.**
Resulting syngas temperature.

Figure 3.
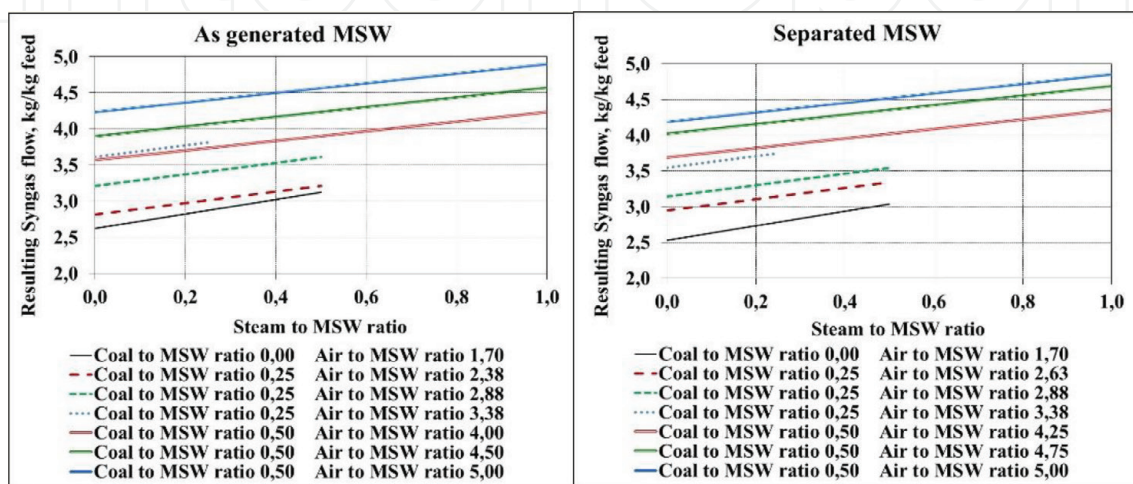*Resulting heat value in syngas as % of feed heat value.*

Figure 4.
Syngas flow, kg/kg feed.

1.70. At higher coal-to-MSW ratios, the air-to-MSW ratio can be higher, all the way to 5.0. Syngas temperatures will be between 600 and 940°C.

Syngas heat values tend to increase for higher coal-to-MSW ratios, but this was not entirely consistent. Syngas heat value simulations showed percentages between 60 and 80% of feed heat value and this does not change with steam-to-MSW ratios and tends to decrease with air to MSW ratios.

Syngas flow is linearly related to the studied variables. It increases with air-to-MSW ratio and with steam-to-MSW ratios. The values for the simulated range oscillate between 2.5 and 5.0 kg of syngas per kg of feed. The syngas flow is, basically, the result of adding the incoming flows, discounting the ash emissions. The behavior and the ranges are quite similar for both situations of MSW studied.

As shown in **Figure 5**, syngas heat value is quite independent of steam-to-MSW ratio. It increases with air-to-MSW ratios and, of course, with coal-to-MSW ratios. As compared to the MSW's lower heat value, it tends to be lower, as expected, for the case of no coal co-gasification. Maximum values tend to be double as compared to MSW heat value, obviously because of the impact of coal co-gasification. The values in **Figure 5** are consistent with the ones shown in **Figure 3**. **Figure 6** shows the total energy content of the syngas, adding its heat value to the sensible heat associated to syngas temperature. Those two amount to a value close to the energy value coming from the total feed. It must be said that the incoming hot air and the
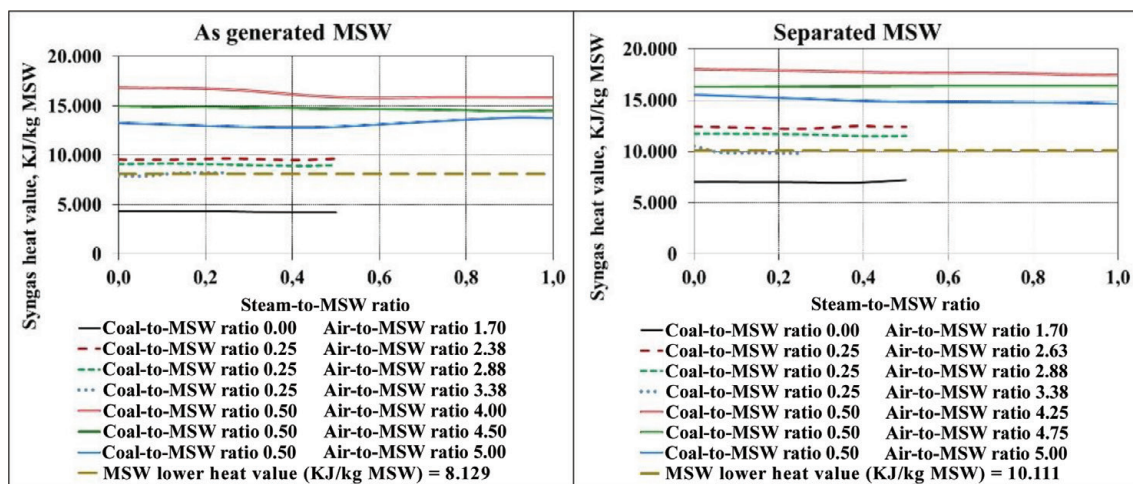

Figure 5.
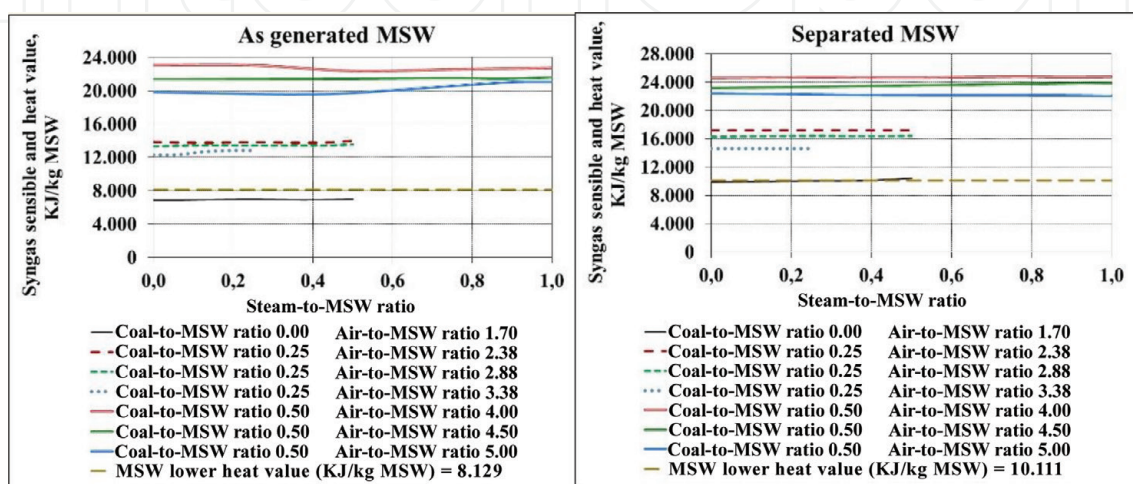*Syngas heat value, kg/kg MSW.*

Figure 6.
Syngas heat value and sensible heat, kg/kg MSW.

steam contribute with some energy also, which adds to the outgoing syngas heat value and sensible heat.

The behavior of the total energy in the syngas (**Figure 6**) is quite similar to the behavior of the heat value of **Figure 5**. The heat value corresponds to the chemical (combustion potential) energy associated to H_2 and CO in the syngas.

Some calculations were carried out in the model to determine the potential of syngas to generate electricity. First, the sensible heat potential was determined based on the hot temperature of the syngas. This can be used to generate mechanical work and electricity removing the sensible heat (lowering the temperature, as indicated in **Figure 1**) in a cycle similar to a Rankine cycle. To determine the potential for this, a Carnot cycle's efficiency was calculated using as hot temperature the syngas temperature and as cold temperature the ambient value (25°C). With this Carnot efficiency, an estimation was obtained of a real efficiency based on existing Rankine cycles in which it is possible to get about 35% of the Carnot efficiency. The second estimation was based on expecting an efficiency of 30% for the cycle that employs the combustion heat value of the syngas. This, considering that it could be taken to an internal combustion engine. Combining these two efficiencies, in proportion to the existing contributions (that of heat value and that of sensible heat in the energy content of the syngas), it was possible to estimate the total efficiency
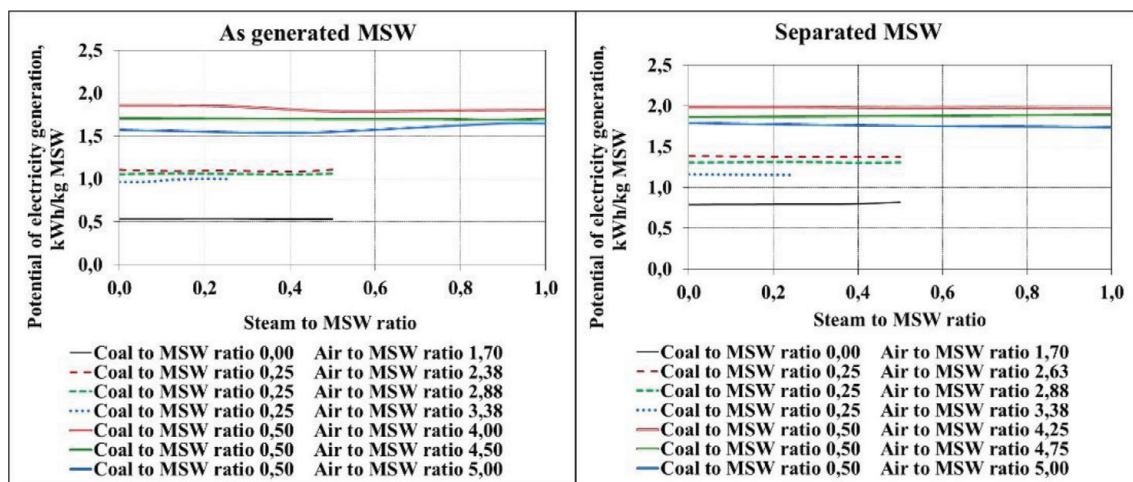

Figure 7.
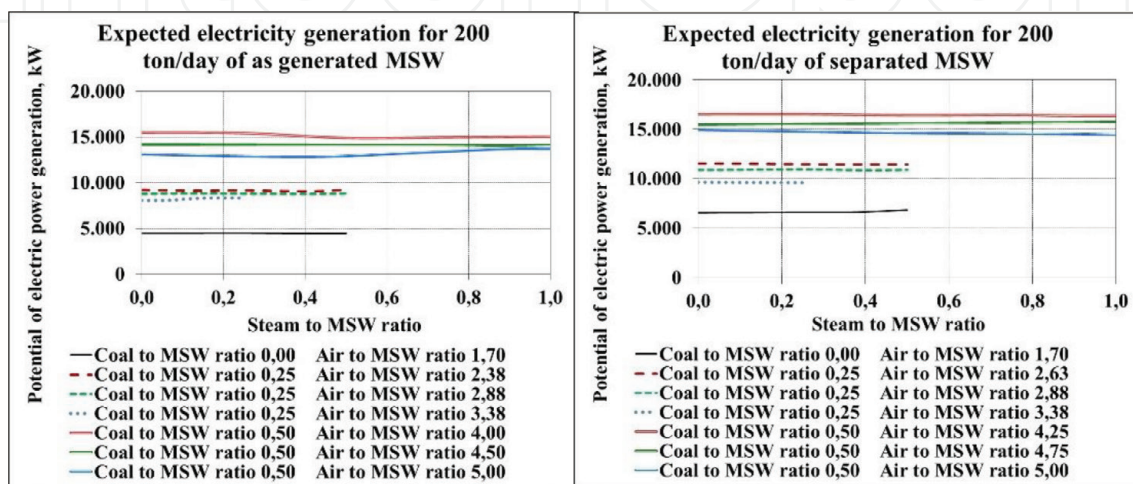*Potential for electricity generation, kW/kg MSW.*

Figure 8.
Electricity generation, in kW, for the processing of 200 tons per day of MSW.

of transformation to electricity and the total potential for electricity generation, which appears in **Figure 7**.

This potential is not affected by steam-to-MSW ratios. It is highly dependent, of course, on coal-to-MSW ratio and it is higher for lower air-to-MSW ratios. The potentials are higher for the case of separated MSW (between 0.75 and 2.2 kW per kg of MSW as compared to a range between 0.5 and 2.0 kW per kg of MSW for the as generated MSW case).

With these potentials, it is possible to estimate the expected electrical generation for a given flow of MSW. **Figure 8** shows the results for a plant processing 200 tons of MSW per day.

These capacities will be between 4800 and 16,000 kW for the as generated MSW and between 6500 and 17,000 kW for the separated MSW. They are not affected by steam-to-MSW ratio, increase clearly with coal-to-MSW ratio, and decrease with air-to-MSW ratio. The ranges indicated in the graphs correspond to the ones for which convergence was found in the iterations, as already mentioned. These plants could generate amounts of electricity quite useful for a given small city in a country like Colombia. Considering a generation of solid waste (as generated) of 0.50 kg/day per habitant, the plant would produce the amounts indicated in **Table 3** for the cases considered. The table compares these figures to the electric consumption of a country like Colombia, estimated at 3.90 kWh per day per capita.

Finally, the simulations permitted to obtain the expected composition of the syngas which will be shown in the next figures.
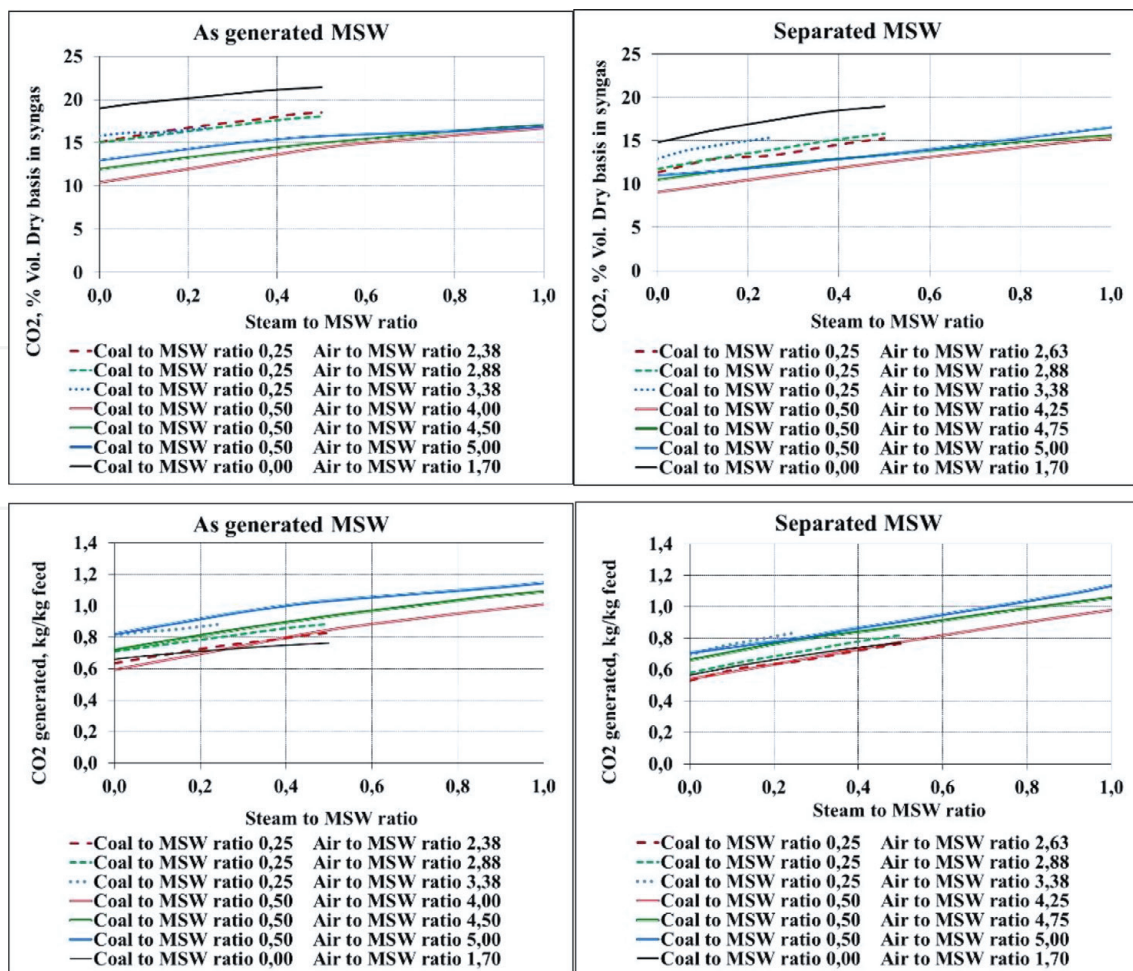

Figure 9.
Syngas CO_2 concentrations and specific emissions.

CO_2 specific emissions increase with steam-to-MSW ratios, with air-to-MSW ratios, and with coal-to-MSW ratios, although in this case depending on the air-to-MSW ratios. Specific emissions are quite similar for both MSW cases.

CO_2 concentrations show a similar behavior but their concentrations in the syngas tend to be somewhat lower for the case of the separated MSW.

CO specific generations decrease with steam-to-MSW ratios and also with air-to-MSW ratios and increase with coal-to-MSW ratios. Specific generations are
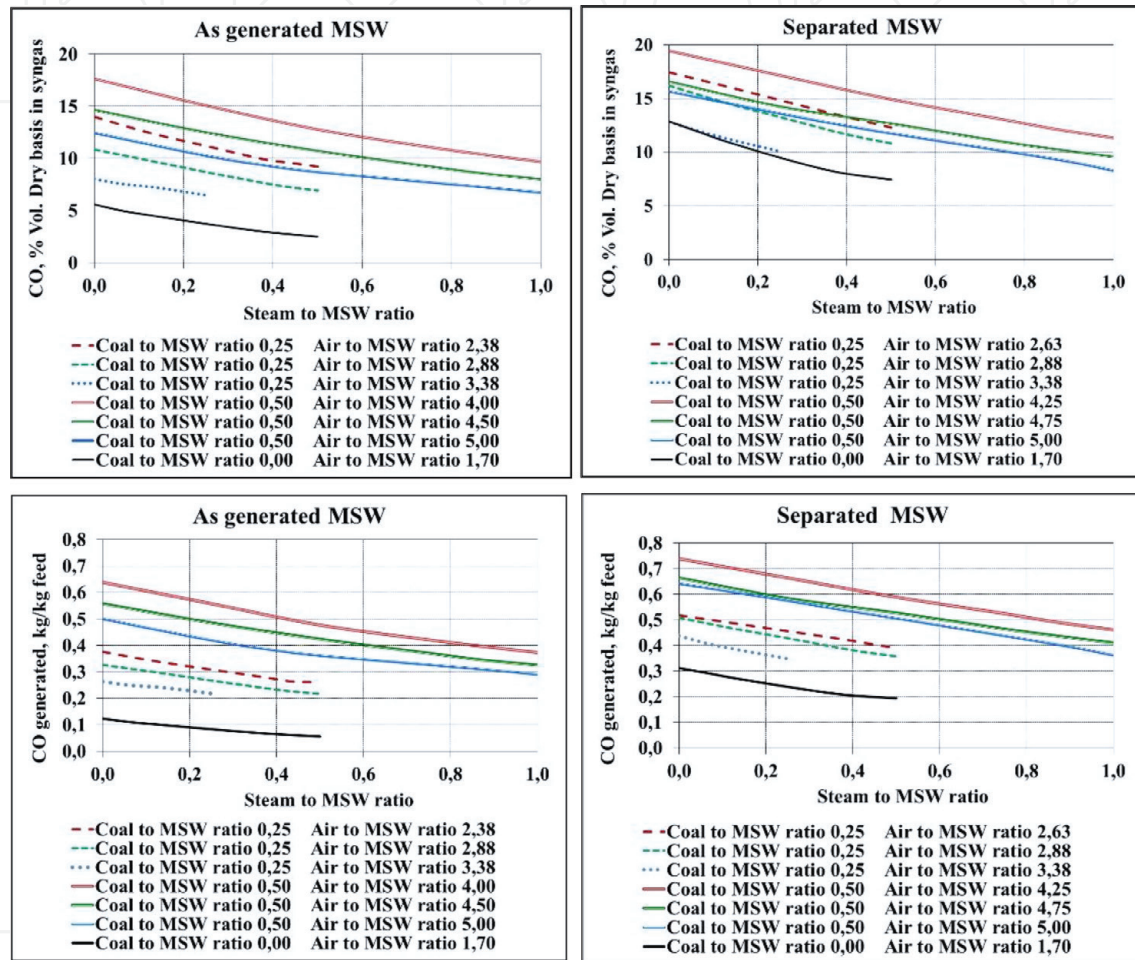

Figure 10.
Syngas CO concentrations and specific generations.

Parameter	Units	As generated	Separated
MSW in Colombia	kg/person day	0.50	0.24
Electricity generated—low	kWh/kg MSW	0.55	0.70
Electricity generated—high	kWh/kg MSW	1.80	2.00
Electricity generated—low	kWh/kg person-day	0.28	0.17
Electricity generated—high	kWh/kg person-day	0.90	0.49
Average electricity consumption in Colombia	kWh/kg person-day	3.90	
Electricity generated—low	% of national use	7.05	4.38
Electricity generated—high	% of national use	23.08	12.51

Table 3.
Per capita electricity generation potential with syngas plants for the considered cases in Colombia.

higher for the case of the separated MSW. CO is one of the two important components of syngas and contributes to its heat value.

CO concentrations show a similar behavior and their concentrations in the syngas tend to be somewhat higher for the case of the separated MSW.

Figure 11 shows the behavior for the H_2 gas as a component of syngas, also one of its two important components and a major contributor to its heat value.

H_2 specific generations increase with steam-to-MSW ratios. This indicates the impact of the conversion of steam to H_2. They decrease also with air-to-MSW ratios. The impact of coal-to-MSW ratios is not entirely clear and is different for the two MSW cases considered. Specific generations are higher for the case of the separated MSW, especially for the case in which no coal is used.

H_2 concentrations show similar behavior and their concentrations in the syngas tend to be somewhat higher for the case of the separated MSW. Concentrations tend to be higher for the low coal-to-MSW ratios.

The water content in the syngas generated with MSW tends to be high, due to the high humidity of the MSW, as shown in **Figure 12**.

H_2O specific generations increase with steam-to-MSW ratios. This indicates a direct relationship coming from the steam added, which is to be expected. They decrease also with air-to-MSW ratios. The impact of coal-to-MSW ratios is evident. When adding coal, the water generation diminishes, as the coal water content is much lower than the one in MSW. Specific generations are clearly lower for the case of the separated MSW, again something to be expected given the lower water content for separated MSW.

H_2O concentrations show a similar behavior in relationship of the direct impact of the steam-to-MSW ratios. The influence of the air-to-MSW ratio is very small.
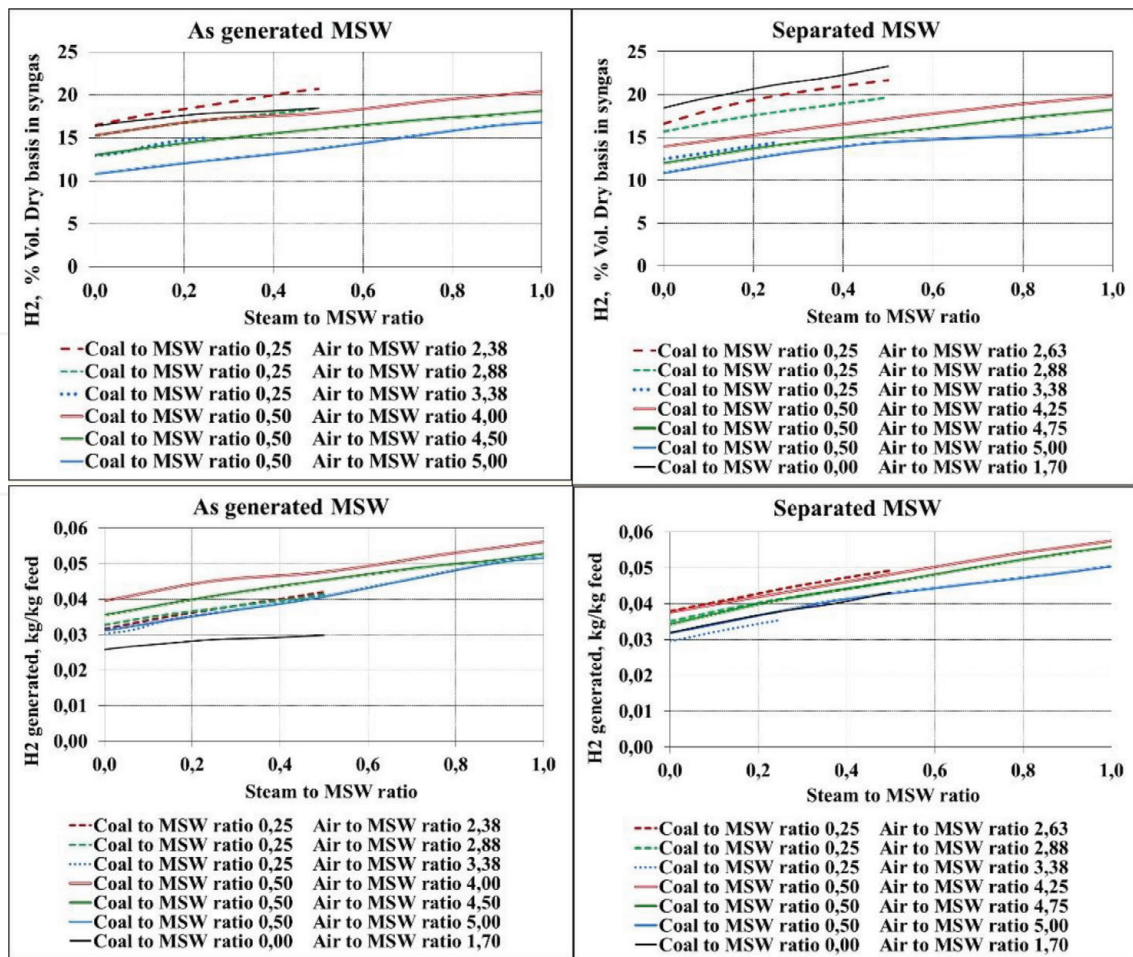

Figure 11.
Syngas H_2 concentrations and specific generations.

The impact of coal-to-MSW ratios is evident as already said. When adding coal, the water generation diminishes as the coal water content is much lower than the one in MSW and their concentrations in the syngas tend to be clearly lower for the case of the separated MSW for the same reasons.

The water content of the syngas has an impact that should be considered in the options for its use. The water concentrations are so high that there could be possibilities of having water condensations on the gases if they reach the dew point
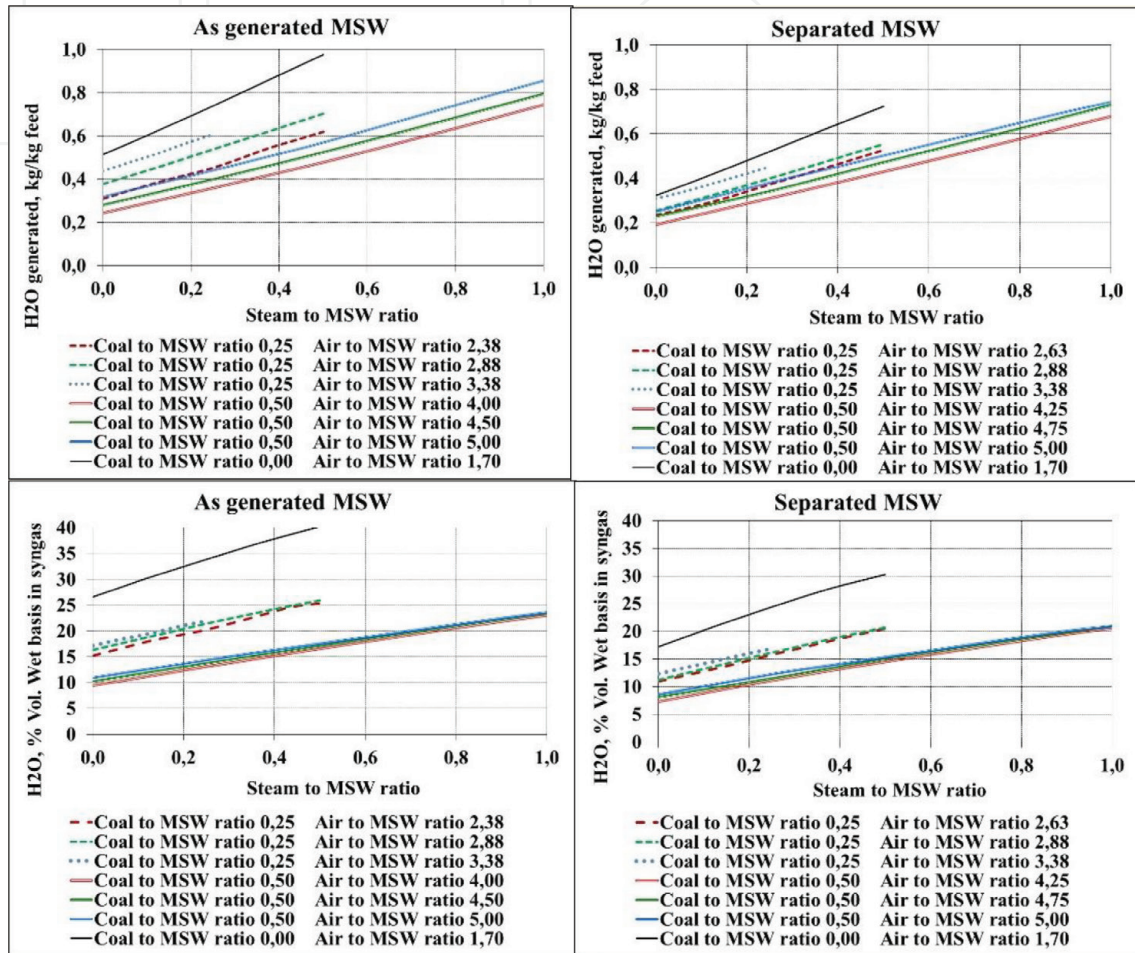

Figure 12.
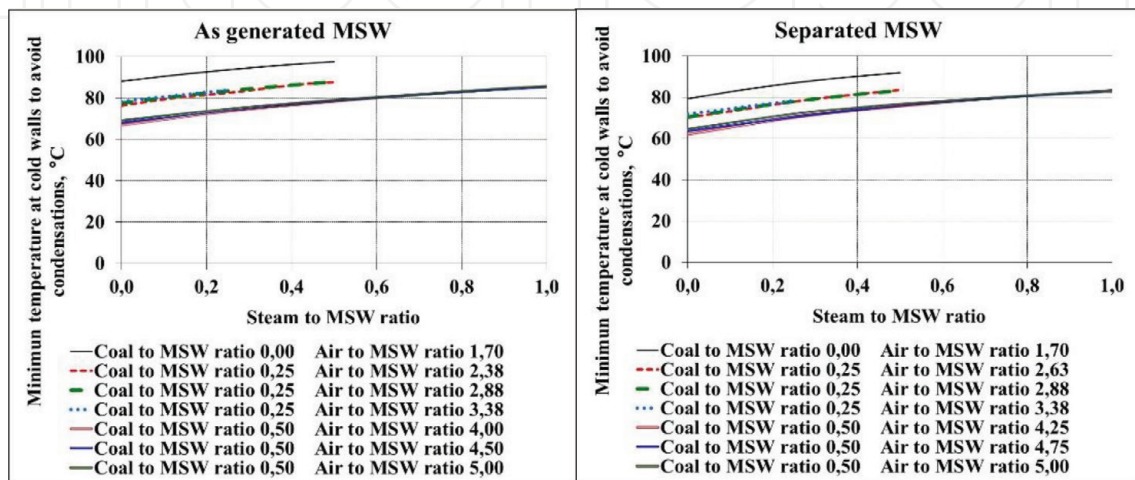*Syngas H_2O concentrations and specific generations.*

Figure 13.
Minimum cool wall temperatures to avoid water condensation.

temperatures, which could occur at low process temperatures near cold areas, for example in the walls of cooling or transportation equipment. To study this, simulations were made of the wet bulb temperatures assuming cooling under constant total pressure and getting the corresponding saturation temperatures. This simulation is presented in **Figure 13**.

The minimum cool wall temperatures estimated in **Figure 13** include a protection of 20°C, over the calculated dew point temperatures. The dew point temperatures were estimated using psychrometry. The minimum temperatures increase with steam-to-MSW ratio, and decrease with coal-to-MSW ratios, as should be expected. The air-to-MSW ratio did not influence significantly. Temperatures are lower for the case of the separated MSW as expected.

These minimum temperatures can be guaranteed with adequate insulation of the processing equipment and pipe walls for the systems handling the syngas.

3. Conclusions

The theoretical model showed quite consistent results. It was possible to develop a way of estimating syngas characteristics for the gasification of MSW in co-gasification, within practical working ranges for the studied variables. This was done under two extreme conditions for the MSW: as generated in a town with high organic material content and after separation of 55% of the initial waste for recycling and organics treatment (e.g., by biological composting and digestion). The model allowed to find the working ranges for steam-to-MSW ratios (between 0 and 1.0); air-to-MSW (between 1.7 and 5), for co-gasification with coal; and cola-to-MSW ratios in the range of 0.0–0.5.

The gasification can generate electricity in all these ranges, with potentials that go from 0.5 to 2.2 kWh per kg of MSW. For the case of a plant processing 200 tons of MSW per day, the generation capacities would be between 4800 and 17,000 kW. These capacities are entirely within the electricity needs of a country like Colombia. They are between 0.28 and 0.90 kWh per person per day, for the current per capita MSW generated in the country. These figures are to be compared to the current daily electricity per capita use, which is 3.90.

From the practical point of view, it is important to use this as a conceptual basis for future work seeking indications on systems that could be feasible. This will help doing the correct steps. Engineering and design are very important components of the technology necessary to impulse WtE in a country. These systems require detailed studies and planning activities and it is advisable to do the projects considering all the engineering stages. There is always the temptation and the idea that the projects can be accelerated and put into place based on the experience and support of suppliers and makers. This by means of EPC developments, in such a way that engineering stages can be simplified or even avoided. This normally is a much costlier and rigid solution and does not contribute to developing local technology and prosperity. With regard to the solution of the problems, there is ample space to develop a region, as compared to relying only on externally provided solutions. MSW co-gasification with coal seems to be a possible alternative.

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References

[1] Posada E. Strategic analysis of alternatives for waste management. In: Kumar S, editor. Waste Management. Rijeka, Croatia: Intech; 2010. ISBN 978-953-7619-84-8

[2] Tello P, Martínez E, Daza D, Soulier M, Terraza H. Informe de la Evaluación Regional del Manejo de Residuos Sólidos Urbanos en América Latina y el Caribe. OPS-AIDIS-BID; 2010

[3] Themelis N, Diaz ME, Estevez P, Gaviota M. Guía para la Recuperación de Energía y Materiales de Residuos. Original study sponsored by Banco Interamericano de Desarrollo 2013. Spanish Edition (Edición en español). Chile/USA: Universidad del Desarollo/Columbia University; 2016

[4] Min Ambiente-Gobierno de Colombia-Noticias. A 2018 Colombia tendrá una tasa de reciclaje del 20%. 2016. Available from: http://www.minambiente.gov.co/index.php/noticias/2291-a-2018-colombia-tendra-una-tasa-de-reciclaje-del-20

[5] Documento Conpes 3874. Consejo Nacional de Política Económica y Social. República de Colombia. Departamento Nacional de Planeación. Política Nacional Para la Gestión Integral de Residuos Sólidos. 2016. Available from: https://colaboracion.dnp.gov.co/CDT/Conpes/Econ%C3%B3micos/3874.pdf

[6] Global Wtert Council, Research, Education, and Information for Sustainable Waste Management. Summary Report of 2018 Activities of WtERT Partner Organizations; 2019

[7] Saenz G, Posada E. Economical aspects on the implementation of a plant for MWWTP biosolid and coal gasification in comparison with the use of the biosolid for soil recuperation. In: 32nd International Conference on Thermal Treatment Technologies & Hazardous Waste Combustors; 21-23 October 2013; San Antonio, TX. 2013

[8] Saenz G, Posada E. Thermal treatment and energy recovering equipment for waste water and gas emissions from a condensation polymerization plant. Paper # 15. In: 33rd International Conference on Thermal Treatment Technologies & Hazardous Waste Combustors; 13-15 October 2014; Baltimore, MD. 2014

[9] Posada E et al. Simple determination of physical and thermal properties as a basis for the design and analysis of waste to energy combustion equipment. Paper # 24. In: 35th International Conference on Thermal Treatment Technologies & Hazardous Waste Combustors; 4-6 October 2016; Baton Rouge, LA. 2016

[10] Zafar S. Gasification of Municipal Solid Wastes. Bioenergy Consult. 2009. Available from: https://www.researchgate.net/publication/285295261_Gasification_of_municipal_solid_wastes

[11] Arena U. Process and technological aspects of municipal solid waste gasification. A review. Waste Management. 2012;**32**:625-639. Available from: https://www.sciencedirect.com/science/article/pii/S0956053X11004314

[12] Klein A. Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes; Earth Engineering Center, Colombia University. 2002. Available from: http://www.seas.columbia.edu/earth/wtert/sofos/klein_thesis.pdf

[13] Koukouzas N, Katsiadakis A, Karlopoulos E, Kakaras E. Co-gasification of solid waste and lignite—A case study for Western

Macedonia. Waste Management. 2008;**28**(7):1263-1275. Available from: https://www.sciencedirect.com/science/article/pii/S0196890417309287

[14] Hu B, Huang Q, Buekens A, Chi Y, Yan J. Co-gasification of municipal solid waste with high alkali coal char in a three-stage gasifier. Energy Conversion and Management. 2017;**153**: 473-481. Available from: https://www.sciencedirect.com/science/article/pii/S0196890417309287

[15] Bhoi PR, Huhnke RL, Kumar A, Indrawan N, Thapa S. Co-gasification of municipal solid waste and biomass in a commercial scale downdraft gasifier. Energy. 2018;**163**(15):513-518. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0360544218316876

[16] Eghtedaei R, Mirhosseini SA, Esfahani MJ, Foroughi A, Akbari H. Co-gasification of biomass and municipal solid waste for hydrogen-rich gas production. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2017;**39**(14):1491-1496

[17] Tanigaki N, Manako K, Osada M. Co-gasification of municipal solid waste and material recovery in a large-scale gasification and melting system. Waste Management. 2012;**32**(4):667-675. Available from: https://www.sciencedirect.com/science/article/pii/S0956053X11004788

[18] Available from: https://enerkem.com/

[19] Available from: https://www.mhi.com/products/environment/pyrolysis_gasification_melting.html

[20] Available from: http://www.abengoa.es/web/es/noticias_y_publicaciones/noticias/historico/2017/11_noviembre/20171107_NP_Fulcrum.html

[21] Available from: https://ariescleanenergy.com/case_studies/fluidized-bed-gasification/

[22] Available from: https://ariescleanenergy.com/case_studies/new-tennessee-waste-to-energy-plant/

[23] Available from: https://ariescleanenergy.com/case_studies/city-of-covington-waste-to-energy-gasification-plant/

[24] Available from: https://ariescleanenergy.com/case_studies/replacing-natural-gas-for-industry/

[25] Tanigaki N, Kashiwabara T, Nagata T. Operating Experience from Japanese Waste Gasification Plants with Direct Melting System. Pyrolysis/Gasification. 2017. pp. 379-388

[26] Available from: https://www.globalsyngas.org/resources/map-of-gasification-facilities/

[27] Altmann E, Kellett P. Thermal municipal solid waste gasification. In: Renewable Energy Information Office. Status Report; Irish Energy Center. 1999. Available from: http://www.bluegreenearth.com/site/INCIN/incin/pdf/gasification.pdf

[28] Jones C. Thermal Processing of Waste. 1st ed. Bookboon. Aberdeen: J.C. Jones & Ventus Publishing ApS; 2010. ISBN 978-87-7681-590-5. Available from: http://www.znrfak.ni.ac.rs/serbian/010-studije/oas-3-2/PREDMETI/III%20GODINA/316-KOMUNALNI%20SISTEMI%20I%20ZIVOTNA%20SREDINA/SEMINARSKI%20RADOVI/2014/S151%20-%20S160.pdf

[29] Valkenburg C, Gerber MA, Walton CW, Jones SB, Thompson BL, Stevens DJ. Municipal Solid Waste (MSW) to Liquid Fuels Synthesis, Volume 1: Availability of Feedstock and

Technology. Richland, Washington: Pacific Northwest National Laboratory, U.S. Department of Energy; 2008. Available from: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-18144.pdf

[30] Tan Y. Feasibility Study on Solid Waste to Energy: Technological Aspects. Berkeley: College of Engineering, Fung Institute, University of California. 2013. Available from: http://funginstitute.berkeley.edu/wp-content/uploads/2014/01/SolidWasteToEnergy.pdf

[31] Gershman, Brickner & Bratton, Inc. Gasification of Non-Recycled Plastics From Municipal Solid Waste In the United States: Thermal Municipal Solid Waste Gasification. American Chemistry Council. 2013. Available from: https://plastics.americanchemistry.com/Sustainability-Recycling/Energy-Recovery/Gasification-of-Non-Recycled-Plastics-from-Municipal-Solid-Waste-in-the-United-States.pdf

[32] Byun Y, Cho M, Hwang S-M, Chung J. Thermal plasma gasification of municipal solid waste (MSW). In: Yun Y, editor. Gasification for Practical Applications. Rijeka, Croatia: IntechOpen; 2012. DOI: 10.5772/48537. Available from: https://www.intechopen.com/books/gasification-for-practical-applications/thermal-plasma-gasification-of-municipal-solid-waste-msw

[33] Rylander H. History of Gasification of Municipal Solid Waste through the eyes. WtERT Blog, posted by Ranjith Annepu. 2012. Available from: http://wtert.blogspot.com/2012/04/history-of-gasification-of-municipal.html

[34] Tangri N, Wilson M. Waste gasification & pyrolysis: High risk, low yield processes for waste management. A Technology Risk Analysis. In: Waste Gasification and Pyrolysis Technology Risk Assessment. GAIA. 2017. Available from: http://www.no-burn.org/gasification-pyrolysis-risk-analysis/

[35] Prepared by Authors Based in Several Studies made During Their Work with Coal Boilers and Power Plants at Colombia