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Zero Waste Through Processing Municipal Solid Waste (MSW) to Refuse Derived Fuel (RDF) and Energy Production While Minimizing Negative Environmental Impact

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Abstract

This study addresses the critical environmental and logistical challenges of modern municipal solid waste (MSW) management by proposing an integrated system that transitions from traditional "in natura" incineration and landfilling toward a zero waste model. Traditional waste disposal methods are often plagued by operational fluctuations, toxic emissions (such as dioxins and heavy metals), and significant contributions to greenhouse gas emissions. This research presents a technological framework that uses mechanical, thermal, and manual processes to convert MSW into refuse derived fuel (RDF), ensuring a more homogeneous and controllable combustion process.

Keywords: zero waste; MSW; RDF; energy; environmental impact; recycling; waste to energy; thermal oxidation

Abbreviations: MSW: municipal solid waste; RDF: refuse derived fuel; EFW: energy from waste

1. Introduction

The incineration of municipal solid waste (MSW) "in natura," with or without energy generation, has been used in the past as a means of properly disposing of MSW. Such traditional incineration plants were subject to operating fluctuations due to changes in the characteristics of the waste during feeding into the combustion chamber. In addition, due to deficiencies in waste preparation, even with advanced gas purification devices, such plants were responsible for emissions of toxic gases such as dioxins and heavy metals. The use of advanced gas purification devices has significantly reduced emissions of toxic gases such as dioxins and heavy metals.

Today, thermal oxidation of waste remains the best way to reduce waste, especially through more suitable plants that pre-process the waste and generate refuse derived fuel (RDF) for thermal oxidation. Depending on the process and the characteristics of the slag or ash, if they are recyclable, it is possible to achieve zero waste at the end of the process. On the other hand, if greenhouse gas emissions are taken into account, the use of fuels derived from MSW in energy generation, rather than waste "in natura," can be a better option when compared to the burning of gases in landfills.

The production of RDF and energy generation are in line with the direction of sustainable waste management, which must consider the combination of reduction, reuse, recycling, recovery of useful content, waste treatment, and only as a last resort, when it is unavoidable, disposal. On the other hand, the European Landfill Directive sets targets for diverting waste to options such as recycling, composting, and energy recovery, so its implementation implies an obligation to restrict the use of landfills. The use of dumps or landfills is no longer acceptable where the aim is to reduce or eliminate environmental impacts.

For example, in the United Kingdom, tax increases and the implementation of the EU Landfill Directive suggest that, in the long term, waste disposal will become the most expensive and least sustainable route to waste management.

Waste-to-energy recovery is a technology consistent with modern management guidelines. The new European Community Emission Directives ensure that EFW plants must comply with rigorous standards and minimize environmental risk. EFW plants can complement existing and proposed recycling services. Many European countries that achieve the highest levels of recycling also have high rates of energy recovery.

2. Objective and Methodology

The objective of this work is to present a process that incorporates known and operational technologies, which, with the appropriate adjustments, allow for the reduction of the volume and final disposal of MSW to the maximum extent possible, down to zero final disposal (zero waste), with the least possible environmental impact, while obtaining economic results in a sustainable manner.

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For this work, facilities were visited, studied, and evaluated. These included facilities for processing MSW "in natura" for recycling purposes; facilities for thermal waste treatment in operation; effluent and emission treatment systems; energy generation units using biomass **(Figure 1)**; and pilot facilities using the integration of these processes **(Figures 2 and 3)**. After meetings with various technicians from different facilities, the application of the concept was defined for a real case. Based on these observations, a team consisting of engineers, administrators, economists, social workers, and lawyers prepared a comprehensive and in-depth study for a city of 700,000 inhabitants in Brazil. A waste management master plan was developed, proposing the implementation of combustion processes with energy generation as a solution. Environmental performance parameters were evaluated based on results obtained at the various facilities visited and in pilot tests carried out **(Table 1)**.

FIGURE 1: Sugar cane biomass thermal power plant in São Paulo State, Brazil.

FIGURE 2: External view of RDF pilot thermal power plant in Rio de Janeiro, Brazil.

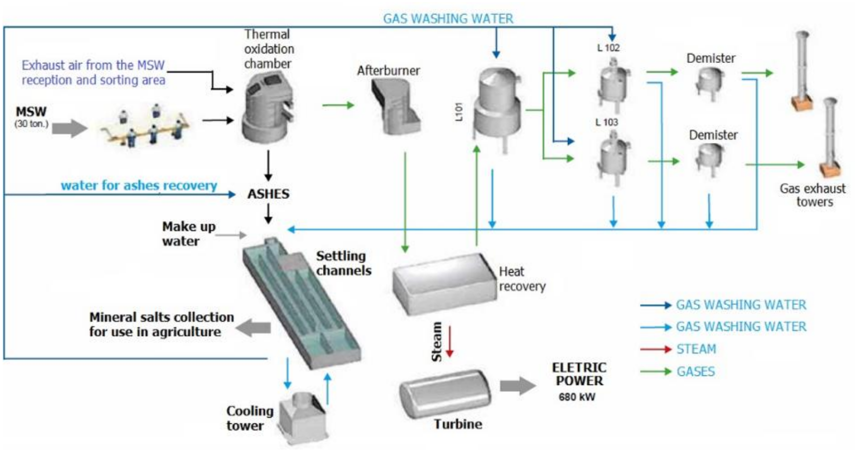

FIGURE 3: Simplified flowchart of pilot RDF thermal power plant (without complete MSW treatment).

TABLE 1: Average gas emission composition based on pilot plant operation.

Temperature (°C)	**Min = 50**	**Max = 60**
Composition	(%)	kg/h
CO_2	0.06	34.29
H_2O	6.6	3772.39
HCl	ND	ND
O_2	10.92	6241.59

SO_x - SO_3	ND	ND
So_x - SO_2	ND	ND
NOx - NO3	ND	ND
NO_x - NO_3	ND	ND
N_2	82.41	4710.41
Total	99.99	57151.68
Other emission parameters		
Dioxins and Furans	≤ 0.093 ng/Nm^3	
Particulate matter = 9 mg/Nm^3		
Cd, Hg, Ta	≤ 0.04 mg/Nm^3	
As, Co, Ni,Te, Se	≤ 0.45 mg/Nm^3	
Sb, Pb, Cr, CN, Cu, Sn, F, Mn, Pt, Pd, Rh, V	≤ 0.45 mg/Nm^3	

ND - Below most restrictive parameters

3. The Process and Its Stages of Development

The process consists of homogenizing MSW in terms of size, moisture content, and composition using a combination of mechanical **(Figure 4)**, thermal **(Figures 5 and 6)**, and manual processes **(Figure 7)**. The latter procedure is preferred in developing countries as a way of generating jobs and income for people without qualifications and who are difficult to employ; so in these cases, it is more of a social component than a technical necessity.

FIGURE 4: Homogenization trommel - part of the mechanical processing of MSW to RDF.

FIGURE 5: Autoclave for thermal treatment of MSW to RDF.

FIGURE 6: Detail of MSW feeding in autoclave.

FIGURE 7: Detail of a manual selection of MSW recyclables in conveyor belt.

The production of fuel from MSW allows almost all (if not all) metal to be removed from the waste stream, as well as some of the chlorinated plastics **(Figure 8)**, resulting in lower emissions into the atmosphere, particularly of heavy metals, and better control over the generation of dioxins.

FIGURE 8: After thermal treatment MSW turn it easier to put apart PVC from other plastics.

The process also provides a homogeneous size for feeding the combustion chamber or boiler. The heat energy can also be controlled by feeding mixtures of waste with clean biomass, such as sawdust or wood waste.

Adequate thermal balance **(Figure 2)**, in addition to increasing calorific energy, allows for emissions management; for example, the most volatile gases, including mercury, when present, can be treated at low temperatures before the boiler or combustion chamber is fully operational. It is also possible to incorporate advanced gas purification systems to ensure better emissions control.

The size of the facilities, costs, and energy generation capacity make controlled MSW combustion a suitable solution for cities that generate more than 390 tons/day of MSW. However, this figure can be reduced to 130 tons/day if non-hazardous industrial waste or agricultural residues are incorporated and/or the steam and hot water from the plant are utilized.

In addition, carbon credits can become another source of income for these projects. These additional resources help to cover the costs of the plant.

4. Results

With the proposed operation, the disposal of MSW in the environment is progressively reduced to zero. Methane emissions from garbage dumps, landfills, or sanitary landfills do not occur, as there is no longer any garbage to ferment.

At the same time, CO_2 emissions from the process are lower than those from other sources of energy generation. The processing of RDF (biomass), replacing the direct burning of MSW, minimizes emissions of heavy metals (volatile) and organochlorine gases, including dioxins. The emission of the latter in the thermal oxidation of MSW is at least 50 times lower than the emissions derived from the burning of waste in open dumps.

Another beneficial result for the operation and society is the generation of carbon credits, based on the generation of energy from renewable and non-fossil fuels, as well as the conversion of CH_4 and CO to CO_2, and the reduction of transportation between waste processing units. In this process, waste generates resources from the sale of cogeneration energy, benefiting the operating company and the municipalities.

In addition, the plant can also generate resources for the operator and royalties for the municipality from the reception and processing of non-hazardous industrial waste and its treatment for energy generation.

The commercialization of the steam generated at the plant for industrial purposes is also a factor that can encourage the industrialization of sectors surrounding the facilities. A summary of the benefits of the operation, compared to a dump site, is shown in **Table 2**.

TABLE 2: Summary of benefits related to energy generation from RDF.

	Open city dump	**RDF production and energy generation**
Waste Water Generation (M^3/day)	456	None
CH4 – Biogas generation (M^3/day)	38874	None
Soil disposal (T/day)	500	25 (only in the start)
CO2 - Biogas generation (M_3/day)	29326	1000
Dioxin generation (PPB)	> 50X	X
Scavengers	Yes	No
Disease vectors generation (/day)	750 million	None
Children's labor	Yes	No
Energy generation (MWH)	None	8,68
Steam generation (T/h)	None	54
Carbon credits (CH^4) (US $/day)	None	2775
Carbon credits (CO_2) (US $/day)	None	158

The productivity achieved with the model is calculated based on the net flow of construction and operating costs and the income from waste disposal, energy sales, and the sale of carbon credits, as well as indirect positive outcomes (such as human health benefits and the commercialization of recycled materials) resulting from the treatment method used by the system.

The liquid effluents from cooling and gas scrubbing, together with small amounts of leachate generated in the plant's reception pit, are used in the process, with no liquid effluent being discharged into the environment, unlike what occurs in landfills and dumps, where leachate can alter surface and groundwater sources.

The ash and slag generated in the thermal oxidation process can be used in the manufacture of ceramic blocks, as a base for paving, or in the manufacture of mineral salts for the correction of acidic soils. Contrary to what happens in landfills, an air control system, through recirculation, negative pressure in the plant, enclosure, and use of filters, prevents the spread of odors from the waste both in the plant and in the surrounding area.

Gas emissions from thermal oxidation are minimized by the removal of metals and organohalogen compounds in the RDF preparation process, in addition to thermal shock treatment in an alkaline environment. The gases emitted have concentrations below the maximum levels permitted by strict European standards.

Because it is not harmful to the environment (and is equipped with a system that prevents the emission of odors from the waste), the RDF production and energy generation plant can be installed close to the communities that generate the waste, allowing for financial and environmental savings in waste transport logistics. One of the facilities in operation in Brazil is located between a hospital and a university restaurant. The benefits of a power plant using MSW compared to a landfill, for a municipality of 700,000 inhabitants over a 20-year period, can be seen in **Table 3**.

TABLE 3: Cash flow summary.

Description	Unit	Annual amount	Unit price (R$)[1]	Annual value (R$)[1]
Waste management cost				(27,621,000,00)
Fee	Ton	162,000.00	(170.50)	(27,621,000.00)
Revenue reverted to the city				15,662.289,00
Energy generation	Mwh	72,000.00	169.08	12,173,760.00
Concession tax	R$	27,621,000.00	1.00%	276,210.00
Carbon credit - CH_4	Ton	9,648.60	315.00	3,039,309.00
Carbon credit- CO_2	Ton	11,534.00	15.00	173,010.00
Externalities				21,568,886.54
Recycling revenue	vb	1.00	2,911,626.00	2,911,626.00
Savings due to recycling	R$			15,526,040.54
Glass	Ton	6,544.80	70.58	461,917.85
Aluminum cans	Ton	486.00	4,118.06	2,001,376.09
Steel cans	Ton	2,511.00	996.61	2,502,487.01
Plastics	Ton	10,692.00	987.68	10,560,259.59
Other savings	R$			3,131,220.00
Landfill area	m2	5,248.80	25.00	131,220.00
Landfill maintenance	mes	12.00	250,000.00	3,000,000.00
Balance	R$			12,620,809.36

1R$2,10 = US$1.00

5. Conclusion

MSW disposal through the proposed method shows clear and combined economic, social, and environmental advantages over other disposal methods. Due to the process, its implementation is recommended in cities that manage MSW and non-hazardous combustible wastes in quantities equal to or greater than 390 tons/day. This number can be reduced if plant efficiency is increased by the use of hot water and steam for industrial applications.