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Incineration and energy recovery from waste materials: Assessment of environmental impact of emitted gases

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Abstract

Energy recovery from waste materials is a herculean task in view of its impact on the environment. Waste materials are becoming increasingly cumbersome considering huge proportion of synthetic materials being used for product formation and developmental projects. The process of energy recovery from these wastes serve to reduce significant quantity that would not be naturally decomposed thereby declining their influence on the safe environment. While global fossil fuel energy is finite in nature, this process provides alternative sources of energy in an environmentally friendly manner. The treatment process of waste to energy has no doubt increase the vulnerability of environment to climate change, among other methods. Studies have shown that waste generated from urban areas globally will increase from about 3.5 million tonnes per day to 6.1 million tonnes per day by 2025. These increasing waste volumes will definitely require the application of sophisticated incinerators to evolve alternative energy that could be used for basic needs. In this paper, the authors access the environmental impact of waste-to-energy recovery taking into considering the existing approaches, as per waste volume and available incinerating plants. The paper also identifies various waste gases associated with incinerating plants which could compromise environment and increase biodiversity dislocation. All these concerns were x-rayed as part of the suggestions to improve material formation towards biodegradability. Taking into consideration how long synthetic materials would continue in industrial space, this paper proposes a countermeasure which could be useful to stabilize the existing energy recovery process while hoping for full adaptation of sustainable and eco-friendly green materials.

Keywords: Waste, Emissions, Energy, Treatments, Minimization

1. Introduction

Incineration of waste is becoming the only approach to mitigate waste volume in many developing countries of the world. This method is being patronized due to various advantages offer in terms of waste reduction regardless of the constituents. Several studies on waste incineration have raised a lot of concerns on emission of dangerous gasses associated with their operations. This emissions could also poise varying risks to the environment among other effects. Sourcing for alternative energy from waste materials have also been on the front burner several years ago in view of the impact of the fossil fuel on the climate. This concerns could have necessitated the evolution of waste-to-energy syndrome where wastes are now a significant sources of energy in many emerging countries. Climate change occasioned by energy sources have evolved the application of lightweight materials where their decomposition is largely a global threats. This has manifested in their reclamation process where in several cases neither retain any biodegradable structure after being subjected to different recycling plants [1-2]. The application of incineration in waste reduction largely requires the use of energy to power these plants. This energy as derived from fossil fuel is a global monster whose emissions is largely responsible for greenhouse gas and other pollutant globally [3-4]. Part of the key goal of sustainable development program of UN is to reduce the impact of fossil fuel use on environment and to ultimately keep the world safe [5]. The emissions, from the fossil fuels is one of the global threat to the environment, heating the global space and resulting in continuous rise in ambient temperature [6-7]. Although, fossil fuel energy have shown to be the more reliable sources of energy in many incineration plants with remarkable outputs [8-9], it has also depicted a gradual contribution of emission releases from these plants. Global energy use is currently saturated with fossil fuel. These industries have also consumed billions of dollars as crude oil demand rises (Figure 1). Waste combustion in an incineration plant is often conducted in an exothermic manner where the key ingredients required are fuel and oxygen (O_2). This is also accompanied by alternative energy in which waste is predominately used as fuel in modern incineration plants to reduce the overbearing impacts of fossil fuels. The flame portion of a many

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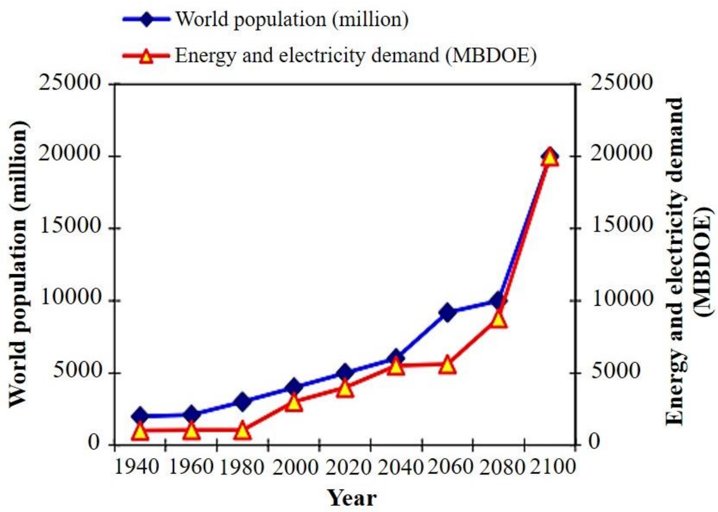

Figure 1 Global population and the corresponding energy demand. Adapted from [10]

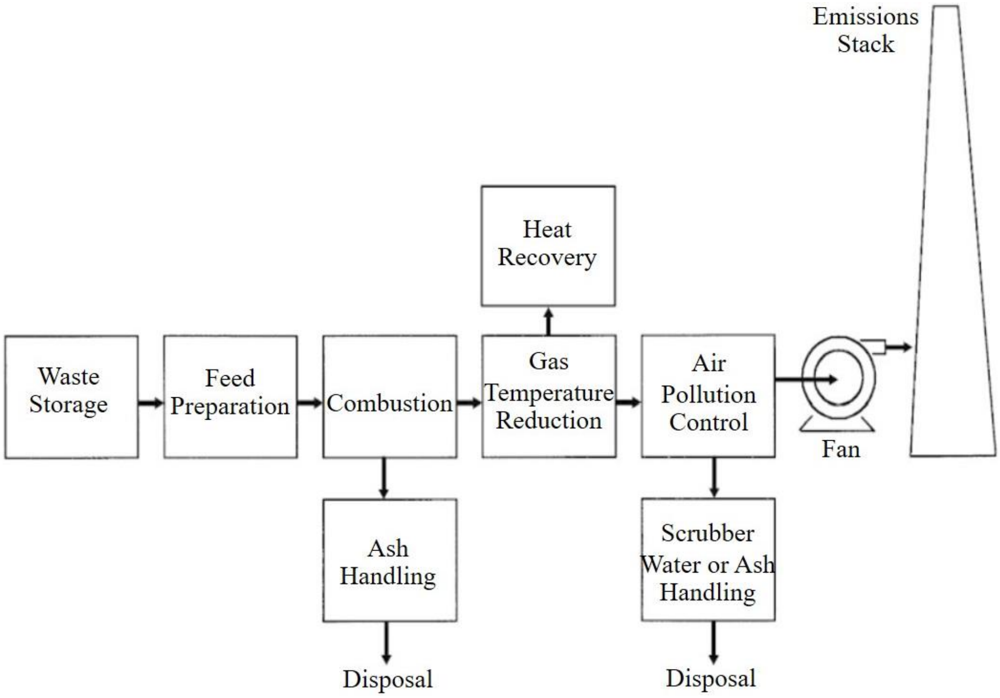

Figure 2 Typical waste-incineration facility schematic. Adapted from [11]

incinerator is extremely hot to decompose all organic and inorganic materials, where several reactions occur between components of the waste materials, oxygen and nitrogen in ambient temperature. One of the significant reaction also involve carbon (C) and oxygen, where carbon (IV) oxide are produced. It is also established that hydrogen (H) and oxygen could also be produced leading to the formation of water (H_2O). Incineration process is also reputed to evolve incomplete combustion of organic compounds where carbon monoxide (CO) and carbon-containing particles are produced in large quantity. Hydrogen, in most cases, during partial combustion, combine with organically-bound chlorine to result into hydrogen chloride (HCl). Several other reactions are also occurring during the process producing combined oxides, like, sulfur oxides (SOx), nitrogen oxides (NOx) and complicated metal vapors from chain-reaction process as shown in Figure 2.

Energy requirement in major incinerating plants appear unending considering the rising of global waste and their links to environmental sustainability [12]. Several gaps have been identified from energy recovery as it relates to many incinerators where their carrying capacity have been overburdened resulting to environmental instability [13-14]. Waste management using incineration technology has been criticised in several papers [15-17] depicting the method as environmentally unfriendly due to its emission during operation and maintenance. The concept of energy from waste is a method in which energy are recovered in the form of useable heat [18] which can be applied as electricity.

Global waste volume is predicted to rise considering the increasing urban population [19]. Waste generation per capita is more in developed countries than that of the developing countries. The reason is that waste generation of any region is a function of economic and social prosperity of

Table 1 Pollutions from US incineration plants. Adapted from [20]

Emissions	Annual emissions 1990	Annual emissions 2000
Dioxins	4260g	12g
Mercury	41.1 tonnes	2.0 tonnes
Cadmium	4.32 tonnes	0.3 tonnes
Lead	47.4 tonnes	4.33 tonnes
Hydrochloric	42.6 tonnes	2429 tonnes
Sulphur dioxide	27.9 tonnes	3705 tonnes
Particulate matter	6300 tonnes	643 tonnes

Table 2 Incineration stages.

Stages		References
1	• Drying and degassing	[21]
	• Gasification and pyrolysis	[22]
	• Oxidation	[23]
2	• Incineration	[24]
	• Energy recovery	[25]
	• Air pollution	[26]
3	• Waste delivery and storage	[27]
	• Combustion section	[28]
	• Energy conservation	[29]
	• Cleaning of flue gas	[30]

any nation. Prediction in many literature shows that in the next two decades, many countries in Africa and Asia will generate more waste than developed countries of the world [31]. This may not be unconnected with rising social integration and awareness in many local regions. Waste build-up in cities and localities are sources of environmental crisis, such as greenhouse gas emission, water pollution and other social vices [32-33]. Several authors [34-35] have raised alarms criticizing the pace at which the human population had grown in this quarter-century, with an approximately four-fold increase from 1.5 to 6 billion this century alone. What is of paramount concern to every researchers is the uncertainty of the environment carrying capacity and with the projection of global population reaching 10 billion by around 2060, it is crystal clear that waste generation and attendant management will impact further on the environment [36]. The process of exploiting valuable ingredient from waste materials is ongoing globally in which recycling approach is part of them. Environmental impact of recycling method is insignificant compared with other waste management methods. Energy recovery from waste materials has been acknowledged to diversify over-reliance on fossil fuel energy but some of their attendant repercussion will be discussed in detail in this work. Some researchers [37-38] have established that recycling of waste is less environmentally than energy recovery process of waste materials.

2. Present status of waste to energy

Waste incineration architecture appear complex as it is being witnessed in some developing part of the world. A lot of incinerators were mounted to curb waste volume with no air pollution controls [27, 39]. Studies showed that an estimated 18,000 residential incinerators and 32 municipal incinerators are available to mitigate waste volume. There are several unaccounted waste incinerators in most remote cities of the United States which invariably left a bad image of incineration in major cities in the United States till date. This further compounded waste volume and environmental threat. Table 1 shows different proportion of emission in the US between 1990 and 2000 with about 10% decline in gas emission over 10 years period. Although, the decline has been consistent over successive years, this success may have been ascribed to adaptation of incineration methods as illustrated in Table 2. These steps were carefully researched by these authors who x-rayed many incineration plants with optimal energy recovery. Part of the submission drawn from their works indicated that many plants in developing countries fail to integrate different stages of incineration process.

Extensive research has evolved incineration plants in developed countries which operate quite well with less environmental pollutions. This may not be the case in some countries where recovering of energy from incinerators have not been optimally achieved. In some Asian countries, Japan is singled out as a country with high preference for waste incineration technology due to improvement on the existing incinerating plants. The limited land area for waste dumping in Japan may have prompted the adoption of waste combustion in the most effective manner. Incineration of waste is not sustainable in many developing countries except those with potentials to technically contain the pollutions. The main reason is basically the high operating cost and the characteristics of the composition of the wastes. Investigative research on the performance of incinerators in many developed countries have revealed conflicting reports with no specific blueprint on emission of pollutants by these incinerators. Findings from literature [40] have shown that China has about 166 operational incineration plants for energy generation using waste materials at the rate of 166,000 tonnes/d with insignificant release of emission into the surrounding. The work as contained in this paper [41] claimed that the waste incineration in china had significantly diversify the renewable energy market leading to enhanced electricity generation. Lombardi, et al. [25] found out that China is currently facing several problems with waste incineration. The authors highlighted sources of the challenge to include poor characterised waste feedstock, partial combustion of waste, and increased air pollution.

Table 3 Rate of emission in major incineration plants in selected regions. Adapted from [42]

	Emission factors as daily average(mg/Nm^3)				
Region/country	**Particulate matter**	**CO**	**SO_2**	**HCl**	**NO_x**
EU	10	50	50	10	200
US	19	89	60	33	270
Japan	44	38		78	523
South Korea	20	57	79	30	131
China	20	80	80	50	250
Average	22.6	63	67	40	275

Table 4 Average power generation from European incineration plants. Adapted from [20, 25]

Parameter		**MWh. of treated MSW**	**Plants sizes**
		Average	
Power	Produced	0.546	8
	Export	0.396	
Heat	Produced	1.922	15
	Export	1.786	

Findings also showed that some of the inherent challenges making incineration difficulty in developing countries are beginning to resurface in China. Some of these waste materials have begun to create multidimensional problems in many operations leading to emissions and particulates as depicted in Table 3.

The evolution of modern incinerators is difficult and unsustainable in some emerging countries like Latin America and Australia. Waste incineration have been misconstrued for waste burning in remote area with air pollution being the aftermath effects. The only waste recovery facility reported is still under reconstruction and assessment in Addis Ababa and the yield production in terms of energy recovery is in the range of 1400 MT/d. Brazil has recorded a significant improvement in the waste to energy recovery with the development of a modern incineration with capacity of about 600 MT/d while Australia recently reported an evolution of incinerators with the projection of energy recovery of 390MT/d [25]. Studies have rated China operating the largest capacity of waste incineration using fluidized bed, with most fluidized bed parts being sourced from Europe. This outsourcing of incinerator parts is currently weighing on China as maintenance becomes frequent. Reviewed literature on incineration and maintenance shows that the largest decline and patronage occurred in the United States as compared to other developed countries of Europe or Asia. The main reason leading to the decline in construction and utilization of new and existing incineration plants was public perception arising from pollution concerns. Another possible reason is the provision of land for new landfills which is cheaper alternative for waste disposal as against waste incineration. The energy quantities of heat and gas recovered from waste incineration plants were studied over a period of time by these authors [20, 25] and presented in Table 4. The finding showed that energy recovery circuits in most incineration plants around the world today are anchored on the existing rankine cycle with end products being released in the form of heat and power (HP) or power and steam (PS) configurations.

3. Identification of complex emission and gases from incineration

Findings have shown that incineration of waste is largely associated with various organic and inorganic releases which in most cases are in the form of stack gases, bottom ash and fly ash. Most researchers have also shown the interaction between inorganic matter, chlorine and metals as the source of poly-chlorinated dibenzo-dioxin/furan (PCDD/Fs) and polycyclic aromatic hydrocarbons (PAHs) in the environment. The work of [43] was explicit on the reaction of this complex compound with the high ambient temperature resulting in the formation of low-temperature macromolecular carbon with different organic precursors such as chloro-phenols. This complex compound of PCDD/Fs is known to exist in most organic waste which is rarely destroyed during incineration process. PCDD/Fs is formed during combustion, and mostly in the region of low-temperature post-combustion zone of incinerations. This compound is also reported to occur when there are some heterogeneous catalytic reactions in the flue gas and fly ash zone. The impact of chlorine content in the waste materials for combustion has been studied in many past works with most results indicating the formation of PCDD/Fs in incineration. Modification of incineration systems have been recorded in many literature with varying waste feed and different component of furnaces to eliminate the formation of polycyclic aromatic hydrocarbons in the waste stream. This approach have resulted in the distribution of PCDD/F emissions and partial combustion of waste materials. Different authors have attempted to reduce the formation of complex compound during combustion process into the ecosystem. Extensive research were conducted by [44] to monitor chlorine emissions from batch combustion of polystyrene materials which is a dominant component materials in waste streams. Further innovation was introduced in the incineration process as contained in the work of [45] deploring batch combustion process with so significant reduction in the emission. Studies have also shown that substantial proportion of inorganic acidic gases, majorly hydrogen chloride and the compound of nitrogen oxides (NOx) were formed as a result of the presence of chlorine, fluorine, sulphur and nitrogen in waste stream and are released by incinerators [46]. It can be inferred that NOx are also formed as a result of the interaction of nitrogen and oxygen under a very high ambient temperature. The presence of chlorine in waste stream has also prompted the emission of hydrogen chloride in most incinerators. Detailed research works were carried out by these authors [47] on waste stream combustion taking into consideration several incineration plants. Part of the conclusion indicated that most heavy metals are from incinerators. These metals sometimes display high level of toxicity at low concentrations and tend to react at interface. Major sources of these metals in the

Table 5 Particle size concentration in the heavy metal of bottom ash. Adapted from [48]

Average concentration (mg kg^{-1})				
Particle	**>9.5**	**4.75-9.5**	**0.5-4.75**	**<0.5**
size	mm	mm	mm	mm
Pb	75.4	115.4	205	369.9
Ag	13.1	172.6	172.6	93.1
Fe	8764.9	89,286.8	89,286.8	27,231.1
Zn	1115.8	5,681.8	5,681.8	8,494.6

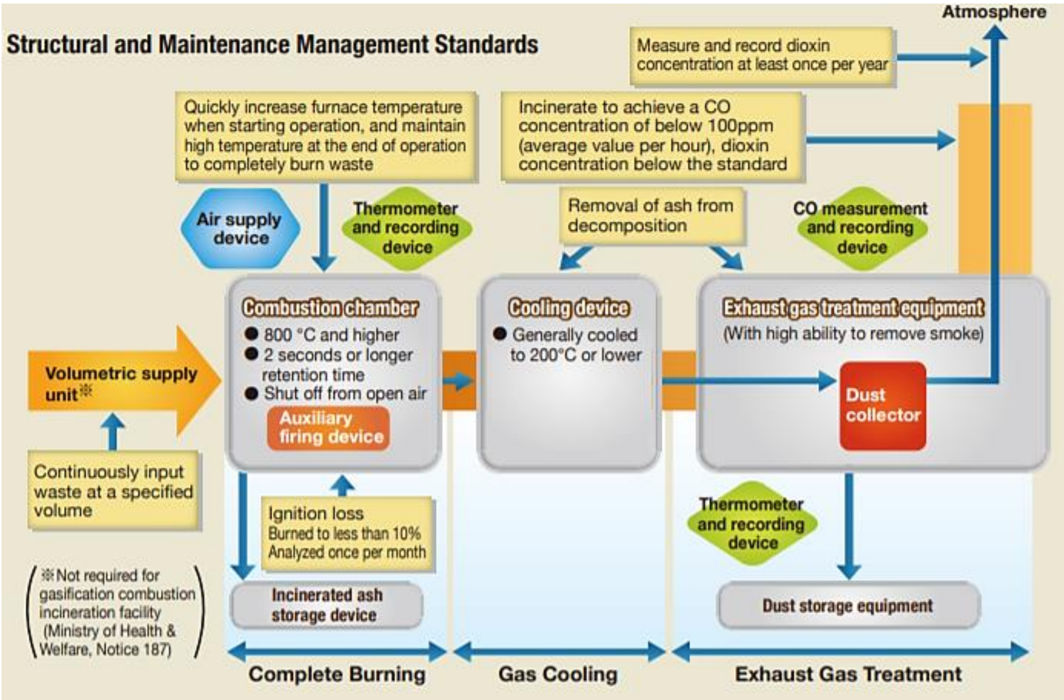

Figure 3 Sustainable management approach on dioxin emission and other dangerous gases. Adapted from [49]

incinerators appear as components of various waste materials at the point of combustion. Reports also had it that a proportion of these toxic metals is released in the stack gases of most incinerators to environment. Part of the concerns is that substantial part of the heavy metals is equally found in fly ash and bottom ash while the mercury is released via the flue stack. Most emitted ashes consists of 22 elements while the variation differs from region to regions depending on the nature of the waste materials. Studies have equally showed that most incinerated plastic wastes were often a source of lead in most underground water. Experimental work carried out to establish the relationship between particle content of waste materials and the resulting heavy metal presence in the emitted ash from the incinerators is summarized in Table 5. All these particle sizes show the degree of heavy metals in the bottom ashes of incinerated waste materials.

4. Countermeasure for the environmental impact from the waste to energy

Waste incineration would have been unnecessary if some of these underlying impact is minimal. Evolution of sustainable measure to reduce the emission from incineration plants is vital to continuous operations. Waste materials are becoming complex and unsustainable going by environmental carrying capacity and reclamation problem. It is therefore necessary to evolve biodegradable materials in product formation to limit waste incineration. The need to adapt lightweight of natural fibre source is an integral part of safe climate. By so doing, waste would be naturally degradable with little or no technological influence. Incineration process is always accompanied with releases like, SOx, HC1, NOx, smoke and dioxin. These emissions pose a threat to environment and to people residing near the plant. The impact of some complex compound are equally felt on the underground water where in several cases tend to be compromised with heavy metals like, mercury, iron. This impact is serious on the continued survival of man and animals. Studies and roadmaps have been evolved in time past to mitigate some of these occurrences. Part of the approach was the development of the countermeasure and subsequent improvements on the existing operation technology. Extensive researches have been conducted on the emission of dioxin and it was found out that their occurrence was as a results incomplete combustion of waste. Some of the measures taken to reduce dioxin was to achieve complete combustion in the furnace where there could be possibility of reducing the duplication of dioxin. Other innovation could involve the introduction of bag filter which can reduce dioxin contained in smoke, which can also be rejigged in an activated coal, thereby adsorbing and eliminating dioxin in exhaust fumes with the aid of a catalyst that decomposes the evolving dioxin. Based on the precautionary studies presented, these may lead to a structural and maintenance management standards for the incineration plants. Existing measures of mitigating the proliferation of dioxin and other poisonous gas emissions are depicted in Figure 3 which offers to reduce dioxin from incineration plants including other poisonous gases like SOx, HC1, NOx and other substances. This approach would be better complemented if wastes are characterised on the basis of origin. Adaptation of natural fibre in part formation and replacement could largely be a pragmatic solution to some of these myriads and complicated waste management.

5. Conclusions

Application of incinerations to treat waste materials have been reviewed in this work with focal point on the associated emissions inherent in the process. Waste materials is a collective, unwanted trash collected from various sources in the environment and their compositions vary considerably based on their sources. Energy recovery from waste materials is an ecologically and economically attractive practice with associated environmental concerns. Substantial progress has been made with the use of incineration in the recovery of energy from waste materials going by the recovery of heat, and steam, gases and char, syngas methane and low molecular weight generated from waste materials. Part of the ongoing concerns is the release of gaseous pollutant to the atmosphere like sulfur oxides (SOx), carbon oxides (COx), and nitrogen oxides (NOx), polyaromatic hydrocarbons (PAH), heavy metals, hydrogen chloride(HCl), hydrogen sulfide (H_2S), and ammonia (NH_3).These emissions has led to public phobia against pollutants during incineration process. Further reports had it that the emission of dioxins in most incinerators has not been checkmated leading to environmental pollutions. Although, the paper has demonstrated that incinerators is still a relevant tool in mitigating waste volume and as such, there is urgent need to reduce emissions from these ashes which will reduce the negative public perception and make incineration a more acceptable technology.

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