University of Baghdad
College of Engineering
JE
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 31 Number 2 February 2025

A Theoretical Incinerator Design for Treatment of Biomedical Wastes Generated from Local Hospitals in Baghdad

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ABSTRACT

A theoretical study is done to treat Baghdad biomedical wastes (5.21 tons/day) using many treatment methods according to construction and maintenance costs, energy and water consumption and decreasing waste volume and mass. Previous published experimental data results and experimental operation conditions are considered in the current research. The thermal energy and generated wastes are computed from the complete combustion of biomedical wastes (100 kg/h) from two hospitals in Baghdad. Survey data shows that the Medical City and Al-Yarmouk Hospital generate about (700 kg /day) of biomedical waste. A multi-chamber incinerator with a capacity of (100 kg/h) has been designed to burn biomedical wastes using diesel fuel to reach (1100˚C) as a burning temperature. The resulting thermal energy was computed to be (0.7178565 MW) which is emitted directly with flue gases to the ambient without any off-gas system. The mass of flue gases is found to be (1895.8175 kg/h) and the gases are (193.20872 kg/h for CO_2 and 1.6352 kg/h for HCl) through using excess air ratios at 150% for solid wastes burning and 20% for liquid fuel burning. The required cement and water are determined for resulting ash to produce concrete suitable for hot weather countries. The results show that incineration has the less costs in construction and operational costs among other modern technologies with a decreasing waste mass to 91.5%.

Keywords: Biomedical wastes, Incineration, Autoclave, Plasma treatment.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2025.02.12

Article received: 07/07/2024
Article revised: 15/12/2024
Article accepted: 03/01/2025
Article published: 01/02/2025

1. INTRODUCTION

Biomedical wastes were combination of dangerous and non-dangerous wastes which were generated in thousands of tons each day all around the world. The continues growth and population increase and increment in human activities were having a huge impact on the environment as result of biomedical wastes generation increment. In Iraq, biomedical wastes represented a serious environmental challenge and need modern technologies to treat and disposal of these continues generated hazardous wastes. **(Al-Hashimi and Al-Mandalawi, 2007)** presented treatment of solid wastes (biomedical and conventional wastes) in many hospitals in Baghdad during the period between 2003 and 2004. The rate production of wastes changed from (0.3 to 1.6 $\frac{kg}{bed.day}$). Their results presented that the density and moisture content for medical wastes was (219.56 kg/m^3, 21%) respectively, and for conventional wastes (298 kg/m^3, 48%) respectively. The study also presented that there was a relatively big concentrations for heavy metals in ash of incinerators of the studied hospitals and this founding indicated that incinerator's ash from those hospitals incinerators represented a dangerous to soil and water pollution and must be land-deposited in suitable sites . They suggested a central incinerator with a proper design and trained operating staff must be provided for the city of Baghdad to treat the generated medical wastes, and to make use of the heavy metals in incinerator's ash.

(Abd Al-Razak, 2009) used theoretically different kinds of liquid fuel on boiler efficiency using different excess air ratios. **(Curkeet, 2011)** studied theoretically the wood combustion characteristics with (50-100)% excess air ratio. **(Ferdowsi et al., 2013)** gave a comparative study between incineration and autoclave in Isfahan hospitals in Iran, their results showed that autoclave is better than incineration with respect to energy consumption, effects on environment, economic except the capital investment. **(Elinwa, 2016)** studied experimentally the hospital waste ash (HWA) from incinerators in concrete production, his results showed that (HWA) was suitable for concrete production with good properties especially in hot weather. **(Al-Obaidy et al., 2016)** studied experimentally the effects of medical city hospital wastes in Baghdad on the suitability of Tigris River, their results showed that the water of the river is unsuitable for human uses because of the high contamination level, these results were the same as **(Al-Hiyaly et al., 2016)** results. **(John and Swamy, 2011; Ganguly et al., 2017)** designed a multi chamber incinerator with burning mass of (100 $\frac{kg}{h}$) to treat (100 $\frac{kg}{day}$ and 500 $\frac{kg}{day}$ respectively) of biomedical wastes for some hospitals in India. They gave a detailed procedure for material and heat balance calculations which was important to design a suitable multi chamber incinerator and it is the same procedure that issued the presented article. **(Pant, 2018)** presented the effects of using the autoclave method on treating biomedical wastes, his results showed that (0.12 L water/bed. day) and the autoclave method was water consumed and pollutants to the ground water with heavy metals.

(Al-Nakkash et al., 2019) assessed health care waste treatment in govermental and special hospitals and general health centers in most cities of Iraq. The hazardous solid wastes were (10-25) % of the total biomedical wastes, their results showed that government hospitals produce (500 $\frac{kg}{month}$); (167 $\frac{kg}{month}$) in special hospitals and (83.3 $\frac{kg}{month}$) of solid hazardous wastes in general health centers. There are 145 govermental hospitals (with 36347 beds), 1717 general health centers and 73 special hospitals. The average solid wastes generating rate per bed was determined as (1.4 - 1.7) $\frac{kg}{bed.day}$. **(Suryawan et al., 2019)** studied experimentally the compressive characteristics of solidification process of bottom and fly ash with cement from incinerators of biomedical wastes with mixing ratio of (70 ash: 30 cement) for 7 and 28 days, their results showed that maximum compressive tests were (682 and 772) tons/ m^2 respectively. **(Nada, 2019)** gave treatment methods of biomedical wastes in twenty of Baghdad's hospitals to develope the surrounding environment. His results showed that most of the studied hospitals used incinerators to treat biomedical wastes and all the incinerators were out of date and with bad maintenance and operation conditions. **(Mensoor, 2020)** presented treatment of biomedical wastes in some of Baghdad governmental hospitals with beds of (5241 bed) including Al-Yarmouk teaching hospital (647 bed) and Baghdad Medical city (956 bed) which are the target of the current research. His results presented that the mean production quantity of biomedical wastes in the studied hospitals was 0.5 $\frac{kg}{bed.day}$ and (0.7 and 0.2) $\frac{kg}{bed.day}$ for Al-Yarmouk and Baghdad hospitals respectively.

(Devi et al., 2020) invented new device to separate the biomedical solid wastes automatically, the new device consists of many different sensors and image processing unit using MATLAB in order to prevent diseases that spreading through manual separation process of medical wastes in hospitals. **(Jena et al., 2021)** presented the influence of improper biomedical wastes treatment on environment during COVID-19 pandemic, they suggested a serious solution and development for incinerators to reduce the hazardous health and environmental impacts resulting from biomedical generated wastes. **(Giakoumakis et al., 2021)** gave a review for biomedical wastes management and treatment of fourteen different technologies to produce energy, fuel and useful materials in laboratory and industrial scales during COVID-19 pandemic and corresponding increase in biomedical wastes generation. **(Cai and Du, 2021)** studied the treatment of biomedical wastes using four types of thermal plasma which were plasma combustion, pyrolysis, gasification and vitrification. They studied the effects of many parameters like feed (composition and rate), temperature of reaction and time of residence of wastes inside plasma reactor on increasing efficiency of treatment and reducing volume and mass of residual ash and increasing the yield of product combustible gases to convert them to energy. The product gases from different processes were CH_4, H_2, CO_2, CO, SO_2, H_2S and HCl, the hazardous gases like SO_2, H_2S and HCl need to be treated using a suitable off gas system. **(Saravanan et al., 2021)** studied the conversion of biomedical wastes to energy using plasma technology, they decided that the net energy conversion was either negative or very low because of these technologies were high costs (0.25 million US$/ton per day TPD) and energy consumption (1.14 MWh/h for TPD). **(Jaber et al., 2021)** studied and analysed experimentally the ashes of the incinerators of biomedical wastes in three main hospitals in Baghdad. Their results presented that the heavy metals concentrations (like Cd, Pb, Hg, Ag, Cr, Fe,…. Etc.) were high and greater than the permissible limits of Iraqi ministry of Environment, the authors suggested that the best solution for these ashes was to mix them with bricks and cement in construction purposes. **(Kaushal et al., 2022)** reviewed references about using plasma gasification on treating of biomedical wastes after COVID-19 pandemic where the biomedical wastes in India were (775 tons/day in 2022) and the technology of plasma gasification was efficient in treating and disposal but it was very expensive with operational difficulties and high establishing cost and still in laboratory scale. **(Galaly, 2022)** studied theoretically the conversion of biomedical wastes in Makkah city

(2835 *10^3 ton/year) to energy using thermal plasma technology depending on technical data and economic analysis of previous works, the resulted electrical energy that can be produced was (21*10^6 MW.h).
(Kim et al., 2022) reviewed references about the present and novel technologies used in biomedical waste management methods. Their results showed that there were five present methods (lanfil, incineration, steam autoclave, sewage and improper disposal) and three novel methods (redistribution, thermal plasma treatment and plasma hydrolysis), they focused on redistribution methods around the world of drugs and medication before they became expired. **(Kollu et al., 2022)** compared between microwave and autoclave technologies in biomedical wastes treatment, their results showed that the microwave technology (8 ml water + 3 kW /cycle) was better than autoclave (130 L water + 6 kW / cycle) in energy and water consumption, maintenance, operation and efficiency but not the initial construction cost. **(Sahin et al., 2022)** computed the energy losses from an autoclave in Turkey; their results showed that the energy losses were 10%. **(Wang et al., 2022)** studied experimentally the effects of three disinfections treatment (NaClO, H_2O_2 and autoclave) on the biomedical's characteristics of personal prptective equipment (PPE) in order to sterilize them before recycling process, their results showed that there were no significant changes so the PPE were suitable feedstock for recycling process. **(Bartet et al., 2022)** studied using Leopold matrix the environmental impact of two treatment methods of biomedical wastes (incineration at 1200˚C and pyrolysis at (540-830) ˚C), their results showed that both methods were environmentally pollutants but pyrolysis was less than incineration especially in Carbon footprint. **(Ansari et al., 2023)** designed an autoclave using (Autodesk fusion 360) and they solved the problem of treated material adhesiveness in the inner wall of autoclave by using a suitable construction material. **(Messerle et al., 2023)** discussed the results of numerical (Universal TERRA Program) and experimental studies of using plasma gasification in treating of medical wastes, agricultural wastes and wasted wood industry. Their results showed that the thermal energy of combustible gas was produced from plasma gasification (430 MJ/h) were three times the thermal energy which was produced from burning the same quantity of biomedical wastes (145 MJ/h). **(Jie et al., 2023)** studied experimentally on pilot scale of (22min/500g) capacity the biomedical waste (P.P., P.E., PET and PVC) treatment using microwave plasma, their system was supplied with tray scrubber and three-way catalytic converter to treat hazardous gases like HCl, NH_3 and NO_x which were treated completely and not detected in flue gases analyzer. Their results showed that the best operation conditions were the resulted ash mass was (≤5%), water-waste ratio was (30%), the biomedical waste temperature (≥ 600˚C) and gas volumetric flow rate (≥ 40 liter/min). **(Sureshkumar et al., 2023)** reviewed references about using the ash of biomedical wastes from incinerators in concrete industry as a partial replacement of cement which produced large quantity of CO_2 in concrete production process. **(Edy et al., 2024)** used a hybrid technology incinerator of capacity (50 kg/h) of biomedical solid wastes utilizing an evaporative cooling system and operating temperature between (800-1000)˚C with high burning efficiency more than 90%. **(Hadi et al., 2024)** computed theoretically the requirements of the conversion of Baghdad municipal solid wastes to electrical energy, the same corresponding author in another work **(Hadi et al., 2024)** determined theoretically the thermal energy and quantity of wastes produced from burning contaminated soil with crude oil in Basra, Iraq where the same procedure is considerd in the current article in stoickiometric calculations for Baghdad city in computing thermal energy from burning of Baghdad biomedical wastes. The present research aims are to design a multi chamber

incinerator to dispose the biomedical wastes in two hospitals in Baghdad which are Baghdad medical city with (956 bed) and Al-Yarmouk hospital (647 bed) depending on the experimental results of **(Mensoor, 2020).**
An important current aim is the determination of the cost and environmental impacts of Baghdad biomedical wastes in three treatment technologies which are incineration, autoclave and plasma treatment depending on previous published experimental data and experimental operation conditions.

2. THEORETICAL ANALYSIS

2.1 Assumptions

The following assumptions and procedure are the same as **(John and Swamy, 2011; Ganguly et al., 2017)**:
1- Complete combustion process (suitable for theoretical work).
2- Air consists of 23% O_2 and 77% N_2 by weight, and 21% O_2 and 78% N_2 by volume.
3- The volume of ($1 \frac{kg}{mole}$) ideal gas equals to 22.4m^3 at (0˚C, 1 atm).
4- The incineration process occurs where the average ambient maximum temperature between (6 A.M. and 4 P.M.) for the whole year is 30.8˚C.
5- The used fuel in the incineration process is diesel with a chemical composition ($C_{12}H_{23}$) and a burning temperature is 1100˚C **(Hadi et al., 2024)**.

2.2 Quantification of Biomedical Wastes

The quantity of biomedical waste which are generated, the number of beds, the average waste generation rate for each bed per day and the quantity of waste per day and month from the two studied hospitals are listed in **Table 1**.

Table 1. Waste production in Investigated hospitals in Baghdad.

Name of hospital	Number of Beds	Average generation rate kg/(bed.day)	Mass of waste generated kg /day	Mass of waste generated kg /month
Baghdad educational hospital (Medical city)	956	0.2	191.2	5736
Al-Yarmouk educational hospital	647	0.7	452.9	13587
Total	1603	-	644.1	19323

The total quantity of biomedical waste generated from the two studied hospitals is estimated to be ($644.1 \frac{kg}{day}$), thus the presented research design will depend on ($700 \frac{kg}{day}$) as total input biomedical wastes mass generation with an incineration rate of ($100 \frac{kg}{h}$). The biomedical wastes are separated into many colored bags as shown in **Table 2** according to its contents, assuming that red and yellow bags have (30 % and 70%) respectively from total biomedical wastes which is the same procedure depended in **(John and Swamy, 2011),** that means from the ($100 \frac{kg}{h}$) there are ($30 \frac{kg}{h}$) of red bag wastes and ($70 \frac{kg}{h}$) of yellow bag wastes as shown in **Tables 3 and 4** respectively. In **Table 3**, the quantity of moisture in the red bag is assumed (70 % of 30 $\frac{kg}{h}$) which is equal to (21 $\frac{kg}{h}$), this assumption depends on the results of **(Al-Hashimi and Al-Mandalawi, 2007)** that moisture content in the total biomedical wastes is (21 %).

Table 2. Characterization of biomedical wastes.

Waste type	Waste description	Heat value of waste as fired (MJ/kg)	Waste type	Waste description	Heat value of waste as fired (MJ/kg)
A1 (Red bag)	Human anatomical	3.45	A3(a) (Yellow bag)	Paper, swabs, cellulose	22.65
A2 (Red bag)	Animal anatomical	3.5	A3(b) (Yellow bag)	Lab wastes	22.62
(Orange bag)	Plastic, Glass, Bedding, Shaving	5.9	A3(c) (Yellow bag)	Swabs, Pads.	23.53

The total heat generation from wastes input (Q_i) is listed in **Table 5** where (Q_i = 2014.2221 $\frac{MJ}{h}$) which is the sum of high heating value for the Carbon components content.

Table 3. Waste production for Red bags from two main hospitals in Baghdad.

Compound	Chemical composition	Assumed fraction	Generation (kg/h)
Tissue (dry)	$C_5H_{10}O_3$	0.25	7.5
Water	H_2O	0.7	21
Ash	-	0.05	1.5
Total Red bag		1	30

Table 4. Waste production for yellow bags from two main hospitals of Baghdad

Compound	Chemical composition	Fraction assumed	Generation (kg/h)
Polyethylene	$(C_2H_4)_x$	0.35	24.5
PVC	$(C_2H_3Cl)_x$	0.04	2.8
Cellulose	$C_6H_{10}O_5$	0.51	35.7
Ash	-	0.1	7
Total Yellow bag		1	70

Table 5. Total heat production from input wastes (taking yellow and red bags)

Compound	Chemical Composition	Calorific Value (kJ/kg)	Total input (kg/h)	Total heat in (kJ/h)
Tissue	$C_5H_{10}O_3$	20471	7.5	153532.5
Cellulose, Swabs	$C_6H_{10}O_5$	18568	35.7	662877.6
Plastic (Polyethylene-96%)	$(C_2H_4)_x$	46304	24.5	1134448
PVC 4%	$(C_2H_3Cl)_x$	22630	2.8	63364
Ash	0	0	1.5+7=8.5	0
Moisture	H_2O	0	21	0
Total heat generation Q_i	100	2014222.1		

2.3 Material Balance

2.3.1 Stoichiometric calculations

The following equations represent oxidation reaction (incineration) to produce carbon dioxide and water as followed:

1-$Tissue$: $C_5H_{10}O_3 + 6O_2 \rightarrow 5CO_2 + 5\,H_2O$
The molecular weights of reactants and products are listed in the following equation:
$118 + 192 \rightarrow 5(44) + 5(18)$

By dividing the above equation by (118) to get the calculations for 1 kg as below:

$$1\,kg\,Tissue + 1.627\,kg\,O_2 \rightarrow 1.86\,kg\,CO_2 + 0.76\,kg\,H_2O \quad (1)$$

The required quantity of Tissue can be given in the following equation:

$$7.5\,kg\,Tissue + 12.2025\,kg\,O_2 \rightarrow 13.95\,kg\,CO_2 + 5.7\,kg\,H_2O$$

2- $Polyethylene$: $(C_2H_4)_x + 3O_2 \rightarrow 2CO_2 + 2\,H_2O$

By repeating the previous procedure for the following equations:

$28 + 96 \rightarrow 88 + 36$

$$1\,kg\,(C_2H_4)_x + 3.43\,kg\,O_2 \rightarrow 3.14\,kg\,CO_2 + 1.29\,kg\,H_2O \quad (2)$$
$$24.5\,kg\,(C_2H_4)_x + 84.035\,kg\,O_2 \rightarrow 76.93\,kg\,CO_2 + 31.605\,kg\,H_2O$$

3- PVC: $2(C_2H_3Cl)_x + 5O_2 \rightarrow 4CO_2 + 2\,H_2O + 2HCl$
$2(62.5) + 160 \rightarrow 176 + 36 + 2(36.5)$

$$1\,kg\,(C_2H_3Cl)_x + 1.28\,kg\,O_2 \rightarrow 1.408\,kg\,CO_2 + 0.288\,kg\,H_2O + 0.584\,kg\,HCl \quad (3)$$
$$2.8\,kg\,(C_2H_3Cl)_x + 3.584\,kg\,O_2 \rightarrow 3.9424\,kg\,CO_2 + 0.8064\,kg\,H_2O + 1.6352\,kg\,HCl$$

4- $Cellulose$: $C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5\,H_2O$
$162 + 192 \rightarrow 264 + 90$

$$1\,kg\,Cellulose + 1.185\,kg\,O_2 \rightarrow 1.6296\,kg\,CO_2 + 0.555\,kg\,H_2O \quad (4)$$
$$35.7kg\,Cellulose + 42.3045kg\,O_2 \rightarrow 58.17672kg\,CO_2 + 19.8135kg\,H_2O$$

The total quantities from the above equations are (O_2 (Stoichiometric) = 142.126 $\frac{kg}{h}$, CO_2 = 152.99912 $\frac{kg}{h}$, H_2O = 57.9249 $\frac{kg}{h}$and HCl = 1.6352 $\frac{kg}{h}$).

2.3.1.1 HCl Formation

From the outcomes of Eq. (3) HCl = 1.6352 $\frac{kg}{h}$ as vapor at 1100°C (Burning Temperature), where HCl has a density ρHCl (37% concentration which is the maximum concentration) =

1190 $\frac{kg}{m^3}$, Meaning that the volume of HCl is (1.374 $\frac{liter}{h}$) when it condenses completely at 48°C but HCl (20% concentration) condenses at 108°C.

2.3.2 Moisture and Excess Air Data of Waste's Burning

The required excess air to incinerate solid wastes inside a multi-chamber incinerator is 150% **(John and Swamy, 2011; Ganguly et al., 2017)**, for more information about required excess air for solid wastes see **(Abd Al-Razak, 2009; Curkeet, 2011).** The excess O_2 can be computed from below **(Hadi et al., 2024)**:

$$O_2\ (150\%\ excess) = 2.5\ O_2\ (stoichiometric) = 355.315\ \frac{kg}{h}$$

$$Air\ required = \frac{O_2}{0.23} = 1544.8478\ \frac{kg}{h}$$

$$N_2 = air\ required - O_2 = 1189.5328\ \frac{kg}{h}$$

The required moisture in the incineration air is calculated as below relations **(Ganapathy, 2015)** taking the mean annual ambient temperature (30.8°C) and relative humidity (44.8 %) for design purposes in Baghdad city **(Al-Musawi and Muhsin, 2014; Al-Jubouri and Hadi, 2019)**:

$$Moisture\ (air) = \frac{0.622\ Pw(\frac{kg}{cm2}.a)}{(1.033-Pw)} \quad (5)$$

Where $1\ \frac{kg}{cm^2.a} = 1\ \frac{kpa}{98.0665}$

$$Pw = relative\ humidity\ \ P(\frac{kg}{cm^2}) \quad (6)$$

From thermodynamics tables P_{sat} (30.8°C) = 4.25 kPa = 0.043338 $\frac{kg}{cm^2}$, Pw = 0.0194154, Moisture (air) = 0.0119145 $\frac{kg\ H_2O}{kg\ air}$ and the mass of moisture in the air of combustion equals (0.0119145 × 1544.8478 $\frac{kg}{h}$= 18.406089 $\frac{kg}{h}$$H_2O$). The output moisture is given as:

$$H_2O\ (output) = Air\ moisture + wastes\ moisture + produced\ water\ from\ reaction \quad (7)$$

$$H_2O\ (output) = 97.330989\ \frac{kg}{h}$$

The primary (without liquid fuel) input and output quantities equation for biomedical wastes is given as:

$$100\frac{kg}{h}\ biomedical\ wastes + 355.315\ \frac{kg}{h}\ O_2 + 1189.5328\ \frac{kg}{h}\ N_2 + 18.406089\ \frac{kg}{h}\ H_2O\ (air\ moisture) \xrightarrow{1100°C} 1189.5328\ \frac{kg}{h}\ N_2 + 213.189\ \frac{kg}{h}\ O_2 + 152.99912\ \frac{kg}{h}\ CO_2 + 97.330989\ \frac{kg}{h}\ H_2O + 8.5\ \frac{kg}{h}\ ash + 1.6352\ \frac{kg}{h}\ HCl\ (1.374\ \frac{liter}{h}\ (37\%\ concentration) \quad (8)$$

Thus the input mass is (1663.253889 $\frac{kg}{h}$) which is equal to the output mass (1663.187109 $\frac{kg}{h}$).

2.3.3 Total Output Heat Depended on Temperature of 1100˚C

The output heat Q_o is the sum of radiation loss, heat loss in ash, heat loss in dry incineration products and heat loss with moisture which they can be computed as below (Q_i= 2014222.1 $\frac{kJ}{h}$) **(Hadi et al., 2024)**:

1- $Radiation\ loss\ = 0.05\, Qi\ =\ 100.711\ \frac{MJ}{h}$

2- $Heat\ to\ ash\ = m_{ash}\ cp_{ash}\ (1100 - T_{amb})$ (9)

where m_{ash} = 8.5 $\frac{kJ}{h}$ and cp_{ash} = 0.381 $\frac{kJ}{kg\ ^{\circ}C}$, see **(John and Swamy, 2011)** and T_{amb} = 30.8˚C, substitute in Eq. (9) to get heat to ash = 3.462 $\frac{MJ}{h}$.

3- Heat to dry combustion products (N_2, O_2 residual, CO_2 and HCl)

$$Q_{dp}\ = m_{dp}\ cp_{dp}\ (1100 - T_{amb}) \quad (10)$$

where m_{dp} = m N_2 + m O_2 residual + m CO_2 + m HCl = 1557.35612$\frac{kg}{h}$ see Eq. (8), cp_{dp} = 1.086 $\frac{kJ}{kg\ ^{\circ}C}$, see **(John and Swamy, 2011)** and T_{amb} = 30.8˚C, substitute in Eq. (10) to get Q_{dp} = 1808.3259 $\frac{MJ}{h}$.

4- $Heat\ to\ moisture = m_{moisture}\ cp_{moisture}\ (1100 - 30.8) +\ m_{moisture}\ \ h_{fg}$ (11)

= 671.78467 $\frac{MJ}{h}$.

From previous equations Q_o = 2584.28357 $\frac{MJ}{h}$ = 0.7178565 MW.

2.3.4 Net Heat and Corresponding Auxiliary Liquid Fuel

$$Q_{net}\ =\ Q_i - Q_o\ =\ -570.06147\ \frac{MJ}{h}\ = m_{diesel}\ \ H.H.V.(diesel)$$

The negative sign means add auxiliary fuel, there is 5% heat radiation loss from incinerating fuel, H.H.V. for diesel is 44.8 $\frac{MJ}{kg}$ and density of diesel is 0.845 $\frac{kg}{liter}$. The quantity of diesel can be computed as below:

$$m_{diesel}\ =\ \frac{1.05 \times 570.06147}{44.8} = 12.72458\ \frac{kg}{h}$$

$$Vdiesel\ =\ \frac{12.72458}{0.845} = 15.058\ \frac{liter}{h}$$

2.3.5 Products of Incineration from Auxiliary Liquid Fuel

Taking the chemical formula for diesel as ($C_{12}H_{23}$) in which it burns according to the below equation **(Hadi et al., 2024)**:

$$C_{12}H_{23} + 17.75\, O_2 \rightarrow 12\, CO_2 + 11.5\, H_2O \quad (12)$$
$$167 + 568 \rightarrow 528 + 207$$
$$1\, kg\, C_{12}H_{23} + 3.4 kg\, O_2 \rightarrow 3.16\, kg\, CO_2 + 1.2395\, kg\, H_2O$$
$$12.72458 kg\, C_{12}H_{23} + 43.263572\, kg\, O_2 \rightarrow 40.2096\, kg\, CO_2 + 15.7721\, kg\, H_2O$$

In incinerating liquid fuel, 20% excess air can be given and the required quantities can be computed as below:
O_2 (excess 20%) fuel = 1.2 ×43.263572 kg = 51.91628 kg, in which 43.263572 kg is reacted with fuel and 8.6527 kg exit as residual O_2 with flue gases.
Air excess (fuel) = $\frac{O_2}{0.23}$ = 225.7229 kg and N_2 = 173.8067 kg and air moisture = 225.7229 × 0.0119145 = 2.6893 kg which is added with 15.7721 kg to get the total mass of moisture of the fuel (18.4614 $\frac{\text{kg}}{\text{h}}$). The final fuel burning equation with 20% excess air is as follow:

$$12.72458 \frac{\text{kg}}{\text{h}} \text{ diesel } (15.058 \frac{\text{liter}}{\text{h}}) + 173.8067 \frac{\text{kg}}{\text{h}} \text{N}_2 + 51.91628 \frac{\text{kg}}{\text{h}} \text{O}_2 + 2.6893 \frac{\text{kg}}{\text{h}} \text{ moisture } \rightarrow 173.8067 \frac{\text{kg}}{\text{h}} \text{N}_2 + 8.6527 \frac{\text{kg}}{\text{h}} \text{O}_2 + 40.2096 \frac{\text{kg}}{\text{h}} \text{CO}_2 + 18.4614 \frac{\text{kg}}{\text{h}} \text{H}_2\text{O} \quad (13)$$

The input mass of Eq. (13) is (241.13686 $\frac{\text{kg}}{\text{h}}$) which is equal to the output mass (241.1304 $\frac{\text{kg}}{\text{h}}$).

2.3.6 The Final Equation for Reactants and Products

$$100 \frac{\text{kg}}{\text{h}}\, biomedical\ wastes + 12.72458 \frac{\text{kg}}{\text{h}}\, diesel\ (15.058 \frac{\text{liter}}{\text{h}}) + 407.23128 \frac{\text{kg}}{\text{h}} \text{O}_2 + 1363.3395 \frac{\text{kg}}{\text{h}} \text{N}_2 + 21.095 \frac{\text{kg}}{\text{h}} \text{H}_2O\ (air\ moisture) \xrightarrow{1100^{\circ}C} 1363.3395 \frac{\text{kg}}{\text{h}} \text{N}_2 + 221.8417 \frac{\text{kg}}{\text{h}} \text{O}_2 + 193.20872 \frac{\text{kg}}{\text{h}} CO_2 + 115.792389 \frac{\text{kg}}{\text{h}} \text{H}_2O + 8.5 \frac{\text{kg}}{\text{h}}\, ash + 1.6352 \frac{\text{kg}}{\text{h}}\, HCl\ (1.374 \frac{\text{liter}}{\text{h}}\ (37\%\ concentration) + Q_o\ (0.7178565 MW) \quad (14)$$

The total mass input from reactants in Eq. (14) equals to(1904.39036 $\frac{\text{kg}}{\text{h}}$) and the total mass output from products in Eq. (14) equals to(1904.3175 $\frac{\text{kg}}{\text{h}}$) where it is the sum of (8.5 $\frac{\text{kg}}{\text{h}}$ ash) and flue gases (1895.8175 $\frac{\text{kg}}{\text{h}}$). The flue gases total mass is the sum of dry products (1780.02512 $\frac{\text{kg}}{\text{h}}$) and moisture (115.792389 $\frac{\text{kg}}{\text{h}}$).

The weight fraction for flue gases can be given in the following equation **(Hadi et al., 2024)**:

$$\%\, W_{flue-gases} = 0.71913\, N_2 + 0.117016\, O_2 + 0.101913\, CO_2 + 0.061077\, H_2O + 0.0008625\, HCl \quad (15)$$

The volume fractions of the flue gases are determined by computing the volume of each gas (using ideal gas law) and the total volume of flue gases, the volumetric flow rate of each gas can be found in the following equation **(Hadi et al., 2024)**:

$$V_{gas} = m_{gas} \frac{22.4\,(Tg+273)/273}{Molecular\ weight\ of\ gas} \frac{1}{3600} \quad (16)$$

The molecular weights for flue gases (N_2, O_2, CO_2, H_2O and HCl) are (28, 32, 44, 18 and 36.5) respectively and their volume are (1.523699, 0.216943, 0.137412, 0.2013079 and 0.0014019) $\frac{m^3}{s}$ respectively and the total volume of flue gases equals 2.0807 $\frac{m^3}{s}$. The volume fraction for flue gases is determined as in the below equation **(Hadi et al., 2024)**:

$$\%\,V_{flue-gases} = 0.7323\,N_2 + 0.10426\,O_2 + 0.06604\,CO_2 + 0.09675\,H_2O + 0.0006737\,HCl. \quad (17)$$

2.3.7 Design of multi-chamber incinerator

The multi-chamber incinerator contains primary and secondary chambers, to design The primary chamber for a multi-chamber incinerator a burning capacity of (100 $\frac{kg}{h}$) to burn (700 $\frac{kg}{day}$) with a consideration of a total volume of (700 $\frac{kg}{day}$) of biomedical waste is nearly equal to (10 m^3) as illustrated below **(Hadi et al., 2024)**:

$$V\ primary\ chamber = L \times B \times H = 10\ m^3$$

Assuming a suitable depth of 3 m (H) and assuming ($\frac{L}{B} = \frac{1.75}{1}$) then:

$$Area = \frac{volume}{depth} = \frac{10}{1.75} = 3.334\ m^2 = L \times B = 1.75\ B^2 \text{ therefore:}$$

$$B = 1.38\ m\ and\ L = 2.415\ m$$

$$V_{primary\ chamber} = 2.415m \times 1.38m \times 3m = 10m^3 \quad (18)$$

The volume of the secondary chamber of the multi chamber incinerator which satisfy (1 second) resident time for flue gases at (1100 °C) can be computed from equation (16) for dry products (molecular weight for air = 29) and moisture (molecular weight = 18) then:

$$V_{secondary\ chamber} = V_{dp} + V_{moisture} = 1.9207973 + 0.2013079 = 2.122\ \frac{m^3}{s}$$

This procedure is the same as that used by **(John and Swamy, 2011)**, where they assumed that dry-generated flue gases have the characteristics of air while if dry products are considered uniquely the secondary chamber's volume is equal to the total volume of flue gases (2.0807 $\frac{m^3}{s}$) that used to compute the volume fraction of flue gases in Eq. (17) which is a more accurate value than (2.122 $\frac{m^3}{s}$) **(Hadi et al., 2024)**.

2.3.8 Plasma Combustion Treatment of Baghdad City

There are four types of thermal plasma which are plasma combustion, pyrolysis, gasification and vitrification **(Cai and Du, 2021)**, all types consume high energy and initial cost construction and need to off-gas system to treat produce hazardous gases **(Kaushal et al., 2022)**, the required electrical energy of plasma combustion is estimated as in the below equation depending on experimental results of **(Saravanan et al., 2021)**:

$$E\left(\frac{MW}{day}\right) = M(TPD)\ \ 1.14(\frac{MW}{TPD}) \tag{19}$$

The required quantity of diesel required to generate the required electrical energy using electrical generators (150 $\frac{\text{liter}}{\text{h}}$ diesel is required to operate a 1 MW generator depending on experimental operation conditions) can be computed from the following equation:

$$V_{diesel}\left(\frac{Liter}{day}\right) = E\ \left(\frac{MW}{day}\right)\ 150(\frac{liter}{MW}) \tag{20}$$

The calculation of diesel quantity from Eq. (20) so the comparison with the incineration method of biomedical wastes from Eq. (14) can be more clearly using the quantity of consumed diesel.

2.3.9 Sterilizing of Biomedical Wastes

The sterilization method of biomedical wastes deals with biological contamination only (for yellow bags only and not for red bags) in which it kills all germs and microbes while the chemical contamination like heavy metals contained in biomedical wastes are stayed with the sterilized wastes are deposed to landfill by municipalities of Baghdad city, the volume and mass of sterilized biomedical wastes don't change in the same time the process of sterilization consumes high electrical energy and water in both of the two types of sterilization methods which are autoclave and microwave**(Kollu et al., 2022)**. The red bag wastes can be treated by incineration method only either by conventional incineration or plasma combustion.

2.3.9.1 Autoclave Sterilizing of Biomedical Wastes

Autoclave means using steam at ((121-134) ˚C and (15-17) Psi) to sterilize biomedical wastes, according to **(Pant, 2018)**, a quantity of (0.12$\frac{liter}{bed\ day}$) of water is required to sterilize biomedical wastes. The total quantity of water can be computed from the following equation:

$$m_{water}\left(\frac{Liter}{day}\right) = N_{bed}(bed)\ \ 0.12\ (\frac{liter}{bed\ day}) \tag{21}$$

The electrical energy and water required in an autoclave can be determined from the below equations depending on the experimental results of **(Kollu et al., 2022)** each autoclave cycle requires 120 minutes and four cycles per day:

$$E_{autoclave}\left(\frac{MW}{day}\right) = \ M(TPD)\ \ \left(\frac{6kW}{cycle}\right)\left(\frac{4\ cycle}{0.25\ TPD}\right)\left(\frac{1\ MW}{1000\ kW}\right) \tag{22}$$

$$m_{water1}\left(\frac{Liter}{day}\right) = M(TPD)\ \left(\frac{130\ liter}{cycle}\right)\left(\frac{4\ cycle}{0.25\ TPD}\right) \tag{23}$$

2.3.9.2 Microwave Sterilizing of Biomedical Wastes

The electrical energy and water required in the microwave can be estimated from the below equations depending on the experimental results of **(Kollu et al., 2022)** each microwave cycle required 40 minutes and six cycles per day:

$$E_{microwave}\left(\frac{MW}{day}\right) = M(TPD)\ \left(\frac{3\ kW}{cycle}\right)\left(\frac{6\ cycle}{0.25\ TPD}\right)\left(\frac{1\ MW}{1000\ kW}\right) \tag{24}$$

$$m_{water2}\left(\frac{Liter}{day}\right) = M(TPD)\ \left(\frac{0.8\ liter}{cycle}\right)\left(\frac{6\ cycle}{0.25\ TPD}\right) \tag{25}$$

2.3.10 Ash Solidification

The ash of biomedical wastes is (8.5%) in weight as in Eq. (14), according to **(Elinwa, 2016; Hussain, 2017; Suryawan et al., 2019; Jaber et al., 2021)** the ash containing high concentrations of heavy metals and it can be mixed with cement with ratio (70:30) to produce concrete of high properties and good for hot weather, the mass of cement required can be calculated from the following equation:

$$m_{cement}\left(\frac{kg}{day}\right) = 0.429\ m_{ash}\left(\frac{kg}{day}\right) \tag{26}$$

$$m_{water}\left(\frac{kg}{day}\right) = 0.3\ m_{cement}\left(\frac{kg}{day}\right) \tag{27}$$

The concrete can be produced using industrial wasted water with high concentration of heavy metals and this is a good method to use wasted hazardous materials to produce useful and safety material depending on experimental results of **(Hussain, 2017)**.

3. RESULTS AND DISCUSSION

The results for present research and design are demonstrated in equations (14, 15, 17 and 18) where the equation of burning 100 $\frac{kg}{h}$of medical wastes and the resulted thermal energy, volume and weight fractions of the flue gases, volume and mass rate of diesel fuel, produced ash and the multi chamber incinerator's dimensions are computed.

3.1 Generated Wastes

The generated wastes from burning process of biomedical wastes are dangerous ash and flue gases as in equation (14) and **Table 6**. The ash has a mass of (8.5 $\frac{kg}{h}$) and its volume is less than the initial volume of the wastes by nearly ($\frac{1}{3}$) where it can be treated and landfiled after cooling process to ambient temperature and it contains heavy metals like (Pb, Cd and Cr), the required cement and water for concrete production are listed in **Table 6**. The flue gases weight is (1895.8175 $\frac{kg}{h}$) while the flue gases components are (193.20872 $\frac{kg}{h}$ for CO_2 and 1.6352 $\frac{kg}{h}$ for HCl). The mass of flue gases is huge because of the large quantity of excess air that is required to incinerate solid wastes which is (150%) greater compared with quantity of excess air required for incinerating liquid fuel which is (20%). The biomedical wastes of Baghdad city and the resulted wastes from burning all of Baghdad's biomedical wastes are listed in **Table 6.**

3.2 Thermal Dissipated Energy

From Eq. (14) the resulted wasted heat is (0.7178565 MW), it is thermal energy which is lost as radiation loss and in ash and as thermal content in flue gases (in dry products and moisture) and this wasted heat is dissipated to ambient with flue gases at (1100˚C) directly without any off-gas system because the incineration process is done inside hospitals with old incineration technology and more of incinerators have bad maintenance and non-expert operating staff. This is an important and critical reason to make Iraqi government to establish the Baghdad central site of disposal and treatment for the hazardous biomedical wastes in Baghdad's hospitals with modern technology and the incineration process inside hospitals must be forbidden because it is very dangerous on environment and general health because of high acidic content (HCl of 85.1835 $\frac{kg}{h}$ and 71.58 $\frac{liter}{day}$ as listed in **Table 6**) that is emitted directly to the ambient.

Table 6. Incineration method's wastes

100 kg/h								
	N_2	**O_2**	**CO_2**	**H_2O**	**HCl**	**Ash**	**Required cement**	**Required wasted water**
Mass kg/h	1336.33	221.84	193.208	115.79	1.635 1.374 liter/h	8.5	3.6465 Depending on **(Suryawan et al., 2019)**	1.09395 Depending on **(Hussain, 2017)**
%W	0.719	0.117	0.1019	0.061	0.000862	-		
%V	0.732	0.104	0.066	0.0967	0.000673	-		
Baghdad total biomedical waste per day, 5.21 tons/day								
Mass kg/day	69622.79	11557.86	10066.13	6032.66	85.1835 71.58 liter/day	442.85	189.98	56.994

Table 7. Comparison between incineration, plasma and sterilization methods

Baghdad total biomedical wastes per day, 5.21 tons/day						
Parameter	**Incineration**	**Plasma combustion**	**Plasma gasification**	**Microwave plasma**	**Autoclave**	**Microwave sterilization**
Operation level	Industrial	Industrial	Lab scale	Lab scale	Industrial	Industrial
Initial construction cost, $	1198300	3900000	-	-	1345930.56	3589148.16
Electrical consumption, MW/day	-	85 KW for 9g/s	70KW for 10 g	1.5 KW for 22min/500g, 15.63 MW/day	0.5 for 4 cycle, cycle = 120 min	0.375 for 6 cycle, cycle= 40 min

Corresponding diesel consumption, liter/day	784.52	-	-	2344.5	160	120
Water consumption	Produced water vapor 6032.66 kg/day	-	-	1563 liter/day	10836.8 liter/day	100.032 liter/day
Waste volume reduction %	91.5%	95%	80.78%	94%	Zero	Zero
Availability in Iraq	Yes	No	No	No	Yes	Yes
Reference dependent to compute current results	Current work and **(Sarvanan et al., 2021)**	**(Cai and Du, 2021)**	**(Cai and Du, 2021; Messerle et al., 2023)**	**(Jie et al., 2023)**	**(Kollu et al., 2023)**	

In **Table 7** the plasma technology is higher than other technologies in electrical energy consumption because the ionization process of the gas of plasma needs high energy as it is known in atomic physics. The initial construction cost shows that incineration has the least cost because other technologies are new and mostly of lab and pilot scale and these technologies need more development and researches to reduce treatment costs.

3.3 Biomedical Wastes to Energy

Baghdad biomedical wastes are (5.21 ton/day see **(Jaber et al., 2021)**) and they are less than the municipal solid wastes of Baghdad city (nearly 10000 $\frac{ton}{day}$see **(Hadi et al., 2024)**) so they represents nearly (0.0521 % of municipal solid wastes), the difference between the resulted ash of burning biomedical wastes and the ash of burning municipal solid wastes (to produce electricity) is that the ash of biomedical wastes contains high concentrations of heavy metals for this reason it is not possible to burn biomedical wastes with municipal solid wastes in the plant of electricity from municipal solid wastes in Baghdad, see **(Hadi et al., 2024)**. The conversion of biomedical wastes into energy products using plasma modern technologies gave negative or very low net energy, see **(Saravanan et al., 2021)**.

3.4 Comparisions with Previous Works

In **Table 8**, the current results are compared with previous listed works in many parameters as the location of studied city that is important in determining average annual temperature and moisture quantity in air that affects the volume of secondary chamber as in Eq. (17).

Table 8. Comparison of designed incinerator performance with previous works

Name of reference	**(John and Swamy, 2011)**	**(Ganguly et al., 2017)**	**(Edy et al., 2024)**	**Current research**
Parameter				
City and country	Chikmagalur, India	Chandigarah and Shimla, India	Malang, Indonesia	Baghdad, Iraq
Type of work	Theoretical	Theoretical	Experimental	Theoretical

Capacity of burning	100 $\frac{kg}{h}$, 100 $\frac{kg}{day}$	100 $\frac{kg}{h}$, 500 $\frac{kg}{day}$	50 $\frac{kg}{h}$, 1200 $\frac{kg}{day}$	100 $\frac{kg}{h}$, 700 $\frac{kg}{day}$
Temperature of burning	1100˚C	1100˚C	(800-1000)˚C	1100˚C
Excess air	150% for wastes, 20% for fuel	150% for wastes, 20% for fuel	Not available	150% for wastes, 20% for fuel
Type of fuel	Natural gas	Natural gas	LPG	Diesel
Fuel consumption	27.42 $\frac{m^3}{h}$	29.52 $\frac{m^3}{h}$	Not availble	15.058 $\frac{liter}{h}$
Volume of primary chamber L× B× H	1.857m ×1.238m ×2.2m = 5 m^3	2.16m ×1.23m ×3m = 8 m^3	Evaporative cooling system	2.415m ×1.38m ×3m = 10 m^3
Volume of secondary chamber	2.17 $\frac{m^3}{s}$	3.07$\frac{m^3}{s}$	Evaporative cooling system	2.0807 $\frac{m^3}{s}$
Moisture in air $\frac{kg\ H_2O}{kg\ air}$	0.0132	0.0132	Not available	0.0119145
Relative humidity	60 %	60 %	Not available	44.8 %
Moisture mass in air $\frac{kg}{h}$	24 $\frac{kg}{h}$	27.73$\frac{kg}{h}$	Not available	18.406 $\frac{kg}{h}$

The volume of primary chamber as in Eq. (18) depends on the quantity of wastes per day where these quantity is different from one city to another city while the burning capacity per hour are the same (100 $\frac{kg}{h}$).

4. CONCLUSIONS

1-The multi chamber incinerator design with incineration mass of (100 $\frac{kg}{h}$), the primary chamber lengths are (L× B× H = 2.415m ×1.38m ×3m = 10 m^3), the secondary chamber volume is (2.0807 $\frac{m^3}{s}$). A diesel fuel ($C_{12}H_{23}$) is utilised with volumetric rate of (15.058 $\frac{liter}{h}$).

2- Treatment of biomedical wastes with incineration method in hospitals is an economical and quick process but it generates hazardous flue gases that directly emitted to ambient at (1100˚C) without any off gas system.

3- The resulted thermal energy is (0.7178565 MW) which is dissipated to the ambient atmosphere and the incineration products are 8.5 $\frac{kg}{h}$hazardous ash and 1895.8175 $\frac{kg}{h}$flue gases.

4- The Iraqi government needs to establish a central disposal and treatment site in Baghdad to incinerate biomedical wastes produced from Baghdad's hospitals adopting modern off gas system to treat hazardous gases and must prohibit uncontrolled local incinerators in hospitals.

NOMENCLATURE

Symbol	Description	Symbol	Description
B	Width of primary chamber, m.	N_{bed}	Number of beds in hospital.
c_p	Specific heat, $\frac{kJ}{C.kg}$.	P	Power, w.
E	Electrical energy require, $\frac{MW}{day}$	p	Pressure of boiler, bar.
GCV	Gross calorific value of fuel, $\frac{kJ}{kg}$.	Q	Thermal energy, w.
H	Height of primary chamber, m.	T_a	Ambient temperature, °C.
HHV	High heating value of fuel, $\frac{kJ}{kg}$.	V	Flue gas volume over time for 1 kg fuel, $\frac{m3}{s.kg\ fuel}$.
h_{fg}	Latent heat of vaporization, $\frac{kJ}{kg}$.	%V	Volume fraction of flue gases, %.
L	Length of primary chamber, m.	%W	Weight fraction of flue gases, %.
m	Mass, kg.	ρ	Density, $\frac{kg}{m3}$.

Acknowledgments

This work was supported by Ministry of Science and Technology in the Directorate of Disposal and Treatment of Hazardous Wastes. The current article staff would like to thank the Directorate of Disposal and Treatment of Hazardous Wastes in Iraq for their help to complete this research.

Credit Authorship Contribution Statement

Ahmed H. Hadi: Writing - review & editing, Writing - original draft, Validation, Software, Methodology. Basim A. Hussain: Writing - review & editing, Software. Mais J. Mohammed: Writing - review & editing. Wasnaa J. Mohammed Writing - review & editing. Abdullah F. Abdurazak: Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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التصميم النظري لمحرقة لمعالجة المخلفات الطبية الناتجة من المستشفيات المحلية في بغداد

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[4] أعمال حرة في مجال هندسة الطاقة، بغداد، العراق

الخلاصة

دراسة نظرية قدمت لاتلاف المخلفات الطبية لمدينة بغداد (5.21 طن\يوم) بعدة طرق اتلاف معتمدة عالميا ومقارنة النتائج من حيث تكلفة الانشاء والصيانة واستهلاك الطاقة الكهربائية وتقليل كتلة وحجم المخلفات بعد المعالجة وكمية المياه المستهلكة. تم اعتماد نتائج بحوث عملية منشورة سابقا مع ارقام تشغيلية عملية في البحث الحالي. تم حساب الطاقة الحرارية والمخلفات الناتجة من الاحتراق الكامل للمخلفات الطبية (100 كغم\سا) من مستشفيين رئيسيين في مدينة بغداد. الادبيات المنشورة بينت ان مستشفى مدينة الطب ومستشفى اليرموك تنتج قرابة (700 كغم\اليوم) من المخلفات الطبية. تم تصميم محرقة متعددة المراحل سعتها (100 كغم\سا) لحرق المخلفات الطبية باستخدام وقود الديزل تحت درجة حرارة احتراق (1100°س). كانت الطاقة الحرارية الناتجة تبلغ (0.7178565 ميكا واط) والتي تنبعث مع غازات الاحتراق مباشرة الى الجو بدون منظومة معالجة الغازات. وكانت كتلة غازات الاحتراق الناتجة (1895.8175 كغم\سا) مع كتل غازات الاحتراق كالاتي (ثاني اوكسيد الكاربون 193.20872 كغم\سا، وبخار حامض الهيدروكلوريك 1.6352 كغم\سا) بواسطة استخدام زيادة هواء احتراق بنسبة (150 %) لحرق المخلفات الصلبة و(20 %) لحرق وقود الديزل السائل. الرماد الناتج تم حساب كمية السمنت والماء اللازم لتصليبه وانتاج خرسانة ملائمة للبلدان ذات الدرجات الحرارية المرتفعة. اظهرت النتائج ان طريقة الحرق اقل تكلفة انشائية وتشغيلية من باقي التكنلوجيات الحديثة المتوفرة مع تقليل لكتلة المخلفات بنسبة 91.5%.

الكلمات المفتاحية: المخلفات الطبية، الحرق، التعقيم بالبخار ، المعالجة بالبلازما.