

Process engineering design of pathological waste incinerator with an integrated combustion gases treatment unit

A.F. Shaaban*

Department of Chemical Engineering and Pilot Plant, National Research Centre, 33 El-Behoos Street, PZN 12622, Dokki, Cairo, Egypt

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Abstract

Management of medical wastes generated at different hospitals in Egypt is considered a highly serious problem. The sources and quantities of regulated medical wastes have been thoroughly surveyed and estimated (75 t/day from governmental hospitals in Cairo). From the collected data it was concluded that the most appropriate incinerator capacity is 150 kg/h.

The objective of this work is to develop the process engineering design of an integrated unit, which is technically and economically capable for incinerating medical wastes and treatment of combustion gases. Such unit consists of (i) an incineration unit (INC-1) having an operating temperature of 1100 °C at 300% excess air, (ii) combustion-gases cooler (HE-1) generating 35 m³/h hot water at 75 °C, (iii) dust filter (DF-1) capable of reducing particulates to 10–20 mg/Nm³, (iv) gas scrubbers (GS-1,2) for removing acidic gases, (v) a multi-tube fixed bed catalytic converter (CC-1) to maintain the level of dioxins and furans below 0.1 ng/Nm³, and (vi) an induced-draft suction fan system (SF-1) that can handle 6500 Nm³/h at 250 °C. The residence time of combustion gases in the ignition, mixing and combustion chambers was found to be 2 s, 0.25 s and 0.75 s, respectively. This will ensure both thorough homogenization of combustion gases and complete destruction of harmful constituents of the refuse.

The adequate engineering design of individual process equipment results in competitive fixed and operating investments. The incineration unit has proved its high operating efficiency through the measurements of different pollutant-levels vented to the open atmosphere, which was found to be in conformity with the maximum allowable limits as specified in the law number 4/1994 issued by the Egyptian Environmental Affairs Agency (EEAA) and the European standards.

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1. Introduction

The principal available and potentially sound techniques for treating medical wastes are incineration, steam sterilization, gas sterilization, chemical disinfection with grinding, thermal inactivation, irradiation, microwave treatment, grinding and shredding, as well as compaction. Among those mentioned techniques, incineration of medical wastes has proved itself as the most technically and economically feasible technology particularly in developed countries.

It is always advantageous to practice incinerators-technique as they can: (a) potentially destroy any material containing organic carbon including pathogens, (b) typically reduce the

volume and mass of material that must be disposed off in landfills by 80–95%, and (c) heat of combustion can be recovered and used to generate steam or hot water.

The different medical-waste categories that can be handled by incinerators are: (a) cultures and stocks of infectious agents, (b) pathological wastes, (c) waste human blood, (d) hypodermic needles, syringes, pasteur pipettes, broken glass and scalpel blades, (e) contaminated animal carcasses, body parts and animals bedding, (f) wastes from surgery or autopsy, (g) wastes from medical, pathological, pharmaceutical laboratories, (h) dialysis waste, (i) discarded medical equipment and parts in contact with infectious agents, and (j) biological waste and discarded materials contaminated with blood, excretion, exudates or secretion from human being or animals.

Thus the prime objective of this work is to develop an integrated treatment unit for the incineration of hazardous medical-wastes followed by a subsequent wet and catalytic

* Tel.: +20 2 337 5626; fax: +20 2 337 0931.

E-mail address: drahmedshaaban@yahoo.com.

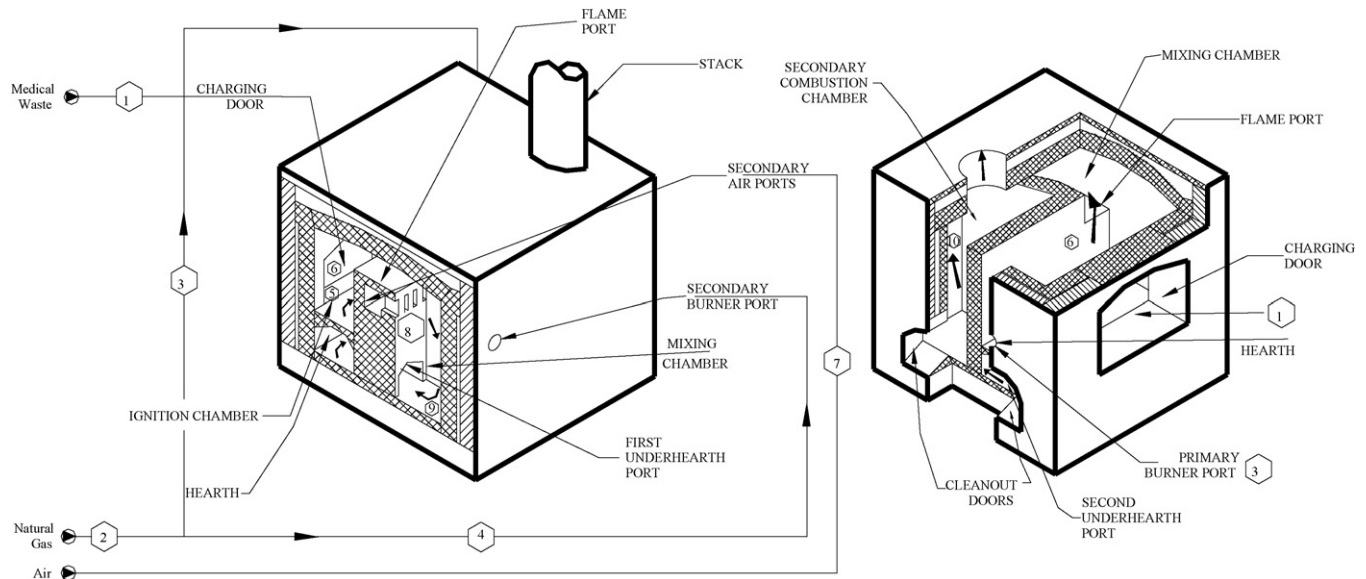


Fig. 1. Multiple-chamber pathological-waste incinerator.

treatment of combustion gases. The analysis of stack-gases vented to the atmosphere has proved the efficient performance and reliability of the proposed system. All contaminant concentration-levels are in accordance with the maximum allowable limits of air pollutants [1,2] inside work premises as specified by the Egyptian Environmental Affairs agency (EEAA) according to the law number 4/1994.

2. Engineering design of the proposed incineration and treatment unit

The main components of the integrated unit together with their design basis and engineering characteristics are given as follows.

2.1. Incineration unit (INC-1)

A modern-multiple-chamber incinerator is used for the combustion of medical refuse. The efficient design is based on the return flow of gases through the “U” arrangement of component chambers. The passage of hot gases below the refuse will maximize utilization of combustion gases heat content. The engineering configurations of the incinerator are given in Fig. 1. The presented design guarantees: (a) efficient air distribution, (b) complete destruction of harmful pathological constituents, (c) intimate contact of refuse and combustion gases, (d) ease of combustion gases circulation, (e) efficient heat transfer, and (f) ease of ash removal.

The optimum capacity of the incinerator that based on thorough local market study, was found to be 150 kg/h, while the average composition of the refuse (by weight) is: (a) 50% pathological wastes, (b) 35% moist paper and other cellulosic fibers, and (c) 15% plastic materials. The operating data of the different incinerator process streams is given in (Table 1) whereas its main components are as follows.

2.1.1. Ignition chamber

Dimensions of the ignition chamber are determined by deriving hearth loading and area, average arch height, and chamber volume (Table 2). The engineering design is based on the application of material and energy balance equations.

The arrangement of the chambers causes the combustion gases to flow through 90° turns in both lateral and vertical directions. The overall average gas temperature should be about 1100 °C [3–5] when calculations are based upon air for the combustible waste at 100% in excess of the theoretical, and upon air through both primary and secondary air ports at 200% in excess of theoretical [6,7]. The indraft velocity through air ports is assumed to be 6.5 m/s at 0.254 cm water column (WC).

2.1.2. Secondary combustion zone

This zone consists practically of a mixing chamber and secondary combustion chamber. Design considerations must, however, be given to one peculiar problem in the burning of this waste material as a result of sudden volatilization of fatty tissues or hair. The latter will cause flooding of gases and vapours that would be beyond the capacity of the secondary combustion zone.

2.1.3. Burners

Two forced-draft gas burners are used. The first burner is located at the ignition chamber (primary burner), while the second is erected in the mixing chamber (secondary burner). The latter should be so located that: (a) the gases flowing from the ignition chamber can first mix with secondary air before passing through the flame of the secondary burner; (b) sufficient residence time of combustion gases is provided in the mixing chamber, after passing secondary burner flame, for secondary combustion to occur. Two Giersch-German gas burners type MG2-ZLN, tested and licensed to prEN 676 and DIN 4788 T2 for natural gas (N), were selected. The natural gas flow

Table 1
Total and components mass and volumetric flow rates of individual process streams

Stream	Component													
	CO ₂		H ₂ O		O ₂		N ₂		NO ₂		HCl		Total	
	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)	<i>m</i> (kg/h)	<i>V</i> (Nm ³ /h)
2	448.313	241.450	362.550	477.303	126.529	93.700	2515.880	2114.946	1.991	1.026	–	–	3455.265	2928.425
3	221.399	119.240	179.045	235.716	62.486	46.273	1242.467	1044.465	0.983	0.506	–	–	1706.382	1446.202
4	226.914	122.210	183.505	241.587	64.043	47.426	1273.413	1070.480	1.008	0.519	–	–	1748.883	1482.223
5	181.818	97.958	129.252	170.348	165.391	121.664	1081.806	915.481	–	–	0.662	0.429	1558.931	1305.882
6	403.217	217.199	308.297	406.064	227.878	167.938	2324.273	1959.947	0.983	0.506	0.662	0.429	3265.313	2752.085
7	–	–	6.375	8.393	329.109	243.042	1083.378	914.303	–	–	–	–	1418.864	1165.739
8	403.217	217.199	314.673	414.457	556.988	410.981	3407.652	2874.251	0.983	0.506	0.662	0.429	4684.177	3917.825
9	630.131	339.409	498.178	656.044	621.031	458.407	4681.065	3944.731	1.991	1.026	0.662	0.429	6433.060	5400.048

Table 2

Design factors for pathological ignition chamber

Item	Designed value
1. Hearth loading (kg/(h m ²))	48
2. Approximate length-to-width ratio	2
3. Primary burner design (Nm ³ /kg waste)	1.25
4. Specific heat of combustion products of waste and natural gas (kJ/(kg °C))	0.38

rates are 20–100 Nm³/h while the corresponding capacities are 200–1000 kW. Two-stage operation mode (high/low) is available for each burner.

2.2. Combustion-gases cooler (HE-1)

A transverse fin exchanger in crossflow is practiced for cooling hot combustion gases from 1200 °C to 150 °C using water as a coolant. The latter at a rate of 35 m³/h is heated from 25 °C to 75 °C by revamping a section of the duct carrying hot gases and installing 1 in. outside diameter × 4 ft. length 14 BWG tubes with (3/8) in. high annular brass fins of 20 BWG metal spaced (1/8) in. apart. The water flows in series from one vertical tube bank to the next. The number of banks was found to be six banks with total tubes surface area of 10 m² and the gas flow is considered to be mixed. The overall pressure drop on the gas-side was low and found to be equivalent to 25 cm WC.

2.3. Dust filter (DF-1)

A bag filter (2500 mm × 3650 mm × 7000 mm) with a filtration area of 224 m² is used as a dust collector. The bags are of nomex needle felt snap ring type (Ø125 mm × 3000 mm), and are arranged in rows with cages and venture (19 × 10). The volumetric flow rate of combustion gases at the maximum operating temperature (200 °C) is 11,260 m³/h. The design values of inlet and outlet particulate-matter concentrations are 500 mg/m³ and 10–20 mg/m³, respectively. The operating pressure is 250 mm WG (suction) while the maximum pressure drop is 100 mm WG. The filter is equipped with a pulse-jet cleaning system. Compressed air at 6 bar-pressure and 0.7 m³/min-volumetric rate is used for this purpose.

2.4. Gas scrubbers (GS-1,2)

Two packed towers are used for continuous countercurrent contact of combustion gases and 10% caustic soda solution [8–16]. The main gas flow is split into two equal streams (2700 Nm³/h each) while the scrubbing caustic liquor is fed to each column top at the rate of 14,655 kg/h. The column diameter (based on a flooding gas velocity of 7645 kg/m² h) was found to be 1.00 m with 4.00 m irrigated packed height. Each tower is packed with 5 cm ceramic Raschig rings cover a contact area of 92 m²/m³ of packed bed. The total packed column pressure drop (dry + irrigated) is equivalent to 10 cm WC.

2.5. A multiple-tube fixed bed catalytic converter (CC-1)

An especially economical solution is given with the simultaneous dioxin/furan destruction [17–21] and catalytic reduction of nitrogen oxides through the addition of ammonia [22–26] in a combi-reactor. According to the international standards concerning emissions from waste incineration not more than 0.1 ng TEQ per cubic meter flue gas is allowed to be emitted to the open atmosphere. The I-TEQs of PCDD/F compounds (poly-chlorinated dibenzodioxins and dibenzofurans) are given equivalence factors according to their toxicity, and their cumulative value is specified as ng I-TEQs [27,28]. In the temperature range from 200 °C to 340 °C, a PCDD/Fs decomposition up to 99% was determined [29–31]. Concentration levels of individual pollutants in converter exhaust gases fulfil air pollution standards of both EEAA and European Community (Table 3) [1,2].

The converter has a shell diameter of 160 cm and 44 tubes of 12.5 cm inside diameter and 1 m length arranged on 7.5 in. triangular pitch. The catalyst is available as spherical pellets of 5 mm diameter and 620 kg/m³ density. The designed gas superficial velocity inside the tubes is 3 m/s and the bed voidage is 65%. The total converter pressure drop is equivalent to 50 cm WC.

2.6. An induced-draft suction fan system (SF-1)

It is used for the efficient suction of combustion gases from the incinerator (IN-1) passing through combustion-gases cooler (HE-1), the dust filter (DF-1), gas scrubber (GS-1,2) and the catalytic converter (CC-1). The suction fan is equipped with a highly efficient electric motor (55 kW) and can handle 6500 Nm³/h of combustion gases at 250 °C. The induced pressure energy of gases can overcome hydraulic resistances up to 150 cm WC.

Table 3
Maximum pollutants emission-levels before and after the integrated treatment unit

Pollutant	Concentration (mg/Nm ³)	
	Before treatment ^a	After treatment ^b
1. Total dust	250	10
2. Total organic carbon	20	10
3. Total chlorides (expressed as HCL)	1000	10
4. Total fluorides (expressed as HF)	5	1
5. Oxides of nitrogen	200	5
6. Oxides of sulfur	250	50
7. Carbon monoxide	100	50
8. Cadmium	0.5	0.1
9. Mercury	2.0	0.1
10. Heavy metals	20	1
11. TEQ (dioxins, furans)	0.02	0.1E-6

^a 1st sampling point just before dust filter (DF-1).

^b 2nd sampling point just after catalytic converter (CC-1).

3. Process description

The developed technology provides an efficient process for the complete incineration of medical wastes in a multiple-chamber incinerator (IN-1), followed by an integrated treatment unit of combustion gases (GS-1,2) and (CC-1). The heat content of combustion gases is recovered by a heat economizer (HE-1) capable for generating hot water or low-pressure saturated steam. An induced draft fan system (SF-1) is practiced to suck atmospheric air (S7) and combustion gases through the individual incinerator compartments in a successive manner venting the innocent gases finally to the open atmosphere.

The thorough mixing of fine magnesium oxide with the refuse before starting-up (1% by weight) will partially remove the formed sulfur and nitrogen oxides by converting them to their corresponding sulphates and nitrates.

The overall gas temperature should be not less than 870 °C, however the primary burner (S3) is designed to guarantee a temperature of 1100 °C for the combustion gases leaving the ignition chamber. The combustion process in a multiple-chamber incinerator proceeds along two stages; primary or solid fuel combustion in ignition chamber (S5 and S6), followed by secondary or gaseous-phase combustion. The secondary combustion zone consists of two compartments, a downdraft or mixing chamber (S8 and S9), and an updraft combustion chamber (S10). The two-stage multiple chamber incineration process begins at the ignition chamber (S5 and S6) and includes the drying, ignition and combustion of the solid refuse. As the burning proceeds, the moisture and volatile components of the refuse are vaporized and partially oxidized in passing from the ignition chamber (S5 and S6) through the flame port (S8) connecting the ignition chamber with the mixing chamber.

From the flame port (S8), the volatile components of the refuse and the products of combustion flow down through the mixing chamber (S9) into which secondary air (S7) is introduced. The combination of adequate temperature and additional air, augmented by mixing chamber or secondary burners (S4) as necessary, assists in initiating the second stage of the combustion process. Turbulent mixing, resulting from the restricted flow areas and abrupt changes in flow direction, furthers the gaseous-phase reaction. In passing through the curtain wall port (S8 and S9) from the mixing chamber to the final combustion chamber, the gases undergo additional changes in direction accompanied by expansion and final oxidation of combustible components. Fly ash and other solid particulates are collected in the combustion chamber through wall-impingement and simple settling.

The average residence time of combustion gases in the ignition chamber is more than 2 s that will ensure complete destruction of any harmful refuse-constituents. An average flue-gases residence time of 0.25 s in the mixing chamber will guarantee their thorough homogenization before passing under the ignition chamber. This will efficiently help in heating the raw-refuse. The residence time of combustion gases in the underhearth chamber was found to be 0.40 s. The secondary

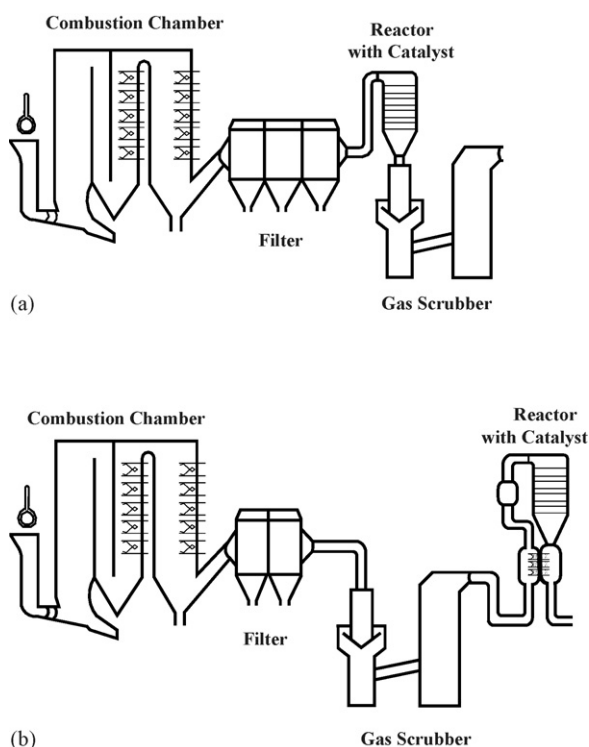


Fig. 2. (a) Flue gas and (b) purified gas configuration.

combustion zone is designed for low velocity gas movement necessary for complete combustion (average flying time of combustion gases is 0.75 s).

Very little PCDD/Fs were detected at the incinerator outlet. As the temperature of combustion gases decreases a spectacular rise in PCDD/Fs concentrations were registered. The latter is increased by a factor of 3 between 900 °C and 500 °C, a factor of 7 with further cooling to 270 °C and a factor 10 at 250 °C [29–31].

Two engineering configurations are practiced in the treatment of flue gases. In the first technique (flue, unpurified gas configuration, Fig. 2a) the catalysts are fitted directly downstream of the dust filter (DF-1). The flue gas temperature is sufficient for the catalytic reaction without further heating being necessary. The gas scrubbers (GS-1,2) are positioned downstream of the reactor (CC-1).

In the preferable second technique (purified gas configuration, Fig. 2b) the catalysts are positioned downstream of the

dust filter (DF-1) and the gas scrubbers (GS-1,2). The operating temperature is generally lower than in the flue gas configuration. In this case, the flue gas is usually heated by means of a heat exchanger. The absence of poisonous heavy metals will prolong the service lifetime of the catalyst. A simultaneous PCDD/Fs destruction together with catalytic NO_x reduction through the injection of ammonia in a combi-reactor is consequently feasible.

4. Overall incinerator material and energy balance calculations

The basis of mass and heat balances on the incineration unit is presented below. A detailed component material balance for all individual process streams is illustrated in (Table 1).

Simplifying assumptions may be made as follows:

- (1) The vaporization and burning rates, auxiliary fuel burning rate, and average waste composition are taken as constant. Design parameters should be based upon that waste containing the highest percentage of moisture that may be expected to be destroyed in the unit.
- (2) The average temperature of the combustion products is determined through calculation of heat losses by storage, convection and radiation.
- (3) The overall average gas temperature should be about 1100 °C [1] when calculations are based upon air for the combustible waste at 100% in excess of theoretical, and upon air for the primary burner at 20% in excess of theoretical. The minimum temperature of the gases leaving the ignition chamber should be 870–1100 °C.
- (4) Indraft velocity in the air ports is assumed to be 6.5 m/s at 0.254 cm WC.
- (5) Secondary air ports are sized to provide theoretical air plus 100% excess air.
- (6) A primary air port is not normally necessary in these units. Sufficient combustion air in the primary chamber is normally provided for both the fuel and waste material by the burner and by leakage at the charge door and other points in this chamber. When primary air port is desired, its sizing should be based on the admission of 200% of the theoretical air necessary for the combustible waste material.

4.1. Incineration of pathological wastes

The percent composition by weight of the pathological materials is 50% from the total refuse weight. The gross heat input is calculated according to the chemical composition and combustion data of refuse (Tables 4a and 4b) together with natural gas characteristics (Table 5). The total heat losses is the sum of (i) heat losses by storage, conduction and radiation, (ii) vaporization of contained moisture, (iii) vaporization of water formed by the combustion of both refuse and natural gas, and (iv) heating the formed ash to the operating temperature.

The design calculations are based on refuse-combustion with 300% excess air whereas that of natural gas with 20% excess air. Air ports are sized for admission of theoretical air plus 100%

Table 4a
Chemical composition of pathological waste and combustion data

Ultimate analysis (whole dead animal)		
Constituent	As charged (% by weight)	Ash-free combustible (% by weight)
Carbon	14.7	50.80
Hydrogen	2.7	9.35
Oxygen	11.5	39.85
Water	62.1	–
Nitrogen	Trace	–
Mineral (ash)	9	–

Table 4b
Dry combustible of empirical formula-C₅H₁₀O₃

Combustion data (based on 1 kg of dry ash-free combustible)		
Constituent	Quantity (kg)	Volume (Nm ³)
Theoretical air	3.269	2.616
40% saturated at 15 °C	3.202	2.633
Flue gas with theoretical air 40% saturated		
CO ₂	0.843	0.455
N ₂	2.450	2.074
H ₂ O formed	0.346	0.453
H ₂ O air	0.014	0.018
Products of combustion	3.653	3
Gross heat of combustion (kJ/kg)	20,505	

excess air. The remaining air enters the incinerator through the open charging door during batch operation and leakage around doors, ports, expansion joints, etc. The volumetric flow rate of natural gas fed to secondary burner is based on thermodynamic calculations to allow the combustion gases to reach a temperature of 1100 °C in the mixing chamber. The heat balance is based on utilizing available net heat and the calorific value of natural gas at the operating temperature.

4.2. Incineration of paper and cellulosic fibers

Thirty-five percent by weight of feed stock is paper and cellulosic fibers whose chemical properties and combustion data are illustrated in Table 6. The net heat input is calculated from the gross heat of combustion minus heat losses. The latter is the sum of (i) heat losses due to radiation, conduction and storage, (ii) vaporization of contained moisture, and (iii) vaporization of water formed by combustion. Combustion of refuse

Table 5
Average typical characteristics of national grid gas for 2004/2005

Component (mol%)	National grid
Nitrogen	0.23
Carbon dioxide	1.34
Methane	91.99
Ethane	4.88
Propane	1.23
<i>i</i> -Butane	0.11
<i>n</i> -Butane	0.10
<i>i</i> -Pentane	0.05
<i>n</i> -Pentane	0.03
Hexane	0.03
Molecular weight	17.63
Relative density (air = 1) at 15/15 °C and 1 atm	0.6093
Density at 15 °C and 1 atm (g/l)	0.75
Gross calorific value at 15 °C and 1 atm	
kcal/m ³	9,415
kcal/kg	12,623
Net calorific value at 15 °C and 1 atm	
kcal/m ³	8496
kcal/kg	11,390
m ³ gas at 15 °C and 1 atm per 1 t of gas	1340.71

Table 6
Chemical properties and combustion data for paper

Material	Sulfite paper ^a (%)	
Analysis		
Carbon (C)	44.34	
Hydrogen (H)	6.27	
Nitrogen (N)	0	
Oxygen (O)	48.39	
Ash	1.00	
Gross kJ/kg dry basis	17,655	
	Constituent (based on 1 kg)	
	Nm ^{3b}	kg
Theoretical air	1.914	2.340
40% saturated at 60 °F	1.927	2.350
Flue gas with theoretical air		
CO ₂	0.396	0.735
N ₂	1.512	1.787
H ₂ O formed	0.334	0.254
H ₂ O (air)	0.013	0.010
Total	2.255	2.786
Flue gas with % excess air as indicated		
0	2.255	2.786
50.0	3.212	3.964
100.0	4.169	5.135
150.0	5.133	6.309
200.0	6.096	7.489
300.0	8.023	9.843

^a Constituents of sulfite paper: cellulose C₆H₁₀O₅, 83%; hemicellulose C₆H₁₀O₅, 8%; lignin C₆H₁₀O₅, 6%; resin C₆H₁₀O₅, 2%; ash C₂₀H₃₀O₂, 1%.

^b Measured at 15 °C and 1 atm.

and natural gas is accomplished with 300% and 20% excess air, respectively.

Air ports are sized for admission of theoretical air plus 100% excess air at 0.254 cm WC and velocity of 6.5 m/s. The heat required to raise the temperature of combustion products to the operating temperature 1100 °C is furnished by natural gas combustion utilizing the net heat input.

4.3. Incineration of plastics

Up to 15% by weight of refuse are assumed plastics. The latter consists of (i) 5% by weight polyvinyl chloride (38.4% C, 4.8% H, 56.8% Cl) and (ii) 95% by weight polypropylene (85.7% C, 14.3% H). Combustion of refuse and natural gas is accomplished with 300% and 20% excess air, respectively. Air ports are also sized for admission of theoretical air plus 100% excess air at 0.254 cm WC. The combustion gases are heated to the incinerator operating temperature by (i) net heat input and (ii) heat supplied by natural gas rated according to thermodynamic calculations.

5. Measurement methodologies and results

Two sampling points are used to measure pollutants level just before the bag filter (DF-1) and just after the catalytic converter (CC-1). The measurement techniques were in accordance

with EPA reference methods using the appropriate instruments. The particulate matter emissions are measured according to EPA reference method 5 where the Andersen instruments sampling train is practiced. The stack gas velocity together with the concentrations of nitrogen oxides, sulfur dioxide, carbon monoxide and hydrocarbons were measured by the ENERAC™ 3000 E portable emissions analyzer. The 3000 E analyzer meets the performance specifications of EPAs: (a) Method 2 for stack gas velocity; (b) CTM-022, 030, and 034; Method 7E and California ARB for NO, NO₂ and NO_x; (c) Method 6C for sulfur dioxide emissions; (d) Method 10 and 10B for carbon monoxide; (e) Method 25B-NDIR for total gaseous hydrocarbons concentration C_xH_x using a non-dispersive infrared analyzer; (f) Method 7E. 5.1.1 for sample conditioning. The concentrations of metal emissions including Hg are measured by using the Perkin-Elmer AAnalyst 400 atomic absorption spectrometers. The analysis is carried out according to EPA-method 29 and the additional test methods 5 and 12. The determination of hydrogen halide and halogen emissions in combustion gases has been carried out by using the Dionex ICS-3000 reagent free ion chromatography system. The analytical procedure is in accordance with the EPA-method 26A. The determination of PCDD/Fs has been carried out by using the Perkin-Elmer Clarus 500 gas chromatograph/mass spectrometer instrument in accordance with the EPA-method 23. The Clarus 500GC is fully automated and equipped with an oven giving excellent temperature control and fast cool-down times for maximum productivity. All temperature and time functions are microprocessor controlled. The Clarus 500 mass spectrometer is a detector with electron ionization that is interfaced to the Clarus 500 GC. The entire system runs through the turbomass GC/MS software.

The analytical measurement of different pollutant-levels vented to the atmosphere were found to be in good conformity with the maximum allowable limits as specified in the law number 4/1994 issued by the Egyptian Environmental Affairs Agency (EEAA) and European standards (Table 3).

An engineering design of an integrated unit is developed for incinerating pathological wastes and treatment of combustion gases. The appropriate design of the individual incinerator compartments and accessories has proved its reliability through (i) verifying maximum combustion temperature in primary, secondary and mixing zones, (ii) satisfactory residence times and superficial velocities of combustion gases in the individual incinerator sectors ensure its homogenization and complete destruction of pathogens, (iii) economic fuel consumption, (iv) efficient mass and heat transfer, (v) unit compactness, (vi) effective incineration time, and (vii) competitive fixed and operating investments.

The heat content of combustion gases is recovered in a finned tube heat economizer generating 35 m³/h hot water at 75 °C (HE-1). The temperature of exit gases will reach practically the operating one of the bag filter (DF-1). The majority of combustion pollutants (particulates, acidic gases, heavy metals, dioxins and furans) are removed in the dust filter (DF-1) and scrubbing columns (SC-1,2), while a sophisticated treatment of PCDD/Fs and nitrogen oxides is accomplished at the catalytic converter.

6. Conclusions and recommendations

A reliable engineering design of an integrated unit for incinerating medical-wastes (at 300% excess air) and treatment of combustion gases is developed. The flying time of flue gases in different incinerator compartments guarantee their homogenization and complete destruction of harmful constituents of the refuse. The unit is equipped with a finned-tubes heat economizer capable for generating 35 m³/h of 75 °C-hot water. The cooled flue gases (200 °C) are fed to the treatment unit comprising a dust filter (DF-1), gas scrubbers (GS-1,2) and a catalytic converter (CC-1). The presented prototype has proved its efficiency through the conformity of different exhaust pollutant-levels with corresponding international standard permissible ones. The capacity of the unit (150 kg/h) was based upon thorough market study comprising all governmental hospitals in great Cairo-zone.

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