JEAS
Journal of Engineering and Applied Sciences13 (2018), 154-166

JOURNAL OF ENGINEERING
AND
APPLIED SCIENCES

THEORETICAL DESIGN OF A NON-ENERGY RECOVERY INCINERATOR FOR AWKA MUNICIPALITY

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Abstract

Waste management in Awka, the Capital City of Anambra State, Nigeria is the principal function of the Anambra State Waste Management Agency. Waste disposal practices in the area are mainly by open dumping and open burning which constitute serious health hazards to the residents and the environment. Use of well designed incinerators and well-built landfills are yet to attract some interest in the said area; probably because of the huge costs of equipment procurement and the expertise involved. The study aimed at designing a hypothetical non-energy recovery incinerating system for municipal solid waste generated in Awka Municipality. The incinerator is rated at a capacity of 45 tons/day, with a charging rate of 5.625 tons/hr. The relation between the refuse and the flue gases and the amounts of water and air required for complete combustion of the refuse and the necessary steps taken to ensure emission of clean gas through the stack are presented. Various assumptions were made which informed the design of the facility's combustion chambers. The materials flow/balance analyses are presented. It is hoped that this hypothetical design will provoke some interests that would lead to actual fabrication of the designed municipal solid waste incinerator for Awka urban area of Anambra State.

Keywords: design, non-energy recovery, incinerator, municipality

1. Introduction

Among the most crucial environmental challenges facing developing countries are the problems and risks posed by municipal/urban solid waste. According to Daskalopoulos et al (1998), the poor state of Solid Waste Management (SWM) in urban areas (of developing countries) is not only an environmental problem but also a major social handicap. Municipal Solid Waste (MSW) refers to the garbage and rubbish which are usually generated during extraction and processing activities in our homes, offices, markets, industries, hospitals, hotels, banks, canteens, agricultural farms, construction sites, mines et cetera, some of which are seen littering our streets and public places or are collected in waste containers kept at various locations in town. This type of waste consists mainly of kitchen waste, waste paper and packaging material like polythene, cardboard, wood, jute dry leaves, grass, twigs, tree branches, PVC and plastic waste, etc. as shown in Table 1. All these waste types can be disposed together at waste dump as a general waste. When waste materials are poorly managed, they present varying degrees of problems to our physical environment.

Table 1: Sources, composition and types of solid waste [Source: Field survey]

S/N	Source	Type of Waste/Waste Generated
1.	**Residential** (Household: single-and multi-family) **homes**	Rubbish (Combustibles: Newspapers, books and sheets/pieces of paper, cartons, ball wood, clothing, disposable tableware, wood furniture, plastics, etc); Garbage (food scraps, from preparation, cooking, and/or serving of food, food packaging, etc); cans and bottles, ashes, and occasionally large waste from house; Hazardous waste (toxic, highly flammables, pathogenic, radioactive materials, explosives, etc); Yard wastes (leaves, garden debris, trimming, pruning, etc)
2.	**Institutions** (schools, libraries, hospitals, prisons, churches)	Cafeteria and restroom trash can wastes, office papers, classroom wastes, yard trimmings
3.	**Commercial establishments**(office buildings, retail and wholesale establishments, hotels and restaurants, eateries, markets)	Rubbish, Garbage, Corrugated boxes, yard trimmings, Hazardous waste, construction and demolition wastes
4.	**Industries/Technical Workshops** (plants, mills, fac-tories, fabrication, pack-aging and administrative; wastes processing ones not included)	Corrugated boxes, office papers, plastic film, wood pallets, iron filings and pieces of metals, lunchroom wastes, construction and demolition wastes
5.	**Municipal** (schools, offices, industries, markets, etc)	Street sweeping, sewage treatment plant waste, wastes from schools and other institutions, Dead animal and man, Abandoned vehicles

Figures 1(a) to (d) in the Appendix are photographs showing a number of locations in Anambra State where solid waste are dumped into and around stationary public used bins. In general, a greater proportion of the waste is biomass. Waste mix varies in nature as it has different physical and chemical characteristics.

Figure 2 is a photograph showing an open burning of refuse, with the smoky environment also captured, at a dump site in Onitsha urban city of Anambra State. A closer look at Plates 1 and 2 quickly reveals how dirty, unkempt and unhealthy these garbage make our environment look. Therefore, the need to protect our natural environment and keep it clean on individual, organizational and governmental levels for the benefit of all cannot be over-emphasized. One of the methods used in maintaining a clean environment is by the use of well designed and built incinerators (or waste furnaces).

2.0 Material and methods

The hypothetical incinerating system for Awka MSW/USW is modelled using the relevant theories and principles governing the design and fabrication of incinerators. Immediate fabrication of the incinerator is not in view. Areas covered include: trash combustion systems, interconnecting duct work, air pollution control systems, materials flow, and extraction/filtration systems. Design drawings and specifications in the work are prepared using computer based drafting systems.Following (Figure 1) is a flow sheet of a typical municipal waste incinerator with the environmental control systems.

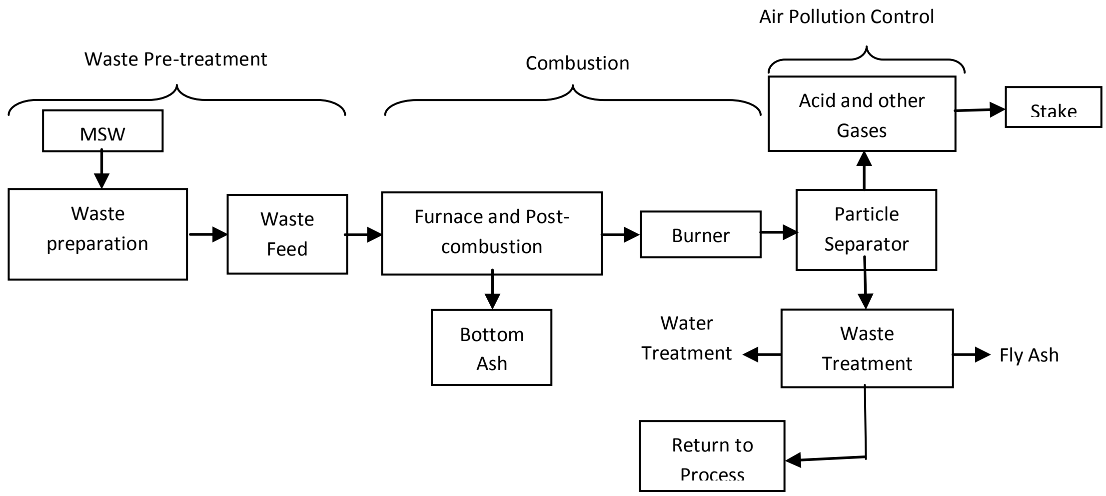

Figure 1: Flowsheet of a municipal waste incinerator including environmental control system [Adopted from Alonso-Torres et al, 2010]

2.1 Theoretical design of municipal solid waste incinerator

$$\text{Quantity of refuse produced per given period} = \frac{q}{t} \quad (1)$$

Assuming a month consists of 28 working days and 8 working hours per day

$$q_{cb/d} = \frac{q_m}{28} \quad (2)$$

$$q_{w/d} = w_s \times q_d \times V_{cb} \quad (3)$$

$$q_{R\text{-}hr} = \frac{q_{w/d}}{8} \quad (4)$$

$$A_{PG} = \frac{q_{R\text{-}hr}}{q_{FR}} \quad (5)$$

$$V_{PCC} = V_{PAG} \times IRC \quad (6)$$

$$V_{PCC} = (L \times W \times h)_{PCC} \quad (7)$$

$$V_{Ash} = (L \times W \times h)_{Ash} \quad (8)$$

$$V_{SCC} = (2\pi r_1^2 L)_{SCC} \quad (9)$$

$$NHRR = \frac{HHV \times q_{w/d}}{V_{PCC}} \quad (10)$$

For a parallelepiped or box enclosure

$$H_{RL} = \frac{T_{hf} - T_{cf}}{[(t_A/k_A) + (t_A/k_B) + R_{air} + \ldots + (tc/k_c) + (1/h_{cf})]} \quad (11)$$

$$H_{RL} = \frac{T_{hf} - T_2}{(t_A/k_B)} \quad (12)$$

$$H_{RL} = \frac{T_2 - T_3}{(t_B/k_B)} \quad (13)$$

$$H_{RL} = \frac{T_3 - T_4}{(t_C/k_C)} \quad (14)$$

For a cylindrical enclosure

$$H_{RT} = \frac{2\pi L_{SCC}(T_{hf} - T_{cf})]}{[\ (1/h_{hf}\, r_1) + \ln(r_2/r_1)/k_A + \ln(r_3/r_2)/k_B + \ldots + (1/h_{cf}\, r_1)]} \quad (15)$$

$$T_{hf} - T_1 = \frac{H_{RT}}{2\pi L_{SCC}\, h_{hf}\, r_1} \quad (16)$$

$$T_1 - T_2 = \frac{H_{RT}}{(2\pi k_A\, L_{SCC})/\ln(r_2/r_1)} \quad (17)$$

$$T_2 - T_3 = \frac{H_{RT}}{(2\pi k_B\, L_{SCC})/\ln(r_3/r_2)} \quad (18)$$

$$T_3 - T_{cf} = \frac{H_{RT}}{2\pi L_{SCC}\, h_{cf}\, r_3} \quad (19)$$

2.1.1 Priori decisions

The average values of the data collected from a thirty six months study conducted on waste generation and evacuation in Awka metropolitan city of Anambra State presented in Table 2:

Table 2: ASWAMA Zones, Awka Urban City of Anambra State

Mnt	Mnt_ Code	Ama-wbia	Zik's Ave.	Ama-ikwo	Ama-enyi/ Amaku	Udoka Estate	Nibo/ Umu-awulu	Iyiagu Estate	Okpuno	Enugu-Onitsha Express Way	Emma Nna-emeka	Ifite	Govt. House	Total Monthly Produc-tion
Jan	1	596	1053	671	665	668	589.5	465	602	420	373	722	664.5	7489.0
Feb	2	619.4	944.9	632.7	574.4	656.1	552.7	574.2	564.4	440	401.6	661	633.8	7255.2
Mar	3	560.8	1042.3	692.2	720.1	686.8	484.2	473.4	668.6	508.3	360.3	743.7	709.9	7650.6
Apr	4	682.8	1184.8	705.3	597.9	755	644.7	574.2	651	535.5	391.7	717.5	749.2	8189.6
May	5	586.9	1031.8	720.8	784.9	715.1	557.4	547.7	681.7	462	463.1	766.2	656.1	7973.7
Jun	6	727.2	1206.6	760.8	719.1	594	591.5	434.6	697.3	579.7	455.1	714.8	823.7	8304.4
Jul	7	583.7	1051.3	700.8	642.5	759.2	525.9	467.6	642.5	467.6	350.4	700.8	759.2	7651.5
Aug	8	713.5	1072.1	583.5	680.5	678.9	534.7	523.7	605.5	499.1	341.8	712.5	663.7	7609.5
Sep	9	592.6	1147.5	711.2	656.1	720.1	647.1	574.1	730.9	487.3	437.6	775.2	741.7	8221.4
Oct	10	735.7	1220.5	769.3	727.4	600.3	598.1	439.1	705.4	586	460	723	833.1	8397.9
Nov	11	658	978.6	601.2	676.4	753.7	550.9	559.6	574.7	439.6	425.5	719.1	685	7622.3
Dec	12	724.1	1123.2	683	651.7	678.3	542.3	537.6	610	471.5	440.2	685.6	631.4	7778.9
Jan	13	153.9	227.1	122.6	143.5	144.7	119.3	111.6	127.5	106.5	72.9	152	141.5	1623.1
Feb	14	130.6	242.7	161.3	167.7	160	112.7	127.5	155.8	118.4	84	173.2	165.4	1799.3
Mar	15	157.3	260.8	164.4	155.4	128.4	127.8	93.9	150.8	125.3	98.4	154.5	178.1	1795.1
Apr	16	171.8	266.5	162.1	154.6	161	128.6	127.5	144.7	111.9	104.4	162.6	149.8	1845.5
May	17	149.8	264.7	168.7	167.3	168	148.2	116.9	151.4	105.7	93.8	181.6	167	1883.1
Jun	18	138.4	243.4	170.1	185.1	168.8	131.5	129.2	160.9	108.9	109.3	180.8	154.8	1881.2
Jul	19	147.2	219.1	134.7	151.3	168.7	123.4	125.3	128.6	98.5	95.2	160.9	153.3	1706.2
Aug	20	142.6	247.5	147.2	124.8	157.7	134.5	119.9	135.9	111.8	81.8	149.7	156.5	1709.9
Sep	21	133.5	258.6	160.2	147.9	162.3	145.8	129.3	164.7	109.9	98.5	174.7	167.1	1852.5
Oct	22	130.2	234.6	156.4	143.4	169.4	117.2	104.3	143.4	104.3	78.2	156.4	169.4	1707.2
Nov	23	145.9	222.5	149	135.2	154.6	130.2	121.3	132.9	103.6	94.6	155.7	149.3	1694.8
Dec	24	168.9	280.1	176.6	167	137.8	137.2	100.8	161.9	134.6	105.6	166	191.2	1927.7
Jan	25	174.6	301.5	180	146.9	188.9	162.8	145	164.4	135.3	98.9	181.2	189.2	2068.7
Feb	26	198.7	329.7	207.8	196.5	162.2	161.5	141.7	190.6	158.4	124.3	195.3	225	2291.7
Mar	27	179.3	316.7	201.8	200	200.9	177.3	139.8	181.1	126.4	112.1	217.2	199.8	2252.4
Apr	28	167.7	311.5	207.1	215.3	205.4	144.8	141.7	200	151.9	107.7	222.4	212.3	2287.8
May	29	169.3	327.8	203.1	187.3	205.6	184.8	163.9	208.7	139.2	124.9	221.4	211.7	2347.7
Jun	30	163.5	287.4	200.7	218.5	199.2	155.2	152.6	189.9	128.6	129.1	213.4	182.8	2220.9
Jul	31	180.2	268.2	164.8	185.3	206.6	151	153.3	157.5	120.6	116.6	197	187.8	2088.7
Aug	32	169	304.4	202.9	186.1	219.8	152.1	135.4	186.1	135.4	101.4	202.9	219.8	2215.3
Sep	33	190.6	290.6	194.6	176.7	201.9	170	158.5	173.6	135.2	123.6	203.4	195.1	2213.8
Oct	34	200.9	311.7	189.6	180.9	188.3	150.5	149.2	169.2	130.8	122.2	190.2	175.2	2158.7
Nov	35	192.4	319.1	201.2	190.3	157	156.4	114.9	184.6	153.3	120.4	189.1	217.9	2196.6
Dec	36	235	346.9	187.2	219.1	221.2	182.3	170.6	194.9	162.6	111.4	232.1	216.2	2479.5
													Overall sum =	142391.4

2.1.2 Assumptions

The following assumptions are made in the design:

- Specific weight of refuse = 74.16 kg m^{-3}
- Estimated unit volume of each chain-up bin fully loaded with refuse = 3.82 m^3
- The total solid residue contains 4% of unburned carbon

- The residue from the grate is cooled from 1300 F (705 ^{0}C) to 240 F (115 ^{0}C) by spraying with water or dropped into water before removal from the ash pit.
- The water vapour produced joins the furnace gases.
- The carry-over of solids with the furnace exit gases is 18.14 kg/ton of refuse, or 181.43 kg/hr
- Furnace wall consists of 250 mm wide refractory brick and 180 mm wide insulating fire brick separated by an air gap, and the outside wall is to be covered with 15 mm thickness of plaster.
- The inner surface of the furnace wall should be 705^{0}C and the temperature of the outside sur-rounding air 40^{0}C.
- The heat transfer coefficient from the outside wall surface to the outside surrounding air is 18 W/m^{2o}C, and the resistance to heat flow of the air air gap is 0.16 K/W.
- The thermal conductivities of the refractory brick, insulating fire brick, and plaster are 1.6, 0.3 and 0.14 W/mK, respectively
- The incinerator charge and the residue discharge are continuous.
- The incineration chambers are maintained at temperatures of between 700^{o}C to 1010^{0}C.
- The residence time for gaseous products in the hot combustion chamber is not less than 1.5 seconds to ensure a good burnout.
- Temperatures of critical points, flows of gases and water are monitored by means of relevant gadgets.
- The incinerator gives out white smokes with minimal pollutants.
- Overfire air are introduced in a fashion that provides good mixing of the combustion products.
- The combustion chamber are constructed with thick steel members which should be adequately protected from the fire and with good quality meeting standards. Access doors for maintenance should have little windows for careful viewing of the fire.
- The outside surfaces of the combustion chambers should be kept to no more that 80^{o}C by the use of adequate refractory and insulation materials.

3.0 Results and Discussions

From the available data, the rated capacity of the incinerator is ≈ 40823.3 kg/day = 45 ton/day (say). Charging rate of the Awka MSW incinerator is taken as 5102.91 kg/hr or 5.625 tons/hr of refuse. Other vital parameters are contained in Table 3:

Table 3: Design parameters for Awka MSW incinerator

Parameter/ Symbol		Assumed Value	Unit	Parameter/ Symbol		Assumed Value	Unit
t	=	36	months	$(T_{hf})_{PCC}$	=	705	^{o}C
w_s	=	74.16	kg/m^3	$(T_{cf})_{PCC}$	=	40	^{o}C
V_{cb}	=	3.82	m^3	$(t_{RB})_{SCC}$	=	0.2	m
q_{cb}	=	142391.4	cb	$(t_{FB})_{SCC}$	=	0.25	m
$(t_{RB})_{PCC}$	=	0.3	m	$(t_{CP})_{SCC}$	=	0.004	m
$(t_{FB})_{PCC}$	=	0.2	m	$(h_{hf})_{SCC}$	=	26	W/m^2 ^{o}C
$(t_p)_{PCC}$	=	0.015	m	$(h_{cf})_{SCC}$	=	15	W/m
$(h_{cf})_{PCC}$	=	18	W/m^2 ^{o}C	$(k_{RB})_{SCC}$	=	1.6	W/m ^{o}C
$(R_{air})_{PCC}$	=	0.16	K/W	$(k_{FB})_{SCC}$	=	0.3	W/m ^{o}C
$(k_{RB})_{PCC}$	=	1.6	W/m ^{o}C	$(k_P)_{SCC}$	=	0.8	W/m ^{o}C
$(k_{FB})_{PCC}$	=	0.3	W/m ^{o}C	$(T_{hf})_{SCC}$	=	1010	^{o}C
$(k_P)_{PCC}$	=	0.14	W/m ^{o}C	$(T_{cf})_{SCC}$	=	40	^{o}C

Some of the computation results from application of the above data are shown in Table 4.

Table 4: Computation/evaluation of facility size/specifications

Parameter/ Symbol	Source/ Equation	Computed Value	Unit
$q_{cb/m}$	(1)	3955.32	cb
$q_{cb/d}$	(2)	141.26	cb
$q_{w/d}$	(3)	40823.31	kg/day
IRC		45.00	tons/day
q_{R-hr}	(4)	5102.91	kg/day

q_{FR}		195.30	kg/m^2-hr
A_{PG}	(5)	26.13	m^2
V_{PAG}	[Kaiser, undated]	0.88	m^3
V_{PCC}	(6)	39.76	m^3
L_{PCC}	Assumed	3.66	m
$h_{PCC} = W_{PCC}$	(6)	3.30	m
V_{Ash}	Assumed	4.77	m^3
L_{Ash}	Assumed	4.57	m
h_{Ash}		0.72	m
W_{Ash}	Assumed	1.44	m
V_{SCC}	Assumed	31.81	m^3
D_{SCC}	Assumed	2.59	m
r_1	SCC	1.295	m
r_2	SCC	1.495	m
r_3	SCC	1.745	m
r_4	SCC	1.749	m
L_{SCC}	(8)	6.03	m
HHV	[Kaiser, undated]	5.54	MJ/kg
NHRR	(9)	682.23	MJ/m^3
$(H_{RL})_{PCC}$	(10a)	565.10	W
$(T_2)_{PCC}$	(10b)	599.10	^{o}C
$(T_3)_{PCC}$	(10c)	508.60	^{o}C
$(T_4)_{PCC}$	(10c)	131.90	^{o}C
$(T_5)_{PCC}$	(10)	71.40	^{o}C
$(H_{RT})_{SCC}$	(11a)	54369.10	W
$(T_1)_{SCC}$	(11b)	1010.00	^{o}C
$(T_2)_{SCC}$	(11c)	881.20	^{o}C
$(T_3)_{SCC}$	(11d)	141.60	^{o}C
$(T_4)_{SCC}$	(11e)	137.40	^{o}C

A schematic representation of the proposed Awka MSW incinerator is depicted in Figure 3.

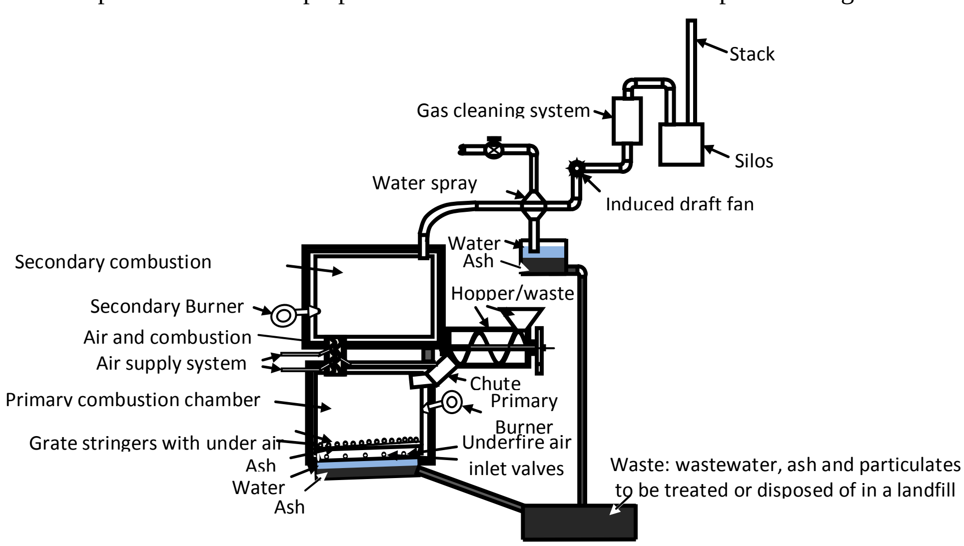

Figure 3: Schematic diagram of the hypothetic incinerator for Awka Municipality, Anambra State

Having determined the facility components' sizes/specifications, materials flow into and out of the incinerator is discussed shortly, following the method of Kaiser (undated). It is further assumed that the primary chamber of the hypothetical incinerator will be continuously charged, with the given waste having the following composition:

Moisture	30.00%
Carbon	22.95%
Hydrogen	3.25%
Oxygen	18.80%

Nitrogen	-
Sulphur	-
Non-combustibles	25.00%
	100.00%

Nitrogen ≈ 0.3% and sulphur < 0.2% of MSW are not included in this calculation.
Net hydrogen available for combustion = 3.25 - (18.80/8) = 0.90 %
Bound water in the refuse, released during combustion = 18.80 x (9/8) = 21.15 % of residue.

Dry combustible matter consists of 4 parts of cellulose, starch and sugar ($C_6H_{10}O_5$) and 1 part of a mixture of protein, fats, oils, waxes, rubber, plastics, etc. The main constituent of cellulose include:

Carbon	44.4 %
Net Hydrogen	0.0 %
Moisture (bound water)	55.6 %

Cellulose has an approximate higher heating value (HHV) of ≈ 17.45 MJ/kg (or 7500 Btu/lb, according to [Ref. 2; Kaiser (undated)]. For practical purposes, the mixture of protein, fats, oils, etc. has an approximate HHV of ≈ 39.54 MJ/kg (or 17000 Btu/lb), with the following composition:

Carbon	77.4 %
Net Hydrogen	10.0 %
Moisture (bound water)	12.6 %

Nitrogen is about 0.3% and sulphur is < 0.2% of the MSW. These are not included in the calculations. The combined HHV for the dry combustible matter consisting the refuse is assumed thus:

$$= [{}^4/_5\,(17.45) + {}^1/_5\,(39.54)] \times 0.45$$
$$= \underline{21.86\ MJ/kg}$$

3.1 Combustion Calculations

Air contains 23% of oxygen by mass. This implies that 1 kg of air contains 0.23 kg of oxygen. This implies that 1 kg of oxygen will be contained in 4.35 kg of air.Burning of carbon to carbon IV oxide is defined by the relation:

$$C + O_2 \rightarrow CO_2$$
$$12\ kg\ C + 32\ kg\ O = 44\ kg\ CO_2$$

i.e. Molecular mass of carbon + molecular mass of oxygen = molecular mass of carbon IV oxide

Therefore,

$$1\ kg\ C + {}^{32}/_{12}\ kg\ O_2 = {}^{44}/_{12}\ kg\ CO_2$$

Implying that $1\ kg\ C + 2.66\ kg\ O_2 = 3.66\ kg\ CO_2$

And since 1 kg O_2 is contained in 4.35 kg air, mass of air required to completely burn 1 kg carbon = 11.6 kg

Now, actual quantities of the above elements in the refuse are calculated as follows:

Carbon = (22.95/100) x 5102.91 kg/hr
= 1171.12 kg/hr

Carbon in residue = (4/100) x (25/100) x 5102.91/(96/100)
= 53.16 kg/hr

Available carbon = (1171.12 - 53.16) kg/hr
= 1117.96 kg/hr

Available hydrogen = (0.9/100) x 5102.91 kg/hr
= 45.93 kg/hr

Initial moisture = (3/100) x 5102.91 kg/hr
= 1530.87 kg/hr

Bound water = (21.15/100) x 5102.91 kg/hr
= 1079.27 kg/hr

Therefore, available water = 2610.14 kg/hr

Residue (ash, metal, glass, etc) = (25/100) x 5102.91 kg/hr
= 1275.73 kg/hr

Therefore total residue = 1275.73 + 53.16 kg/hr
= 1328.88 kg/hr

Total material flow per hr = 1117.96 + 45.93 + 2610.14 + 1328.88 kg/hr
= 5102.91 kg/hr

3.2 Analysis of combustion processes and amount of air required to burn the refuse

The stoichiometric Analysis

1 kg Carbon requires 5.23 kg air to produce 1.66 kg of CO_2 and 4.02 kg N_2

1 kg H2 requires 15.58 kg air to produce 4.05 kg of H_20 vapor and 11.98 kg N_2

Dry air consists of 23.15% oxygen and 76.85% nitrogen by weights, and 21% oxygen and 79% nitrogen by volumes.

Theoretical dry air required for actual burning of the refuse is calculated as:

For the carbon = 1117.96 x 5.23
= 5846.86 kg/hr

For the available hydrogen= 45.93 x 15.58
= 715.36 kg/hr

Therefore, theoretical dry air required hourly= 5846.96 + 715.36
= 6562.22 kg/hr

Excess air required = (130/100) x 6562.22
= 8530.89 kg/hr

Total dry air required per hour = 6562.22 + 8530.89
= 15093.11 kg/hr

The water vapour produced in quenching the grate residue is added to the combustion gas.

Dry grate residue = 1328.88 kg/hr

Carry-over of solids with furnace exit gases = (2/100) x 5102.91 (say)
= 102.06 kg/hr

Therefore the dry grate residue production rate = 1328.88 - 102.06
= 1226.83 kg/hr

Specific heat of refuse is assumed as 0.25 [Kaiser, undated]

If the residue is cooled from a temperature of 705 ^oC to 116 ^oC (say), then the heat liberated by residue
= 1226.83 x 0.25 x (705 - 116)
= 180922.70 kJ/kg

Approximate heat gained by each mass of quenched water evaporated = 2563.25 kJ/kg

Mass of water evaporated in quenching grate residue = 180922.70/ 2563.25 = 70.58 kg/hr

3.3 Materials Balance for the Combustion Chambers

Table 5: Material Balance (Summary of the weights) For Furnace and Combustion

Input

Refuse		5102.91	kg/hr
Dry air		15093.11	kg/hr
Air moisture		90.37	kg/hr
Quench water		70.58	kg/hr
	Total =	20356.98	kg/hr

Output

Dry flue gas:			
CO_2:		1858.52	
O_2		1974.90	
N_2		11599.06	
	Total =	15432.48	kg/hr
H_20 vapour from:			
refuse		2610.14	
air		90.37	
combustion of H		186.15	
ash pit		70.58	
	Total =	2957.25	kg/hr

Grate residue	1865.20	kg/hr
Carry-over solids	102.06	kg/hr
Total =	20356.98	kg/hr

3.4 Flue-Gas Composition and Gas Cleaning

Assuming complete combustion, if the flue gases that leave the secondary combustion chamber were to be sampled and analyzed by Orsat apparatus, the following analysis would be obtained:

Gas	**Weight, kg**	**m^3/kg**	**m^3**	**Orsat, dry vol. (%)**
CO_2	7290.59	0.53	3890.45	8.15
O_2	7744.18	0.74	5713.94	11.96
CO_2	0.00	0.84	0.00	0.00
N_2	45463.11	0.84	38153.50	79.89
	60497.88		**47757.89**	**100.00**

In order to ensure that the carry-over solids/fly ash from the primary and secondary combustion chambers are minimized, the exiting gas is made to pass through a water spray chamber which partially cools the gases and traps some of the fly ash, through a dry-type dust separator, an induced draft (ID) fan and then the stack. If the combustion gases should be cleaned using cyclonic, electrostatic or other dry dust collector, the gases must be cooled or tempered. This cooling requirement is accomplished by means of the water sprays and ambient air supplied as a practical aid to protect the refractors and in temperature control. It is assumed here that the additional air bled into the water spray chamber, including leakage is 12757.3 kg/hr, consisting of 12591.44 kg dry air and 165.84 kg air moisture. To sluice ash out of the spray chamber 600 gph (2267 kg/hr) of water is added. Trapped ash is assumed at 79.38 kg/hr and fly ash in gases at 102.06 kg/hr.

3.5 Hourly material balance for the spray chamber

<u>Input</u>				
Dry gases from combustion chamber:				
Carbon dioxide	4100.96	kg/hr		
Oxygen	4356.10	kg/hr		
Nitrogen	25573.00	kg/hr		
Total amt of dry gases =			34030.06	kg/hr
Dry bleed air			12591.44	kg/hr
H_2O vapour:				
In gas from SSCC	3752.17	kg/hr		
In bleed air	165.84	kg/hr		
Total amount of H_2O vapour =			3918.02	kg/hr
Water supply:				
To sprays (evaporated)	7277.78	kg/hr		
To sluice ash	1275.22	kg/hr		
Total H_2O supply =			8552.99	kg/hr
Fly ash			102.06	kg/hr
Total =			59194.57	kg/hr
<u>Output</u>				
Dry gases:				
Carbon dioxide	4100.96	kg/hr		
Oxygen	7271.02	kg/hr		

Nitrogen	35249.52	kg/hr	
	Total amt of dry gases =	46621.50	kg/hr
Water vapour:		11195.79	kg/hr
Sluice water: 10 gpm		1275.22	kg/hr
Trapped fly ash		44.65	kg/hr
Fly ash in gases		57.41	kg/hr
	Total =	59194.57	kg/hr

Humidity ratio: 0.240, Saturation temperature, 154 F (≈ 68 ^oC)

Steam fog occurs when the mixture is cooled below the saturation temperature [ASRAE Guide and Data Book].

3.6 Combined process materials balance for primary combustion, secondary combustion and the spray chambers

Input			
Refuse, as fired		5102.91	kg/hr
Dry air		45868.05	kg/hr
Air moisture at 0.005987 kg/kg (-i.e. 0.0132 lb/lb) air		605.21	kg/hr
Quench and sluice water, 39 gpm		8845.14	kg/hr
	Total input =	60421.31	kg/hr
Output			
Dry flue gas:			
Carbon dioxide	4100.96		
Oxygen	7271.14		
Nitrogen	35249.40		
	Total amount of dry flue gases =	46621.5	kg/hr
Water vapour		11195.79	kg/hr
Residue:			
Grate		1226.74	kg/hr
Fly ash		57.41	kg/hr
Spray chamber slurry:			
Water	1275.22		
Solids	44.65		
	Total amount of slurry=	1319.87	kg/hr
	Total output =	60421.31	kg/hr

3.7Flue-Gas Scrubber

The gases leaving the combustion chamber should enter the quench section where the gases are cooled and saturated with spray water. The flue-gas is washed (scrubbed) by means of a duct for quenching the gases, a scrubber with demister, lD fan and stack. A small excess of water is supplied to the scrubber to carry away trapped fly ash via an overflow pipe. To ensure compliance with the EU Waste Incineration Directive 76/2000, the exhaust gases should be made to pass through a dry gas abatement system comprising of a bag or ceramic filter house and a reagent storage/feed system. The exiting gases should be injected with lime or sodium bicarbonate and activated carbon which is stored in bulk containers or silos adjacent to the gas cleaning system. This will enable the lime/sodium bicarbonate to react with and neutralize the acid components of the gas stream such as sulphur dioxide and hydrogen chloride within the gas stream; the carbon will absorb the heavy metals and any dioxins. Dust from the combustion process and spent powdered lime/sodium bicarbonate and carbon will be collected on the abatement plants filters. This residue should be released periodically from the filters using compressed air, allowing it to be transported into a sealed container for disposal.

4.0. Conclusion

Design of a hypothetical non-energy recovery incinerating system for treatment (reducing the volume by burning) of Awka municipal solid waste has been presented in the study. The incinerator is rated at a capacity of 45 tons/day, with a charging rate of 5.625 tons/hr. The relation between the refuse and the flue gases and the amounts of water and air required for complete combustion of the refuse and the necessary steps taken to ensure emission of clean gas through the stack are presented. Various assumptions were made in the materials flow process/balance analyses. It is hoped that the present design will provoke some interests that would lead to actual fabrication of the municipal solid waste incinerator for Awka urban area of Anambra State.

5.0 Recommendation

Instead of continuing with the present practice of open waste burning in Awka Municipality, which has continued to pose both environmental and health problems to the residents of the city, it is recommended that an energy or non-energy recovery incinerator be fabricated, stationed and used in treatment of wastes transported to the final waste dump site at Agu-Awka, Awka South L.G.A.

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Nomenclature

Parameter/ Symbol		Meaning
t	=	Period (length of time) taken to generate a given quantity of refuse
w_s	=	Specific weight of refuse
V_{cb}	=	Unit volume of chain-up bin
q	=	Quantity of refuse produced in a given location
$q_{cb/m}$	=	Average number of chain-up bins of refuse produced per month
$q_{cb/d}$	=	Average number of chain-up bins of refuse produced per day
$q_{w/m}$	=	Average weight of refuse produced per month
$q_{w/d}$	=	Average weight of refuse produced per day
IRC	=	Incinerator rated capacity
f_s	=	Volume which PCC has above the grates per ton of rated capacity
$q_{R\text{-}hr}$	=	Incinerator hourly charging rate
q_{FR}	=	Grate loading or firing rate
A_{PG}	=	Grate projected plan area

PCC	=	Primary combustion chamber
SCC	=	Secondary combustion chamber
V_{PAG}	=	Volume of the primary combustion chamber above the grates
V_{PCC}	=	Volume of the primary combustion chamber
h_{PCC}	=	Height of the primary combustion chamber
V_{Ash}	=	Volume of the furnace ash tray
L_{Ash}	=	Length of the furnace ash tray
h_{Ash}	=	Height of the furnace ash tray
W_{Ash}	=	Width of the furnace ash tray
L_{PCC}	=	Length of the primary combustion chamber
W_{PCC}	=	Width of the primary combustion chamber
HHV	=	Higher heating value of the refuse
NHRR	=	Nominal heat release rate
t_{CP}	=	Thickness of chamber cover plate
h_{hf}	=	Inside heat transfer coefficient of the fluid
h_{cf}	=	Outside heat transfer coefficient
t_{RB}	=	Thickness of refractory brick
t_{FB}	=	Thickness of insulating fire brick
t_p	=	Thickness of plaster
h_{cf}	=	Heat transfer coefficient from the outside wall surface to the (air) surroundings
R_{air}	=	Resistance of air gap to heat flow
k_{RB}	=	Thermal conductivities of refractory brick
k_{FB}	=	Thermal conductivities of insulating fire brick
k_P	=	Thermal conductivities of plaster
T_{hf}	=	Temperature of the hot fluid inside the combustion chamber/Inner surface temperature of furnace wall
T_{cf}	=	Furnace outside environment temperature
H_{RL}	=	Rate of heat loss per m^2 of surface area
$(T_2)_{PCC}$	=	Temperature of the refractory brick at its interface with the air space
$(T_3)_{PCC}$	=	Temperature of the insulating fire brick at its interface with the air space
$(T_4)_{PCC}$	=	Temperature of the insulation fire brick at its interface with the plaster
$(T_5)_{PCC}$	=	Temperature of the outside surface of the plaster wall
k_{mp}	=	Thermal conductivity of the metal cover plate
T_{cf}	=	Temperature of the cold fluid outside (environment) the furnace (atmospheric air)
L_{SCC}	=	Length of the secondary combustion chamber
D_{SCC}	=	Diameter of the secondary combustion chamber
r_1	=	Internal radius of the SCC
r_2	=	Outside diameter radius of the cast cylindrical refractory brick of the SCC
r_3	=	Outside diameter radius of the insulating material of the SCC
r_4	=	Outside diameter radius of the insulating material of the SCC
H_{RT}	=	Rate of heat transfer
$(T_1)_{SCC}$	=	Temperature of the refractory brick at its interface with the hot fluid
$(T_2)_{SCC}$	=	Temperature of the refractory brick at its interface with the insulation fire brick
$(T_3)_{SCC}$	=	Temperature of the insulation fire brick at its interface with the refractory brick
$(T_4)_{SCC}$	=	Temperature of the insulation fire brick at its interface with the metal cover plate
O_2	=	Oxygen
H	=	Hydrogen
C	=	Carbon
N	=	Nitrogen
S	=	Sulphur
H_{sp}	=	Specific heat of refuse

H_2O = Water

Appendices

a: A refuse dump inside Ekwulobia Motor Park, Aguata L.G.A., Anambra State

b: A refuse dump at Eke Awka Market in Eke Awka Zone, Awka City, Anambra State

c: A refuse dump behind Ekwulobia Motor Park, Aguata L. G. A

d: A refuse dump at Ogbalingba in Amaikwo Awka Zone, Awka city

Plate 1: Roadside dumpsites at different locations in Anambra State. [Source: Field survey]

a: An open refuse dumpsite in Onitsha, Anambra State [Source: UN-Habitat, 2012]

b: A chain-up bin used in collection and open burning of refuse at dumpsite in Awka

Plate 2: Scenes of open burning practice in Anambra State