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DESIGN OF MUNICIPAL SOLID WASTE INCINERATOR FOR USE IN SEMI-ARID REGIONS

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Abstract

The paper treats the design of a municipal solid waste incinerator suited to the semiarid regions with northern Nigeria and Niger Republic in West Africa as the study area. Proximate and ultimate analyses results from the solid waste were used as basis for calculations, using standard formulas and correlations. The calorific value of the solid waste samples in the study area is not high enough to sustain an incineration process and it ranges from 5.024 MJ/kg to 5.867 MJ/kg. For these types of low calorific value fuels, the parallel flow concept was found to be the appropriate type of incinerator. The solid waste to be fed in the incinerator needs to be mixed with 50% of supplementary fuel in the form of readily available bagasse to make it up to the required lower calorific value. Major characteristics of the designed municipal solid waste incinerator were: total volume of incinerator chamber: 82.5 m^3, length of the incinerator bed: 11m; width of the incinerator bed: 3m and height of the incinerator chamber: 2.5 m, while the suitable adiabatic flame temperature was found to be 1,587 K.

Keywords: municipal solid waste, incineration, semiarid regions, calorific value, bagasse.

1. Introduction

Municipal solid waste (MSW) is defined as non-air and sewage wastes created within and disposed by a municipality, including household garbage, commercial refuse, construction and demolition debris, dead animals, and abandoned vehicles (Cointreau, 1982).The majority of substances composing municipal solid waste, in the study area, include paper, vegetable matter, plastics, metals, textiles, rubber and glass (Oumarou *et al*., 2012). Treatment methods differ in dealing with different waste streams, and huge amounts of wastes are generated by municipalities and need to be removed from the environment. Amidst various waste treatment methods like recycling, composting; incineration is the thermal treatment method of solid wastes dealing with the non-reusable and non-organic portion of wastes; it offers the advantages of: recovering the heat content of the wastes, reduction in the volume and mass of wastes (up to 90% of the volume and up to 75% of the mass); detoxification (incineration can achieve almost 100% destruction of any pathogen, toxic, or hazardous substance contained in the waste, to make them suitable for final disposal) and destruction of organic components of biodegradable waste that may generate landfill gas (LFG).

The semiarid areas are presently devastated by desertification and they are also characterized by yearly rain falls of 125 to 500 mm (SFSA, 2007) and daily temperatures may sometimes reach a peak of 40 to 45^{o}C during the hottest months.

This paper presents the design of a municipal solid waste incinerator to provide energy and thus protect the environment, through the knowledge of the basic composition of the refuse in the area of study.

2. Incinerator design

2.1. Incinerator internal sizing requirements

This volume is a function of the total heat released per hour from the burning refuse. The internal volume requirement excludes the ash pit and can be evaluated from (Cheremisinoff and Young, 1976):

$$Q_{thr} = \frac{M_b}{Q_{av.}} \tag{1}$$

$$Vi_{min} = \frac{Q_{thr}}{258{,}750\ W/m^3} \tag{2}$$

where:

Vi_{min} is minimum theoretical internal volume (m^3), Q_{thr} is total heat released (W), M_b is the mass of refuse burned per hour (kg/h) and Q_{av} is average heating value (kJ/kg).

2.2. Chamber sizing

Chamber sizing is based on heat release. There is a limit to the quantity of heat that can be released in a particular furnace chamber. Heat release is the amount of heat generated when combustible material burns. The furnace volume must be large enough to allow release of the heat generated by the anticipated waste and the supplemental fuel (Cheremisinoff and Young, 1976).

$$V = \pi \mathrm{r}^2 (L) \tag{3}$$

where:

r is radius of the kiln (m), L is length of the kiln (m) and V is the furnace volume, (m^3).

2.3. Incinerator residence time

Residence time means the length of time that the combustion gas is exposed to the combustion temperature in an incinerator. This is an important criterion in the design of waste incinerators, and it is calculated at the typically mandated 990^o or 1100^{o}C (Hasselri *et al.*, 2001). Residence time is determined by the velocity of the gases and the distance they travel through the combustion chamber as shown below:

$$t = \frac{V}{q} \tag{4}$$

where:

t is residence time (s), V is combustion chamber volume (m^3), q is combustion gas flow rate, (m^3/s), t is (chamber volume, m^3) / (gas volume flow rate, m^3/s) (5)

or

t= (chamber length, m)/ (gas velocity, m/s) (6)

2.4. Turbulence and mixing

In order to achieve high combustion efficiency in incinerators, it is particularly important to achieve good mixing between the primary combustion products (primarily CO and organics) and a stoichiometric excess secondary combustion air (Skrotzki and Vopat 1960). Some of the physical parameters which are used to promote mixing include location and direction of secondary air jets, the volume and pressure of secondary air addition. To the provision of overall mixing using the above methods, promote local mixing of the combustible gases and air. The degree of turbulence is typically assessed by use of the Reynolds number (Re).

$$\mathrm{Re} = {VD}/{K} \tag{7}$$

where:

V is average velocity (m/s), D is diameter (or equivalent diameter) of flow stream (m) and K is kinematic viscosity (m^2/s).

For a rectangular or other shape of flue, the equivalent diameter (D_e) should be used.

$$D_e = \frac{2ab}{(a+b)} \tag{8}$$

where: *a* and *b* are the dimensions of the sides of the rectangle (m), and this value of D_e would be used in lieu of D (m) when applied to noncircular cross section.

2.5. Theoretical flame temperature

The heat released by combustion (Q) raises the temperature of the flow stream of the products of combustion. The calculation of the theoretical flame temperature is based on the assumption that the heat released by the combustion process is completely absorbed by reaction products and excess air. The temperature of the product gases is the flame temperature of interest (Lee *et al.*, 2001; Weisman and Eckart, 1985; Perry, 1976) often termed T_{exit} , T_2 or T_f.

$$Q = W \times c_p \times (T_2 - T_1) \tag{9}$$

$$T_2 = T_1 + \frac{Q}{(W \times c_p)} \tag{10}$$

where:

Q is heat released by combustion (w), W is flow stream of products of combustion (kg/h), C_p is specific heat at constant pressure (kJ/kg.K), T_{exit}, T_2, T_f are exit and flame temperatures (^oC or K) and T_1 is initial or intake temperature (^oC or K).

3. Results and discussion

The calorific value of the samples in the study area ranged from 5.024 MJ/kg to 5.867 MJ/kg (Oumarou *et al.*, 2011) and was not high enough to sustain an incineration process. Lower calorific values (LCV) of 7.5 to 12 MJ/kg are the ones within which combustion and gas residence conditions of 850 ^oC/2 sec can be sustained without auxiliary fuel (auto-thermically). There is need to supplement the refuse with a supplementary fuel to make it up to the required value. The waste to be fed in the incinerator would therefore be mixed with a supplementary fuel in the form of a high calorific value material. However, since the focus is on wastes, there is need to consider and give a preferential choice to other waste materials. The waste fiber residue from sugar cane commonly known as bagasse has a gross calorific value (GCV) of 8.59 MJ/kg at 50% moisture content. At 30% moisture content, the GCV increases even to 13.60 MJ/kg (Assefa and Omprakash, 2013**)**. An addition of bagasse to the solid waste fed into the municipal solid waste incinerator would raise the calorific value of the mixture to the required LCV. Table 1 shows the summary of the important design parameters of the municipal solid waste incinerator.

Table 1: Summary of calculated design parameters

Initial feed rate	8,000 kg/hr
Moisture	32.593%
Water in waste	2,607.44 kg
Solid quantity	5,392.56 kg
Combustible quantity	3,658.85 kg
Heat generated	21,283.53 MJ
Theoretical Air	44,908.24m^3
Excess Air	22,454.12 m^3
Total Air	67,362.36 m^3
Incinerator residence time	4.39 seconds
Primary to secondary air ratio	40/60
Incinerator volume	82.25 m^3
Incinerator bed length	11 m
Incinerator width	3 m
Incinerator height	2.5 m
Reynolds number, Re	451,520
Adiabatic flame temperature, T_2	1,587 K

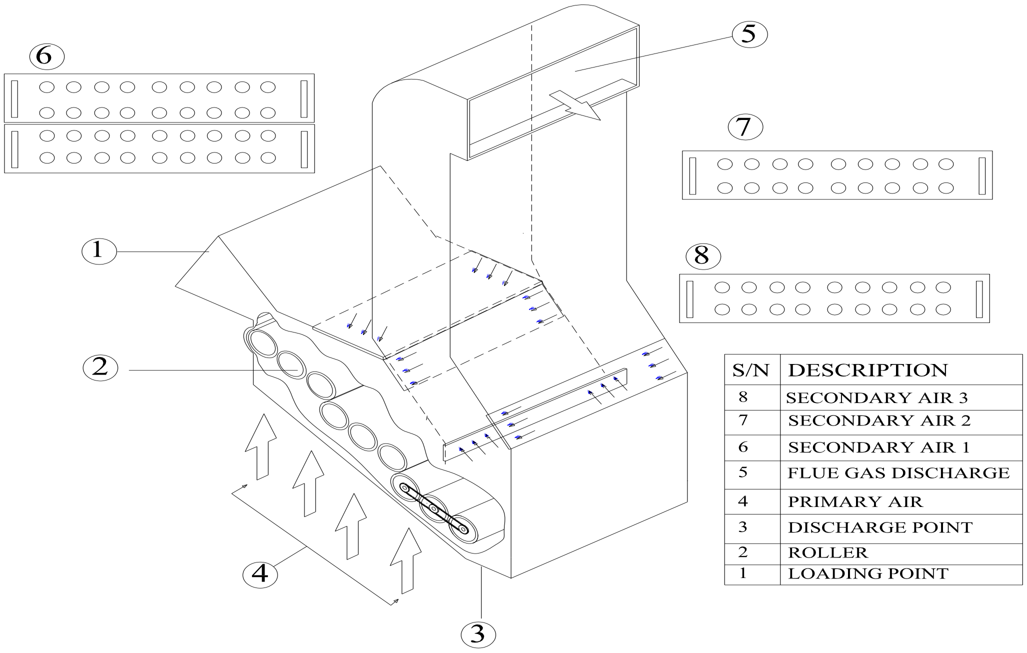
Population density and geographic locations are not real determining factors as whether refuse quality may change or not but rather the life style of the population and the level of awareness of the population towards waste management. To help in adjusting and setting the incinerator in case of lower moisture contents, the air supplies and the supplementary fuel quantity supply rates need to be modified and altered respectively. Municipal solid incinerators are often classified according to wastes types and streams, nozzles arrangement and number, calorific value of wastes among others. Three (3) standard geometries for municipal waste incineration plants have been established: the parallel flow, the counter flow and the centre flow concepts.

Furnace geometry is one of the main features to influence and to optimize the primary combustion. The direction of the flue gas flow in comparison to the waste transport on the grate is one of the most important factors. The burnout of the gaseous species is very well done in parallel flow geometry, where the flue gas is directed through the hottest zone by a distinctive nose. Also in the parallel flow concept, pyrolysis gases pass through the hottest area and therefore are burnt out satisfactorily. This concept is well suited and appropriate for the semi arid regions being considered in this study because of their lower LCV.

Air injection nozzles arrangement and number play an important role in MSW incineration. The Klasen and Goerner (1999) suggested arrangement leads to uniform temperature, velocity and species distributions resulting from the improvement to the mixing process. Furthermore, it could reduce the concentration of the incomplete product of combustion CO by 150%.

The total combustion air (having an over-stoichiometry of 1.3 to 1.8) is mainly divided into primary and secondary air as to control the combustion conditions to give near-stoichoimetric conditions (Jorgensen and Madsen, 2002). The partitioning ratio of primary to secondary air is between 80/20 (old plants) to 40/60 (for new plants) (Goerner, 2003). The task of secondary air is to complete the burnout of the hydrocarbons and carbon monoxide (Berkowitz, 1979) to bring the air –to- fuel to the required level. Furthermore, secondary air can be used as a mixing device for flue gases. Basically, secondary air injection concepts are Normal, Tangential configurations; Static mixing device and Rotating cylinder with additional secondary air nozzles, respectively. The grate bars are cooled by the primary combustion air. However, the cooling effect is limited for every high calorific values of the refuse and the bars can be damaged or destroyed by intense heating.

Figure 1 shows the conceptual design of the municipal solid waste incinerator with its part list.



S/N	DESCRIPTION
8	SECONDARY AIR 3
7	SECONDARY AIR 2
6	SECONDARY AIR 1
5	FLUE GAS DISCHARGE
4	PRIMARY AIR
3	DISCHARGE POINT
2	ROLLER
1	LOADING POINT

Figure 1: Conceptual design of the municipal solid waste incinerator

Conclusions

The parallel flow type of incinerator was found to be suitable for the category of low calorific value municipal solid wastes produced in the semiarid region under study. There is need to supplement the municipal solid waste with bagasse at 50% at least to raise the calorific value to the required level to sustain industrial incineration. Bagasse was selected due to the fact that sugar cane is available in the study area. Critical internal sizes of the designed incinerator are: 11m as length, 3m as height and a width of 2.5m thus giving an internal volume of 82.25 m^3. The municipal solid waste incinerator would treat 8 tonnes of moist refuse and produce about 21.30 GJ of net, usable heat per hour. The suitable adiabatic flame temperature was found to be 1,587 K.

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