THE DEVELOPMENT OF NEW GENERATION OF SOLID WASTE REFUSE INCINERATORS

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ABSTRACT
The use of bricks in the construction of new generation of incinerators has proved adequate in clearing large unplanned dumps of refuse in both cities and rural areas of Ghana. These incinerators have been moulded to attain very high temperatures with excellent heat preservation capabilities that no more auxiliary fuel is needed after the initial start up. The heat retention is so high that it allows incineration of subsequent rubbish. Results indicate total destruction capability of wet to dry rubbish into their mineral constituents. The design of these incinerators does not allow combustion products directly into the atmosphere as was in the case of the older ones and with available excess air the organic components of waste are turned in to ashes and the non organics such as tins, cans, bottles perish and eventually fall through the grates and crumble in the high heat of the incinerator. The mode of feeding the Incinerator by the use of wheelbarrows on an inclined plane proved more adequate than the use of steps.

Keywords: *Crack-free Incinerators, heat retention, energy saving, and waste characteristics.*

INTRODUCTION

Waste combustion or incineration is basically a controlled burning process. In Ghana the large unplanned dumps of refuse are essentially mixtures of combustible refuse such as paper, cardboard, vegetable matter, cartons, wood boxes and combustible floor or ground sweepings containing approximately 15% moisture and incombustible solids and some 10% of oily rags. The incineration of such composites poses no known hazards once efficient incinerators are used.

Apart from town refuse, there are wastes from agriculturally based industries especially the abattoirs which produce large volumes of organic wastes which rapidly become offensive in hot climates (Pickford, 1977)

Another class of waste is the industrial waste. These may be toxic, caustic acidic or inflammable and would require special incineration facilities. (Cairncross, 1999)

However, Rudden, (2004) explained that efficient combustion of any fuel including municipal solid waste depends on careful control of the 3T's (time, temperature and turbulence). The new European Directive on incineration of waste (adopted November 2000) requires that combustion gases must be kept at a temperature of at least 850^0C for at least 2 seconds in the presence of excess air. This enables complete combustion and to minimize the formation of dioxins and furans. Fig 4 explains the holding time of combustion products before final exit into the atmosphere.

In the developing countries rubbish is dumped indiscriminately either in demarcated sanitary areas or any open field near human habitation. Very large and unplanned dumps of refuse are common scenes where goats, dogs, rats children and adults scavenge on them. These activities cause serious public health risks and aesthetic problems.

Due to the nature of our wastes the volume quickly increases and before long the demarcated areas get filled up and dumping areas near streams, choke the streams and create various health problems as well as choking gutters leading to flooding during raining seasons.

According to public health operators Environmental Protection Agency, (2002), such uncovered piles of rotting refuse encourage fly breading which encourage mechanical transmission of feaces leading to faecal – oral diseases. In addition to the above, such areas contain mosquito-breeding sites where the mosquito Aedes aegypti breed and may transmit dengue, yellow fever and other arboviral infections. Rats also find these sites perfect breeding grounds and encourage variety of diseases including plague, leptospirosis, flea-borne typhus, rat bite fever and salmonellosis. Communities live side by side such huge threats to life and in very helpless situations.

Statistics generated from hospitals near such communities indicate the prevalence rates of such diseases and form the bulk of cases treated in such hospitals (Agogo Hospital Annual Report, 2002)

Due to the high volume of refuse generated on daily basis most known interventions including refuse collection services are over stretched as vehicles breakdown very frequently increasing the desperation in this area of environmental sanitation. Dumping of refuse on land fill sites became more problematic as concerns relating to cost; leachete and land fill gas management, noise, flies, rodents and most importantly resistance of most communities leaving near landfill sites appear to render this intervention impossible.

At the moment it is common to see uncontrolled fires lit at every refuse dump sites to burn solid wastes. In the wet weather burning is virtually impossible and can lead to fire accidents.

In the developed countries various incinerators are employed in dealing with the refuse instead of the usual dumping of refuse in large areas known as refuse dumps in most parts of Africa which becomes the starting point of most dreadful contagious diseases.

There are various types of incinerators on the market and the choice is a function of capacity and inter alias the mode of refuse disposal and cost.

The rotary kiln incinerators are vessels lined with refractories, which sit on trunnions, and rotate slowly (0.5 to 2 rpm) on their longitudinal axis. They are mainly for hazardous waste, infectious, cytotoxic pharmaceutical and human anatomical wastes. (LaGrega, 1998)

They operate at very high temperatures, which transform refuse into molten state before quenching into water. With irregular electricity supplies in Ghana such facilities can have contents caked and discharge will be almost impossible since the ash builds a semi-solid ash that cannot be discharged either as dry or as a liquid.

The cost is high since it is capable of handling liquid and solid as well as hazardous materials.

The multiple-health incinerators are more complicated because they are highly mechanical and used mainly in treating sludge. The variation of this design is called “mono-health” which is seldom used and needs a secondary combustion chamber for fairly good combustion.

The bottle neck furnaces found considerable use in solving Ghanaian refuse problems in the 50’s and 60’s but technical failures rendered their continuing use impossible hence the present situation where refuse has engulfed our cities.

In this paper, an attempt is made to analyze the failure modes of the then bottle incinerators leading to development and construction of new generation of solid waste incinerators which are friendly to the environment with ceramic engineering principles of high temperature maximum heat retention and firewood fuelled incinerators within the budget of most District Assemblies.

MATERIALS AND METHODS

These new generation of solid waste refuse incinerators are designed in the round with various locally manufactured special bricks for maximum stability and with minimal use of angle irons except for the doors since they are susceptible to rusting.

The four fire boxes apart from allowing the stoking of the fire, double up as channels in allowing excess air for the chimney to pull the air through the refuse for efficient incineration. The speed of the air through the refuse with the advancing heat from the fire boxes causes some turbulence and as the ash drops by gravity, freshly dried refuse is exposed for further incineration.

The modifications to the old bottle incinerators were developed by carefully assessing the failure modes over duration of their existence. Four main areas on which failure occurred were:

The sub-structure or the foundation
The superstructure
The crown or the dome
The chimney - the exit for combustion products

Solutions to the above resulted in the right choice of materials and the available technology that was developed led to the development of high temperature, fuel efficient but low -cost new generation of solid waste incinerators.

RESULTS AND DISCUSSION

Sub-structure

Most of the older incinerators were not built on any good foundation. The result is that land shifts or subsidence of the ground destroys the incinerators by the base caving in. In addition, since the old incinerators were not built on raised platforms, rain water enters the fireboxes and at most times continuously pack erosion soil into the fire boxes and succeed in blocking excess air flow through the charge and also quench any fire in the fireboxes beneath. Incineration becomes difficult and slow and, in extreme cases the rubbish does not burn at all.

Figure 1: Foundation plan and superimposed incinerator the floor plan

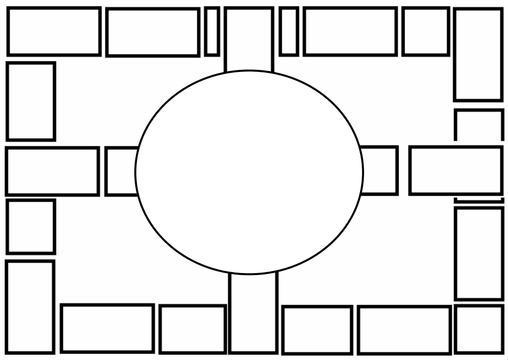


Fig.2 The Incinerator at Kade in the Eastern region

The solution to this is that our incinerators are built on 20 ft x 20ft x 4" (6m x 6m x 0.1m) reinforced concrete slab and the clearance between the floor and the base of the incinerators is 18" (0.45m) (Fig. 1).

Superstructure

The superstructure of the older incinerators does not allow useful heat to remain in the incinerators to help consume the next charge of rubbish. The heat escape by conduction was so high that it causes cracks, which lead to large gaps in the structure and eventually causes the entire incinerators to collapse.

To overcome this problem an application of heat transfer model in a stationary state was developed and its application generates the difference between the hot face and the outer wall temperatures. The calculated values also help to determine the number of bricks layers needed to form the wall thickness which will not allow too much heat to escape through the walls thereby attacking the Portland cement mortar at the outer face leading to cracks. (Kwawukume unpublished)

In combustion of town refuse heat is usually generated. (Rudden, 2004b).states that calorific values of waste vary from 5.6MJ/Kg for organic wastes to 25-30 MJ/Kg for plastics with conservative average for municipal solid waste of 8-10 MJ/Kg . Generally, high temperatures are involved in incineration of refuse since the larger the volume of combustible material in town refuse, the higher the temperature rise on the inner/hot face bricks that line the incinerator. There is therefore the need to adequately insulate the walls so as to minimize the heat from escaping.
The concept of our modern incinerators is to keep much of this generated heat to remain for subsequent incineration of the next batch of rubbish charge. Fig 6 portrays high enough temperatures around 750-800^{0}C after the first cycle of incineration which is enough to start and to complete the next charge of refuse coming in the following day.

In addition to the above, these incinerators are designed to stand outside within sanitary areas without any roof over them (Fig. 2).

Most superstructure failure of the older incinerators happened because of thermal mismatch between the temperature inside the incinerator and the cool temperature of the outer wall especially during the raining seasons (Fig. 3).

Heat transfer through the incinerator wall takes place mainly in the heat conduction mode as expressed by the following equation.

To find the temperatures, the calculation is as follows:

$$
\begin{aligned}
Q &= (t_i - t_1)\ (\lambda_1/(\ell_1) \\
&= (t_1 - t_2)\ (\lambda_2 / \ell_2) \\
&= (t_2 - t_0)\ (\lambda_3/\ell_3) \\
&= (t_i - t_0) / (\ell_1 / \lambda_1 + \ell_2 / \lambda_2 + \ell_3 / \lambda_3) \ \ldots. \quad (1)
\end{aligned}
$$

Q = volume of heat loss Q (Kcal/m^{2}h) through the wall and boundary
t_i = temperature of the inner surface of the incinerator wall
t_1 = temperature of the outer surface of the first layer
t_2 = temperature of the outer surface of the second layer
t_3 = temperature of the outer surface of the third layer
t_0 = temperature of the outer surface of the incinerator
$\lambda_1, \lambda_2, \lambda_3 =$ 1.5 Kcal/m hr^{0}C (Heat conductivity of bricks used for the first, second and third layers)
$\ell_1, \ell_2, \ell_3 =$ 0.114m (The thickness of the first, second, and third layers.) The bricks are laid as in the stretcher course construction of masonry walls.

From - 1Q $= \dfrac{(1100-100)/(0.114+0.114+0.114)}{1.5 \qquad 1.5 \qquad 1.5}$

$=$ 4,385Kcal/m^{2}h

From - 1Q $=$ $(ti - t_1)\ (\lambda_1/(\ell_1) = 766.74^oC$

$t_1 = ti - Q\ /(\ell_1 \lambda_1) = 766.74\ ^oC$
$t_2 = ti - Q\ /(\ell_2 \lambda_2) = 433.48\ ^oC$

The super structure wall failure of most of the older bottle neck incinerators is basically due to the constant high temperatures at the boundary of the first layer ordinary bricks which is about 766.74^{0}C and the boundary temperature of over 400^{0}C.

The additional concept incorporated in the design of our modern incinerators is based on minimizing temperature at the outer face as well as keeping temperature within the incinerator very hot which helps to rekindle the next charge of refuse. There is no need purchasing firewood each time there is incineration of refuse.

The larger the difference between the inner face temperature and the utter temperatures the easier there is the tendency for crack propagation.
From the above diagram, the 3 layer bricks are laid to give the total wall thickness of 342mm generating

measurable outer wall temperature of less than 100^0C which is safe and cannot cause any differential cracks as was the case of the older refuse incinerators.

Dome

The under surface of the dome bricks are arranged in a checkered form with the aim of slowing down particulate matter from the combustion gases flying out easily as it is with the old bottle neck incinerators (Fig. 4) .The dome bricks are very porous with the same thermal wall arrangement as the side walls which also help to trap into their pores some of the particulate matter or the flying ash.

The opening channel into the chimney from the dome has retention walls which apart from absorbing the particulate matter further slows down the combustion products from exiting freely into the environment. In view of the fact that the dome bricks are usually exposed to very high temperatures, care was taken in the construction to insulate the upper layer from any heat leaking from the combustion chamber to the outside.

Fig 3.: Heat conductivity through the 3-layer composite wall of the new generation of refuse incinerators.

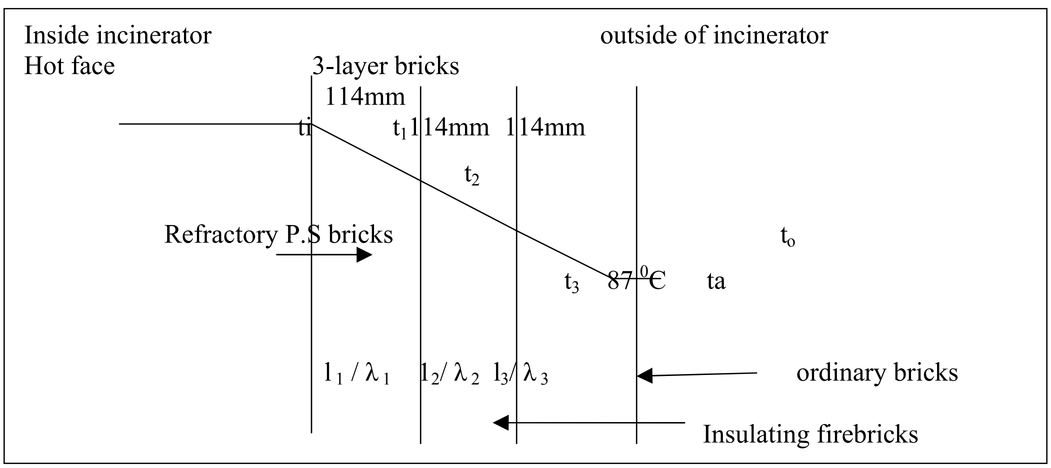


Fig. 4: The new generation refuse incinerators showing Integrated chimney serving also as the refining chamber with excess air way from the bottom and mode of escape of combustion products

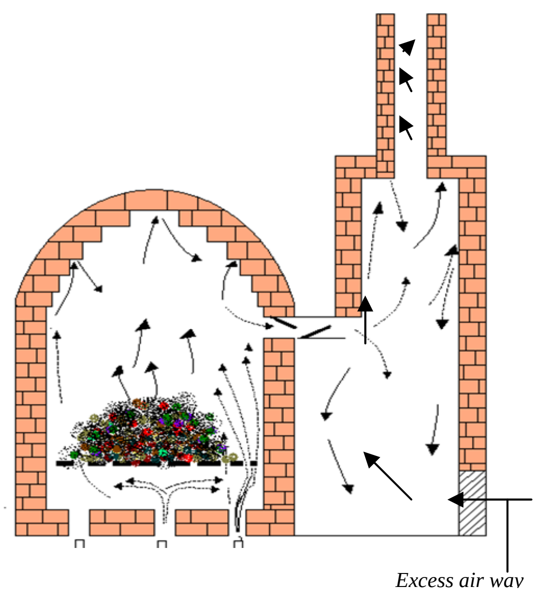
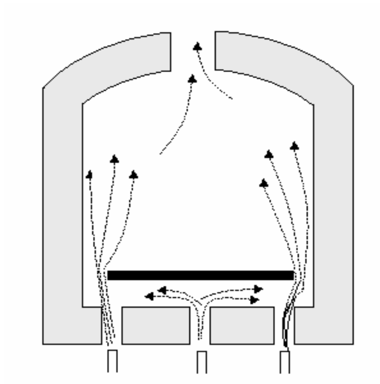


Fig 4b: The old bottle incinerators showing direct outlet of combustion products into the environment



Given that the dome bricks are all very porous, rain water can easily soak the bricks and drip in to the incinerator causing cracks. This is prevented by spreading a thin layer of specially prepared portland cement mortar over the entire dome. This serves as a roof over the incinerator. This innovation rules out the extra cost of erecting shelter over the incinerator in the demarcated sanitary areas.

The perfect dome shape of the new generation of solid waste incinerators without any chimney opening directly into it is desirable in that it helps even distribution and circulation of heat throughout the entire circumference of charge matter. This developed technology helps greatly in the attainment of good combustion and total transformation of refuse into their mineral constituents within the entire volume of the incinerator.

THE CHIMNEY

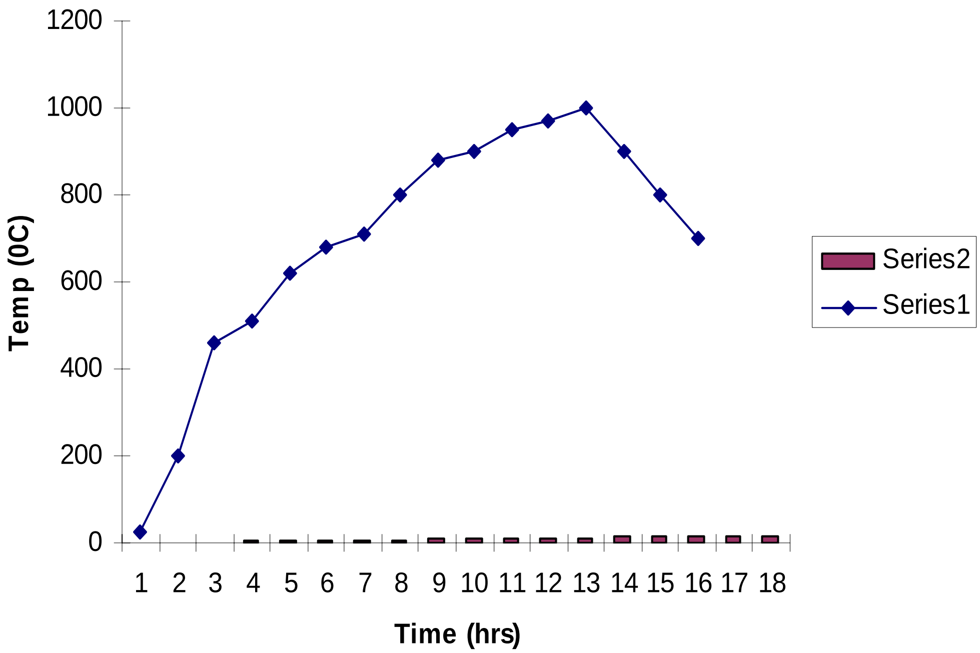
Since incinerators require chimneys to furnish sufficient draft or pull to draw the spent gases as well as drawing secondary air from beneath the refuse setting through fire boxes to the outside, care is taken in the calculation, design and construction of this structure. The older incinerators have limited choice in their design of chimneys to ensure adequate draft or pull since those chimneys were placed directly on the crown/ dome, therefore their heights are limited to few bricks so as not to put stress on the incinerator dome which might lead to cracks or disintegration. (Fig. 4b) Due to the above design, chimney heights are limited thereby restraining the creation of any strong pull to enable quick rise in temperature (Rhodes,1977a). This results in serious failure as excessive pressure is built up in the incinerator causing leakage of hot gases through the external wall. Cement mortar is used in laying the ordinary bricks for the entire outer wall which provides strength to the incinerator. The outer wall is essentially composed of cement mortar, which cracks easily with contact with the hot gases leaving large openings for rain to enter through. The result is difficulty in incineration coupled with high fuel cost and total collapse thereafter.

The new generation of incinerators is designed to have free standing chimney, which is integrated with the incinerator from the base with the flue area opening into the side of the dome. This design allows the chimney to attain good heights leading to very efficient incineration since tall chimneys increase velocity in the firing chamber.

The design of these incinerators took advantage of available literature that the up-draft furnaces are inefficient since heat accumulated at the base of the furnaces are higher than at the top most parts (Rhodes, 1977b). Therefore this uneven heat distribution made this furnaces unsuitable in ceramic product firing.

This uneven heat distribution by up draft furnaces is rather ideal in the design of refuse incinerators since the base temperature quickly dries and incinerates the refuse and the ash falls through the grates and allows the top refuse to drop down to the base already dried for further incineration.

Fig. 5: Time and temperature for the incineration of town refuse in Ashanti-Akim North Town



The wall arrangement helps in maximum heat retention and the usual stocking of the fire by auxiliary firewood does not become necessary again. The heat of incineration after the initial firing is enough to continue incineration of subsequent refuse, which is a great saving on energy cost to most District Assemblies who are using them.
The firing circle is also designed to allow for this kind of continuous firing which is so unique to this type of incinerators. An observation about the mode of refuse disposal in most districts start in the morning and by 4pm is finished. This allows incineration to start about 4pm and ends by the morning of the following day. However fresh refuse is added again just as the initial refuse is completely incinerated and the temperature just begins to fall. This incineration cycle as in Fig 6 also substantially helps in low fuel use, which hitherto made incinerators very expensive equipment to be recommended for disposal of refuse.

CONCLUSION
Results indicate that these new generation of refuse incinerators have solved refuse problems in the Ashanti Akim North and other District Assemblies where these facilities are installed and are working.
The normal situations where scavengers, vultures, children and domestic animals freely feed on the usual refuse dumps are no more in existence in these district Assemblies.

The energy saving capability of these incinerators is so significant that the burden of sourcing for funds to purchase auxiliary fuel has become unnecessary. Furthermore, the excess air way located at the bottom of the chimneys helps in cooling the combustion gases as well as introducing excess air into the chimney for complete combustion of refuse.

These incinerators can be fitted with filters to cope with the incineration of all forms of plastics as it is in advanced countries. The residue will then be moved to an engineered landfill facility for residues which are not recycled. This will go a long way in reducing garbage volume as well as odour and leachete emanating from the deposition of raw garbage at the sanitary land fill sites. In refuse management, there is no one stands alone intervention process. The incinerator should be seen as part of an integrated waste management plan where incineration is encouraged before sending the residue to landfill sites. Major problems associated with hazards at these sites including protecting the ground water from contamination will be prevented.

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