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Assessment of healthcare waste Pyrotec model 8 incinerator efficiency as a performance indicator at Muhimbili National Referral Hospital in Dar es Salaam, Tanzania

William Wanasolo[1*] and Samwel Victor Manyele[2]

[1]Department of Mining, Chemical and Petroleum Engineering, Faculty of Engineering, Kyambogo University, Kampala - Uganda.
[2]Department of Chemical and Mining Engineering, College of Engineering and Technology, University of Dar es Salaam, Tanzania.

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The performance of a healthcare waste Pyrotec Model 8 incinerator at Muhimbili national referral hospital in Dar es Salaam, Tanzania, was investigated using two different types of healthcare wastes namely sharps waste and other waste (mass/weight) and as fractions. The other independent factor used in the investigation was diesel oil consumption. The incinerator performance was evaluated by determining how these factors affected the amount of ash residue, the percentage of weight reduction, incinerator capacity and efficiency. The numerical quantities used for independent variables were randomly selected which included low, mid and high levels. The Factorial method with Mixture Historical Data Design type of research methodology was selected for data analysis. The analysis tools included Design Expert Version 7.1 and SigmaPlot 10.0. Results showed that weight reduction increased with increase in sharps waste for all quantities of the fraction of sharps waste investigated. It was concluded that the level of other waste charged had no significant effect (p > 0.05) on the percentage of weight reduction at quantities of total waste below 940 kg/weight but in the presence of high levels of total waste above 960 kg/weight there was a possible interactive effect that influenced the observed high percentage of weight reduction. As a recommendation, it is better to operate the Pyrotec Model 8 incinerator in terms of weight of sharps waste than in terms of the fraction of sharps waste.

Key words: Incinerator efficiency, healthcare waste incineration, ash residue, weight reduction, sharps waste.

INTRODUCTION

Literature has shown that huge quantities of medical waste is generated in Dar es Salaam and other large

*Corresponding author. E-mail: wanasolo@gmail.com.

cities of Africa (Kihila et al., 2021; Mwaria et al., 2021; Ntapanta, 2021). This has been attributed to the numerous healthcare centers in the developing cities of Africa (Askarian et al., 2004; Chisholm et al., 2021). It has also been attributed to large numbers of both out-quantities of healthcare waste; the numerous healthcare patients and in-patients visiting the medical centers (Chang et al., 2000; Sahn et al., 2003). The large centers; and the huge numbers of both in-patient and out-patients visiting the healthcare centers called for a need to assess and establish the efficiency of the existing healthcare waste incineration facility in order to pave way for a more sustainable and efficient process. As is the case with most healthcare centers in the world, the healthcare solid waste generated in Dar es Salaam City is handled and managed via incineration process as a means of controlling and reducing it. The present study therefore aimed at assessing the Pyrotec Model 8 incinerator efficiency at one of the healthcare center in Dar es salaam City namely Muhimbili National Referral Hospital (MNRH). If results show inefficient performance then studies of other methods of healthcare waste disposal would be investigated. The MNRH is located at 6°81' South, 39°27' East in the center of Dar es Salaam City of the United Republic of Tanzania.

Several researches have been done on healthcare incinerators in the world mainly focusing on establishing the quantities and composition of the healthcare waste generation (Shinee et al., 2008). It was shown that about 945 kg/weight of healthcare waste is generated per day in MNRH in Dar es Salaam City (Matee and Manyele, 2015; Sahn et al., 2003; Tudor et al., 2008). This large volume generated from a single healthcare unit implies that the numerous healthcare units located in Dar es Salaam City could be contributing to large quantities of medical solid waste generated and released into the environment. The effects of which could be devastating due to the fact that the healthcare waste could contain highly infectious and poisonous components (Nwachukwu et al., 2013). Furthermore, the same study assessed the performance of Pyrotec Model 8 incinerator in terms of fuel efficiency and found out that between 2.0 to 3.0 L of diesel oil consumption was used to burn 1 kg/weight of waste to ashes. This implied that large volumes of diesel oil consumption would be needed to handle the corresponding huge quantities of the medical solid waste generated in all the healthcare centers. Consequently, the incineration process carries huge cost implications and affects the healthcare budget negatively.

Other researches about healthcare waste incineration and healthcare centers have also been done focusing on determining the composition of flue gases generated (Adu et al., 2020; Honest et al., 2020; Mmereki et al., 2017), categorizing the waste generated (Anicetus et al., 2020; Khajuria and Kumar 2007; Ozder et al., 2013); waste management practices (Askarian et al., 2004; Das et al., 2021; Hassan et al., 2008; Odonkor and Mahami, 2020; Zand and Heir, 2021) and many others. This data informed the need for the present study on the healthcare Pyrotec Model 8 incinerator with the objective of establishing its current efficiency and therefore plan for its repair or replacement if need be.

MATERIALS AND METHODS

Sample preparation

The healthcare waste from MNRH was segregated at source, transported in plastic bags to the location of the Pyrotec Model 8 incinerator at the MNRH and weighed. It consisted of sharps waste and other waste. The Pyrotec Model 8 incinerator was then charged with all the daily segregated healthcare waste and the combustion chamber was fueled with a measured quantity of diesel oil consumption ready for combustion process. The primary chamber was switched on first followed by the secondary chamber after about 10 min. The recording of the primary and secondary chamber temperature was started immediately after switching on the secondary chamber. Temperature was recorded at intervals of 1 min for 8 h daily while ash residue was collected at the end of the 8 h after cooling the incineration chambers. The process was repeated and data for temperature and ash residue was collected over a period of 65 days non continuous.

Experimental and data analysis

The data was analyzed using Design Expert 7.0.0 and Sigma Plot 10 data analysis software tools. The Design Expert was used to determine significant and non-significant factors in the two-way ANOVA analysis while Sigma Plot was used to generate the surface plots. The Design Expert was also used to filter the raw data free of outliers. The variables investigated were four namely: Diesel Oil Consumption (DOC) kg/weight, Total Waste (TW) kg/weight, Sharps Waste (SW) kg/weight, Other Waste (OW) kg/weight, fraction of SW, and fraction of OW. The dependent variables were: Ash Residue (AR) kg/weight, Weight Reduction (WR) kg/weight, percentage of Weight Reduction (%WR), incinerator efficiency (%), and incinerator capacity. The numerical quantities for independent variables of DOC, SW and OW were randomly selected depending on the daily generation of the medical waste. They included low and high levels shown in Table 1. The incinerator temperature was not considered as input variable because of the inability to vary it, that is, it was not possible to control temperature in the given incinerator setup. However, the incinerator temperature was dynamic at the initial stages of firing and it attained a fairly steady level thereafter. This trend occurred similarly for all experimental runs.

The 2-Level Factorial methodology experimental design type was selected because of its capability to allow for the investigation of the main and interaction effects between the independent variables and on the response variables (Haaland, 2020; Salkind, 2010). In order to study the interactive effects, the factorial design of 2-Level-three independent factor combinations resulted in 8 experimental runs which were replicated to 32 experiments spread out over a period of 65 days non-continuous. The AR was weighed as remains at the end of the incineration process. WR (waste incinerated) was computed as the difference between TW charged and AR. The incinerator capacity was the quantity of WR (waste incinerated) per unit time (Zhong et al., 2020). In this case it was the ratio of waste incinerated to the duration (cycle time) of the incineration process. The Pyrotec Model 8 incinerator capacity was evaluated from Equation 1 derived from the above definition.

Table 1. Levels of independent variables.

Parameter	Low	High
DOC (litres)	355	370
SW (kg/weight)	15	86
OW (Kg/weight)	800	934

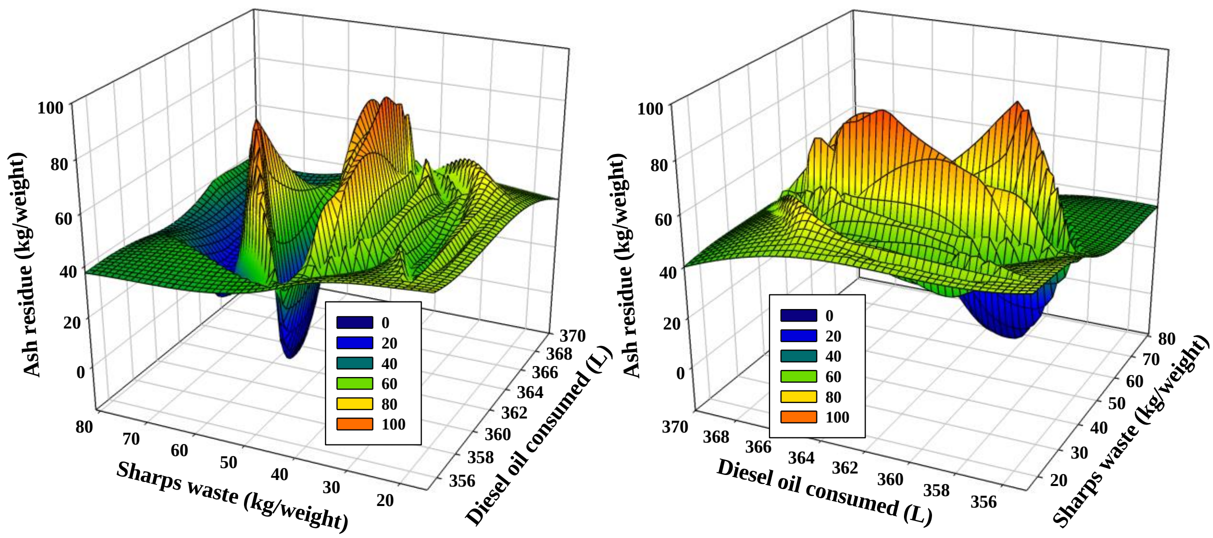

Figure 1. Effect of the quantity of diesel oil consumption consumed and sharps waste on the amount of ash residue.

$$Incinerator\ capacity\ = \frac{weight\ reduction\ (waste\ incinerated)}{Cycle\ time} kgh^{-1} \quad (1)$$

Since the cycle time was constant at 8 h in all experiments, the incinerator capacity was equivalent to the amount of daily WR. The percentage of WR was evaluated from Equation 2 as:

$$Percent\ weight\ reduction\ (\%WR) = \frac{Weight\ reduction}{Total\ Waste\ charged} x100\% \quad (2)$$

The Pyrotec Model 8 incinerator efficiency was evaluated to be equivalent to the percentage of weight reduction and calculated using the same Equation 2.

RESULTS AND DISCUSSION

Effect of diesel oil consumption (L) and sharps waste (kg/weight) on ash residue

The results for variation of AR with DOC and SW are shown in Figure 1. The data shows that AR was lowest at SW between 50 and 60 kg/weight and DOC between 360 and 362 L indicated by the dark-green surface. The mean value of DOC was 362.08 ± 2.93 L and that of SW was 38.25 ± 14.94 kg/weight. This implied that the lowest quantity of AR (kg/weight) recorded was obtained at SW above the mean quantities investigated and at nearly mean value of the DOC investigated. On the other hand, there were two peaks associated with the highest quantities of AR and these occurred at SW of approximately in the range from 40 to 50 kg/weight and from 60 to 70 kg/weight for the second peak. The two peaks occurred at DOC of approximately 360 to 368 L with one having a sharp slope while the other had a gentle slope (Figure 1). The valley in between the peaks could have occurred at weights of SW between 50 and 60 kg/weight. The lower the amount of AR observed, the better was the incineration process. Therefore, DOC (360 to 362 L) and SW (50 to 60 kg/weight) would be preferred for better performance of the Pyrotec Model 8 incinerator. The relationship between amount of AR with SW (kg/weight) and DOC is rather complex necessitating

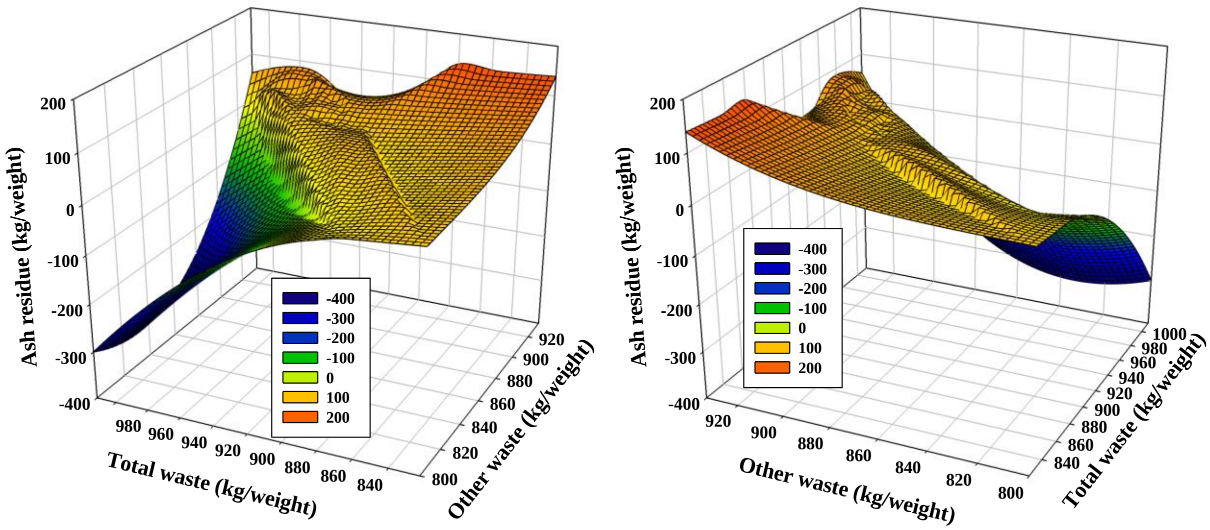

Figure 2. Effect of total waste and other waste on ash residue.

further studies.

Effect of total waste (kg/weight) and other waste (kg/weight) on amount of ash residue

The effect of TW (kg/weight) and OW (kg/weight) on AR is shown in Figure 2. The surface plots looked like a cone and spade in the first and second parts of the diagram, respectively. The data shows that AR increased with increasing amount of OW (kg/weight) for all TW (kg/weight) experimented. The highest AR in the range from 100 to 200 kg/weight were at the highest OW levels of 900 kg/weight and above. Also, the highest AR was observed at the lowest levels of TW at 880 kg/weight and below. With small amount of TW below 880 kg/weight, the chamber did not reach temperatures high enough to completely incinerate most of the waste. It has been reported that the primary chamber uses the burning waste and burner heat to raise its temperatures (Jouhara et al., 2018; Matee and Manyele, 2015), the latter is limited and the former increases the temperature to the maximum depending on the amount of waste loaded. Thus, with low TW (kg/weight), the quantity of AR proportionally increases due to lower maximum temperature reached in the primary chamber.

Effect of other waste (kg/weight) and fraction of other waste on ash residue

The data for effect of OW (kg/weight) and fraction of OW on AR (kg/weight) is shown in Figure 3. The data shows that AR increased with higher fraction of OW up to approximately 95 kg/weight of AR after which the amount of AR begins to decrease with additional increase in fraction of OW. The highest level of AR was observed at the fraction of OW in the range from 0.93 to about 0.97 while the OW (kg/weight) was in the range from 900 kg/weight to about 920 kg/weight as shown by the brown-yellow surface.

Effect of other waste (kg/weight) and fraction of sharps waste on ash residue

The effect of OW (kg/weight) and fraction of SW on AR (kg/weight) was also investigated and the results shown in Figure 4. The data shows that AR generally increased with increase in OW for all quantities of the fraction of SW. However, the increase was sharper at OW quantities above 900 kg/weight. The highest value of AR was observed at fraction of SW occurring in the range from 0.04 to 0.06. Also, for any value of OW, the AR initially increased to a maximum then decreased as the fraction of SW was increased. The maximum value corresponding to the highest level of AR occurred at OW above 920 kg/weight and at the fraction of SW in the range from 0.04 to 0.05.

Effect of sharps waste (kg/weight) and its fraction on ash residue

The effect of SW (kg/weight) and fraction of SW on AR (kg/weight) is shown in Figure 5. The data shows that AR decreased from about 200 kg/weight to about 10 kg/weight as indicated by the green-black surface showing the decrease in fraction of SW, at quantities of SW (kg/weight) below 50 kg/weight, while at high quantities of SW above 50 kg/weight the AR (kg/weight) was low and approximately constant as shown by the

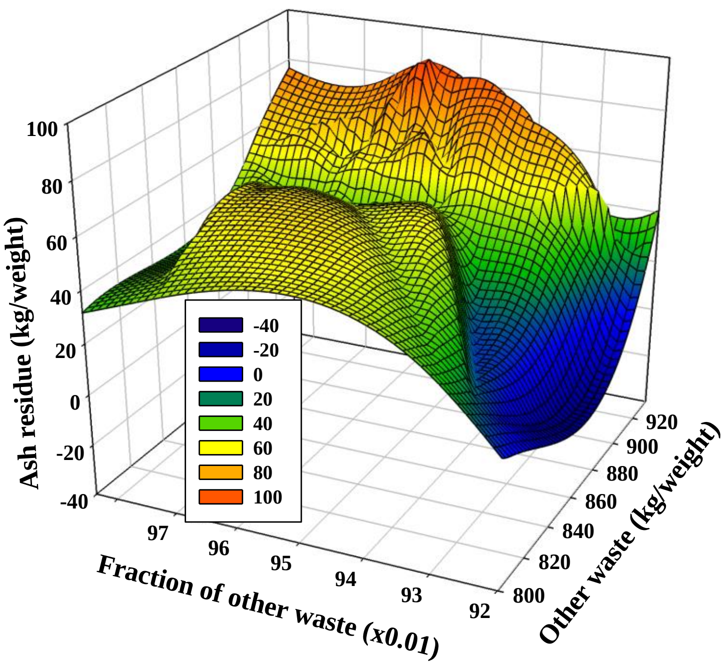

Figure 1. Effect of the quantity of other waste and its fraction on ash residue.

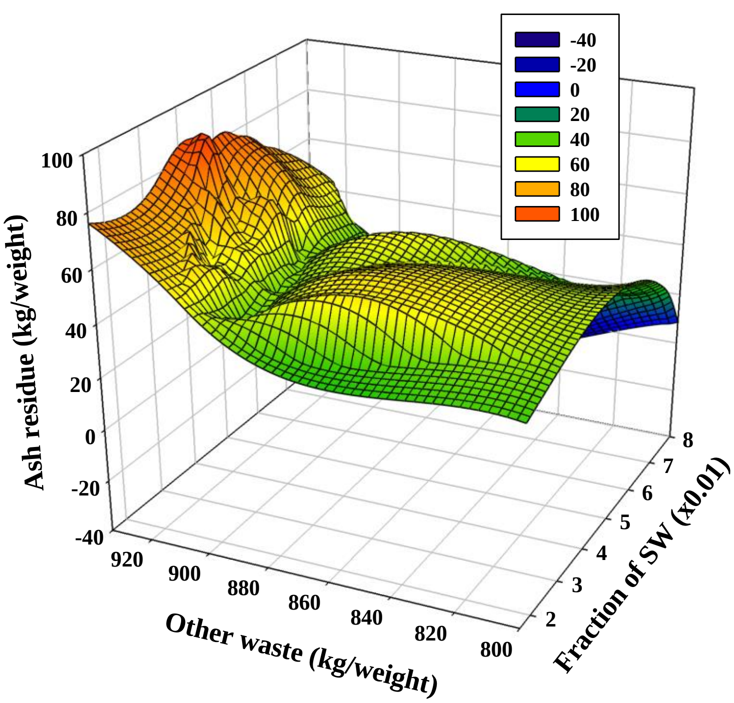

Figure 4. Variation of ash residue with other waste and fraction of sharps waste.

blue-black coloration of the surface. On the other hand, the AR (kg/weight) increased with increase in SW (kg/weight) at lower quantities of the fraction of SW. The highest amount of AR was between 300 kg/weight and

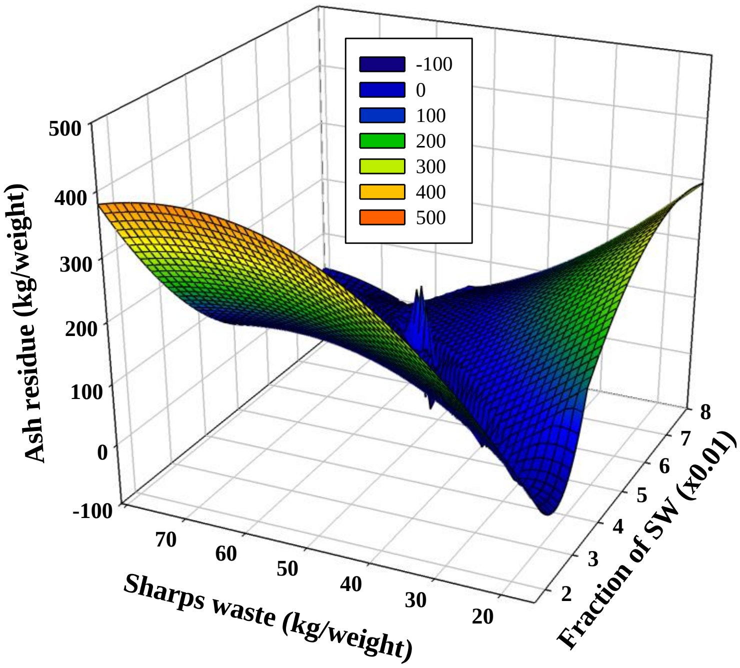

Figure 5. Variation of ash residue with sharps waste and its fraction.

400 kg/weight as shown by the red-brown coloration at SW above 50 kg/weight. Also, at high quantities of fraction of SW and low SW (kg/weight), the AR was again high at nearly 300 kg/weight shown by the green region. This implied that the lowest value of AR (kg/weight) is along the diagonal of the fraction of SW and SW (kg/weight). Furthermore, increasing the amount of SW (kg/weight) could have resulted into high quantities of SW (kg/weight) such as metal needles which could have contributed to high AR (kg/weight). Also, the lowest AR (100 kg/weight) was observed at low quantities of SW (25 kg/weight) and low fraction of SW (0.03). The low level of AR (100 kg/weight) was maintained as the quantities of SW (kg/weight) and fraction of SW was increased proportionately leading to creation of a trough.

Effect of sharps waste (kg/weight) and diesel oil consumption on weight reduction

The effect of SW (kg/weight) and DOC (L) on WR (kg/weight) was also investigated and the results reported in Figure 6. The data shows that generally at quantities of SW below 60 kg/weight the WR was low at 800 kg/weight for all quantities of DOC used as indicated by the blue-dark coloration on the surface. At SW above 70 kg/weight, the WR increased from 900 to 1,000 kg/weight shown by the brown-yellow coloration of the surface. The highest value of WR was observed at the highest SW (kg/weight) and at the highest DOC (L) in the ranges from 70 to 80 kg/weight and 366 to 370 L, respectively. This implied that in order to achieve high quantities of WR, the amount of SW (kg/weight) and DOC (L) had to be high.

Furthermore, WR (kg/weight) was observed at higher SW (kg/weight) and higher DOC (L). Increasing DOC increased WR (kg/weight). Increasing SW (kg/weight) led to higher WR (kg/weight), due to ease of destruction of SW, forming the pyrolytic gases which could speed up waste combustion, and hence higher WR (kg/weight). A saddle was observed in WR for amount of SW (kg/weight) ranging from 30 to 70 kg/weight and DOC from 356 to 366 liters. The WR (kg/weight) increased exponentially with SW (kg/weight) at higher DOC with a slightly linear increase at lower DOC. Moreover, WR increased in s-shape exponentially with DOC at higher SW (kg/weight).

Effect of other waste (kg/weight) and fraction of other waste on weight reduction

The effect of OW (kg/weight) and fraction of OW on WR (kg/weight) is shown in Figure 7. The data shows that the WR increased with increase in OW (kg/weight) for all quantities of OW (kg/weight). The highest value of WR (kg/weight) recorded was in the range from 950 to 1,000 kg/weight at highest quantities of OW above 880 kg/weight and at lowest fraction of OW which were from 0.93 and below. On the other hand, for a given value of OW, the WR (kg/weight) seemed to be constant at all quantities of fraction of OW. This implied that the fraction of OW investigated did not influence the amount of WR

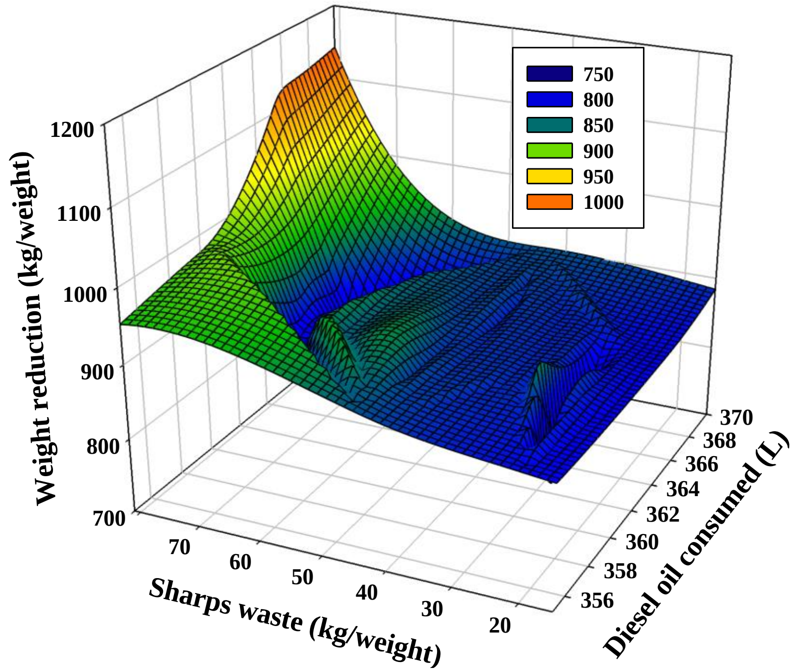

Figure 6. Effect of sharps waste and diesel oil consumption used on weight reduction.

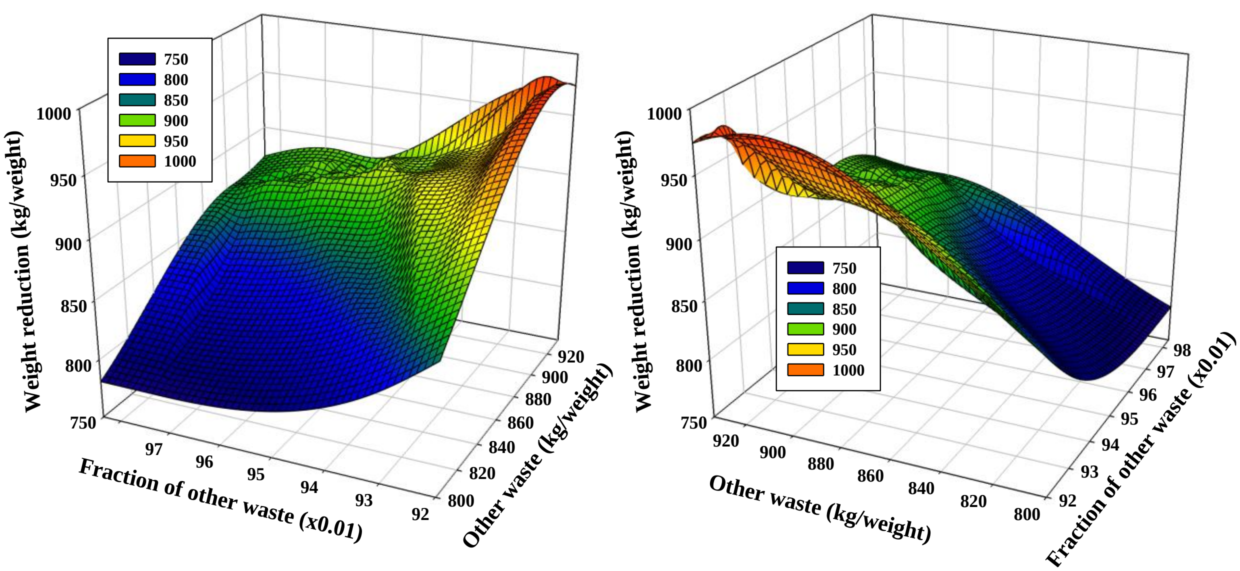

Figure 2. Effect of other waste and its fraction on weight reduction.

(kg/weight) during the incineration process.

Effect of quantity of sharps waste (kg/weight) and fraction of sharps waste on weight reduction

The results for the effect of SW (kg/weight) and fraction of SW on WR (kg/weight) are shown in Figure 8. The data shows that WR increased with increase in SW for all quantities of the fraction of SW. However, the increase was more pronounced at lower fraction of SW than at high fraction of SW. This implied that lower fraction of SW favored high levels of WR (kg/weight) but only at high quantities of SW (kg/weight). Also, for a given amount of

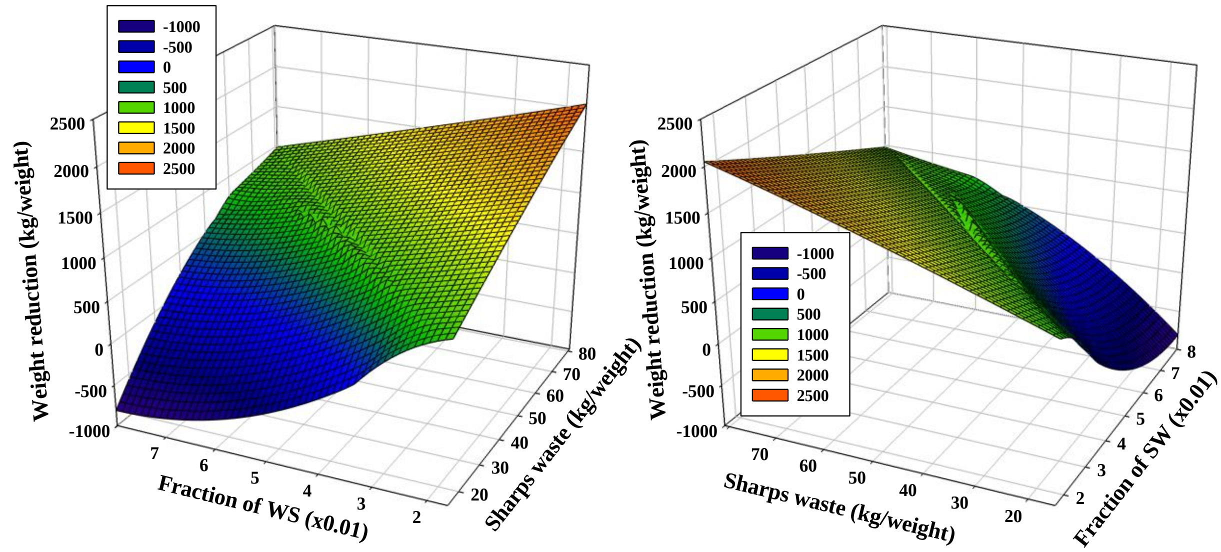

Figure 8. Effect of sharps waste and its fraction on weight reduction.

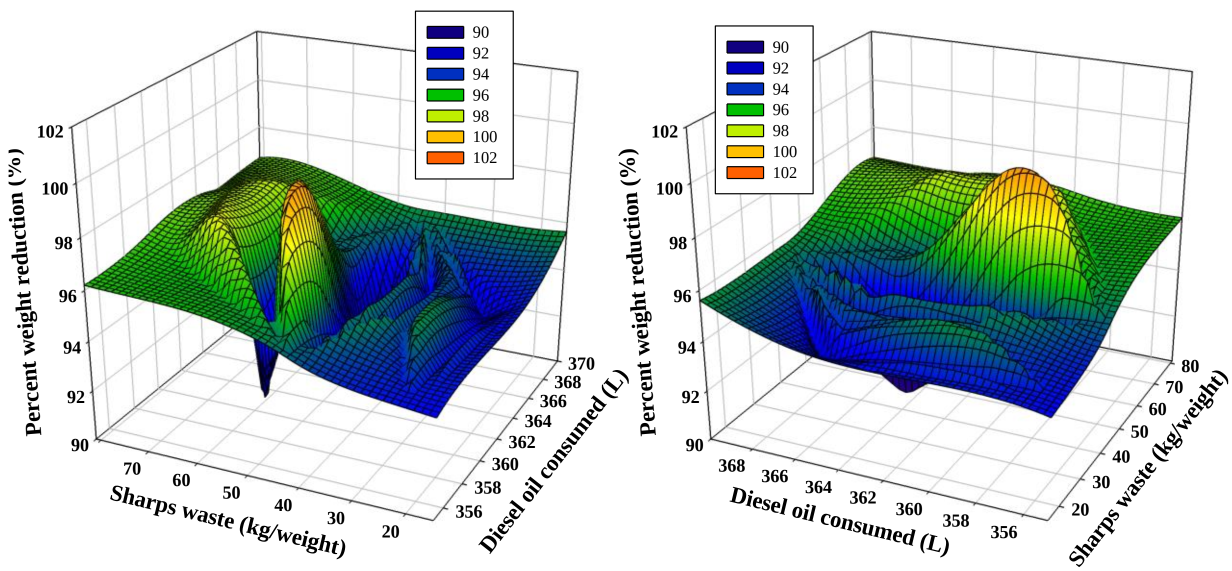

Figure 9. Variation of percent weight reduction with quantity of sharps waste and diesel oil consumption consumed.

SW (kg/weight), the WR (kg/weight) decreased with increase in fraction of SW. Generally, the high levels of WR (kg/weight) were realized at high quantities of SW (kg/weight) compared to the quantities obtained at high fraction of SW. This also implied that it was better to work in terms of the weight of SW than in terms of the fraction of SW. It was the quantity of SW rather that its proportion to total weight which strongly affected the WR. This is can be attributed to the fact that a faster increase in WR (kg/weight) occurs with increasing SW (kg/weight) than with SW fraction. The lowest WR (kg/weight) was observed again at highest fraction of SW, while the highest WR (kg/weight) was observed at highest SW of 80 kg/weight.

Effect of diesel oil consumption and sharps waste on percent weight reduction (Pyrotec Model 8 incinerator efficiency)

The effect of DOC (L) and SW (kg/weight) on %WR or incinerator efficiency is shown by the surface plot in Figure 9. The data shows a high %WR of close to 100% at DOC of approximately 364 L and SW load of 55

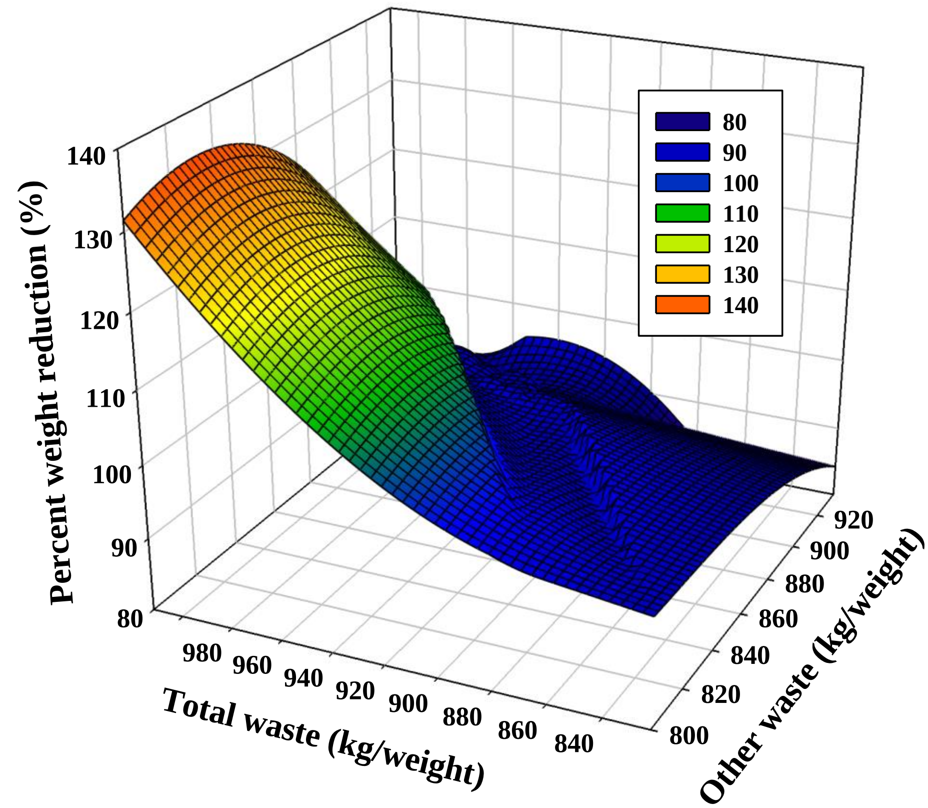

Figure 10. Effect of total waste and other waste on percent weight reduction.

kg/weight. This is shown by the yellow-orange tint characterized having a sharp rise in the surface near the mentioned coordinates. These conditions of DOC and SW (kg/weight) imply these to be the most favorable operating conditions for obtaining efficient %WR of nearly 100%.The green surface which indicated moderate %WR in the range from 96 to 98% occurred at SW above 65 kg/weight for all levels of DOC used, while the blue surface indicated the lowest %WR which occurred in the range from 92 to 94%. There was a sharp depression in the surface as indicated by the black coloration which represents a weight reduction of 90% and below. This point occurred at SW (kg/weight) of slightly above 60 kg/weight and DOC of approximately 361 L. These variables showing the lowest %WR should therefore be avoided in practice. Also, during incineration process, a parameter that can be controlled easily was the amount of SW (kg/weight) loaded into the primary chamber together with OW (kg/weight) in order to achieve high %WR.

Variation of percentage weight reduction with mass of total waste and other waste

The variation of %WR or incinerator efficiency with mass of TW (kg/weight) and OW (kg/weight) is shown in Figure 10. The data shows that a higher %WR (100%) was attainable at higher levels of mass of TW charged above 980 kg/weight for all quantities of OW charged to the Pyrotec Model 8 incinerator. This is shown by red-brown coloration of the surface plot which turns to the yellow-green at points below 980 kg/weight of the mass of the TW charged for all quantities of OW (kg/weight) investigated. At points of TW below 940 kg/weight, the %WR reduced to below 100% as shown by the blue-black coloration. This was also observed for all the amounts of OW charged and it implied that the mass of OW (kg/weight) charged had no effect on the %WR. This was in agreement with ANOVA analysis which showed that the OW (kg/weight) charged did not significantly influence ($p > 0.05$) the %WR during the incineration process. However, in the presence of high levels of mass of TW charged above 960 kg/weight, the combined interactive effect of mass of TW and OW (kg/weight) charged could have influenced the observed high %WR. Furthermore, the lower TW (kg/weight) loaded into the primary chamber led to a decrease in %WR regardless of amount of OW (kg/weight) charged. Moreover, above the TW of 940 kg/weight loaded, the %WR increased sharply, especially at OW of 880 kg/weight. Thus, it can be deduced that lower mass of TW (kg/weight) loaded

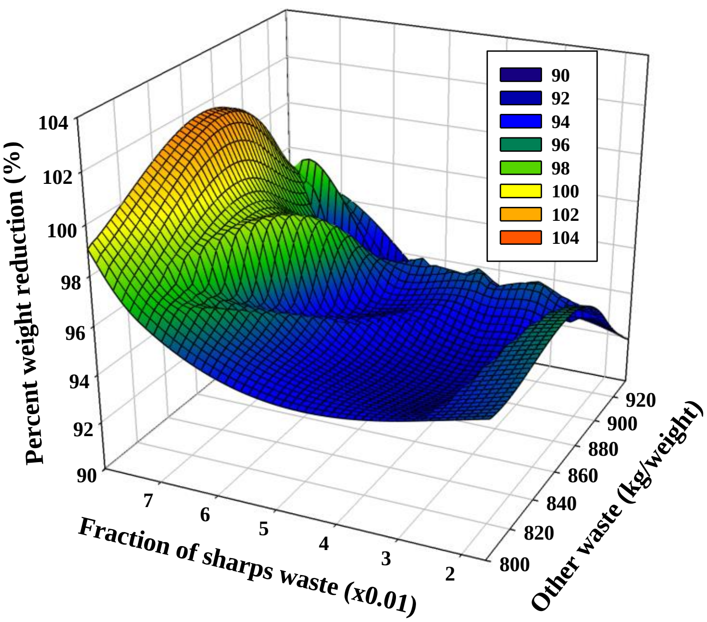

Figure 11. Effect of other waste and fraction of sharps waste on percentage weight reduction.

into the chamber lead to lower %WR attributed to lower temperatures and insufficient heat energy required to heat up the refractory walls to higher temperatures required for the latter to emit radiant energy towards the waste and hence high %WR.

Variation of percentage weight reduction with mass of other waste and fraction of sharps waste

The variation of %WR of the Pyrotec Model 8 incinerator efficiency with quantity of OW (kg/weight) and fraction of SW loaded is shown in Figure 11. The data shows the surface plot from the highest %WR of 100% indicated by the red-yellow surface to the lowest blue-dark surface of 92%. The highest percentage weight reduction occurred at fraction of SW of about 0.07 and above for all quantities of OW (kg/weight) charged. The general trend was that for a given amount of OW (kg/weight) loaded, the %WR increased with increase in fraction of SW. On the other hand, for a given fraction of SW, the %WR increased with increase in mass of OW (kg/weight) charged to a maximum value observed at 860 kg/weight of OW then declined as the amount of OW (kg/weight) increased. This implies that the best combined operating conditions of mass of OW and fraction of SW for the Pyrotec Model 8 incinerator occurred when the mass of OW (kg/weight) was in the range of 840 to 880 kg/weight and the fraction of SW of more than 0.07. Furthermore, high SW fraction in the loaded waste led to higher combustion efficiency due to the ease of generation of pyrolytic products from SW loaded, which were mainly plastics. With large amount of pyrolytic gases, the combustion temperature increases faster leading to faster combustion of waste in the primary chamber and also high temperature in the secondary chamber. Hence, higher Pyrotec Model 8 incinerator performance was observed in terms of %WR at conditions of mass of OW (kg/weight) in the range from 840 to 880 kg/weight and the fraction of SW of more than 0.07.

Conclusion

It was concluded that DOC of 364 L and mass of SW of 55 kg/weight combination offered the highest %WR. Accordingly, these points were recommended for the actualization of efficient and highest %WR. This has practical implication of choosing the levels for these parameters for efficient operation of the Pyrotec Model 8 incinerator. It was also concluded that the mass of OW (kg/weight) charged had no significant effect ($p > 0.05$) on the %WR at low quantities of TW below 940 kg/weight. However, in the presence of high levels of TW loaded above 960 kg/weight there was a possible interactive effect of DOC and mass of SW (kg/weight) influencing the observed high %WR. The best combined operating conditions occurred when the mass of OW (kg/weight) charged was in the range from 840 to 880 kg/weight and the fraction of SW was more than 0.07. The fractions SW and OW did not generally influence the magnitude of WR. It was further concluded that in order to realize high values of WR during the incineration process, the mass of SW (kg/weight) charged and DOC should be high. The high levels of WR were favored at high SW (kg/weight) loaded compared to the quantities realized at high fraction of SW. Consequently, it was better to operate the Pyrotec Model 8 incinerator with parameters expressed in terms of SW (kg/weight) than in terms of the fraction of SW.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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