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THE EFFECT OF THE THERMAL RADIATION ON THE IGNITION OF HAZARDOUS WASTE MATERIALS COMBUSTION

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Abstract. *Due to the growing energy demands of the world and the rapid depletion of fossil fuels, it is necessary to study new energy sources. The waste heat have a great potential to be tapped, as besides being a raw material abundant, their use helps in reducing the level of environmental pollution and curbing the volume of waste in cities. However, one should know well the combustion process these waste before using them as fuel. Thus, Ignition behavior of combustible wastes was studied in a built fixed bed reactor. It consists of a vertical cylindrical combustion chamber of 91 mm internal diameter and a height of 450 mm. To provide a controlled thermal radiation for the ignition instant, a radiative heat flux is generated by a metal surface called a cone heater made from stainless steel and then calibrated to establish the radiative heat flux density provided by a thermal resistance of 2 kW. The maximum radiant cone heater temperature obtained was 570 °C to impose a heat flux of 25 to 30 kWm*$^{-2}$ *over the top surface of the fuels. To validate the process, experiments with charcoal were performed varying the diameter of particles and air flow. After this, the hazardous materials: polyethylene and human feces were analyzed. Their effects were investigated on the ignition time.*

Keywords: *ignition, hazardous waste, thermal radiation, fixed bed*

1. INTRODUCTION

Energy has been throughout history the basis of civilizations development. Nowadays, it is increasing energy requirements for the food production, consumer products, products and service production, leisure, and finally to promote economic, social and cultural development. It is thus evident the importance of energy not only in the major context of industrialized nations, but especially those in developing, whose energy needs are even more dramatic and urgent. Within this context, alternative energy sources are gaining more and more followers, and strength in their development and application to minimize dependence on fossil fuels by the world, in view of these are becoming scarce. Moreover, the emphasis on the preservation and the environment conservation in order to ensure sustainable development is constantly addressed and discussed in events involving several nations and organizations around the globe. Thus, it is necessary to develop clean alternative fuels to replace the existing energy demand without compromising the planet. For example the biomass, it has become an excellent alternative that combines the high energy production capacity to low levels of emissions. Sustainable production of biomass and its use for power generation through combustion does not lead to increased levels of CO_2 in the atmosphere, because the CO_2 released during combustion is kidnapped during new growth. Furthermore, the biomass utilization can lead to a net reduction in CO_2 emissions to replace fossil fuels.

It should be noted further that one of the great villains to environmental preservation are the solid waste produced by humans as garbage and even sewage waste, especially hazardous waste. These wastes are usually disposed improperly and take too long to undergo spontaneous degradation, in addition to the damage caused in the region that were discarded, and when burned indiscriminately produce substances toxic to human health, flora and fauna. However, it cannot be disregard the high potential energy contained in these waste disposal since they are mostly composed of organic elements, like biomass, products and high energy capacity can therefore be reused consciously for power generation cheap and easy to obtain.

An efficient way to take advantage of the solid waste from many different backgrounds, for example, the strings producing biofuels or even the urban and industrial waste, is through combustion. However, it is necessary to do so, a detailed study of the process of combustion of such waste.

The ignition is an essential step of a successful combustion process. It is generally regarded as the beginning of the process of combustion phenomenon. It's an important stage of combustion, as it influences the flame stability, formation and emission of pollutants and flame extinction. In practice, it is important to understand the behavior of different waste fuel ignition in order to identify an optimal point for their injection in industrial combustors. Many studies have been made through pyrolysis and combustion of solid (Torero J.L. and Fernandez-Pello A.C., 1996; Liang L. *et al.*, 2008; Yang Y.B. *et al.*, 2005). Surprisingly, research in the area of ignition is scarce. So make up necessary studies in this strand of combustion.

The ignition of a material can be accomplished in various ways, and the present study focuses on ignition via a radiant (Blijderveen V.B. *et al*, 2012; Harada T., 2001; Park S. H. and Tien C. L., 1990). The influence of some factors such as the rate of air supply and granulometry of the particles are first observed through the use of coal. After this,

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experiments are performed with PET (polyethylene) and human feces. These two waste deemed hazardous, were chosen due to their immense availability, its high damage to the environment and its great potential energy.

2. METHODOLOGY

2.1 Experimental apparatus

The behavior of the combustion ignition of solid waste was studied in a fixed bed reactor designed and built by Monhol F. A. F. *et al* (2013) for applications such as this, see Fig. 1.

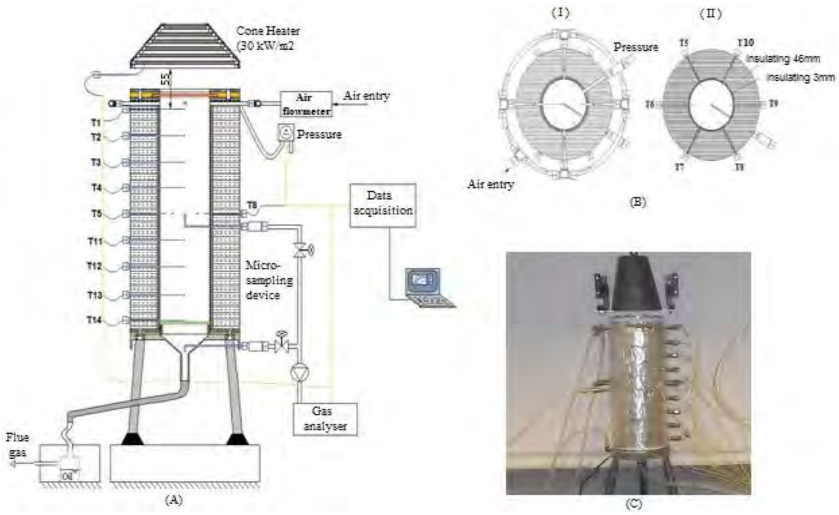

Figure 1. (A) Combustion cell developed with micro-sampling system and data acquisition. (B) Cross section at the reactor top (I) and at the crown of thermocouples (II). (C) Cell photo.

It consists of a vertical cylindrical combustion chamber of 91 mm internal diameter and a height of 450 mm. It is made of a 2 mm thick stainless-steel material, surrounded by two types of insulating material: a 3 mm thick layer of wool (Superwool 607 blanket, Thermal Ceramics, $k = 0.28$ $Wm^{-1}K^{-1}$ at 982 °C) and a 50 mm thick layer of refractory fiber bloc (Kaowool HS 45 Board, Thermal Ceramics, $k = 0.21$ $Wm^{-1}K^{-1}$ at 1000 °C). To provide a controlled thermal radiation for the ignition instant, a radiative heat flux is generated by a metal surface called a cone heater made from stainless steel and then calibrated to establish the radiative heat flux density provided by a thermal resistance of 2 kW. To calibrate the cone heater, the top surface of the reactor was placed in three different heights (0 mm, 25 mm and 50 mm) from the cone and exposed to the radiation that crosses a quartz porthole that ensures the sealing of the reactor closure. The maximum radiant cone heater temperature obtained was 570 °C to impose a heat flux of 25-30 kWm^{-2} over the top surface of the fuels. It was possible establish a mapped surface temperature reached on the fuels for the different heights tested, as showed in the Fig. 2 for 50 mm of distance from cone which was used in the experiments. This surface was obtained from the data generated for several thermocouples strategically located in a plane 50 mm below the cone. Then, with the temperature values at various points of the plan, an interpolation was made to find the temperature in the remaining points with the help of computational software.

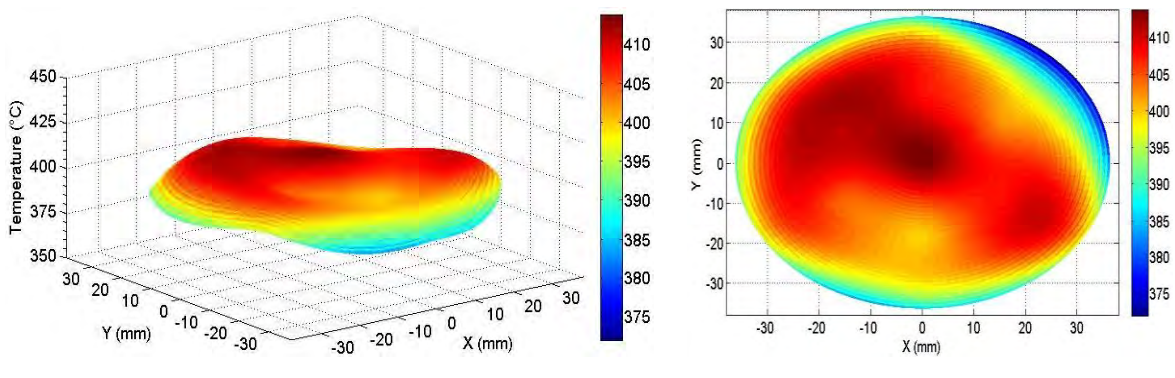

Figure 2. Temperature Surface generated by the cone at 50 mm of distance.

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The thermocouple at the top of the reactor was used to record the temperature at the time of ignition of the material. The pressure is also recorded during the experiment. A gas analyzer is connected to the output of the products produced by the combustion of the material, thus allowing a detailed study of the ignition and their products formed.

2.2 Experimental procedure

To study the influence of factors such as the granulometry of the particles and the air flow on ignition of solid waste were conducted four experiments to validate the device used in the experiments. Experiments 1 and 2 were compared to observe the influence of particle size on the ignition. Among the experiments 2 and 3 could observe the influence of air flow. In experiments 2 and 4 to influence a given percentage of coal, as would be done later in the experiment with PET, was analyzed. The sand was used because it is an inert medium during the process, enabling the analysis of the influence of distribution of the coal in the fuel.
After being known influences of these factors were chosen particle sizes, flow rates and mass ratio appropriate for each material: PET in experiment 5 and Feces in the experiment 6. Table 1 shows the main characteristics of each experiment. The results of the validation experiments and experiments with PET and feces are described in the following section.

Table 1. Parameters of each experiment

Experiment	Material	Granulomety (mm)	Mass ratio	Air flow (Kg/h)
1	Charcoal	4	1	0.676
2	Charcoal	2	1	0.676
3	Charcoal	2	1	0.151
4	Charcoal/Sand	2	3:20	0.676
5	Charcoal/Polyethylene	2	10:2	0.676
6	Human feces	5	1	0.676

To know the composition of each fuel used in the experiments was made a proximate and ultimate chemical analysis. Table 2 shows the results.

Table 2. Proximate and ultimate chemical analysis of each material (average values in wt %).

Fuel	Moisture	Ash	C	H	O	N	S
Charcoal	11.5	8.5	62.56	3.94	10.64	1.16	1.35
Polyethylene	0.05	0.25	85.7	14.3	0	0	0
Human Feces	20	10	48.25	7.15	32.1	5.49	1.6

3. RESULTS AND DISCUSSION

There are several criteria to analyze the ignition. For example, the temperature increase of the particle (Du X.Y. *et al*, 1995), the inflection temperature x time profile (Du X.Y. *et al*, 1994), analysis of the gas composition produced (Sun C.L. and Zhang M.Y., 1998) or visual observation. The present work also uses the study of heating rate (dT / dt) of the particles (Sun C.L. and Kozinski J. A., 2000; Essenhigh R.H. *et al*, 1989), and the pressure increase as the ignition analysis criteria. In this work, the ignition point is determined as the point where the heating rate, the pressure in the bed and the percentage of CO_2 in the exhaust gas increases abruptly, indicating the profile versus time instant temperature and the temperature at which ignition is starts.

Figure 3 shows that this criterion is satisfactory because, as noted, the ignition really starts as soon as the heating rate and the pressure increases suddenly in the bed, as is evidenced by the analysis of the combustion gases (CO_2 increases and O_2 decreases suddenly).

The ignition of the fuel particles can be attributed to homogeneous reactions (gas phase ignition) or heterogeneous reactions. (Essenhigh R.H., 1989) The heterogeneous reaction involves the direct attack of oxygen across the sample particles, oxidizing all matter that would otherwise be expelled as volatile. In the homogeneous behavior pyrolysis is the initial step and immediately after the ignition of volatiles occurs, followed by ignition of the coal. Thus, in this experiment, since the products formed in the ignition are carried below the bed, it is observed that in the homogeneous behavior occurs an increase of the pressure in the bed due to the fact the volatiles formed in the pyrolysis accumulate in the later parts of the bed and interrupt the flow the gases. In the heterogeneous ignition behavior, as the volatiles are immediately consumed by the flame, there is not an increase in pressure in the bed. For validation experiments were observed parameters mentioned above.

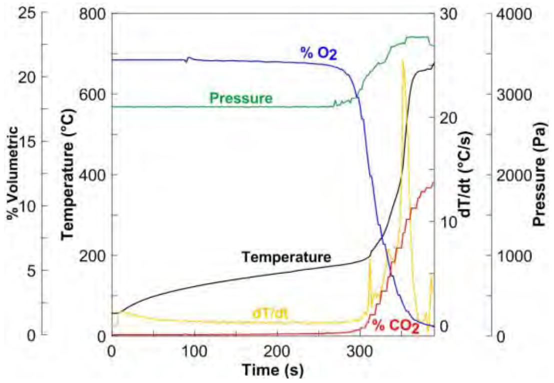

Figure 3. Curves to identify the time and ignition temperature.

The temperature profile, the heating rate and pressure in the bed was plotted as shown in Fig. 4. It was clear observing the experiments 1 and 2 that the increase in particle size results in a decrease of the ignition timing. Observing the experiments 2 and 3 it was identified a influence of air flow in the experiments, a higher flow rate results in a lower ignition temperature and a longer time to start it, it may be due to cooling of the sample by air entering the bed at room temperature. In the experiment using small fractions of coal can be observed that the ignition temperature is lower and the time to start it is higher.

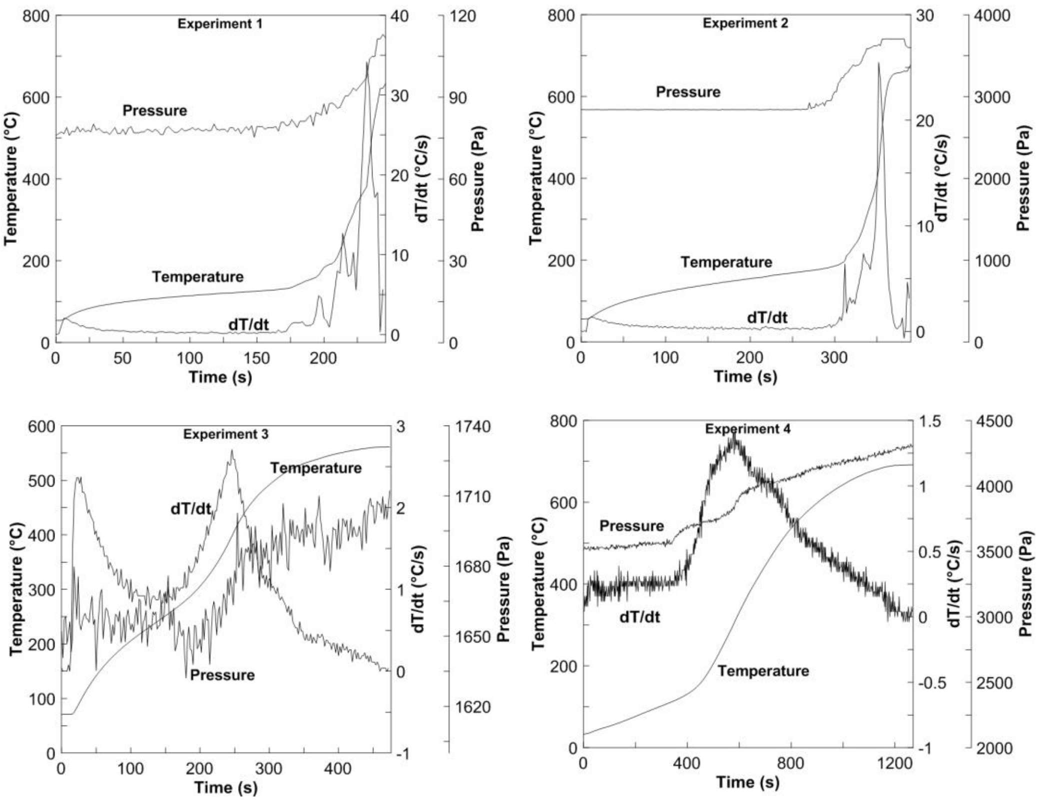

Figure 4. Profile temperature, heating rate and pressure for the validation experiments.

Figure 5 confirms the influence of particle size on the result of time ignition of the fuel. It can be seen clearly that the time for experiment 1(E1 in the Fig. 5) which used a particle size of 4 mm is smaller than time for experiment 2 (E2 in the Fig. 5), which used a particle size of 2 mm.

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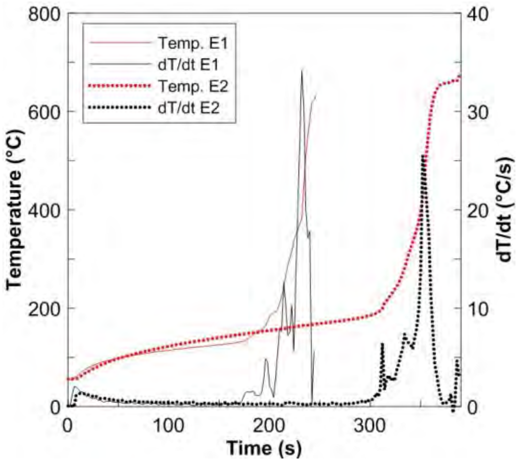

Figure 5. Comparison experiments with different particle sizes.

For the experiments with PET and Feces found the graphics shown in Fig. 6. It was noted that for PET and charcoal ignition timing is high, about 500 s to a radiative heat flux of 30 kWm^{-2}. This indicates that PET although in much smaller proportion greatly influences the ignition timing in order to slow it down, because the pure charcoal under the same conditions has an ignition time of 300 s. The ignition temperature is about 175 °C at an air flow rate of 0.676 kg/h, having increased about 10 °C compared to pure charcoal. This indicates that PET had little influence on the ignition temperature. There was a homogeneous combustion behavior for this experiment, as can be observed pressure increase due to volatiles are being carried by the bed so that ignition starts.

For feces was noted that the ignition time is about 300 s to a radiative heat flux of 30 kWm^{-2}, this is due to its larger particle size (5 mm), which was precisely determined to accelerate the ignition timing. Yet, their ignition time is high because the charcoal having a particle size of 4 mm takes 200 s to start ignition. The ignition temperature of feces is around 380 °C at an air flow rate of 0.676 kg/h. This ignition temperature is much higher than other materials. The pressure within the bed had a a delayed increase, it indicates that the volatiles are initially consumed in combustion and are released only after the appearance of the combustion front in the bed, and generate higher temperatures along it. There is, therefore, in these conditions, a heterogeneous ignition behavior.

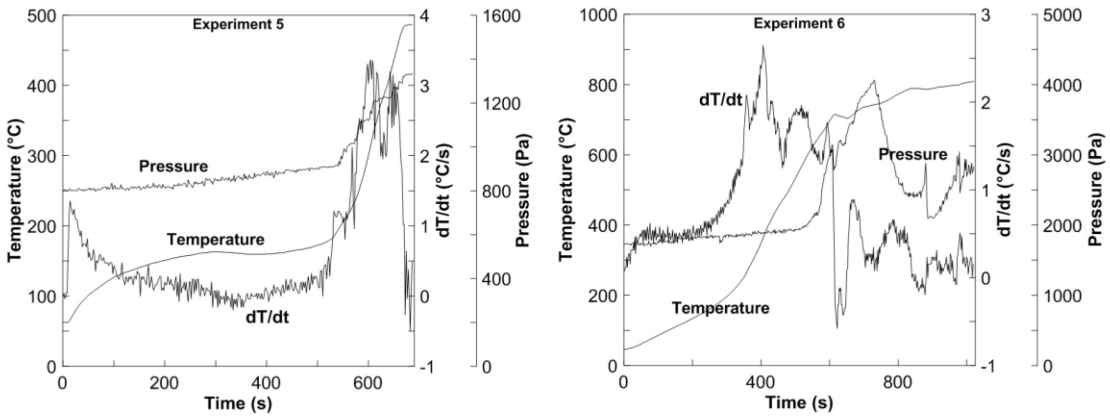

Figure 6. Results for hazardous solid waste.

4. CONCLUSION

The experiments gave significant results. It was observed that the criterion adopted for the ignition timing was consistent with the reality, which can be confirmed by gas analysis in validation experiments. The ignition is affected by several factors. The larger particle size tends to accelerate the ignition process of the material. A lower flow increases the ignition temperature and shortens the time for it occurs, which can be explained by the fact that the incoming air is ambient temperature and cools the bed and delays the start of ignition.

For the PET and charcoal was observed ignition timing is high, about 500 s indicating that the PET greatly influences the ignition timing in order to slow it down, since the pure charcoal under the same conditions has a longer ignition time, 300 s.

The ignition temperature is about 175 °C, very close to pure coal, indicating that PET had little influence on the ignition temperature. There was a homogeneous combustion behavior for this experiment, as can be observed in the increase of the pressure due to the volatiles are being carried by the bed so that ignition starts.

For feces was noted that the ignition time is about 300 s this is due to their large particle sizes (5 mm), which accelerates the ignition timing. Your ignition timing is high because the charcoal having a particle size of 4 mm takes 200 s to start the ignition. The ignition temperature of feces is around 380 °C, temperature much higher than other materials. Therefore, observed for the feces in these conditions heterogeneous ignition behavior.

Therefore, with this information will be possible to facilitate the process of combustion of the waste, since its ignition temperature, time and behavior on certain conditions are now known. So, just to continue the work by studying the temperature and time of ignition and the ignition mechanism that will be present under the conditions used in industrial combustors.

5. ACKNOWLEDGEMENTS

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