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RESEARCH ARTICLE

# SIMPLE DETERMINATION OF PHYSICAL AND THERMAL PROPERTIES AS A BASIS FOR THE DESIGN AND ANALYSIS OF WASTE TO ENERGY COMBUSTION EQUIPMENT

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**ABSTRACT**

Waste to Energy equipment design and operation is highly depending on the physical and thermal properties of the waste to be used. While this seems obvious, there are practical complications when a study is undertaken, because of lack of proper determination of the waste characteristics. This paper proposes the use of a set of physical and thermal properties as the basis for the design and the study and analysis of the actual functioning of WTE equipment, characterizing them by using simple determination techniques. A rational method is proposed for the use of these in the design and analysis, illustrated with practical examples derived from the experience of the authors with these systems. It is proposed that, by using this approach, it will be easier to determine important aspects of the feasibility of a new project and derive appropriate conclusions when auditing working WTE equipment.



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## INTRODUCTION

The classification of waste can be subjective; there are a lot of residuals that can be considered as waste from a specific process which could be used to obtain energy. The ample spectrum of possibilities include materials derived from vegetable and animal process, such as wood, seaweed, leftovers from agricultural and forestry processes, and more directly waste materials such as pulp mill liquor, sawdust, food processing waste, water coffee grounds, cardboard, bark from plywood operations and bagasses, among others. Of course, municipal garbage is considerate as a waste with energy applications. The major part of the organic matter can be burned to generate heat for steam and power generation. The consideration of this material as residuals opens the possibility that they materials could be less expensive than the traditional fuels as heat resources. The required equipment for these applications have design and operative challenges, which depend heavily on the physical and thermal properties of the waste. This has to do with different requirements related to the shape of the material, storage difficulty, the ability to flow, the influence of humidity, the uniformity of the material, the density, the thermodynamic properties, and so are a set of variables that are interesting to be studied and sometimes are disconnected in the design and operation process. This especially can happen in places like underdeveloped countries, in which there is not a tradition of using waste materials for energy production. Our objective here is to offer a perspective that facilitate conceptual analysis for the initial stages when considering a possible application in this field. In addition, it is desired to give some basic ideas to examine operative issues when the systems are operating. This wok initially presents some definitions of the main proprieties to considerate in a waste characterization, their ranges of variation, their relevance in a waste to energy process, some simple techniques to characterize them and to obtain general ideas for variable estimation, and considerations that allows a better understanding of the design and operation of WTE equipment. A rational method is proposed for the use of these in the design and analysis, illustrated some practical industrial examples of challenges and their solutions. This paper facilitate a new approach to a simple determination of important aspects of the feasibility of a new project and derive appropriate conclusions when auditing working WTE equipment. Its basic tenet is that the knowledge of the properties facilitates the design work and the operation of the systems.

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### Some relevant properties. How to determine and use them in simple ways

### Types of Waste

One important consideration is that combustible waste is heterogeneous and very variable in all aspects. Commercial liquid and solid fuels are manufactured under clear specifications and have been subjected to many years of regulations. There is ample information on their properties and the user can find in the market several options to choose from, when selecting a supplier, which is going to send the fuels within known specifications every time. This is not the case for waste fuels. Because of this, quality control issues are going to be very important. In general, the user should establish a system to determine some basic variables when receiving shipments and when using the waste. The first consideration is that waste could come in many different forms, sizes and shapes and mixed with irregular materials that could not be combustible. This surely causes operational and design difficulties. As there are ample types of combustible waste, it is useful to have a general idea of them and of the general available equipment and their applicability for a given type. It is important to identify the origin of the waste and to be familiar with the way it is generated. The following list of waste types is just an indication of this need: forestry residuals, agriculture crop and harvesting residuals, agriculture industrial residuals, animal farm residuals, animal processing residuals, chemical, construction, food manufacturing, green waste, hazardous waste, organic municipal waste, sewage waters biosolids and mixed waste. These materials can be presented as pellets, chips, fibers and bagasse, grains, chunks, pastes, liquids and other irregular and variable shapes. If possible, the designer and the operator should spend some time in the sites that generate the materials and try to understand what irregularities in shapes, presentations and sizes might occur. Tables describing the variations and categories should be prepared and some characterization of them should be part of these tables. An effort should be made to stablish, in collaboration with the supplier, some basic limitations and specifications that should be taken into account before sending and receiving shipments.

## Waste sampling

To determine waste properties, it is necessary to have available waste samples, which should be representative of the bulk of the waste. In many cases, adequate sampling of waste is quite complicated, because of the very variable and irregular nature it has. Given the practical impossibility of studying the whole material, is important to get representative samples. They should be small, because of laboratory and analytical limitations. The problem to be solved in a simple and practical way is how a small quantity of something accurately, reflects its larger entity. The characterization of a solid residue should be performed for a given number of days, compounds, users, etc., in order to obtain a representative sample of the universe of generators and of the origins of the materials. For proper sampling and characterization of solid waste (especially organic matter), it is useful to consider the following strategies (Tchobanoglous and Kreith, 2002):

**Zoning the material**: It is important to define areas with similar characteristics, depending on the origin of the waste, to make a classification of the material, taking care of the origin and type, trying to take samples of zones with similar qualities.

**Number of samples**: Statistically it is convenient to take a number of samples that could be determined under some mathematical formulation (Pacheco *et al*., 2009), related to size, variance, reliability and permissible error in the property to be studied. In practical situations, it could be that only a few samples can be obtained. If that is the case, statistical formulations help determining the variations that could happen. Figure 1 shows a graph relating sample size with error and variance.

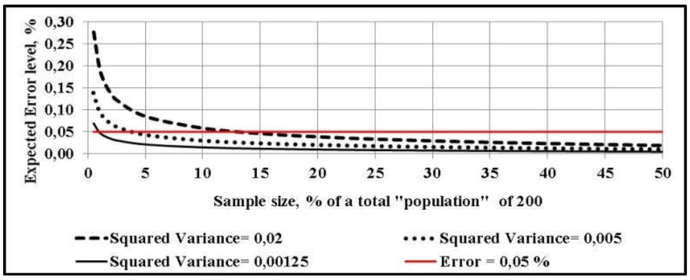


**Figure 1. Expected error as a function of variance and size for a given population**

## Quartering

It is a type of sampling technique very well suited to the case of sampling of irregular solid materials. A simple practical way of doing this is as follows: A fairly large pile of waste material should be placed in a paved area or on a large plastic. The large pile could have a size of some 2 x 2 m, prepared by using a shovel to retire materials from the bulk of the solid waste. The taking of materials should ensure that all visually differenced types are included, from different parts of the bulk. In order to homogenize the sample, bulkier residues are broken with some appropriate tool until a resulting manipulated size (for example 3 cm or less is suggested). Then, by using the shovel, the material on the sampling pile is mixed up until there are not noticeable large differences. After this, this pile is divided into fourths such that there are no large visual differences in them, and three of the fourths are retired. In this way a smaller sample with sizes under 3 cm is obtained, which now should be spread on the 2x2 m surface. The procedure is repeated several times, looking for smaller sizes of the pile and of the chunks. At the end, it is reduced further, homogenized and divided into four parts again, choosing a quarter of the total for testing purposes and keeping the other three fourths as a retained sample for additional study or verification needs. The final sample should have small sizes suitable for general laboratory work, such that any reasonable part of it can be taken for that. Figure 2 illustrates the quartering method just described. It is necessary to mention the importance of the protection of body parts as they will be exposed to substances that can be infectious or cause damage to eyes or skin.

## Density and study of changes with temperature

Density is defined as the amount of mass per volume of a substance. In general, the density is compared to that of a standard substance, usually water, obtaining in this way the specific or relative density. For the solid waste, the density can be the "true" density, which does not include the effect of internal porosities in the sample and is dependent on the solid material as such. More important for design and operation is the bulk or "apparent" density, which includes the volume of porosities in the sample. This can vary a lot, depending on the way the waste is stored, mixed or treated. Such a simple property is truly essential in the effect that it has on combustion equipment design, especially for the case of solid waste. A mass of waste is composed of irregular particles of different sizes and forms, so they can arrange themselves randomly.

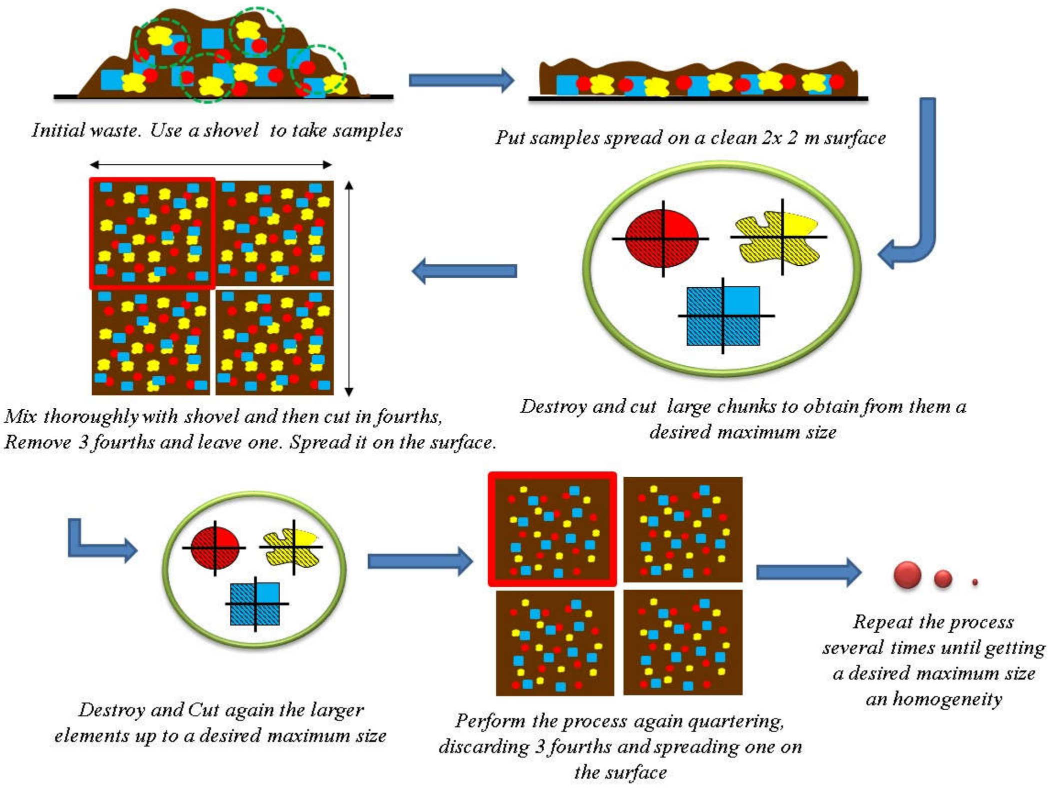


**Figure 2. Illustration of quartering method**

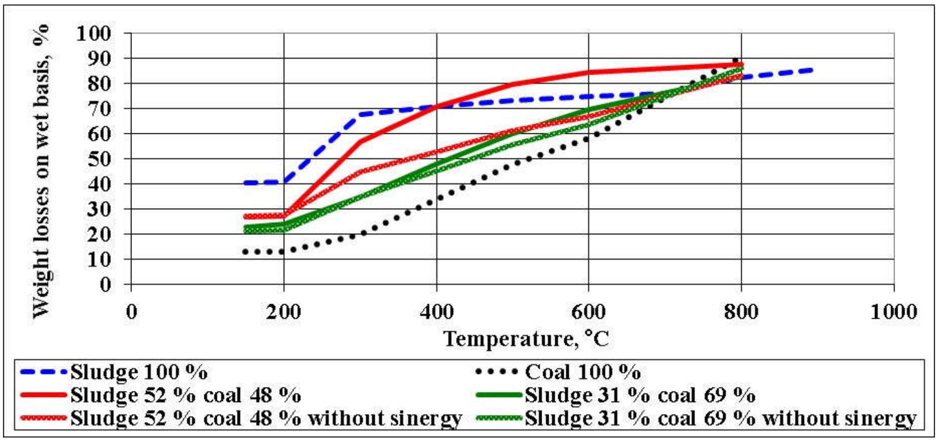


**Figure 3. Furnace testing of waste paper sludge and coal samples**

When it is tightly compacted, the path that the heat needs to go through becomes tortuous. Then the density affects directly the combustion rate, the higher the density is, potentially greater the combustion rate. Besides, for a particle to ignite, it needs the presence of oxygen, then, in the same way, the higher the density (more compact) a sample is, the less oxygen will seep through, the dense material will have less oxygen to burn, making it harder to ignite. Combustion chambers require enough residence time for a complete combustion and the space occupied by the solid waste while undergoes combustion is related to solid bulk density and the way it evolves with the combustions process. It is convenient to determine the changes in waste volume against temperature. For visualizing this, a simple technique is to prepare a sample of the waste and subject it to heating at different temperatures (for example each 50 °C) in a laboratory furnace under the presence of air, playing with heating time. For each time and temperature up to, for example, 800 °C, the sample is retired from the furnace and weighted after letting it cool. Photographs are taken in all stages to visualize how combustion proceeds and how it changes shapes and aspects. The treated sample bulk density is measured using a small recipient of known volume, which is completely filled, with not intent of applying any packing effort.

Usually, at 400 °C the organic material is going to disappear and the waste should show this and a gradual impact on weight loss and density change with temperature, for each heating time considered. It is convenient to perform these tests using in parallel a given solid fuel or waste of known behavior for comparative and calibration purposes. This simple idea will give very valuable information on the combustion difficulties of the waste. The relative weight losses differences between the waste and the calibration sample can be quantified and interpreted, from the point of view of required combustion residence time and volume. Figure 3 shows a comparative graph in which samples of waste paper sludge were compared to coal, in a case in which the possibilities of using the sludge as an auxiliary fuel for a coal boiler were studied.

## Moisture-water content

Moisture refers to the presence of water in the waste. Control and knowledge of moisture in waste fuels is a vital part of the design and operation of WTE systems. In general, waste fuels contain substantial amounts of moisture, even in materials that seems to be dry matter. See Table 1. The water in the waste have different effects, it can promote bacterial or mold formation and cause risk or health concerns in the handling of the waste. It has a direct effect on combustion and energy generation; the drying of the waste, previously to combustion, should be considered. In addition, the presence of water tends to diminish combustion efficiency and promote the formation of undesired combustion products and incomplete combustion, particulate matter, emissions and smoke. There are several classical ways to perform a moisture analysis (Heating tests in laboratory ovens to determine weight losses at given temperatures, Karl Fischer titration, color indicator tubes, chilled mirrors, electrolytic sensor, piezoelectric sorption, aluminum oxide and silicon oxide or spectroscopy). There is also the simple recourse of finding the weight loss under drying as weigh loss curves resulting from exposures at a set of temperatures under certain time exposures to the temperature. In this technique, a sample of material is weighted, heated in an oven for a control periodic, cooled and reweighted. As in the case of the furnace test already described, it is important to photograph and observe the behavior, to report form, texture, shape and volume changes and analyze the curves from a heat and enthalpy point of view. Of course, this can be done with equipment that automatically gives a drying curve and additional information in a faster way, but the proposed manual way can give a good physical sense of the phenomena that occur during the drying stage of the waste in the combustion or in a separate operation.

**Table 1. Moisture content for some common waste**

| Waste type | Moisture Content, % |
|---|---|
| Food Waste | 50-70 |
| Paper | 4-6 |
| Cardboard | 5-7 |
| Plastic | 2-4 |
| Textile | 8-10 |
| Rubber | 2-4 |
| Wood | 20-25 |

The loss on drying classical method is used to determine the percentage of water in a sample by drying the sample to a constant weight, the water content is expressed as the percentage, by weight, of the dry sample. The drying equipment can be an oven, a hot plate, a field stove or any other suitable element for drying moisture samples. This at uniform temperatures, usually up to 115ºC, and using a balance or scale to weight the example before increase the temperature and after it is cool. Some authors associate the selection of the example with the size of the particles (Hosetti, 2012).

**Table 2. Size of the suggested sample associated to particle size**

| Maximum Particle Size | Minimum Weight of Sample, grams |
|---|---|
| No. 4 (4.75 mm) | 100 |
| 3/4 in (19.0 mm) | 500 |
| 2 in (50 mm) | 1000 |

Figure 4 shows some drying curves obtained when drying a paper sludge in a laboratory oven. This information was part of the design for a drying system.

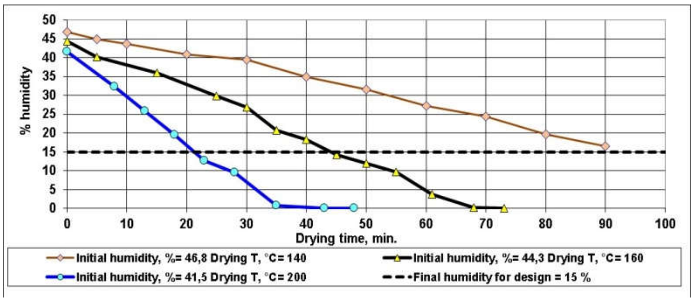


**Figure 4. Oven drying curves for samples of waste paper sludge**

## Particle and bulk size

Solid waste will have particle and bulk sizes highly dependent on the processes that generate it and on the operation performed previously to the combustion or heat treatment. In many cases, the waste comes in large sizes that difficult the combustion process and require milling and size reduction before it. Sizes are closely related to shapes and forms. Because of this, their measure can take into account one or several dimensions, weight, volume, surface or form compared with the sphere. The sphere is the only tridimensional form that can be described with a unique number in terms of its size, this is why most of the particle sizes are reported in reference of an equivalent sphere. The particle size affects in many ways the physical properties of the product, and clearly influences the combustion processes. There are some common techniques to measure this property, such as granulometric analysis, particle counting, sedimentation separation, light diffraction or dispersion. The simpler technique is the granulometric analysis, which could be done in mechanical or manual procedures, separating the particles according to sizes, which could be standardized. The ASTM has published several methods of standard measure for the analysis by mesh. Visual observation is important here. For small sizes could include the use of a microscope or stereomicroscope, with the help of a grid, to determine sizes. For the case of burning waste liquids, particle sizes are important for spraying operations in combustion chambers (Miikkulainen *et al*., 2005).

## Properties related to waste handling

Some of the more complicated aspects of operation and design of waste to combustion systems are the ones related to the behavior of materials, especially solid irregular ones that are generated with no quality and standardization considerations as such. The designer and the operator should pay attention to several aspects that can be examined with simple observational methods.

## Angle of repose

The angle of repose, a critical parameter for a granular material, is the limit in which a material can be piled without slumping. At this angle, the material on the slope face is on the verge of sliding. The angle of repose can range from 0° to 90° and is associated to the morphology of the waste. Sometimes is important to modify the angle of repose using solvents, or an additional product to allow modifications. It is important in the design of hoppers, silos transportation and storage of material.

It can also be used in determining situation on which a pile collapse is likely. This is in some ways a geometrical variable that can be observed easily and there are several methods for measuring it. Results are sensitive to the methodology of the experimenter. As a result, data from different labs are not always comparable. Methods include the triaxial shear test, the direct shear test, the fixed funnel method and the revolving cylinder method. A simple method is to prepare several piles of the material (at least three) and take measures of their height and their spread to determine the angles. The observation of the variations and the behavior of the material when forming the piles, is a good indication. From another perspective, if the coefficient of static friction is known for a given material, then a good approximation of the angle of repose can be made with the following function, which applies well when individual objects in the pile are minuscule and piled in random order, $\tan(\emptyset) \approx \mu_s$.Where, μs is the coefficient of static friction, and θ is the angle of repose. There are some tabulation of this angle for given materials (table 3), but in general is better to complement them with actual measurements on the waste (Clover, 1995). It is clear from this, that flow properties, related to static friction, can be correlated with angle of repose (Table 4).

**Table 3. Common angle of repose**

| Material | Angle of Response (degrees) |
|---|---|
| Ashes | 40° |
| Clay | 25-40° |
| Coffe bean | 35-45° |
| Sand | 45° |
| Wheat | 27° |

**Table 4. Flow properties and Corresponding Angles of repose**

| Flow property | Angle of Response (degrees) |
|---|---|
| Excellent | 25-30 |
| Good | 31-35 |
| Fair | 36-40 |
| Passable | 41-45 |
| Poor | 46-55 |
| Very Poor | 56-65 |
| Very difficult | >66 |

**Figure 5. Changes in color of combustions residues after calcination on a laboratory furnace**

**Color**

Things that can be observed easily and physically in the waste material indicate the possibility of variations in the quality of the residual and give ideas about process and operation difficulties. Some of them could be as simple as color, that can give indications related to moisture, composition of the material, decomposition of the material, and variations of the state of the material. For example, poor combustion of organic waste is in general, correlated with black color. Ashes tend to be whitish or light brown in color. When the residues from the combustion are dark and blackish, it is almost sure that they are rich in black carbon and soot, undesirable components that cause serious environmental problems. When this happens, it is advisable to take samples of the residues to a laboratory furnace and perform calcination loss determinations. These losses, associated with the whitening of the sample after calcination, can be related to loss of efficiency in the combustion system.

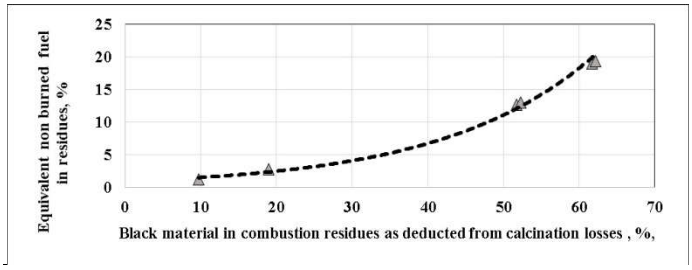


**Figure 6. Sample correlation derived from analysis of combustion residues based on calcination loss after whitening of calcined residue. The relationship between fuel and black material (assumed as black carbon) is 70 %**

Figure 5 shows pictures for an actual case, the combustion residues coming from a fique WTE boiler. Figure 6 shows a sample correlation derived from these considerations for the same process.

**Abrasion indications:** Abrasive behavior can be related with differences in hardness between materials, comparing that is hard and abrasive and other that material that suffers the effect of the contact when there is relative motion. When a material is crushed, its grade of abrasion in general increases. Factors that influence wear and abrasion include differences in hardness between the two substances; grain size (grit size), with larger grains cutting faster and deeper; adhesion between grains and the materials that support them, which determines how quickly grains are lost from the abrasive and how soon fresh grains, if present, are exposed. Usually the hardness in the waste will be associated with the presence of grits and mineral components and non combustible materials. Understanding this property is important for the storage of the substances, the selection of materials in equipment. Sometimes it will be required the use of lubricants or protection for the surfaces. Physical test done by forcing contact between waste samples and sheets of different materials, both hard and soft, will give indications in this sense, based on carful observation of marks and scratches in the materials.

### Salt content and impurities

Salts and inorganic components may be present in the organic or combustible waste, particularly when it comes from industrial process in which chemical operations (such as precipitations, scrubbing, neutralization) are part of the processing of the waste. Salts can be a problem in the combustion process as such. One case is the presence of chlorine, as is the case of wood or some plastics. Chlorine can form salts and components with some minerals, such as NaCl, KCl or HCl. This could enhance the production of harmful halogenated compounds. Some of the waste use in the waste to energy process come from vegetables and plants rich in minerals like K and P. They are present at trace concentrations in wood, but at higher levels in the bark and leaves. Other minerals can be taken up into growing biomass if present in the soil, water or atmosphere. It must be noted that even small amounts of soil inclusion in the fuel, as result of poor storage or handling practice, will lead to increased levels of ash, once again underlining the importance of keeping track of the quality of the fuel (Saidur *et al*., 2011). Most of these will contribute to the ash which could be rich in various salts. Larger particles fall through the grate as bottom ash, while smaller particles can be carried up with the flue gases, together with any particulate unburned carbon, as fly ash. When burning liquid waste fuels, the salt content will cause difficulties related to the formation of deposits on combustion chamber and heat exchanger surfaces. These deposits can cause significant damage. Figure 7 shows an example, for the case of the burning of waste waters rich in organic components, coming from a sodium scrubbing system.

before and after washing with distilled water. In a case, related to Figure 6, it was found that the liquid waste fuel had ashes almost fully soluble in water.

**Figure 7. Salt deposits causing damage on combustion chamber surface**

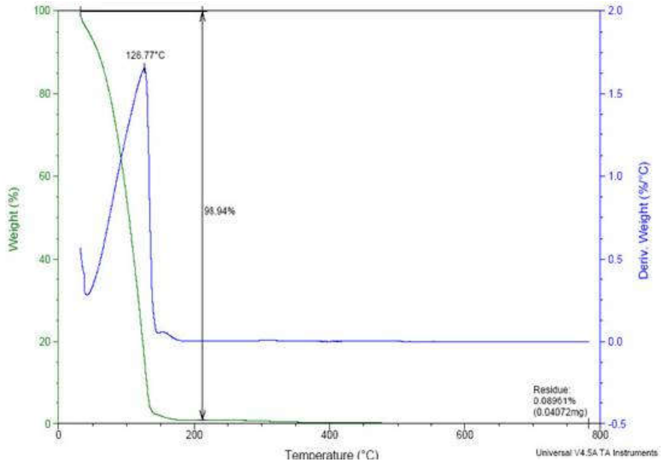


**Figure 8. TGA of liquid waste rich in organic compounds**

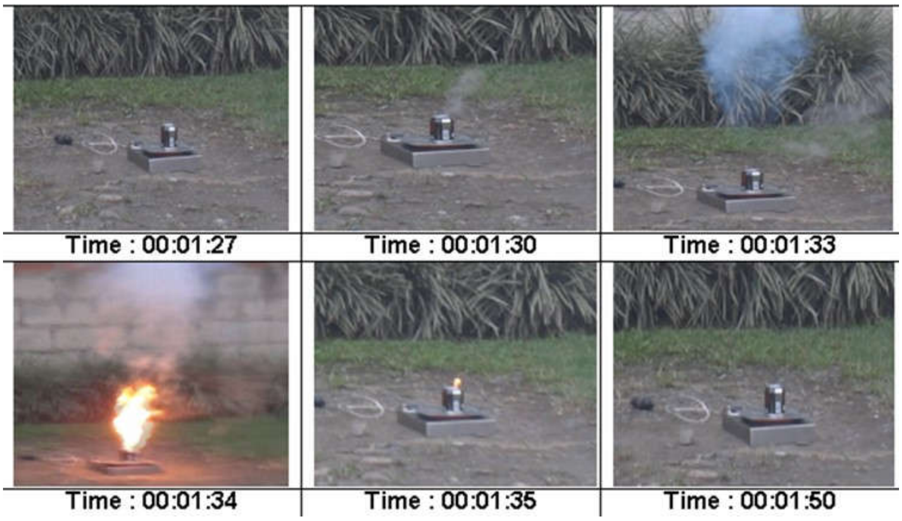


**Figure 9. Flammability simple test**

An indication of soluble salt content can be obtained easily performing a washing test of the ashes obtained after calcination of a sample. In this test the dry ashes are weighted

One very interesting test is a thermogravimetric analysis, which shows loss of mass for the waste material. As shown in the case, figure 8, the analyzed liquid waste had lost more than

99 % of its mass at 800 ° C, but the remains, 0.089 %, were confirmed to be soluble salts. This analysis was done at the designing stage and it was clearly said at that time, that those salts should be eliminated from the waste. In actual practice, the fuel showed even larger presence of salts, which caused the problems illustrated in Figure 7. This is a case of not having really representative samples of the waste during the designing stage.

**Explosiveness and flammability**

Waste fuels can easily have explosive and inflammable properties. That happens usually when they contain volatile organic compounds with flammable characteristics, Because of the complexity and particularity of waste fuels, it could be that there is not information on explosive limits and flammability or that could be difficult to apply to them the standardized methods to determine these properties. A possible simple way to approach these situations is to perform a test in which a recipient containing small samples of the waste is subjected to controlled heating and apply to its free surface some starting flame source, such as a spark igniter. If the waste shows a tendency to ignite itself at low temperatures, then a careful analysis of the situation should be part of the design, making all efforts to avoid risks and having the correct classification of the waste in existing hazard scales. Figure 9 shows an example of the suggested simple test.

**Viscosity**

This property is important for the handling of liquid waste and is easily determined using standard laboratory equipment.

**The instruments used generally follow one of three physics principles:** Flow rate of liquid through a tube, speed of a falling body through a liquid or viscous friction force exerted on a rotating body. A simple way of having an approach to this property is to take the fluid to test in a translucent container, filled to a known height. With a known weight marble, report the time that takes the marble to reach the bottom and use the well-known terminal velocity equation, which relates viscosity to densities differences between the liquid and the marble, the radius of the marble and its settling velocity.

**Concluding remarks**

Simple techniques have been described and illustrated based on real experience in design and operation of WTF equipment in Colombia, which is a region with very ample possibilities for WTF applications, but with not enough experience in designs and construction of these system. These simple techniques are easy to apply as a means for a conceptual understanding of projects that could make use of available waste as fuels.

## REFERENCES

Clover, T. J. 1995. Pocket Ref. Sequoia Publishing

Hosetti, B. 2012. Prospects and Perspective of Solid Waste Management, Chairman of Applied Zoology, Kuvempu Uni., Shankarghatta, Karnataka.

Miikkulainen, P., Kankkunen, A., Järvinen, M. & Fogelholm C.-J. 2005. "Predicting droplet size from black liquor spray characteristics", TAPPI Journal, vol. 4, no. 5, pp.11-17.

Pacheco, H.; Beverly, K.; Chamorro, A. 2009. Caracterización de Residuos Domiciliarios del Distrito de Matucana. Revista de Investigación Universitaria, 59-66.

Saidur, R.; Abdelaziz, E.A.; Demirbas, A.; Hossain M.S.; Mekhilef, S. 2011. Renewable and Sustainable Energy Reviews. 15, 2262-2289

Tchobanoglous, G.; Kreith, F. 2002. Solid Waste Management; McGraw Hill Handbooks, Second Edition.

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