The Relationship of Stoker Burnout to the Properties of Residue

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INTRODUCTION

A reliable relationship of stoker performance to burnout is one which engineers and scientists will be struggling with for a fairly lengthy period of time. At the present state of the art, a minimum of knowledge is available, and it is impossible to develop any numerical applications for a specific relationship. One of the most spurious shortcomings in the development of a burnout relationship is the unanimous disagreement on what basis the particular interaction should be defined. The interaction or relationship which is desired may be thermodynamic, biological, or chemical in nature with all systems having equal validity.

To complicate matters even more, a relationship could be developed using air quality criteria rather than incinerator residue quality. Although the relationship of air quality criteria is very important, and a definition of this quality is much closer to reality than is one for residue quality, it is probably very unfair to equate the two qualities at this time. Definitely the future problems relating water and land use, planning and zoning, and potential pollution, to residue quality must be considered in depth alongside of an air quality-residue quality relationship.

THERMODYNAMIC

For very obvious reasons, there is a lack of definition of residue quality and no specific relationships will be presented in this paper. What will be discussed, however, is the possible basis upon which such a definition can be developed for the interrelationships between incinerator residue quality and stoker performance. In order to do this, we will have to revert back to some basic principles and examine the parameters governing combustion processes - such as solid waste incineration.

Thermodynamically, how do we define efficiency of an incinerator? From the basic laws of thermodynamics, the efficiency of a combustion process would be given by the ratio of the energy output to the energy input of the system. This is stated semi-mathematically in many textbooks, and is the classical definition of efficiency of any machine or system. This is, Efficiency = output ÷ input.

An incinerator, however, cannot be analyzed as would a typical combustion process or system. For example, a steam electric station would be a process that could be analyzed from the classical theory of combustion, but an incinerator and other

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boiler installations have intermediate steps such as heat exchangers, and the output from the system can be measured quite accurately in terms of useful work. The input to each of these systems is also homogeneous in the form of several kinds of fuels. Thus, with the two quantities known, computing the efficiency of the particular system becomes rather routine.

Looking at an incinerator, however, we see that it cannot be analyzed in a like manner. First, there is no useful work being done by the incinerator as far as energy transfer or the utilization of heat evolved. Thus, the entire process becomes one of designing inefficiency into the process in order to maximize the efficiency of the incineration process. At first it appears that this statement is double talk and the statements are contradictory, but the entire philosophy of solid wastes or refuse incineration is in itself a rather unique process. The inefficiency of the heat exchange system in an incinerator, that is, the excessive heat losses due to design, such as high radiation and convection losses, the gross amounts of excess air used, and other uniquely devised areas to maximize inefficiency are actually the measure of the efficiency of an incinerator. Because an incinerator is designed to reduce the weight and volume of refuse in a safe and sanitary fashion, the efficiency of an incinerator lies in its ability to dissipate the heat resulting from the combustion process. With no specifically designed heat removal system, the process inefficiencies have to be used in the dissipation of this heat.

If we try and develop some model for estimating the efficiency of an incinerator by using the thermodynamic efficiency of the unit, we must return again to the classical relationship of output and input. Since the output of the incinerator is the heat evolved, often referred to as the external heat losses, this becomes a starting point for predicting the performance of an incinerator. The input to the combustion system is the total quantity of heat made available in the system. In the typical solid refuse even this quantity is very difficult to measure, largely as a result of the nonhomogeneity of the input refuse. The heat input can be measured by the calorific value and each of the individual particles comprising the total refuse population has its own calorific or heat value. Thus, the process becomes one of averaging the calorific value of each refuse fraction. The calorific input to an incinerator can be estimated on an average basis by using a statistically designed number of sample determinations in a calorimeter, and the appropriate size reduction of all refuse to allow using smaller sample sizes. This system is being developed and publication of the methods employed will be forthcoming in the near future.

In addition to the nonhomogeneity of the solid refuse, other external factors can effect the calorific value of the solid waste in the system. Some of these factors are shown in Table I.

Table I is by no means a complete list of the variables affecting the character of refuse, but it does include the more salient factors which cause the largest variation in the calorific value of the refuse. It can easily be disputed that the moisture content does not have an effect on the calorific value, since the calculation of heat value is on a dry weight basis. However, the gross value is affected by the moisture content, and the grate design of most incinerators is based upon this gross value rather than the lower heating value on a moisture and ash free basis. The moisture content is quite important because only a small percentage of the existing municipal incinerators have adequate facilities for drying and preignition. Thus, rather than having recirculation of the hot gases for drying, the refuse moisture must be expelled due to endothermically supplied heat. Under these burning conditions, the net design is a lowering of the calorific value of the refuse.

Other variables listed in Table I, such as the plastic content, the quantity of ashes, the amount of

TABLE I. EXTERNAL FACTORS EFFECTING CALORIFIC VALUE

1. Moisture Content – Meteorological and Climalogical.
2. Non-Combustible Fraction – Special Conditions, refuse trends.
3. Plastic and High Volatile Components – Special Conditions.
4. Industrial Waste Products.
5. Demolition Products.
6. Collection System – separate or combined practice.
7. Coal Ash Quantity – Seasonal, Geographical.
8. Lawn Clippings and Other Greens – Geographical, Seasonal.

lawn clippings, etc. play a big part in affecting the calorific value, both seasonably and geographically. It follows that an area economically situated to a source of coal will have more ashes in the refuse than will a population center adjacent to a ready supply of oil. Most coal ashes, being noncombustible, have a great bearing on the calorific value of the refuse by lowering the net calorific value. Admittedly the percentage of ashes found in municipal refuse is sharply decreasing even in areas where mining is still practiced, such as the bituminous and anthracite coal fields of Pennsylvania, West Virginia and Kentucky. The problem has not totally diminished, and ashes still do require disposal in quite significant quantity in some geographical locations.

If a system can be established to analyze the calorific value of refuse, correcting for the pertinent values listed in Table I, then by revising some of the analytical steps, the performance of the incinerator can be estimated. By the use of a selective sampling system and a modified technique of peroxide calorimetery, the calorific value of municipal refuse can be estimated. If the heat value of the refuse is known on an average basis, then the input to the system, such as listed in the theoretical equation of work, can be used. Measurement of the calorific value of the incinerated residue does not yield a straight line relationship for the estimation of stoker burnout. In order to complete the relationship some correlation between the two densities and the weight reduction must be developed.

Burnout is by far the best estimate of the thermodynamic efficiency of the incinerator. Until several unknowns have been solved, namely a quick and accurate relationship between the density of refuse being charged and the density of residue, the amount of calorific value remaining in residue is not useable. Theoretically speaking, the burnout efficiency of an incinerator can be given by the relationship:

$$\text{Burnout} = \left(\frac{\text{100-Combustible weight of residue/\#}}{\text{Combustible weight of refuse/\#}}\right)\left(\frac{\rho}{\rho'}\right)$$

PHYSICAL

The evaluation of stoker performance by the physical, chemical or biological properties of residue is even farther from solution than on a thermodynamic basis. These properties affect the air and land resources, and thus represent interrelationships with the other natural media. The physical properties could well dictate the ultimate use of any site which has been landfilled with incinerator residue. Some of the properties of the refuse which need to be considered in this analysis are: the particle size, which affects the compaction and degree of compaction; the inplace density; future settlement; and the ultimate use of the site and other construction considerations. Particle size also is related to air pollution insomuch that if traffic is being routed over the placement area, the particles will become entrained, resulting in dusty conditions. Also the fine particle sizes of refuse tend to become cementatious and can easily affect both the surface and the underground drainage of water.

CHEMICAL

The chemical properties of the residue are even more subtle in their effect on the surrounding environment. Primarily the chemical properties would affect the underground waters or the surface waters as a result of the leaching of inorganic and organic material. Surface infiltration most likely will be discharged directly into the underground waters, and the quantity of water soluble material can greatly affect the quality of the underground waters.

Organic reactions which are also present, are determined by the condition of the residue as it is placed in the field. Under most conditions the residue would quickly become anaerobic in nature, and if the geology of the surrounding terrain is such that saturated soil conditions exist, then unknown secondary reactions will probably be the result.

TABLE II. ENVIRONMENTAL PROBLEMS OF RESIDUE LANDFILLS

Objectionable Result	Reason
1. Odor	Decomposition of Putrescible Fraction
2. Fly and Insect Attraction	Warmth, Nutrients and Moisture
3. Rodent Breeding	Food Supply and Shelter
4. Pathogenic Organisms	Food, Moisture
5. Ground Water Pollution	Inorganic Leachate, Organic Decomposition
6. Dust	Dry Surface

Table II lists some of the insidious problems of both raw solid wastes and incinerated residue as they relate to the biological and chemical environment.

The correlation of a relationship between the burnout, or more specifically the complement to burnout, and any of the problems shown in Table II is going to require a significant amount of research into all of the interactions. A quick glance at the objectionable characteristics listed in Table II indicates that while not all of the problems are expected to be present at the same time, there does exist a certain amount of interdependency. For example, if the proper environment exists for the attraction of rodents, and the food supply is sufficient to support rodent growth and propagation, then it would probably be expected that breeding and/or attraction of insects, notably flies, would occur. However, it is possible to have attraction and propagation of flies, but yet not have a sufficient concentration of food available for the attraction and propagation of rodents. Under practically all conditions, microorganisms will be present, although they need not necessarily be pathogenic in nature.

BIOLOGICAL

In order to better establish the relationship between stoker burnout and the objectionable characteristics, it will be necessary to perform detailed laboratory studies as well as field studies on some of the suspected problems. The first area of concern with most public health agencies is the breeding and propagation of flies and mosquitoes. Although considerable research has been performed on the development cycle and the food requirements of flies, very little is known regarding their critical nutrient levels. It is known that flies must have a minimum concentration of nitrogen in order for development to take place, but the exact nature and quantity is unknown. Similar investigations using mosquitoes have placed the minimum nitrogen concentration necessary for growth and development at between ½ and 1% by weight of the food supply. The necessary concentration for flies is assumed to be similar. A significant fraction of this nitrogen must be present in the form of amino acids and protein. The nitrogen present in incinerator residue could well be in excess of ½ percent, but might be in a form which is unuseable to the insects.

In order to establish the concentration of nitrogen necessary for propagation, artificial cultural media and laboratory studies are being carried out. The nitrogen and other nutrient dependencies can be established by varying the concentration of the nutrients present under controlled conditions. The problem becomes extremely complicated when other variables such as the carbohydrate concentration, moisture and temperature are also included as variables. They too have a definite effect on the growth cycle of the fly.

In addition to the effect on the growth cycle by residue, the attraction of flies and other insects is a somewhat related, but yet slightly different consideration. Before propagation can occur, it will be necessary to first attract the insects to the surface in order for them to lay their eggs. Isolation of specific organic constituents that have attractant qualities from the large number of odoriferous compounds that are present will be a difficult task. That attraction will probably depend to some extent on the nutrients which are present, the carbohydrate level, and will be largely dependent upon certain specific chemical compounds which exhibit an attractive quality. These compounds most likely will be odorous in nature, and will greatly manifest themselves in the attraction of the flies.

Preliminary studies have been made on the propagation of flies in the laboratory, using the common fruit fly (Drosophila Melanogaster). In this experiment, the water extract from residue was used to moisten several types of media, including sterilized sawdust, autoclaved incinerator residue, and nutrient agar. It was found that the flies did develop through all stages of their life cycle at a temperature of approximately 25° C under moist conditions on both the residue and the agar. Maintaining the proper moisture content of the sawdust was the biggest drawback to assessing the possibility of development on that media.

It is possible that the attractants of the insects or rodents could also be contributing to odor and other aesthetic problems present at a landfill of incinerated residue. The odors which could be present come from a variety of contributors including products of decomposition, intermediate products of combustion, as well as some objectionable secondary products of combustion. These odor producing compounds are quite important due to their possible interaction with the biological balance of a landfill, and also due to potential ground water contamination. When quantities of residue possessing these objectionable characteristics are placed in a landfill, it must be assumed that a newly filled area will at least temporarily be unuseable without adequate cover. While the discussion on odor and aesthetics encompasses a good deal of latitude from biological balance to ground water contamination, the microorganisms responsible for decomposition and the products of decomposition must also be mentioned. If the residue contains nitrogen and other nutrients necessary for fly growth, then the potential for bacterial activity exists. Bacteria are very adaptive to the many varied conditions that may exist in a landfill. Many of the bacteria have the ability to change their enzyme systems and to grow under extremes of temperature and moisture conditions. Thus, if microbial activity is to be minimized, the sources of nutrients must be removed. This is best accomplished by adequate burnout of the incinerated refuse. The use of microorganisms to classify incinerator residue and degree of stoker burnout could be of significant advantage.

Since most residue will contain a variable fraction of decomposible organic constituents, an endothermic reaction will prevail within the landfill. Depending upon the depth of fill and other geological conditions, the decomposition could be either aerobic or anaerobic in nature. The heat release and rate of reaction is highly variable depending upon the material, stage of decomposition and oxygen tension. A landfill of incinerated residue will also act as a heat absorber because of the black surface, thus accelerating many reactions. During certain months of the year, this ability to act as a black body could very well account for the presence of many microorganisms which would become spores during the greater majority of the year.

As a result of the endothermic reaction occurring within the landfill, it is possible for fly breeding to occur the year round even in temperate climates such as found in New York and Pennsylvania. This is not to say that propagation does occur the entire year, but simply states that the potential does exist for this to occur. One of the determining factors as to whether or not propagation will occur the year round is the amount of biological material present for decomposition, the resultant heat evolved from the decomposition process, and the age of the landfill.

This brief outline of the potential relationships between stoker burnout, biological, chemical, and thermodynamic problems, raises many unanswered questions. It is not known when and where all of the answers will be obtained, but it is hoped that a direct relationship will be coming soon. Until then, the design of all new and the operation of existing incinerators must be accomplished using criteria that at the present time is speculative, empirical and very sketchy.

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