Theoretical Model of Solid-Waste Combustion Process

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The authors of this paper are to be commended for attempting an analytical approach to the prediction of the temperature distribution in and above a bed of burning solid waste. However, the simplifying assumptions used to permit straightforward analytical solutions and the model of the combustion process which was used substantially reduce the applicability of the resulting conclusions. For example, it is suggested in the Conclusions that the model allows prediction of the grate speed and length for a traveling grate incinerator for a specified solid waste. Since the constants for the equations were selected to yield surface regression rates of the same order of magnitude as those obtained by Essenhigh [1] for Type 1 rubbish, it would be expected that the calculated values should approximate those found in practice. No numerical values, however, are given.

It is also stated that the greatest uncertainties in the applicability of the results arise in connection with the proper selection of the Arrhenius parameters. This suggests that the most difficult aspect of calculation concerns the chemical reaction dependent aspects of refuse pyrolysis. Studies by Howard [2] suggest that pyrolysis is, by and large, a heat transfer-limited process in the temperature ranges of interest in an incinerator; and thus the kinetic description is of little importance, i.e., once a given surface temperature has been attained (about 500 °C), pyrolysis takes place at high rates.

Addressing the model itself, it would appear that the authors have assumed a high level of homogeneity within the waste bed and in the overbed flame. This is, indeed, not the case. Also, as suggested by Mayers [3], the thermal conductivity used to describe heat flow within the bed should be expressed as effective thermal conductivity due to radiation within the bed. Calculations by Essenhigh [4] emphasize the importance of this assumption in obtaining better predictions while maintaining linearity in the equations. Another major difficulty with the model occurs in the assumption that the heat generation term (Q) is assumed to occur at the boundary only. This approximation is justified by the authors based on an assumed analogy with solid rocket propellant combustion. In consideration of the vast difference in gas phase mixedness between that extant at the surface of a composite solid propellant where the oxidizer grain size is measured in microns and that for a refuse bed where the "particle size" is of the order to inches or feet, the applicability of the results of the reported analysis to incinerators would be most unlikely. For example, the calculated values of flame zone thickness reported in the paper (of the order of microns) should be compared with the turbulent diffusion flame of pyrolysis products in an incinerator furnace which often towers 10-15 feet above the burning refuse bed.

It is suggested, therefore, that the authors consider a model such as that now under development at M.I.T. [5] which incorporates many of the complex realities of refuse combustion on a grate.

References

[5] Personal Communication, Prof. A. F. Sarofim and J. Rogers, Chemical Engineering Department, Massachusetts Institute of Technology.
DISCUSSION by R. H. Essenhigh, The Pennsylvania State University, University Park, Pa.

I would like to compliment these authors on their bold and sophisticated approach to an extraordinarily complex problem. This is in spite of the fact that it is fairly easy to show that several of their assumptions and conclusions are inapplicable to the solid waste problem, and critics are therefore presented with substantial quantities of ammunition if they choose to be hostile. The authors should perhaps be warned that there are some who seem to believe that combustion of garbage doesn't obey the laws of nature so it is a process that is not therefore amenable to scientific analysis! The real point is that these are early days yet so far as theoretical analysis of solid waste combustion is concerned, and at this point in time a wrong or inadequate theory is better than no theory at all. Argument can therefore focus on the details of the physical model. If this is wrong, then the mathematical model will be wrong, and so will the results and conclusions, and I believe this to be the case for the model presented by these two authors. However, correction of the physical model will correct the results and conclusions. If the authors are prepared to accept argument that the physical model may be wrong then a continuing correction of their model will generate a steady convergence with reality, both for the model and the predicted behavior.

I would therefore suggest that the authors might find the following points worth considering.

The solid rocket approximation of heat generation in a boundary on a thin flame region is almost certainly inapplicable to the solid waste problem. There is sufficient experimental evidence to show that reaction occurs throughout substantial volumes in both Regions I and II. Consequently a $Q$ term should appear in both equations (1) and (2). For Region I there is some history of analysis of a solid fuel bed (some references are to be found in our papers given at this conference) and the visual assumption to obtain solutions — also arguable! — is that of uniform temperatures throughout the bed. [The assumption of pyrolysis at a plane at the top of the bed is also arguable though it is also one that we made ourselves.]

In the Region II, I believe there is also sufficient experimental evidence to show that the pyrolysis products react relatively slowly in air (compared with premixed gases or solid propellant reactants) so the reaction distances are substantial. Cooling, with distortion of the temperature profile is therefore possible, and eq. (8) is therefore inapplicable since the assumption of approximation of temperature gradients no longer holds. The thickness of the flame zone is therefore measurable in meters, not milli meters.

Our own calculations (see Kuo, et al., this Conference) range from 1 to 100 meters for conditions ranging from realistic to not realistic.

So far as the numbered conclusions are concerned, the authors will find some attempt to investigate items (1) and (2), (4) and (5) described in the set of six papers presented by the Penn State Combustion Laboratory at this Conference. This does not mean, of course, that we are necessarily right; but we are certainly interested in hearing constructive comment on our own physical models since if we can all reach agreement on these, our joint interests, and those of the waste burning community, will be well served.

In summary, I don't believe that the authors' results have too much validity at present but I don't think anyone would dispute that their analytical approach is sound in principle, which is what matters for the long run. As models converge with reality so will results and prediction. The basis of all combustion analysis is still knowledge of heat and mass transfer, reaction kinetics, and aerodynamics, etc., and this basis is as applicable to combustion of wastes as it is to rockets, and solid waste combustion is probably the more complex scientifically. It is to be hoped that the authors will continue, refine, and extend this extremely important analysis.