DISCUSSION by J. Agrest, Argentina.

The papers and speeches presented by Dr. Essenhigh and his graduate students aroused in me a feeling of happiness as well as sadness. Happiness, because at last a scientific approach is being brought to a field in which only a few years ago this approach seemed to be an unnecessary luxury. Sadness, because after working a lifetime in the combustion of vegetable industrial remanents at a slow and short-step pace, I cannot help realizing that not only would some of my own pitfalls and trials and errors have been avoided had I had available such basic information as Dr. Essenhigh presented, but I might well have arrived at my present stage of development at a much earlier time.

What we engineers are expected to do in our communities is to produce the least irreversible ways of solving problems, compatible with all the other aspects besides the purely technical ones. Instead, with waste, refuse or garbage - terms which carry pejorative connotations - leading to an "incineration" concept, a way of reducing bulky annoying materials produced by living, into a smaller, easier to handle volume of ash, we go precisely to the most irreversible ways. By doing so, it becomes more difficult to avoid concomitant perturbations of air, water and soil cleanliness.

It is hard for me to understand how this can happen in a rich and powerful country which is supposed to be an example of sound community living for the rather poorer Latin American countries, such as mine.

How could I not be amazed when learning that municipalities in this country are reluctant to finance carefully studied projects and research in this field is being slowed down due to the lack of funds imposed by a national restrictive policy?

Last century's plagues, pestilences and epidemics were overcome only after communities realized the absolute need for soundly engineered sanitary and sewage systems without setting any conditions for profit.

Why, then, should our attitude now be different toward clean air and clear water, when the problem is essentially the same: a threat to health and life? I hope that the deciding persons and boards will enlighten and act accordingly and that my colleagues will work out the least irreversible solutions for a problem to be taken in the most ample and organic context.

Now, some considerations are to be stressed in connection with combustion systems for remanents of mainly organic and vegetable origin.

a) This field deserves the use of basic scientific knowledge and requires research as much or even more than any other sector in the life of mankind due to its vital character.

b) To work on the sink side of a process is as important as to work on the source side of it.

c) To believe in the easiness to extrapolate to these "fuels", the existing coalburning methods and equipment may be awfully misleading. Experience shows that really satisfactory results were never obtained even at a high maintenance expense.

d) Among the influencing properties of such different "fuels" are not to be forgotten the following:

1. The relation of volatiles to fixed carbon in the order of 4:1.

2. The heat value of volatiles content is 2/3 or more.

3. The adiabatic temperature of combustion of moisture ash free residues is very high.

4. The ash is highly fusible and its nature makes it useful as fertilizer components.

5. Ash decomposes leading to sublimation and recondensation at lower temperature zones.

6. Pyrolisis products are tarry and smoky and provide a radiant luminous flame.

7. Fixed carbon left back by pyrolisis is very light and highly reactive.

8. The heterogeneity points to the need to separate and regain non-burnables up to the highest economical degree so as to simplify, instead of complicating, the problems.

e) These and other properties impose limits on some designs, influencing aspects and conditions such as:

1. Whether high temperature and molten slags or controlled temperature and solid ash.

2. Solid ash implies intense heat absorption and transfer to a working agent (steam, water, etc.)

3. Humidity content being variable not to be let perturbing combustion process.

4. Heterogeneity faced by separation and re-
gain of unburnables up to an economical degree, therefore simplifying instead of complicating the problems.

5. Solid carbon left back by pyrolysis to be kept moving in the highest oxygen concentration zones and gasified into combustible gases which are to be incorporated into the flow of volatiles form pyrolyzed particles.

6. The well stirred reactor section should be the one leading to the overstep form, the heterogeneous to the homogeneous phase and the mixing of reactants within it.

7. The plug flow reactor section should lead to final high degree of completion or burn out.

8. Both should take place under the most iso-thermal conditions at a temperature slightly below that of ash softening point.

9. Excess air duly preheated, should be kept to a minimum and introduced only into the plug flow reactor section reducing the handling and depuration of flue gases.

10. Gas depuration should be started at the hot zones by due aerodynamical means, to keep pace with final depuration and emission regulations.

If one observes Dr. Essenhigh’s papers carefully one can find that conditions for both important steps are being investigated and reported by them, and the State College group should be encouraged and helped to keep working along these lines.

The writer’s own experience, with one of the many possible solutions, is clearly on the correct track.

Up to now some 25 installations in Argentina and one in Italy, for quite different industrial remanents like sunflower seed husks, cotton seed husks, olive kerns, grape skins and exhausted pips, linseed stalks, wood, sawdust, bagasse, spent quebracho, cork residues etc., can show non-conventional ways of doing things with smaller irreversibilities than just incineration.

A liability can become an asset if a community-oriented effort is devoted to it, and the last project under erection now shows a case where 10 ton/hour of sunflower seed husk will produce 47 ton/hour of steam at 900 psi 900 F to supply power and process steam to 1000 ton/day seed processing plant, without any commercial fuel addition.

I wish to conclude these comments by restating my hope to find in my future visits to this country a more reversible approach to this overwhelming problem, as can be observed in other money producing fields.

References


I. DEVELOPMENT OF PHYSICAL AND MATHEMATICAL MODELS OF INCINERATORS, PART I: STATEMENT OF THE PROBLEM

R. H. Essenhigh and T. J. Kuo

DISCUSSION by R. C. Bailie, West Virginia University, Morgantown, W. Va.

Dr. Essenhigh and his associates in this series of papers present an approach for investigation and study of incinerator operations that has received little attention in the past. The incinerator is an extremely complex chemical reaction system and mathematical modeling offers attractive possibilities for the evaluation of their performance.

There can be little argument that the reactions taking place in the incinerator obey certain physical relations and constraints placed upon the system by basic laws of nature. If one knew all of the laws and were able to apply them to each small element in the incinerator and state the proper interaction between these elements, then a complete analysis of an incinerator under any operating conditions could be made. To be realistic, we do not understand all of the laws of nature that are required and cannot state the interrelationships between each element of volume. The authors of these papers have attempted to make meaningful assumptions in order to attain a solution.

Although the purpose stated in the paper was to obtain information for prediction and design of an incinerator, there are several subordinate types of useful information that might be obtained, even if this goal is not achieved. Even crude analysis might point out the sensitivity of operations to certain physical changes and operating variables and a model analysis would direct attention to the conditions that are meaningful. Along the same line it would guide the planning of an experimental investigation.

Dr. Essenhigh and his group have brought together a large number of experimental facts, observed pheno-

NOTE: See Errata, page 104.
materia and knowledge from various fields of research into a mathematical model for waste incineration. The model obtained is not in conflict with the three 'T's' of incinerator design but attempts to quantify these values. Based upon fundamental principles, problems and questions such as

1. What do we mean by turbulence?

2. Where is turbulence most important and why?

3. Is the same temperature required everywhere? are attempted. Whereas there is great potential in this general approach, in any design there are many dangers in using the information without fully evaluating the assumptions.

In the first paper Dr. Essenhigh gives an overview of his methodology and model development. The bed is broken up into two zones: a solid zone where solid is gasified into CO and CO₂, and a gas zone where complete combustion takes place. The gas zone is further divided into two sub-zones. In one, gas from Zone 1 is completely mixed with secondary air and in a second section no mixing occurs.

The lower section is associated with heterogeneous reactions and is a difficult problem to solve even for uniform size and combustion fuel. The upper section considers which homogeneous gas phase reactions and theoretical analytical solutions are possible. The combustion of a mixing section followed by a plug-flow section for complete reaction has received considerable attention in the study of chemical reactions.

Simultaneous solutions to heat generation rate (with consideration of temperature on reaction rate) and heat loss rates are used for prediction, ignition, and extinction of reactions. A similar procedure is in common use in analyzing and designing chemical reacting systems.

It is my feeling that the numerous references to literature unfortunately tended often to obscure the visualization of the physical model being developed. As an example, the literature review proceeding the discussion of Fig. 1 in the paper did little to help in understanding the concept presented.

There is some doubt in my mind as to the validity of some of the assumptions made in the analysis as well as hesitancy to accept, in principle, that the complex phenomena occurring in an incinerator can be reduced to a simple manageable mathematical relationship or series of relationships. There is no doubt however, that the methodology is needed and will result in a significant improvement in future incinerator design.

DISCUSSION by K. A. Bueters, Combustion Engineering, Inc., Windsor, Conn.

The six "Penn. State" papers which were presented actually comprise an interlocking set. Regrettably, the scant time available for study and the subsequent preparation of comment limits me to the paper by Dr. Essenhigh and Dr. Kuo. Having read the paper carefully, an immediate general comment is that, as expected, it merits careful reading. The authors are to be congratulated on a comprehensible paper which makes a specific and important analytical contribution.

This paper, which appears to be the foundation of the "Penn. State Set" is, in turn, a successful extension of a fundamental paper presented by Dr. Essenhigh at the 1968 Incinerator Conference. The word "fundamental" in this case is to be taken in the sense of describing an original or generating source.

I am in full agreement with the authors on the value of the computer as an "experimental facility" as stated in the introduction. This is precisely one of the computer uses for which, in our opinion, there is no effective substitute. In terms of "computer experiments" when these are employed to establish (speaking from personal experience) furnace design standards, we have found it imperative to verify and/or "anchor" these by selective test measurements on operating industrial installations or by some specific laboratory experiment sequence, whichever is appropriate to the problem at hand. Taken in this context, I would be inclined to revise the authors' phrase "it is always wise" (p. 262) to "it is necessary". Actually this is clearly implied by the authors in the very next two paragraphs (p. 262) which lucidly present the engineering scientist's desired modus operandi.

Eq. (1), given as Eq. (10) in the original 1968 paper ("Burning Rates in Incinerators" - parts I & II - R. H. Essenhigh), is, in my opinion, an elegant consequence of a perceptive thermodynamic analysis by Dr. Essenhigh. The authors clearly recognized that the generality of Eq. (1) was unnecessarily circumscribed by the available data. That is to say, restricted by past experience as indicated by them on p. 263; where "past experience" is represented by \( \bar{T} \) in Eq. (1). The break-through presented in this paper is the derivation of \( \bar{T} \) on the basis of zoned heat release, Eq. (6), the THRING RCS factor, Eq. (9), and a gas analysis ratio \( r \), Eq. (10). Approximation (7) seems to me to be immediately design useful provided, of course, it is applied within the restrictions indicated by the authors. In conjunction
to relation (7), the well-reasoned definition of an effective fraction $\theta$ resulting in Eqs. (3) & (4) and then quantitatively evaluated through Eq. (11) is particularly ingenious.

In the section “Comparison of Zone Calculations” (p. 265, as well as the “conclusion” p. 270), the authors are quite correct in indicating that the dependent variable $F_A$ in Eq. (8) can assume status as independent variable in Eq. (1). This implies, of course, the construction of a “computer experiment” (in line with the authors’ previous comments) where we program Eq. (1) (using the “1968 form”) as:

$$\frac{(1/B)^{2/3}(ab)^{-1/3}F^{1/3}}{F_A} = 1 \pm \epsilon$$

Where a computer (e.g. a G.E. Time-Sharing Mark II) operates on numerator and denominator, independently, within their domain of definition and prints out the values of compatibility (within some $\epsilon$ of, say, 10^{-4}). This type of computer “experiment” which is clearly aimed in the direction of constructing a design standard is, I am sure, included in the authors’ suggestions in regard to imaginative computer applications.

The authors divide the overbed combustion chamber into two zones which, I am sure they will agree, we can represent as follows:

From this P.S.R. model assumption the authors obtain Eq. (16). This equation appears to have a typographical transposition error. I believe that the authors meant to define:

$$\bar{I}_{HB} = \frac{1}{t} \int_0^t R_0^0 B_o e^{-\tau} d\tau$$

where the units are

$R_0^0$ in lb/ft^3 $-$ hr, $B_o$ in Btu/lb, $\tau$ in (sec)^{-1}

and where $\tau$ can be defined as

$$L_{HB}/\bar{V} \frac{ft}{ft/sec}$$

The above therefore becomes

$$I_{HB} = R_0^0 B_o \left[ 1 - e^{-(L_{HB} \tau)/\bar{V}} \right] \bar{V}/(L_{HB} \tau) \text{ Btu/ft}^3 \text{ $-$ hr}$$

where

$$\bar{I}_{HA} = \frac{I_{HA}}{\bar{V}}, \text{ large, Eq. (17) as}$$

$$I_{HB} = \frac{\bar{I}_{HA} \bar{V}/(L_{HB} \tau)}{\bar{I}_{HA} + \bar{I}_{HB}} \text{ Btu/ft}^3 \text{ $-$ hr}$$

The authors are probably already aware of the inadvertent slip and the above comment is, therefore, probably redundant. In terms of relation (7) we can therefore define $I_H$ as

$$I_H = \frac{\bar{I}_{HA} L_{HA} + \bar{I}_{HB} L_{HB}}{L_{HA} + L_{HB}}$$

The problem here, of course, is the quantitative evaluation of $L_{HA}$ and $L_{HB}$. In looking over the remainder of the “Penn. State Set” I come to the conclusion that Professor Essenhigh and his colleagues have already addressed themselves to this problem and, I have no doubt, will solve it at least to engineering satisfaction.

In closing I should like to venture the opinion that Prof. Essenhigh and his colleagues are well on the way to reducing incinerator behavior to a sound scientific and engineering basis. The body of analysis generated by the investigators at Penn. State is assuming a structure that deserves to be re-worked into a monograph. I expect that a monograph on the subject by Dr. Essenhigh would rapidly become a definitive classic and in light of the current preoccupation with air pollution would appear to be sorely needed.

DISCUSSION by William T. Reid, Battelle Memorial Institute, Columbus, Ohio.

Mathematical models of combustion systems of necessity must be involved and complex. Nearly two-thirds of a century ago the earliest studies of combustion in fixed beds of fuel led to quite simple relationships between the reactivity of the fuel, the
size of the fuel particles, and the rate and direction of air flow. Later, when considering combustion of fuel particles suspended in air, the concepts of time, temperature, and turbulence were added and the relationships became more intricate. Now, thanks to modern analytical methods of modelling, even the most complex combustion systems can be evaluated with respect to the many variables that influence combustion rate. The paper here is a good example of the case where the most sophisticated mathematical approach is taken in an attempt to solve a practical problem.

The authors point out quite properly (although this fact may be missed by the fuels technologist who seeks here a panacea for all his combustion problems) that a lack of information generally hinders the writing of computer programs for usual combustors as they have been written so successfully for rocket and jet-engine systems. High-intensity combustion systems invariably are based on fuel of known and constant characteristics, and the combustor itself is amenable to careful and controlled design. Such is not the case for incinicators, where the "fuel" varies from tin cans to moldy grapefruit with most of the Btu coming from cellulose in hundreds of different forms, and where cost considerations influence incinerator size and shape.

The problem with mathematical modelling of the kind done here is almost entirely in defining the conditions in the combustion system. Anyone who has looked into a large municipal incinerator of the kind common in Europe cannot help but be impressed with the great heterogeneity of the combustion process—lanes of cold refuse interspersed with small areas having exceedingly high combustion rates, and with random high-velocity jets of air through the grates lifting lighter paper fragments to burn in suspension. The view is no less than shocking to a fuels technologist for whom a conventional coal-fired chain grate or underfeed stoker poses problems enough in non-uniformity.

The series of papers here, of which this first one is mainly the introduction and description of the problem, must of necessity stress the mathematical statement of the model. Probably it does this quite well. Some of the papers in the series describe experimental work, but under such idealized conditions that translation to field operation will be most difficult. For example, it is a far cry from burning cylinders of cellulose or computer-card punchings to the practical case of cardboard and newspapers and bread wrappings and corrugated shipping cartons, all intermingled with noncombustible material in hundreds of different forms.

The problem, then, is how to relate these preliminary "theoretical" analyses to the real-life situation. Although the test incinerator at Penn State is a step in the right direction, it scarcely meets the requirements posed by full-size units. Complete demonstration of the utility of the models developed here will come only when the design characteristics suggested by the models are proved in the field, with large incinerators handling the polyglot mixture of sizes and substances collected from a typical community. Certainly the next step is for these capable researchers and the designers of municipal incinicators to find some common ground whereby the results of these basic studies can be converted into useful design information. That day will come only when research people and design engineers develop lines of communication and understanding. Despite the valiant efforts of Dr. Essenhigh and his associate, that day is apparently not here as yet.


The authors should be congratulated for this paper. I do believe, however, that the analysis presented requires considerable refinement before it will provide real insight into incinerator behavior. The conclusions, therefore, should be viewed cautiously before attempting their use in incinerator design.

It would appear, following a somewhat difficult digestion of the analytical development, that the authors have based their analysis on a model by which refuse undergoes a low-energy pyrolysis process yielding a "volatile matter fraction" and moisture which pass overhead unburned, and leaves a residue on the grate consisting of ash and fixed carbon. The latter portion of the residue (fixed carbon) is the only material which is permitted to burn with the undergrate air in the bed and, indeed, it is this char-burning reaction which characterizes the entire bed burning model. For example, the relationships shown in equations 8 and 9 and that in 13 apply only to a carbon or coke bed. In view of the importance of the pyrolysis process within the bed, which undoubtedly competes very effectively for the available oxygen and affects rather substantially the oxygen, carbon monoxide and carbon dioxide concentrations expressed in the relative carbon saturation factor, it is unlikely that these equations will have much relevance in describing
incinerator combustion ahead of the burnout region of the grate. At that point, however, many new and probably unknown initializing and boundary conditions will be required.

The analysis of the ignition/extinction process is a good review of the existing theory but would not seem to be particularly useful in this paper.

Lastly, the suggestion of the authors that smoke burnup kinetics (referring to the volatile matter) is important in providing pollution-free effluent seems in conflict with much data (1) which suggests that at incinerator temperatures turbulent diffusion processes will control the combustion rate rather than chemical kinetics.

References


As an aside, I would encourage the reading of many of the literature references quoted in this paper as useful and, in fact, needed background information for the review of this and the subsequent papers of this series.

2. BURNING RATES AND OPERATIONAL LIMITS IN A SOLID-FUEL BED

M. Kuwata, T. J. Kuo, and R. H. Essenhigh


The authors are to be commended for their paper. Although a number of simplifying assumptions are made, fair agreement of the calculated values with the data of Mayers are obtained. The authors would appear, however, to have generated approximate solutions which plot to the right shape and to have used scaling constants from Mayers' data to cause the fit to take place. The glossed-over reasoning and unrevealed plots mentioned on page 278, perhaps weaken the arguments too much. Their reasoning and the methods used to generate the calculated values in Figure 1 should be elucidated.

It is most important that it be made clear that this paper refers to the burning of a char (carbon plus ash) bed and that the entire model and the empirical expressions developed were derived from data on burning in coke beds. Although the authors make this qualification within this paper, references to conclusions drawn from this evaluation of non-pyrolyzing solid fuel beds are made in subsequent papers of the series as applicable to burning refuse beds.

DISCUSSION by R. C. Bailie, West Virginia University, Morgantown, W. Va.

As discussed in the comments on the previous article one must carefully consider the assumptions that go into the development of any model to assure that they are applicable to the physical system under investigation. Some of the assumptions made are listed below.

1. The bed is made up of char and inerts. Apparently it is assumed that cellulosic material

\[ C_\circ H_{10}O_5 \]

breaks up in the manner

\[ C_6H_{10}O_5 \rightarrow 6C + 5H_2O \]

and the break-up into hydrocarbon pyrolysis gas does not occur.

2. The bed is packed randomly in a manner similar to that of uniform size and shape particles (spheres for example). No account was made for large voids or blow holes that would be found in unsized-untreated refuse feed. Uniform flow over bed cross section is assumed.

3. No change in bed temperature occurs in the bed. Change in temperature affects gas velocity through bed, reaction kinetics, gas concentration heat loss, etc.

4. There is no allowance for other reactions such as carbon-steam. Only reactions allowed for are

\[ C + CO_2 \rightarrow CO \text{ (solid-gas)} \]

\[ C + O_2 \rightarrow CO_2 \text{ (solid-gas)} \]

\[ CO + H_2O \rightarrow CO_2 \text{ (gas-gas)} \]

5. Diffusion is the only resistance to mass transfer. Any resistance caused by build-up of ash is not considered important. No consideration is given to change in particle size with burn-up. If there is no ash layer then particle must shrink with consumption.

In the first part of the paper material balance and stoichiometric equations are used along with the stated assumptions to derive an equation for the relative saturation factor RCS that had been empirically developed from experimental results. The independent derivation presented in this paper based upon a physical model contributes to the usefulness of the equation for RCS. The model developed for
RCS has been tested against results obtained for solid combustion of char and shown to follow the experimental values. Using these data values, the parameters in the model were predicted.

The second part of this paper dealt with the maintenance of ignition and is based upon energy balance and reaction rate relations. The effect of chemical reaction kinetics and partial reactivity is described. Based upon the model developed, the conditions for ignition and extinction are discussed in terms of energy loss to walls, energy leaving with hot gas, temperature and air flow-rates. The authors point out that experimental data is sparse and apparently limited to char beds.

The methodology of approach used in the analysis is sound and the information that could result important for the purpose and understanding of refuse incineration. However, no evidence has been presented to establish the model as being applicable to unsized solid waste. The authors state “Test against refuse-char beds has yet to be carried out since this was self-evidently redundant until existing data had been analyzed” (this data being for coke beds). A necessary condition for such a statement would be assurance that the assumptions made in development of the model of burning of coke are equally applicable to waste incineration. The authors assume they are applicable but they do not present experimental verification.

The approach does give direction in developing an experimental program, and this is one of the valuable objectives of modeling. It has presented mathematical relationships for testing in an experimental program. If experimental results do not verify the model, one begins to investigate the assumptions. This paper does furnish a starting point for development of useful design relationships based on fundamental principles.

4. STUDIES ON COMBUSTION BEHAVIOR AND EXTINCTION LIMITS OF SMOKE FLAMES

B. K. Biswas, T. Kuo, and R. H. Essenhigh

DISCUSSION by R. C. Bailie, West Virginia University, Morgantown, W. Va.

The authors present an analysis of the gas phase reaction that is based upon solution of an energy balance relating the energy released by reaction to the energy carried away from the reaction zone through the vessel walls and by the hot combustion gases. The rate of reaction is dependent upon the concentration of the reactant and the temperature of the reactor according to the Arrhenius expression. The reaction zone is assumed to be completely mixed.

Using their analysis the extinction temperature was quite low and the amount of excess air necessary for extinction quite large.

However, the data available cannot be used to substantiate the calculations and assumptions. Reviewing Figure 2, the data all fall in a region of complete conversion. It is not possible from this figure to evaluate the activation energy, the effect of residence
time, the effect of mixing patterns or the pseudo-first order assumption and the effect of flame concentration. Almost any mixing pattern with a wide range of activation energies, reaction orders, and residence times would give a similar relation.

In order to verify the assumptions made in the development of the equations presented, experimental data is needed where complete burnout is not achieved. The presentation is extremely valuable in directing experimental efforts toward areas that would most likely prove fruitful. Providing that experimental results establish the model validity, a basic relationship is provided that is necessary to establish optimum design.

5. CHARACTERIZATION OF STIRRING FACTORS BY COLD-MODEL SIMULATION

S. T. R. Rao, T. J. Kuo, and R. H. Essenhigh


The authors are to be commended for this fine presentation and the obvious care with which the experimental program was conducted and the results reported. The design principles revealed in the course of these experiments should have application to on-site and municipal scale incinerators, and, although additional work is necessary, the application of these concepts should be given careful consideration by system designers.

DISCUSSION by R. C. Bailie, West Virginia University, Morgantown, W. Va.

This paper describes and develops mathematical relations for investigation of mixing patterns in a homogeneous system and presents some experimental results. By adjusting air jets the experimental unit was shown to exhibit the characteristics of a plug-flow region (where no mixing occurs) and a backmix region (where complete mixing occurs) in series. The authors are careful to point out that a simple tracer experiment cannot differentiate between the location of the plug flow section in relation to the backmix section. (The plug flow section may be split and a fraction appearing before and the remainder following the mixed section.) Although it does not affect the tracer concentration it has an important effect on the amount of reaction that would occur.

The purpose of these series was to allow for sizing and design of an incinerator from "first principles". A question remains as to how this information can be used for predicting the size and design of an incinerator. Reference is made to 'appropriate scaling methods' to give quantitative results. Are such appropriate methods available that can predict the mixing patterns that are necessary to assure that Bragg's criterion can be satisfied? The problem of scale-up of chemical reacting systems is often unreliable and one of the major reasons is the inability to scale up mixing phenomena.

If no meaningful scale up procedures can be established, design remains with present day techniques to assure "time and turbulence" without being able to quantify these quantities.

6. DEVELOPMENT OF PHYSICAL AND MATHEMATICAL MODELS OF INCINERATORS, PART II: INITIAL TESTING OF A REAL SYSTEM

T. J. Kuo, M. Kuwata, W. Shieh, and R. H. Essenhigh

DISCUSSION by R. C. Bailie, West Virginia University, Morgantown, W. Va.

This paper is a very brief presentation limited to a discussion of the height of gas space required for burnout. A computer program was used to calculate the fraction of unburned gas converted in a combination of a completely mixed section followed by a plug flow section. There appears to be an inconsistency between the data used for the computer program in this section, and the data used in the evaluation of the kinetics of the gas phase reaction covered in an earlier paper. In the prior paper the activation was $E = 25 \pm 5 \text{kcal/mol}$ and a frequency of $k_0 = 4 \times 10^8 \text{sec}^{-1}$. However, in the computer calculation in this section the value of activation energy, $E = 30 \text{kcal/mol}$ and a frequency factor $k_0 = 10^8 \text{sec}^{-1}$ were used.

This is the final paper in a series of papers in which the authors have developed a methodology of approach to understanding of refuse incineration that
should prove extremely valuable. The comments to follow apply not only to this final article but to the series of articles just presented.

The relationships presented in this series of papers must be considered a first and important step in attempting to relate the refuse incinerator operation to first principles. A great deal of effort must follow before one would consider using these results in either the design or comparison of incinerator systems. Experimental effort must be provided to verify and establish assumptions that were made in the development of these equations. The relationships developed must be thoroughly tested against the experimental results. The assumptions made in the development of the models must be thoroughly reviewed and the range of validity established. However, by stating the assumptions made in developing the model and by establishing the functional relationships based upon the model, direction is given to any experimental effort. An experimental program can now be developed that has such objectives as the following: to establish the validity of the mathematical relationships, to verify an assumption, to establish the sensitivity of a particular independent variable on the operation of the system, etc.

Designing a refuse incinerator based upon first principles can not be achievable at this time. I feel that the authors may be guilty of expressing more confidence in the application of the present information to the design of an incinerator than is justifiable based on the available experimental verification. However, they took this first step toward establishing relationships between observed phenomena and first principles. This is necessary in developing new design procedures, selecting optimal operating conditions, and establishing optimal control policy from the point of view of burnout, air pollution, etc.

A great deal of criticism to this approach may result from the practitioners of the 'art of refuse incineration' who feel that the discussion here has been strictly academic. It is unfortunate and, in many ways, is the fault of the scientific and academic community that they often fail to communicate what they are trying to do to the practitioner. I feel, unfortunately, that the authors have not done a good job of presenting in a way that can be accepted by the practitioner what they are trying to accomplish by their mathematical modeling. I found the presentation difficult to follow at times. Numerous references in this series of articles to reports by Professor Essenhigh which are not published in recognized journals make it impossible or very difficult to determine the basis for many of the statements made in the paper.

However, the value of the methodology of approach presented in consideration of future refuse incineration must not be overlooked. The practitioners of the art often refer to the 3 T's of incineration — time, temperature, and turbulence. There is no disagreement on the importance of these three factors in the design of any incinerator. The development of the mathematical model is an attempt to quantify these three factors so that various schemes can be studied and compared on a more quantitative basis before costly construction and possible failure of a unit. However, by developing a mathematical relationship to describe these terms one has made the first step in developing a sound basis for future incinerator design and development. The academic and scientific community must build upon this information and learn to relate this information to practitioners of the art in a manner that will be valuable to them. We need to establish a dialogue between the academic and scientific community and the practitioners of the incinerator art in order to come up with a realistic solution to better incinerator design. Maybe this series will serve as a starting point.