Research on

COMBUSTION

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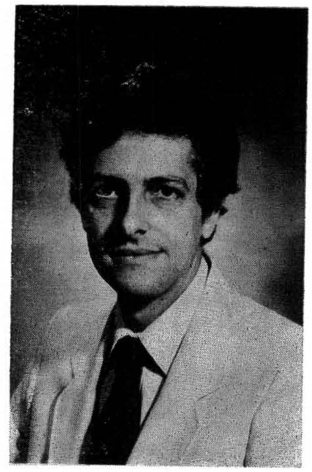

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IT IS WIDELY recognized that there is a need for better understanding of the chemical and physical phenomena involved in the combustion and gasification of fuels such as coal and oil. Such understanding could lead to the development of more efficient methods of preparation and conversion. That would reduce the levels of pollution and operating costs.

Various aspects related to combustion are presently being investigated at Michigan Technological University, MTU. Work on characterizing and modifying diesel emission is being performed in the Mechanical Engineering Department [1, 2]. Semiquantitative dose-response data on the biological activity of exhaust particulate emission [3] is being obtained at the Biology Department using the Ames Test [4] as modified by Belser et al [5]. Bacterial mutagenicity tests are widely used today because of the correlation between mutagenicity in bacteria and carcinogenicity in humans [6]. In the Chemistry and Chemical Engineering Department research focuses to a large extent on coal pyrolysis, combustion and corrosion. Experiments on the effect of flame retardants on the smoking tendency of high and low temperature polymers is underway. In the following paragraphs only the work related to coal will be discussed.

COAL RELATED RESEARCH

Since the renewed interest in coal, numerous studies were performed as may be judged from the proliferation of publications and the rise in the number of symposia and technical meetings on the subject [7]. Since the work is being performed in various laboratories it is not surprising that there is much overlapping of effort. For this reason papers that describe the state of the art [8, 9] are needed to make us aware of other people's activities and to identify areas in need of further investigation.

The main thrust of the work which is the subject of this paper was aimed at improving coal combustion and reducing operating expenses by using additives (catalysts). The introduction of additives was intended to tackle certain problems in industrial boilers such as 1) to improve combustion by reducing the unburned carbon in the ash and carbon monoxide in fuel gas atmosphere, 2) reduce excess air and lower exit temperature to minimize the heat loss up the stack, 3) reduce particulate emissions into the atmosphere, and 4) control corrosion of tubes and other parts of a boiler. Single or mixed additives that produce some or all of the above effects exist [10-13]. They vary in composition, effectiveness and cost. Most of the additives studied fall into one of three groups: alkali metal salts (Li, Na, K), alkaline earth metal salts (Ca, Mg), and transition metal salts (Fe and Ni). The first group was extensively studied because of its influence on coal gasification and also for the purpose of understanding the corrosion mechanism. It is generally believed that alkali iron trisulphate complexes [$M_3Fe(SO_4)_3$ where M = Na, K] are the principal contributors to high temperature coal-ash corrosion [14]. The alkali and sulfur constitute part of the impurities in the fuel. The production of the alkali metal complex requires the presence of sulphur trioxide. The rate of formation of SO_3 is related to the amount of SO_2 available.

Our studies on coal combustion parameters [12, 13] were performed in a tubular combustor (Fig. 1) and using thermal analytical techniques. The combustor construction was similar to that used by Horton et al. [15]; however the burner section was slightly modified for stability. Pulverized coal was fed to the top of the burner section using a screwfeeder into a downflow flat premixed flame of methane and air. The system shown in Fig. 1 had a number of windows which made it possible to probe the test furnace along its length for chemical species and solid material as well as to place metal specimens for studies on corrosion. Electron microscopy, X-ray analysis and Auger spectrometry were used to characterize the deposits on the metal specimens. This made it possible to probe the metal specimens to various depths.

In addition to the above combustor, a DuPont 950 thermogravimetric analyser (TGA) was used to obtain kinetic data related to coal decomposition. These instruments possess a high degree of precision and speed in producing data. It is also possible to observe continuously the change of mass (TG) and rate of mass change (DTG) with time or temperature. This makes it possible to observe details that are liable to be missed using a flow combustor. For example, mixed additives are found to be more effective than single additives on an atom per atom basis. It is difficult to determine, for instance, in a steady-state flow system such as that used in our experiment, the time during the decomposition stage at which the synergetic effect of the mixed additive occurs. However this is a simple task in TGA work, since the decomposition profile is completely available. There is evidence that the promoting effect occurs mainly during the initial stage of coal conversion. In this region single additives inhibit decomposition of coal [13]. The TGA was found to be useful in identifying the experiments to be studied in the flow combustor and in performing corrosion-related studies under very controlled conditions.

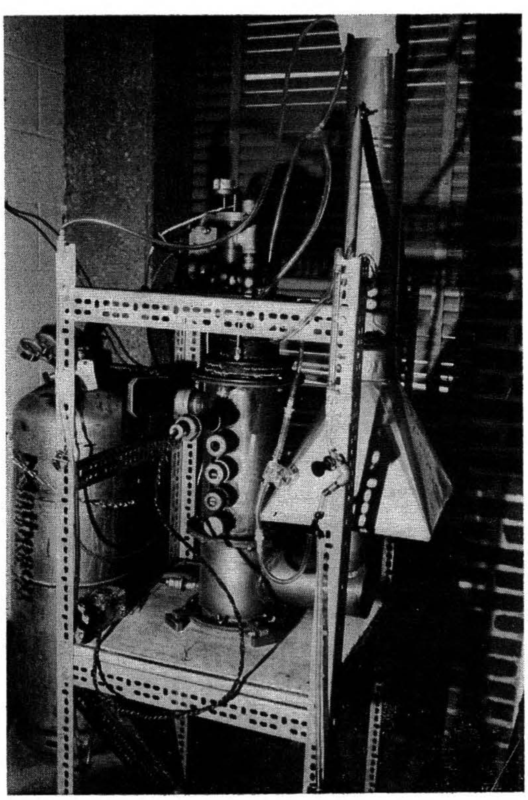

FIGURE 1. Coal combustor.

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Thermogravimetric analysis has been extensively used judging from the number of books and specialized journals. Nevertheless, several aspects need to be investigated to understand what is being measured

- **The meaning of activation energies of solids such as coal obtained from TGA experiments is not clear.**
- **The values of the activation parameters are dependent on the operating conditions [16] such as heating rate and gas flow rate.**
- **To calculate E first order kinetics for coal decomposition is usually assumed using one thermogram obtained at one heating rate. However, it was proposed (on the basis of theoretical considerations) that methods involving more than one heating rate will give more precise values of E [17].**

A detailed investigation of several methods, using the same coal, showed that methods using one heating rate are preferred. Methods which use multiple heating rates will give values of E which are dependent on the heating rate combination [18]. The latter method is also time consuming. In an attempt to explain the meaning of the activation energy obtained from TGA work the enthalpy of reaction, ΔH_R was measured using a Differential Thermal Analyser; DTA [13]. A linear relationship was found between E and $|\Delta H_R|$. This suggested the influence of the heat of reaction on the chemical change typical of elementary reactions [19] and would, therefore, reinforce the previous postulate that coal decomposition follows first order kinetics [20]. The change in operating parameters such as heating rate will favor different reactions, thus producing different values of ΔH_R and E. Therefore, comparison of the effectiveness of different additives should be performed under identical operating conditions.

CONCLUSION

Much work is needed before one is able to completely understand the role played by additives in the combustion of coal used in industrial and utility boilers. The chemical state of the additive in promoting combustion of $CO \rightarrow CO_2$ is still speculative [8]. Also, the behavior of the coal during combustion will vary according to the physical state of the coal, i.e. molten or dry. It will also depend on the aerodynamic properties such as density and shape and the adhesive quality known as the wettability of coal [21]. We also have to distinguished between combustion of small, and combustion (and gasification) of large, coal particles. □

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ChE book reviews

CHEMICAL REACTOR ANALYSIS AND DESIGN

By G. F. Froment and K. B. Bischoff
John Wiley and Sons, New York

Reviewed by
Arvind Varma
University of Notre Dame

This book is a welcome addition to the growing number of books now available in the area of reaction engineering. It is comprehensive, and contains more topics than are covered in most books. The book has two particularly strong points. One is the wealth of *real* examples, and the second is a

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