Rates of Combustion of Solid Fuel Particles

DURING the combustion of liquid fuel drops, the chemical oxidation occurs in the vapour phase. The rate-controlling process is thus the transfer of the heat necessary for the evaporation of the drop[1].

In the case of solid fuel particles, the primary combustion occurs at the surface of the particles. If the surface temperature is high enough (experimental evidence published by Tu, Davis and Hottel[2] suggests a threshold temperature of about 850° C.), the rate of the gas–solid reaction is so high that the chemical resistance is negligible, and thus the rate-determining process is the rate at which oxygen is transferred through the gas film surrounding the particle.

Methods of calculating this mass transfer-rate have been proposed by several authors, making use of the analogies between fluid friction, heat transfer and mass transfer[2,3]. It should be emphasized here that in calculating the fluid friction it is only the skin friction component of the total drag that is of significance. Furthermore, in cases in which a laminar boundary layer exercises a controlling influence, the simple turbulent flow forms of the analogies need modification by a function of the Prandtl number in the case of heat transfer[4] and of the Schmidt number in the case of mass transfer[5]. In cases where the Prandtl and Schmidt numbers approach unity, as can occur in gas-phase systems, these modifications may, in fact, be numerically small.

Some notes have been written recently by Edmondson[6], making particular reference to the equations based on Reynolds's analogy proposed by Silver[3] for the combustion-rates of solid particles, and presenting an analysis in these terms of published experimental results. Some reference was made in Edmondson's notes to the influence of laminar conditions, but the equations as applied were those based on the original form of Reynolds's analogy appropriate to the turbulent flow range.

However, rather than making use of the analogies between fluid friction, heat transfer and mass transfer, there is a more direct method of undertaking the calculation for the case of individual particles. There are already available several theoretical and experimental results on the transfer of mass to and from spherical surfaces. In particular, Frössling[7] has presented a semi-empirical equation expressing the mass transfer as a function of the Reynolds number and the Schmidt number. The range of Reynolds numbers examined experimentally was from 2 to 800.

It is suggested in the present communication that Frössling's equation be used, with appropriate values of the physical constants, for calculating the transfer of oxygen to burning spherical solid surfaces and hence the burning-rates.

For example, for carbon spheres in air, assuming that the main primary product of the heterogeneous reaction is carbon monoxide[8,9], it can be shown that the reaction-rate at a representative mean gas-film temperature of 1,200° C. may be expressed by the non-dimensional equation :

$$F = 0.347 \ (1 + 0.272 \ Re^{1/2}).$$

In this equation, Re is the Reynolds number, and F, a non-dimensional reaction-rate factor, is equal to $Sd/\rho D$, where S is the specific reaction-rate at the surface of the sphere (gm. sec.$^{-1}$ cm.$^{-2}$), d is the diameter of the sphere (cm.), ρ is the density of the gas (gm. cm.$^{-3}$), and D is the coefficient of diffusion of oxygen in the gas (cm.^{2} sec.$^{-1}$).

It may be noted that the value of the numerical factor 0.347 in the above expression for F is directly proportional to the partial pressure of oxygen in the free gas stream. Over the range of at least 800°–1,400° C. at any given Reynolds number, the influence of the gas-film temperature on the numerical form of the above non-dimensional equation for F is slight.

Comparison of theoretical values of the rates of burning calculated in this manner with published experimental measurements on the rates of burning of carbon spheres[2,10] shows evident agreement. This being so, the theoretical equation may be used to calculate in particular the effects of Reynolds number and partial pressure of oxygen on the rates of combustion.

Acknowledgment is made to the Chief Scientist, Ministry of Supply, for permission to publish this communication.

G. A. E. GODSAVE

National Gas Turbine Establishment,
Ministry of Supply.
June 20.

[1] Godsave, G. A. E., Nature, 164, 708 (1949).
[2] Tu, C. M., Davis, H., and Hottel, H. C., Indust. Eng. Chem., 26, 749 (1934).
[3] Silver, R. S., Nature, 165, 725 (1950).
[4] von Kármán, Th., Trans. Amer. Soc. M.E., 61, 705 (1939).
[5] Sherwood, T. K., Indust. Eng. Chem., 42, 2077 (1950).
[6] Edmondson, P. D., Ministry of Fuel and Power. Chief Scientist's Division. Paper Reference Sc. 19/1, Sc. 343/2 (Oct. 1950).
[7] Frössling, N., Gerlands Beiträge zur Geophysik, 52, 170 (1938).
[8] Arthur, J. R., and Bowring, Miss J. R., J. Chem. Soc., S. 1 (1949).
[9] Arthur, J. R., Trans. Farad. Soc., 47, 164 (1951).
[10] Smith, D. F., and Gudmundsen, A., Indust. Eng. Chem., 23, 277 (1931).

Effect of Irradiation on the Intensity Distribution of the Second Positive Nitrogen Bands excited in a Nitrogen Ozonizer

MORE exact measurements have now been made of the changes in the relative intensities of several bands of the second positive system of nitrogen, brought about by irradiation with the 3650–3660 A. group of mercury radiations, using an ozonizer discharge tube excited under conditions yielding the maximum negative Joshi effect when the pressure of the gas is 20 mm. These confirm, in general, the results of preliminary investigations[1] and show further that the percentage decreases of intensity are in the following order of bands :

In sequences : (1,4) > (0,3) ; (1,3) > (0,2)
In progressions : (0,3) > (0,2) > (0,1) ; (1,4) > (1,3).

The results show that a change in the relative intensity distribution of the second positive bands of nitrogen is thus brought about, not only in sequences but also in progressions.

A detailed study of the band systems and their intensities developed in the ozonizer tube, excited as above, has revealed that the excitation of the nitrogen molecule is brought about not only by electron collisions but also that collisions with particles of atomic or ionic masses play an important part[2]. Since the variations in electron collisions are less