Technical Comments

Comment on "Investigation of the AP Composite Solid-Propellant Deflagration Mechanism by Means of Experimental Analog Techniques"

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IN the paper of Ref. 1, the authors make some remarks on the work performed at the University of Louvain applying the porous plug burner technique.[2] The authors compare two methods of cementing the AP particles, either by humid wetting or by washing with a solution of 3 g PMM in 100 ml acetone. They conclude first that the grains cemented by the first method expell small particles when submitted to methane throughput rates larger than those corresponding to stoichiometric combustion. Furthermore, the authors point out that the results obtained with grains cemented by the second method are influenced by the presence of PMM binder. The writer agrees with this observation provided a non-negligible amount of PMM has been introduced in the cementing method. However, in our own work, a solution of 4 g PMM in 1000 ml acetone has been used (7.5 times less concentrated); in these conditions we believe that the influence of PMM cement is negligible;[2] still, we did not observe a noticeable expulsion of AP particles.

As to our working hypothesis about the flame stoichiometry, it seems to be also the choice of the authors themselves since they make the same assumption as ours about the AP decomposition, when calculating the equivalence ratio for PS-AP or PMM-AP loose granular mixtures. At atmospheric pressure we have observed the maximum regression rate at an equivalence ratio of one, in quite a lot of systems: CH_4/AP; C_3H_8/AP; neo C_5H_{12}/AP; C_2H_4/AP; H_2/AP; MMM/AP; PMM/AP, etc. From these observations, in the same way as the authors did from their observations on the PMM/AP system, we considered this as a strong argument in favor of the "one stage" flame model. In one single case, namely that of the NH_3/AP system, the maximum regression rate corresponded to 0.4 equivalence ratio and afterburning was observed at the top of the tube.[3]

Further considerations were emphasized[2] about the structure of the one-stage flames; these are to be considered as nearly perfect premixed flames, provided the dead space between the regressing surface and the flame zone remains smaller than the diffusion distance between fuel and oxidizer. Elementary theoretical equations lead to the introduction of a dimensionless number $D_i = a\dot{m}/\rho\mathfrak{D}$ (a = radius of the solid particles; $\dot{m}$ = total mass burning velocity; ρ = density and $\mathfrak{D}$ = interdiffusion coefficient in the gas phase). We consider that the flame is premixed when $D_i \leqslant 8$. In the case of conventional fuels, the following criterion can be used: $a\dot{m} \leqslant 10^{-3}$ g· cm^{-1}s^{-1}. At atmospheric pressure $\dot{m}$ is generally of the order of magnitude of 10^{-1} g· cm^{-1}s^{-1} and the hypothesis of premixed flames would be valid if the particle size (2a) remains lower than 200 μ. Our, and the author's, experiment were performed with AP particle size of 250-500 μ, and the premixed model is a fairly good approximation. A further study on bundles of microjet flames is in progress at the University of Louvain[4] applying the analogical burner technique.[5]

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References

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[2] Burger, J., "Contribution à l'Étude de la Déflagration des Propergols Hétérogènes," *Revue de l'Institut Français du Pétrole et Annales des Combustibles Liquides*, Vol. XX-9, 1965, pp. 1–52; also Transl. 1986, Bureau of Naval Weapons.

[3] Burger, J. and Van Tiggelen, A., "Étude de la Combustion de Propergols Hybrides et Composites," *Bulletin de la Société Chimique de France*, 1964, pp. 3122–3130.

[4] Lys, X., "Étude Analogique du Mécanisme de la Déflagration des Propergols Solides," thesis, Louvain, 1968.

[5] Burger, J., Van Tiggelen, A., and Poncelet, J., "Technique du Brûleur Analogique en Vue d'une Application aux Propergols Solides," *Astronautica Acta*, Vol. II, 1965, pp. 57–34.

Reply by Authors to J. Burger

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BURGER'S comments deal with differences between the findings from this laboratory and his concerning 1) the conditions at which our respective test specimens lose structural integrity and expel unburned AP particles, and 2) conclusions regarding the stoichiometry of AP porous-plug burners.

1) Several questions still remain in this area. Our method of cementing was apparently very close to Burger's, yet we have found that plastic concentrations (in the cement) much higher than his are required to insure structural integrity of the cemented porous plugs. Contrarily, while we have had success in using water AP solution-bonded specimens in a limited range of operation (without loss of structural integrity), Burger apparently has observed expulsion of unburned AP particles from such plugs under similar operating conditions (Ref. 1, p. 12). These differences may be due either to differences in detailed procedures for specimen preparation or to differences in experimental resolution of the threshold for losing structural integrity. These differences might be resolved by an exchange of specimens and/or detailed descriptions of preparation techniques or by more extended investigations of influences of such techniques on combustion behavior.

2) We have never chosen to use or present the nominal, over-all reaction stoichiometry hypothesized by Burger as anything more than an arbitrary, but convenient, basis for normalizing values of $\dot{m}_f/\dot{m}_0$. Burger's view apparently has been that this stoichiometry is "justified" by a regression rate maximum near $\phi = 1$ (based on this stoichiometry)

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