# Reply by Author to M. H. Bertram's Comment

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IN the original article on "Viscosity of Air," the author inadvertently referred to the Bromley-Wilke results as "data." The author wishes to thank Mr. Bertram for correctly pointing out that the Bromley-Wilke results are obtained from kinetic theory considerations. It should be mentioned that this point should be obvious to the reader of the original article since the reference used to obtain the Bromley-Wilke results was given in the article and does indeed show the results to come from the kinetic theory. The author also wishes to thank Mr. Bertram for pointing out that the linear viscosity form given in the original article is within 1% of the Keyes relationship in the temperature range $50°R \leqq T \leqq 200°R$. With this fact in mind, it would appear that the linear form lends itself to hand calculations much easier than the more complex form of Keyes. Finally, in the range of temperatures given by $200°R \leqq T \leqq 3400°R$, both Sutherland's and Keyes' equations are in good agreement with experimental data; therefore preference as to which form to be used is a matter of personal choice.

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# Comments on $Al_2O_3$ Temperature for "Radiant Heat Transfer to an Enclosure from Two-Phase Flows"

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THE purpose of this comment is to point out that Byrne's[1] assumed temperature for $Al_2O_3$ particles is much higher than would be encountered in practice for both liquid and solid propellant rockets. Consequently, some of his conclusions concerning the relative importance of radiant heat transfer in the rocket chamber should be modified, in particular the effect of the chamber wall temperature.

Byrne performed an analytical investigation of the radiant heat transfer from hot combustion particles to the walls of a rocket chamber. This investigation was concerned mainly with showing the trends of several important parameters influencing radiant heat transfer from solid or metalized combustion products. In particular, calculations of radiant heat flux from $Al_2O_3$ particles were made wherein the location along the thrust chamber wall, particle size, chamber pressure, wall reflectivity, wall temperature, and aluminum mass fractions were varied to show the relative significance of these parameters.

Byrne stated that the conclusions reached in his analysis are based on the assumption used and that generalizations of his evaluations are not recommended because of the strong effect of particle temperature and problem geometry. With respect to the significance of particle temperature, I would like to point out that Byrne's basic assumption of a particle temperature for $Al_2O_3$ of 8464°F is much higher than would be experienced in actual practice with both liquid and solid rockets utilizing aluminum additive in a fuel carrier. Thermochemical calculation of the equilibrium temperature of $Al_2O_3$ liquid in typical solid and liquid propellants indicates maximum temperatures of from 6500° to 7200°F.

In general, calculation of the radiant heat flux from $Al_2O_3$, based on assuming the particles at the propellant's equilibrium flame temperature, is high compared to experimental data for both liquid and solid propellant firings. Based on this experience, it appears that the temperature of the $Al_2O_3$ particles is below the equilibrium flame temperature, and certainly well below the temperature assumed by Byrne.

If a particle temperature representative of typical equilibrium values was used in Byrne's work, the over-all values of the heat flux presented in his work could be reduced approximately by a factor of 3. In addition, the chamber wall temperature would be of significance in reducing the radiant heat flux since the particle temperature would be closer to high operating wall temperatures. For example, the difference of a 6500–7200°F particle temperature with the wall constitutes a larger percentage change of the initial difference than would be the case with an 8466°F particle temperature. The affect of the higher percentage change with wall temperature for the lower particle temperatures would indicate a significant reduction in heat flux, particularly as the wall temperature increased above 5000°F. Wall temperatures greater than 5000°F are currently operating in certain solid metalized rocket application.

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### Reference

[1] Byrne, W. M., Jr., "Radiant heat transfer to an enclosure from two-phase flows," J. Spacecraft Rockets **3**, 919–924 (1966).