journal of heat transfer

discussion

Reduction of Heat Transfer to Gun Barrels by Wear-Reducing Additives[1]

E. G. Plett.[2] *The problem of how to evaluate the heat being* transferred to the walls of a vessel containing high temperature gases for a very short time period presents itself from time to time. Measurements of temperature rise within the wall together with appropriate analysis can be used for this purpose. Care must, however, be exercised to be sure that no unnecessary assumptions are made which lead to erroneous computations. One such error was made in the Brosseau-Ward paper. This note is intended to point out how the reasoning in that paper was erroneous with respect to the heat transfer computation, and to point out the correct criterion for detecting the cessation of heat input. It is only fair to add that the error mentioned probably did not change the conclusions of the paper, and that the paper is a very worthwhile contribution to the study of wear in gun barrels.

The statement under scrutiny is that when the thermocouple nearest the gun bore had reached its maximum temperature, no further heat was transferred to the barrel from the hot gases. This may be so in isolated cases, but is not generally true. This can be demonstrated by solving the one-dimensional heat conduction equations for a transient case. The point to be illustrated is that the temperature in the slab near the surface, or at the surface, could be falling with time while heat is flowing into the slab. This simply means that heat is flowing away from the surface (into the slab interior) faster than it is being introduced to the surface from the hot gases. There can, however, still be a substantial heat transfer rate to the solid while the surface temperature is falling.

Consider the one-dimensional, nonsteady heat conduction in a planar slab or cylinder,

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{\partial^2 T}{\partial x^2} \qquad \text{(slab)} \tag{1}$$

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right). \qquad \text{(cylinder)} \tag{2}$$

By simply integrating equation (1), it can be shown that for a thick slab with zero temperature gradient at some distance b from the surface, the heat flux at the surface is

$$\left.\frac{\partial T}{\partial x}\right|_{x=0} = -\left[\frac{1}{\alpha}\frac{\partial}{\partial t}\int_{x=0}^{x=b} T\,dx + \left.\frac{\partial T}{\partial x}\right|_{x=b}\right] \tag{3}$$

This equation illustrates that for $\partial T/\partial x = 0$, at $x = b$, the heat flow ends when the time derivative of the integral of the temperature over the slab thickness is zero, not when the time derivative of the surface temperature is zero. Similarly, integration of equation (2) from r_i to r_0 yields

$$\left.\frac{\partial T}{\partial r}\right|_{r=r_i} = -\frac{1}{r_i}\left\{\frac{1}{\alpha}\frac{\partial}{\partial t}\int_{ri}^{r0} Trdr + r_0\left.\frac{\partial T}{\partial r}\right|_{r=r_0}\right] \tag{4}$$

This also clearly shows that the time of peak temperature for the inner surface does not coincide with the cessation of heat flow into the cylinder, as stated by Brosseau and Ward. The time for which the temperature ceases to rise at the surface is the time for which the heat transfer into the slab (or cylindrical solid) balances the heat flow to the slab from the outside. This is a common phenomenon in shock-tube or gun-tube flows for which the initial heating rate is high, then gradually decreases as the gases cool. Heat continues to flow into the solid, however, as long as the spatial temperature gradient is such that the temperature just beneath the surface is less than the surface temperature. Therefore, the correct criterion for detecting the cessation of heat input is when the surface spatial temperature gradient is zero.

Authors' Closure

Professor Plett is correct when he asserts that a thermocouple near the bore surface reaching its maximum temperature is not a necessary and sufficient condition for cessation of all heat transfer into the gun barrel.

We merely wish to demonstrate in this reply that the assumption we made, namely, that no significant heat transfer occurred after 100-ms is valid. If the total heat transfer estimates are made with the temperature versus radius curve at 100 ms extrapolated horizontally from the thermocouple nearest the bore surface to barrel surface, then the condition of no further heat transfer from the propellant gases to the gun barrel is satisfied. When this is done, the heat transfer estimate is less than 0.5 percent of the estimate of heat transfer made in the paper. This difference is well within experimental error of our technique. The reason for this is that the thermocouple nearest the bore surface has dropped considerably at 100 ms from its maximum value, and consequently, the temperature gradient close to the surface is shallow. Hence, no significant further heat is transferred to the gun barrel after the 100 ms time interval.

[1] By T. L. Brosseau and J. R. Ward, published in the Nov. 1975 issue of the JOURNAL OF HEAT TRANSFER, TRANS. ASME, Series C, Vol. 97, pp. 610–614.

[2] Assoc. Professor, Department of Mechanical and Aeronautical Engineering, Carleton University, Ottawa, Ontario, Canada.