$$\sqrt{\frac{k}{k-1}\,\frac{r_1^{\frac{k-1}{k}}-1}{r_1^{\frac{k-1}{k}}}}$$

and is plotted in Fig. 8 for various values of k.

The over-all efficiency of a burner-nozzle combination is found by plotting measured values of

$$\frac{F/M+V_b}{\sqrt{2gRT_{2_{\text{th}}}}}$$

on the same chart. The ratio of the actual to the theoretical value is C_v. The over-all energy efficiency Φ, is equal to C_v^2.

If the nozzle velocity coefficient C_n, is known, the combustor effectiveness can be found from the equation

$$\epsilon = \frac{\Phi}{C_n^2} = \frac{C_v^2}{C_n^2} \qquad [19]$$

Discussion

J. R. Parsons.[4] The author presents a very useful method of combining the effect on combustion-chamber evaluation of pressure drop and combustion efficiency into one term, "energy efficiency." This tool for comparison of combustion chambers on an energy basis is a start in the standardization of evaluation terms. Knowledge of combustion-chamber effectiveness is useful to both the engine designer and the burner designer. The engine designer needs to compare available combustion chambers on an energy basis so that he may select the one with lowest energy losses for his design. The burner designer needs this tool to know which of several competing configurations is best.

After several years of association with the author, the writer is sure that he is cognizant that comparison of burners on an energy basis comes only after each has been made to satisfy many other conditions such as carbon deposition, temperature profile, liner temperature, size, and stability.

For instance, carbon deposition usually cannot be tolerated. However, a rocket engine which employs fuel cooling along the inside wall of the combustion chamber accumulates a small amount of carbon. This fuel does not enter into the combustion process but discharges unburned. Energy efficiency in this example is secondary and is intentionally sacrificed.

Flat temperature profile in a thrust-producing device, such as a rocket or burner exhausting directly to atmosphere, is of no consequence except as it affects liner temperature. Thrust efficiency in this case is paramount in burner comparison. The gas turbine, however, requires a flat temperature profile, but is not penalized by weight or size to the same degree as a burner at the tip of the rotor of a jet-driven helicopter. Once the burner competing for use in a gas turbine has satisfactorily demonstrated (*a*) lack of carbon formation over the range of operating conditions; (*b*) flat temperature profile; (*c*) satisfactory liner life; (*d*) satisfactory stability and ignitibility, it may then be compared with others for acceptance in a given gas-turbine cycle.

It should be noted that the combustion-effectiveness number which is assigned to a liner is significant only for a given compressor-turbine combination. This effectiveness number does not identify the liner at all times regardless of application. Like turbine or compressor efficiency it is applicable only when considered as part of a specific cycle.

Pressure drop occurring in all combustion chambers results principally from incomplete recovery of velocity pressure from impinging jets, or similar entry, required to get sufficient mixing of air and fuel for good burning. The burner designer needs frequently to know during a development how much combustion efficiency he can exchange for pressure drop. The "minimum" pressure drop is determined by instability or carbon deposition; the "optimum" is determined by its effect on energy effectiveness.

Author's Closure

The author expresses his sincere appreciation to Mr. Parsons for his clarifying comments on this paper. In amplification of his discussion, the author wishes to re-emphasize that the purpose of this paper, as Mr. Parsons has clearly described, is to promote and demonstrate the use of a fundamental definition of the performance of a combustion chamber in the strict thermodynamic sense only.

It has been the author's conviction that the combustion systems in gas turbines, and so on, have not enjoyed the common use of fundamental definitions common to other power-plant components, such as turbines and compressors. There is no apparent reason why this should be so. True, the state of the art of combustion-chamber design is not yet advanced to the stage that compressor and turbine design have, but the fundamental thermodynamic laws are available and should be used wherever they apply.

Long before the advent of the gas turbine, and its attendant needs for combustors, compressor and turbine-performance characteristics were defined by fundamentally sound terms, based on energy concepts, which were in common usage in describing performance of industrial compressors, superchargers, and steam turbines. No similar efficiency term was developed for combustion chambers. The combustor effectiveness as developed in this paper, therefore, is suggested for application to combustion chambers in the same manner that compressor efficiency, for example, is applied to a compressor. Neither term can in itself guarantee a good design for a combustor or compressor, but both define the intended or finished product as to thermodynamic value.

Naturally, many other properties of a combustor exist in addition to effectiveness, just as there are other properties of a compressor than efficiency, such as pulsation limit, flow range, and so on. The fact that these other properties are not yet amenable to exact numerical description does not detract from the value of standardized definitions of those properties to which fundamental and numerical descriptions do apply.

For lack of a true efficiency definition the trend has been to use the combustion efficiency as the definition of combustor performance. As shown in this paper, this is not only fundamentally unsound, but in many instances can be misleading. For this reason, the author offers a more basic definition, which he has personally found convenient and accurate, for wider evaluation and possible acceptance in the field.

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[4] Sverdrup & Parcel, Inc., St. Louis, Mo.