Thermodynamics
The guidepost of effective use of energy

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***Abstract*— The empirical theory of thermodynamic equilibrium states has guided engineers and scientists to ameliorate the use of energy resources during the past two and a half centuries. In this brief essay, I illustrate the great progress that has been made in designing and manufacturing engines for land, sea, air, and outer space applications, and contemplate the opportunity to use a novel theory of thermodynamics [1] that applies to any small or large system (such as one spin only, or one particle, or many constituents), in any state (unsteady, steady, nonequilibrium, different kinds of equilibrium, and stable equilibrium) so that energy may be used even more effectively.**

I. INTRODUCTION

Thermal and thermodynamic efficiencies. In rigorous performance analyses of different types of engines, we use two indicators. One is the ratio of the work (work rate) output of the engine divided by the heating value (heating value rate), and is called the *thermal efficiency*. The second is the ratio of the work (work rate) output divided by the availability (availability rate) of the fuel with respect to the environment of the engine treated as a reservoir, and is called the *thermodynamic efficiency*.

In practice, different measures are found to be more convenient as illustrated by the coordinates of the experimental results in Figures 1 to 5. Figure 5 is especially noteworthy because in addition to representing the large growth of thermal efficiency η, it also honors the names of some of the great inventors over the past three centuries.

It is interesting to estimate the thermodynamic efficiency of a power plant that uses liquid CH_2 as fuel. The heating value of CH_2 is 291,000 Btu per pound-mole. Upon combustion in air consisting of 1.5 mole of O_2, and 5.65 mole of N_2, the availability of the products of combustion is 2×10^5 Btu or about 0.7 times the heating value. It follows that the thermodynamic efficiency of the combined cycle is 0.63/0.7 or 90%, where 0.63 is the thermal efficiency taken from Fig. 5.

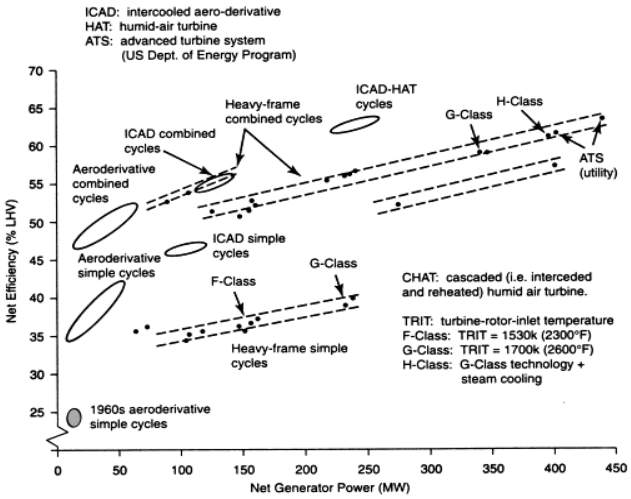

Fig. 1. Thermal efficiency (with respect to lower heating value (LHV) of fuel versus power and type of different power plants [2].

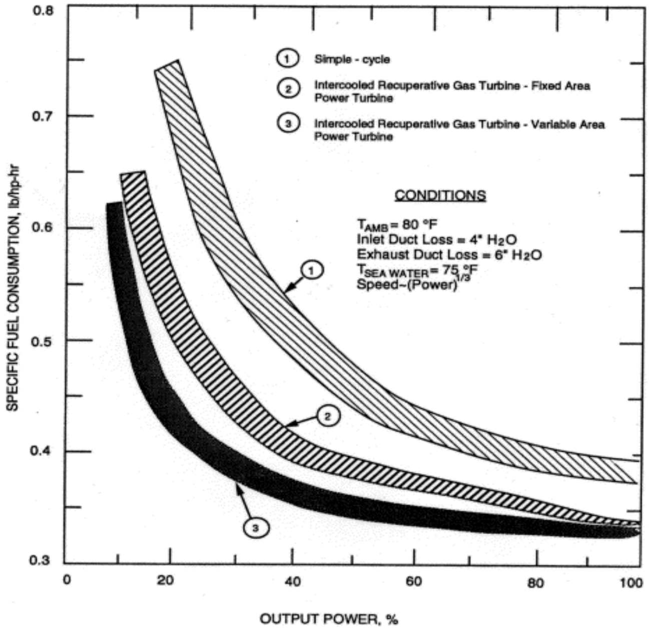

Fig. 2. Part load fuel consumption characteristics of different turbine cycles [3]. The specific fuel consumption in inversely proportional to the thermal efficiency.

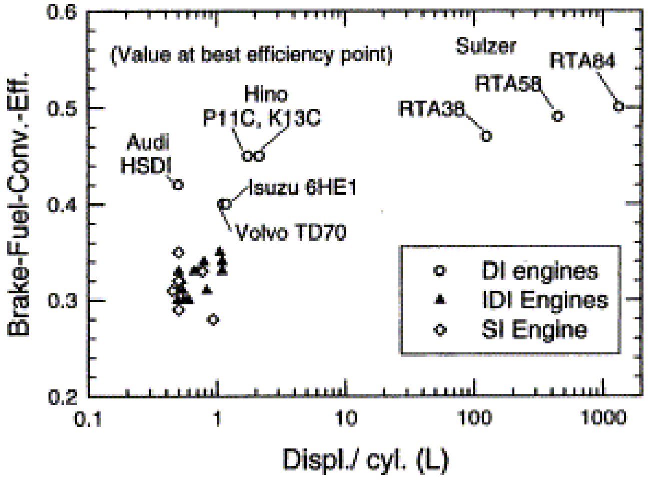

Fig. 3. Thermal efficiencies versus displacement per cylinder of diesel engines [4]. The displacement is proportional to the power rating: DI = direct injection; IDI = indirect injection; SI = spark ignition.

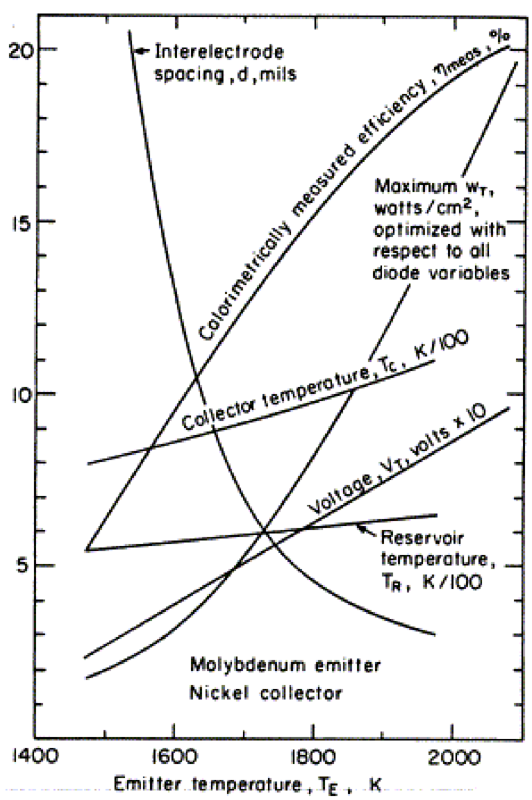

Fig. 4. Measured thermal efficiency versus emitter temperature of a thermionic converter at terminal output power density maximized with respect to cesium reservoir temperature, interelectrode spacing, and collector temperature [5].

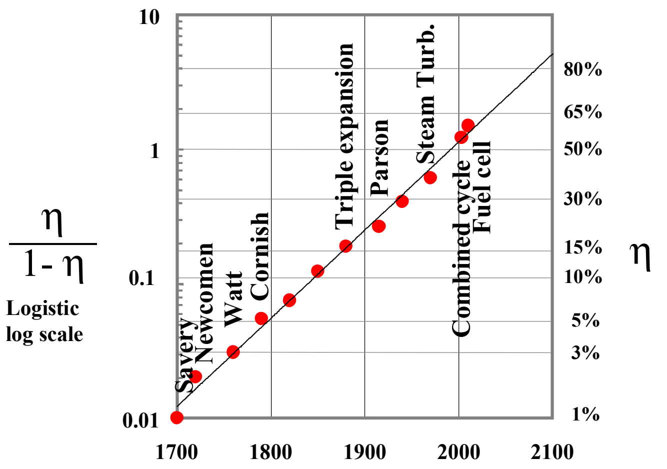

Fig. 5. The evolution of thermal efficiency over the past three centuries [6].

The challenge of more effective use of energy sources. Practically all the methods of energy utilization involve systems that pass only through thermodynamic, i.e. stable, equilibrium states. For given values of energy *E*, amounts of constituents ***n***, and volume V, the value of the entropy *S* of the corresponding unique stable equilibrium state is larger than the entropy of any other state with the values *E*, ***n***, *V* just cited, and as a result the usefulness of the stable equilibrium state is not as large as that of its relatives. We already have two practical applications of this idea. One is the battery that powers a cardiac pacemaker, and the other the little battery that does the work required by an electric wrist watch. In each of these two applications, the time constant for self discharge is longer than the many years during which useful work is performed.

I feel confident that other opportunities will arise from applications of nanotechnology, and special types of chemical reactions, applications that will achieve more effective uses of energy resources than have been achieved by restricting our thinking to the empirical theory of thermodynamic equilibrium and its statistical mechanics interpretation.

Another opportunity arises in reducing the irreversibility of combustion processes. Preheating the fuel-air mixture, and diluting it with products of combustion (exhaust gas recirculation in internal combustion engines) does achieve some reduction of the amount of irreversibility during oxidation. But the greatest hopes are on technologies that allow better control of the oxidation processes by slowing it down while simultaneously some mechanical or electromechanical process extracts as much of the nonequilibrium availability that is made accessible by the fuel oxidation. Fuel cells achieve the oxidation through an exchange of ions and electrons that flow in some porous polymer membrane or some electrolyte, and the flow of charge is the simultaneous process which extracts part of the availability while the fuel is being oxidized [7].

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