11.1: Introduction

In my rarefied, theoretical, academic and unpractical mind, a heat engine consists of a working substance obeying some idealized equation of state such as that for an ideal gas, held inside a cylinder by a piston, and undergoing, in a closed cycle, a series of highly idealized processes, such as reversible adiabatic expansions or isothermal compressions. At various stages of the cycle, the system may be gaining heat from or losing heat to its surroundings; or we may be doing work on the system by compressing it, or the system may be expanding and doing external work.

The *efficiency* η of a heat engine is defined as

$$\eta=\frac{\text{net external work done }\textbf{by}\text{ the engine during a cycle}}{\text{heat supplied }\textbf{to}\text{ the engine during a cycle.}} \tag{11.1.1}$$

By "net" external work, I mean the work done **by** the engine during that part of the cycle when it is doing work *minus* the work done **on** the engine during that part of the cycle when work is being done on it. Notice that the word "net" does not appear in the denominator, which refers only **to** the heat supplied to the engine during that part of the cycle when it is gaining heat.

During the compression part of the cycle, the system gives out heat, and only the difference "heat in *minus* heat out" is available to do the external work. Thus efficiency can also be calculated from

$$\eta=\frac{Q_{\text{in}}-Q_{\text{out}}}{Q_{\text{in}}}. \tag{11.1.2}$$

although the definition of *efficiency* remains as equation 11.1.1.

No heat engine is 100% efficient, and we need to ask what is the most efficient heat engine possible, what are the factors that limit its efficiency, and what is the greatest possible efficiency? Obviously things like friction in the moving parts of the engine limit the efficiency, but in my academic mind the engine is built with frictionless bearings and all processes in the cycle of compressions and expansions are reversible.

During a cycle, a heat engine moves in a clockwise closed path in the *PV* plane, and, if the processes are reversible, the area enclosed by this clockwise path is the net external work done **by** the system. It also moves in a clockwise closed path in the *TS* plane, and, if the processes are reversible, the area enclosed by this clockwise path is the net heat supplied to the system. The two are equal, and when the system returns to its original state, there is no change in the internal energy. That is, internal energy is a function of state.

Depending upon the nature of the various processes during the cycle, the cycle may carry various names, such as the Carnot, Stirling, Otto, Diesel or Rankine cycles. Of these, the most important from the theoretical point of view is the Carnot cycle. I do not know whether anyone has ever built a Carnot heat engine. I do know, however, that no one has ever built an engine working between a hot heat source and a cold heat sink that is more efficient than a Carnot engine; for, for a given temperature difference between source and sink, the Carnot engine is the most efficient conceivable. There is another important thing about the Carnot cycle. In Chapter 3, we struggled to understand that most difficult of all the thermodynamic concepts, namely *temperature*, and we wondered if we could define an *absolute* temperature scale that was independent of the properties of any particular substance. Consideration of the Carnot cycle enables us to do just that.

Of real heat engines I know very little. I know that one pedal of my car makes the car go faster and the other makes it go slower – but what is under the hood or bonnet is beyond my ken. Real heat engines may resemble some of the theoretical engines of academia to a greater or lesser extent. Thus a motor car engine may resemble an Otto cycle, or a steam engine may resemble a Rankine cycle, or a real Diesel engine may resemble the theoretical Diesel cycle. Engineering students may wonder whether they need bother with learning about "theoretical" engines that bear little resemblance to the metal and fuel that they have to work with on a practical basis. I cannot answer that, but there is just one thing I *do* know about real engines, and that is that they are subject to and follow all the fundamental laws of thermodynamics that theoretical engines have to follow; and I suspect that the engineer who designed the engine in my car had a pretty thorough knowledge of the fundamental principles of thermodynamics.