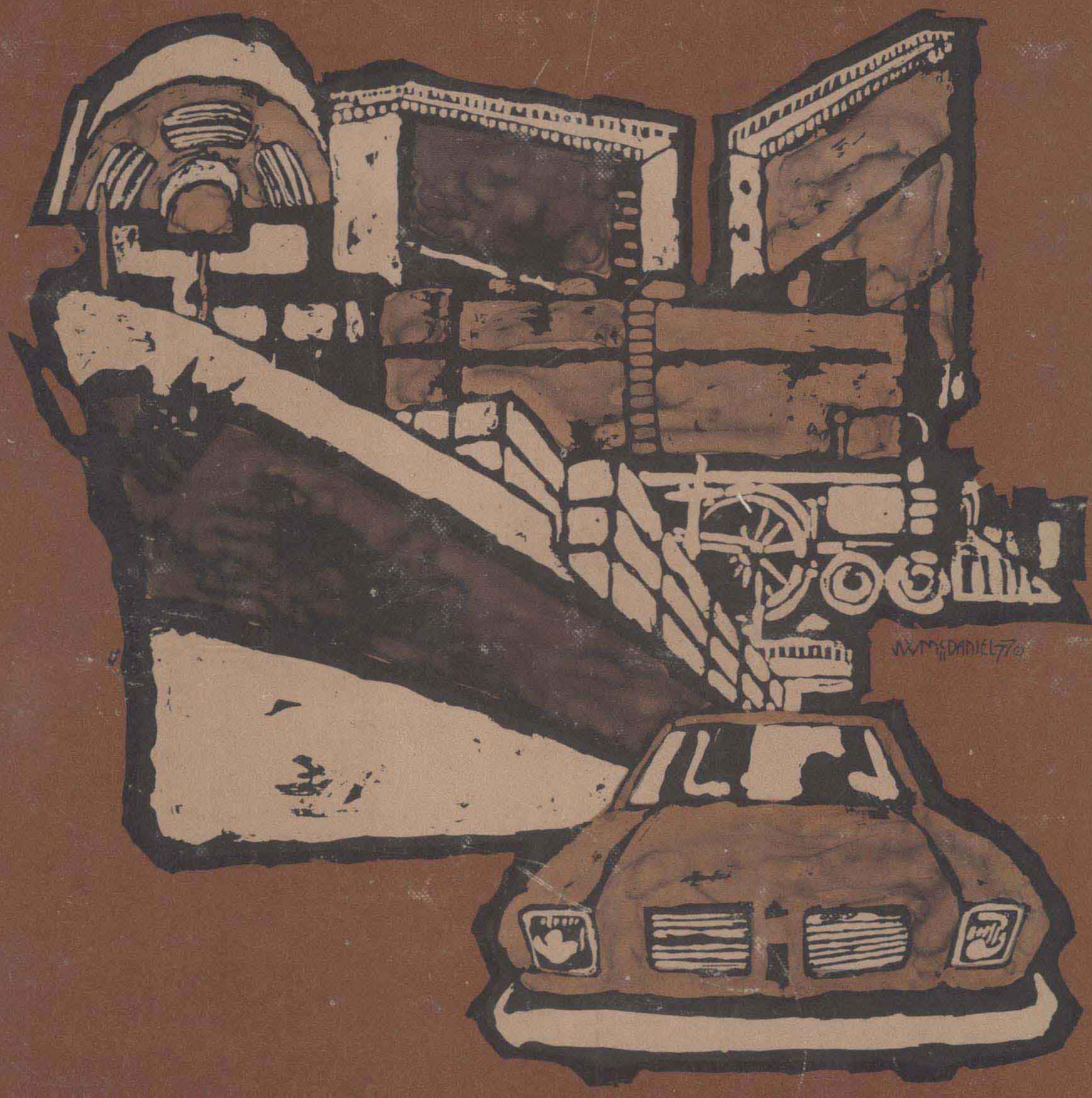
ENGINEERING THERMODYNAMICS WITH APPLICATIONS

M. DAVID BURGHARDT



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ENGINEERING THERMODYNAMICS WITH APPLICATIONS

To
E. R. B. and M. B.

PREFACE

The purpose of this text is to help undergraduate engineering students learn thermodynamics—the theoretical foundations of the science and their application to realistic situations. The first section of the book is devoted to developing the student's ability to undertake thermodynamic analyses; the second section is devoted to the application of these skills.

Since students are able to effectively use their new knowledge only if they fully understand it, they must first master thermodynamics before they can reach the goal of undertaking systems analysis. To this end, a large number of examples are included in the text. It is my hope that when students study a theory, see its application in examples, and perform similar analyses, they will be able to understand and effectively use the principles of thermodynamics. The text demonstrates that the same four thermodynamic postulates are repeatedly applicable regardless of the system to which they are applied.

The text provides engineering students with a solid theoretical background, because the emphasis and discussion of the fundamental principles are coordinated with their application. The juxtaposition of what is happening theoretically to what is happening physically is emphasized strongly. Because engineering students leave college as potential professional engineers, they must be provided with the necessary tools of analysis. This text provides these tools.

SI units are used in conjunction with English units throughout the book. The unit systems are completely developed, and problems are presented in both systems, thus allowing students to become comfortable with both systems—not just with conversion formulas. When the tables are available in English units only, the text problems using these tables reflect this circumstance.

The text is suitable for either lecture or combined lecture-laboratory presentation. The material forms the basis of a three-quarter course in thermodynamics, of which the last two quarters includes a laboratory coordinated with the lecture sequence.

Although my debt to many authors may be apparent in instances, I have endeavored to acknowledge the ones that have been particularly helpful to me in the reference section at the end of the book.

In addition, several individuals helped—directly and indirectly—in the *development of the text. In the latter category are Professors Wallace W. Bowley and Domina Eberle Spencer of the University of Connecticut, who unknowingly helped me set the highest standard by following their example. In the former category, several people deserve special mention, particularly my good friend and former colleague, Professor Eugene L. Keating of the U. S. Naval Academy. The results of our many discussions and his suggestions and constructive criticisms are incorporated in the text. Professors Edward Ferenczy and Joseph Jannone of the U. S. Merchant Marine Academy have been very helpful in pointing out ambiguities and suggesting improvements during the preparation of the manuscript. As the text evolved from lecture notes, my students have been helpful by asking questions in those areas that needed clarification. I am also indebted to Ms. Vivian Rosenberg for typing the final manuscript.*

The text represents an amalgam of numerous ideas, influences, and data from many sources, yet the ultimate responsibility for the material is my own. It is my hope that the text will form a useful part of an educational program in engineering.

M. David Burghardt

CONTENTS

CHAPTER 1
Introduction

The study of thermodynamics covers many areas of engineering, from power plant analysis to the analysis of fuel cells. What follows in this chapter is an indication of some, by no means all, of the types of situations and systems that may be analyzed thermodynamically. The strength of thermodynamics lies in one's ability to analyze with the use of a few tenets—four to be exact—a wide range of systems. It may also be of interest to the student to know of some of the great men and their discoveries that advanced the science of thermodynamics.

1.1 ELEMENTARY STEAM POWER PLANT

One of the first systems to look at is the steam power plant, an energy device basic to modern life. It is necessary for the generation of electric power as well as in transportation systems, ships, for example. (Many other power systems are also used and these, too, yield to thermodynamic probing.) Figure 1.1 depicts a simple steam power plant. Just as in the oil-fired boiler in the basements of many homes, fuel is burned to generate heat. This heat is used to boil water under pressure in the steam generator (boiler). The steam leaves the generator and passes through superheater tubes, where more heat is added to the steam; it then passes through the turbine, where it increases in volume, decreases in pressure, and performs work, which is used to generate electric power or drive a ship. The steam is then condensed, liquefied, and pumped back to the steam generator.

This system seems simple enough and not too great a challenge for an engineer, but life and circumstances are not that kind or simple. Several additions have been made to the plant, and we will consider these in greater detail later. Water heaters, for instance, preheat the water before it enters the steam generator; also, some of the steam is taken from the turbine, reheated, and returned to the turbine; and before the air reaches the fuel-oil burners, it is reheated, which improves the combustion process. These are some of the considerations that an engineer using thermodynamic analysis must include in analyzing a steam power plant.

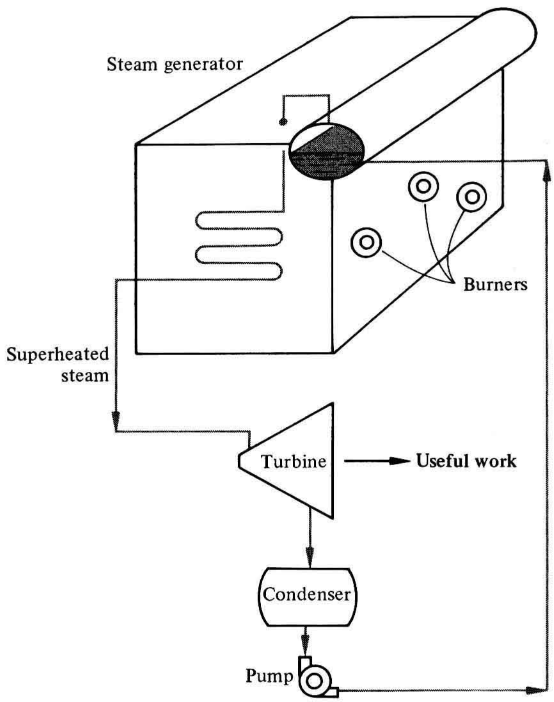

Figure 1.1 *Simple steam power plant.*

1.2 COMBUSTION ENGINES

Another standard power plant that we use almost every day is the gasoline engine—the automotive engine (Figure 1.2). Innovations have been made, such as the Wankel engine (Figure 1.3), but even this follows the same principles. The engine may be viewed as a small power plant: Fuel is burned and the energy from the burning fuel is transferred to the pistons, which, through gears, turn the wheels, thus moving the automobile.

There are many problems associated with the engine: the combustion process in the piston and containing the energy of the burning flame, to mention two. The thermodynamic analysis seeks to determine ahead of time how much work we may expect from an engine and through experiments how efficiently the engine is performing. This is very important if the pollution from exhausts is to be minimized.

The gas turbine (Figure 1.4) is another automotive power source, more commonly found in jet planes. There is an upsurge in the development of gas-turbine plants, in both electric power generation and ship propulsion. Air is compressed and energy added to it by burning fuel in a combustion chamber; this mixture—the products of combustion, air, and burned fuel—expands through a turbine, doing work, which drives the electric generator or the ship. The analysis is similar to that of most power plants, and all these analyses have a common

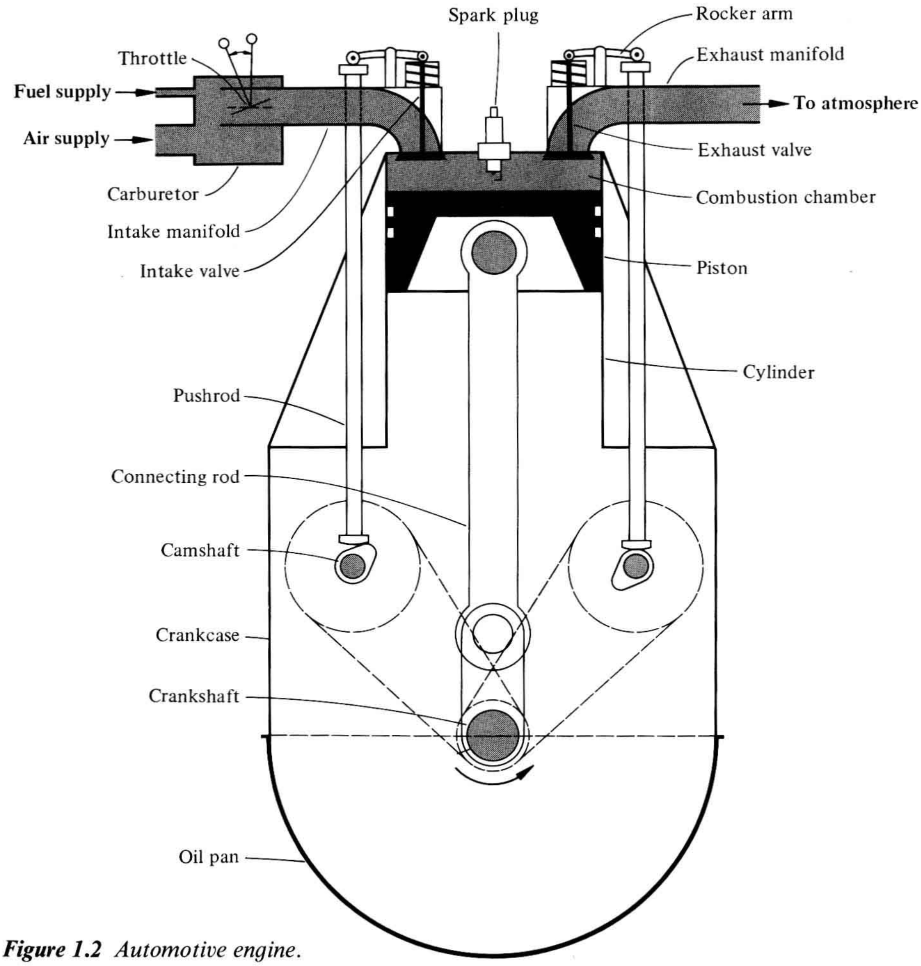

Figure 1.2 *Automotive engine.*

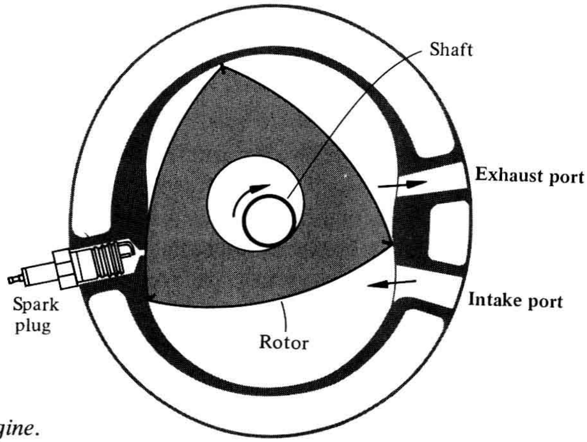

Figure 1.3 *Wankel engine.*

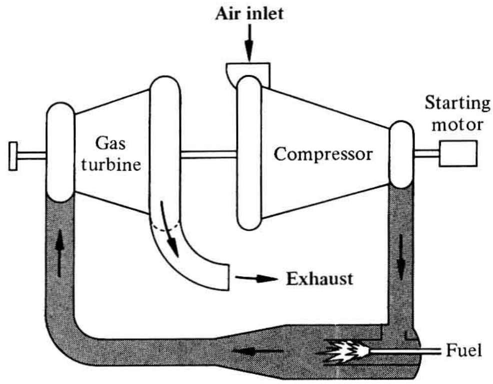

Figure 1.4 *A gas turbine unit.*

purpose, which is to consider how efficiently the chemical energy of the fuel is converted into mechanical energy. The processes of converting the energy are different but the principle of energy conversion remains the same.

1.3 DIRECT ENERGY CONVERSION

There are energy converters that do not rely on an intermediate device to produce the desired energy form, in this case work or electric power. These devices are called direct energy conversion devices and two will be mentioned. The one that may be most familiar is the fuel cell, in which chemical energy is converted directly into electric energy. In Figure 1.5, a simplified fuel cell using hydrogen and oxygen is shown. The hydrogen is oxidized at the cathode, giving up two electrons, and the oxygen is reduced at the anode by picking up the two electrons. Connected to the two poles is the load.

The half-cell reactions are

$$H_2(g) \rightarrow 2H^+ + 2e^- \qquad V = 0.0 \text{ volts}$$

$$\tfrac{1}{2}O_2(g) + 2H^+ + 2e^- \rightarrow H_2O(l) \qquad V = 1.23 \text{ volts}$$

Thus the voltage of the cell is 1.23 volts, and if the load resistance is known, the current flowing through the load may be determined by using Ohm's law.

A second type of direct energy conversion device that may not be so well known is the thermoelectric generator, in which heat is supplied to the junction of two dissimilar metals. Because the metals are dissimilar, there is an electron flow, caused by the electrical potential difference of the two metals at the same temperature. If the leads of the dissimilar metals are joined by a load (Figure 1.6), then the circuit is connected and current will flow. If a battery is connected in place of the load, a current is passed through a junction of dissimilar metals and heat is either liberated or absorbed. If it is absorbed, then the junction acts as a refrigerator.