Introduction

Charles E. Baukal, Jr.

Combustion is a critically important and extremely visual phenomenon. When properly controlled, combustion is important for a wide range of processes. For example, it is the primary source of power generation for our vast array of electrical equipment and electronics. However, when combustion is not properly controlled, it can be a source of great devastation. For example, uncontrolled wildfires are still a major concern in many parts of the world.

While knowledge continues to expand on the subject of combustion, there is still much that remains to be learned. Considerable research continues on reducing pollution emissions and increasing thermal efficiencies from combustion processes. However, combustion continues to be an extremely complex phenomenon. The fluid flow is typically turbulent, which is difficult to model. The heat transfer is nonlinear due to the importance of thermal radiation. To further complicate matters, the radiation is spectrally dependent due to the effects of water vapor and carbon dioxide in the combustion products. Combustion chemistry is extremely complicated, where the reaction of a relatively simple fuel like methane with air consists of 325 reactions and 53 species, most of which last only a fraction of a second in the flame [1]. In many cases, the rate constants for the numerous reactions are not well known, which makes modeling that much more difficult. There may be acoustic and pressure effects in certain types of combustion processes. There may also be a wide disparity in the length scales in some systems where, for example, the fuel injectors may have very small holes while the flames may be inside very large furnaces. When these systems are discretized for numerical modeling, there may be tens of millions of control volumes. In some systems, the combustion process is time dependent, which greatly increases the computational requirements. This means very large computational power and storage may be required for modeling many important types of combustion processes.

Since computational models are not currently adequate to accurately predict all aspects of combustion, experiments continue to be important in furthering the understanding of the physics of the many processes in combustion. One of the important outputs from these experiments is often graphic images that can greatly add to understanding those processes and can also be invaluable in validating computational models. Both aspects of the images are of interest here.

Flames may exhibit a range of colors such as yellow, red, and/or blue depending on factors such as the specific combustion process, the fuel, and the operating conditions. For example, it is possible that a given burner can produce yellow or blue flames with the same fuel under fuel-rich or fuel-lean conditions, respectively. This book is a compendium of combustion images accompanied by explanatory text. Low-gravity, atmospheric pressure, and pressurized flames using solid, liquid, and gaseous fuels, ranging from small-scale laboratory up to full-scale industrial flames under controlled and uncontrolled conditions, are included. Photographs, drawings, and computer-generated images, some of which were winners in combustion and fire science art contests, are included.

Most combustion books are published in black and white, which makes it nearly impossible to show the colorful and dynamic nature of flames. It also makes it more difficult to determine what is happening in the combustion process. The purpose of this book is to present color images of a wide range of aspects of combustion. While there are analogous graphical books for fluid flow, no such book was found for combustion. This book is designed to fill that gap. It can also serve as a supplement to existing books describing the combustion phenomenon.

The book is divided into six chapters. Chapter 1 is on combustion fundamentals and is divided into eight sections: simple flames, laboratory and idealized flames, practical flames, spherical flames, gas jet and liquid fuel flames, flames at high speed, coal and solid-particle combustion, and combustion of metals. These are generally smaller-scale combustion processes studied in great detail in the laboratory.

Chapter 2 contains a range of images concerning the numerical simulation of flames commonly referred to as computational fluid dynamic (CFD) modeling. Some humorously refer to CFD as *colorized* fluid dynamics because of the impressive graphics that can be generated from a simulation. Because of advancements in numerical techniques, combustion physics, and computer hardware, CFD has become a standard tool for designing and analyzing combustion processes. In CFD, the challenge when generating images can be what to include and what to exclude because of the numerous combinations of variables that can be plotted. A wide range of flow types and analysis techniques are displayed in this chapter.

Chapter 3 includes images related to internal combustion engines and turbines used in cars, trucks, and airplanes. These are inherently more difficult combustion processes to visualize because the flames are normally contained inside pressurized metal combustion chambers and are very transient in nature. Significant advancements have been made in optical access to generate images that can provide both qualitative information and quantitative measurements in these systems.

Chapter 4 concerns low-pressure combustion processes that are important in space applications. While removing gravity may simplify the combustion in some aspects, making experimental measurements and producing images are more complicated due to the challenge of either creating low-gravity environments on earth or conducting experiments in space. This is an active area of combustion research, and a wide range of flames is shown in this chapter, which has been divided into the following sections: gaseous fuels, liquid fuels, and both thick and thin solid fuels.

Industrial flames are the subject of Chapter 5. These are divided into six sections: metals industry, process heating, power generation, infrared heating and drying, flares, and oxygen-enhanced flames. Some of these are very large-scale flames; for example, flare flames could be 100 m or more in length. Conducting experiments on these types of systems can be challenging because of the scale involved and because access can be difficult, particularly if there is a possibility of adversely affecting whatever is being produced with the combustion system. The section on oxygen-enhanced flames shows examples of how a traditional combustion process using air as the oxidizer may be improved by using an oxidizer with a higher concentration of oxygen up to using pure oxygen for combustion.

The final chapter contains a wide range of images related to fire. Some distinguish between a flame that is considered to be a controlled combustion reaction and a fire that is often considered to be an uncontrolled combustion reaction. Fires can range from very small-scale like those in Chapter 1 up to very large-scale like those in Chapter 5. A wide variety of materials with varying degrees of flammability may be unintended “fuels” in fires. Fire suppression is also considered. This chapter has sections on pool fires, flame spread and fire growth, fire suppression, fire whirls, wildland fires, and smoldering combustion.

Reference

1. Stephen R. Turns, *An Introduction to Combustion: Concepts and Applications*, 3rd ed., McGraw-Hill, New York, 2011.