Coal-Fired Power Generation Handbook

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Preface

Coal accounts for approximately one quarter of world energy consumption, and of the coal produced worldwide, approximately 65% is shipped to electricity producers and 33% to industrial consumers, with most of the remainder going to consumers in the residential and commercial sectors. The total share of total world energy consumption by coal is expected to increase to almost 30% in 2035.

This book describes the steps and challenges by which electricity is produced from coal and deals with the challenges for removing the environmental objections to the use of coal in future power plants. New technologies are described that could virtually eliminate the sulfur, nitrogen, and mercury pollutants that are released when coal is burned for electricity generation. In addition, technologies for the capture of greenhouse gases emitted from coal-fired power plants are described and the means of preventing such emissions from contributing to global warming concerns.

The book is divided into chapters that introduce the reader to:

- The occurrence of coal and the various resources.
- The origins of coal that cause differences in coal properties such as rank and classification.
- The properties of coal and the properties that are particularly relevant to combustion and electricity generation.
- The mechanism of combustion and the various combustion systems currently available.
- The conversion of coal to electric power either as a single fuel, a blended fuel, or as a fuel combined with biomass.

- The manner in which coal properties can influence electricity production.
- The technologies available for cleaning the combustion off-gasses to reduce the potential for pollutant emissions.
- The environmental aspects of coal-fired power generation.
- The future of coal-fired electricity generation through upcoming clean coal technologies with an overview of the future of electricity generation from coal.
- The role of coal in energy security scenarios.

The book is written in an easy-to-read style and is also illustrated by diagrams and tables. It describes the performance of power plants and power generation as influenced by coal properties. Specifically, coal quality impacts not only coal cost, but also net power output, as well as capital and operating and maintenance costs and waste disposal costs.

There is also a comprehensive glossary that will help the reader to understand the various terminologies that are used in this important energy field.

Dr. James G. Speight,
Laramie, Wyoming.
December 2012.

Coal-Fired Power Generation Handbook.
by James G. Speight.

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Occurrence and Resources

1.1 Introduction

An ever-expanding human population relates to a corresponding ever-increasing demand for energy to the extent that the world is presently faced with a situation of energy demand exceeding the energy in circulation, even from a variety of sources (Speight, 2008, 2011a). The production and consumption of energy have been associated with adverse environmental impacts such that the United Nations conference in Kyoto, Japan, in 1997 had to have what is known as the Kyoto Protocol that sets limits on carbon dioxide emissions into the atmosphere (Hordeski, 2008; Irfan *et al.*, 2010).

Coal (the term is used generically throughout the book to include all types of coal), geographically spread across all inhabitable continents of the world, is a black or brownish-black *organic sedimentary rock* of biochemical origin that is combustible and occurs in rock strata (*coal beds, coal seams*) and is composed primarily of carbon with variable proportions of hydrogen, nitrogen, oxygen, and sulfur.

Coal has been a vital energy source to human populations for millennia. For example, in approximately 1000 BC, the Chinese relied on coal to smelt copper that served as the basis for their currency, and the Greek philosopher Aristotle made reference to it in his writings when he alluded to a dark charcoal-like rock (World Coal Institute, 2008). Furthermore, the discovery of coal cinders among Roman ruins in England suggests that the Romans relied on coal as a source of energy prior to 400 AD.

The first written record of coal in the Americas was taken in 1673 by Louis Joliet, who noted *carbon de terra* while mapping out the Illinois River region. In more recent times, the Nanticoke Indians, a Native American tribe who lived in Pennsylvania, were using local anthracite coal as a source for energy and jewelry during the 1760s (Dublin and Licht, 2005). In the modern world, steam coal, metallurgical coal, and industrial coal all play a vital role in the economy of many counties, especially the United States.

Coal continues to power vital industries. The iron industry still relies on basic oxygen furnaces that require a special type of coal, known as metallurgical or coking coal, to produce steel. Coke from coking coal is combined with limestone in a furnace where iron ore is blasted with pure oxygen and converted to steel. However, more pertinent to the present text, the electricity that powers electric arc furnaces is usually generated by burning pulverized thermal coal.

Coal was the key energy source for the Industrial Revolution, which has provided amenities that most of people take for granted today, including electricity, new materials (steel, plastics, cement, and fertilizers), fast transportation, and advanced communications. Coal replaced wood combustion because of coal's abundance, its higher volumetric energy density, and the relative ease of transportation for coal (Ashton, 1969; Freese, 2003).

The Industrial Revolution itself refers to a change from hand and home production to machine and factory. The first industrial revolution was important for the inventions of spinning and weaving machines operated by water power, which was eventually replaced by steam. This helped increase growth and changed late-eighteenth century society and economy into an urban-industrial state. New fuels such as coal and petroleum were incorporated into new steam engines, which revolutionized many industries, including textiles and manufacturing.

The demand for coal decreased for transportation and heating purposes due to intensified competition from petroleum, but activity increased in the post-World War II industrial sector as well as the electricity generation sector after the 1960s. As the demand for power increased, the demand for coal has continued to rise over the years.

The 1973 oil embargo renewed interest in the vast domestic coal reserves of the United States. This sharp rise in coal production helped solve the growing problem of scarce oil resources that were in high demand.

The demand for coal was also impacted by the Power Plant and Industrial Fuel Use Act (FUA) of 1978, which required most oil or natural gas burning power plants to switch to coal. As a result, the energy of the United States became significantly more dependent on coal. After repeal of the Power Plant and Industrial Fuel Use Act in 1987, natural gas use in electric power plants increased by 119 percent between 1988 and 2002. Indeed, the spike in natural gas consumption goes to show the influence the Power Plant and Industrial Fuel Use Act had on increasing the reliance of the United States on coal as a source of energy.

As developing countries such as China and India require more energy to meet their rapidly growing demand, competition for coal will continue increase. The United States has 96% of the coal reserves in North America, which accounts for approximately 26% of the total known coal reserves. As a result, the United States will be expected to export more coal to meet the strong demand from the world market. In doing so, the price of coal will remain stable, and developing countries will be able to meet their energy needs.

Coal is currently responsible for generating approximately 50 percent of the world electricity. In fact, the demand for coal in the United States is primarily driven by the power sector, which consumes 90 percent of all domestic coal production. In 1950, however, only 19 percent of coal was used by the power sector due to its high demand by other sectors such as industry, residential and commercial, metallurgical coke ovens, transportation, and electric power, which all accounted for an amount on the order of 5 to 25% of the total coal consumption at the time. Of the coal produced worldwide, approximately 65% is shipped to electricity producers and 33% to industrial consumers, with most of the remainder going to consumers in the residential and commercial sectors. The total share of total world energy consumption by coal is expected to increase to one third (approximately 30 to 33%) in 2035, although growth rates of coal consumption are not expected to be even in all countries where coal is used as an energy source (International Energy Agency, 2010; Energy Information Administration, 2011, 2012a, 2012b).

Coal-fired power plants, also known as electricity generations plants and power stations, provide approximately 42% of U.S. electricity supply and more than over 42% of global electricity supply. In fact, the electricity generation sector is essential to meeting current and future energy needs (MIT, 2007; Speight, 2008; EIA, 2012a, 2012b; Speight, 2013).

Furthermore, global demand for electricity will continue to rise steeply until at least 2040, as the fuels used for electricity generation continue to shift to lower-carbon sources, such as natural gas, nuclear, and renewables. Even now, the demand for electricity continues to rise in all parts of the world. Population and economic growth are two main reasons, just as they are for the projected demand growth in other fuels. But with electricity, there is the switch to electricity from other forms of energy, such as oil or biomass for lighting and heating in the home, or coal in the industrial sector. The key to this growing demand is to make electricity generation more efficient than is currently observed.

Current trends in the electric power market have many coal-fired generators in the United States slated for retirement (Energy Information Administration, 2010, 2011, 2012a, 2012b). Most of the coal-fired power plants projected to retire are older, inefficient units, primarily concentrated in the Mid-Atlantic, Ohio River Valley, and Southeastern United States, where excess electricity generating capacity currently exists. Lower natural gas prices, higher coal prices, slower economic growth, and the implementation of environmental rules all play a role in the retirements. Coal-fired generators in these regions, especially older, less efficient ones that lack pollution control equipment, are sensitive to changing trends in fuel prices and electricity demand, which are two key factors that influence retirement decisions.

The coal-fired power plants vulnerable to retirement are older power plants generators with high heat rates (lower efficiency) that do not have flue gas desulfurization (FGD) systems installed. Approximately 43% of all coal-fired plants did not have flue gas desulfurization systems installed as of 2010, and such plants will be required to install either a FGD or a dry sorbent injection system to continue operating in compliance with the mercury and air toxics standards (MATS).

Coal capacity retirements are sensitive to natural gas prices. Lower natural gas prices make coal-fired generation less competitive with natural gas-fired generation. Because natural gas is often the marginal fuel for power generation, lower natural gas prices also tend to reduce the overall wholesale electricity price, further reducing revenues for coal-fired generators.

Installation of environmental control systems will add internal energy requirements reducing the efficiency of the plant. There are some changes that can be employed to make an existing unit more efficient. However, these changes typically will only result in an improvement to efficiency of a percentage point or so. In order to produce higher efficiency ratings, higher pressure and temperatures are required. This increases the cost of the plant, as special alloy materials will be needed. Technology improvements can assist by lowering the cost of these special materials through discovery and better manufacturing process.

In the context of this book, the more efficient use of coal is the focus, since electricity from coal represents more than 50% of current electricity generation in the United States.

Electricity generation in coal-fired power station requires combustion of the coal, after which the energy released during the combustion is used to generate steam, which is then used to drive the turbine generators that produce electricity. The power station can be conveniently divided in five separate but, in reality, integrated operations, which are (1) the combustor or firebox, (2) the boiler, (3) the turbine generator, and (4) the condenser.

Before the coal is burned in the *combustor*, it is pulverized (often to an extremely small size that has been stated to have the appearance of a black talcum powder), after which the coal is mixed with hot air and blown into the combustor. The coal is burned in suspension, which provides the most complete combustion and maximum heat possible.

In the *boiler*, purified water is pumped through pipes inside the boiler, which converts the water to steam. At temperatures up to 540°C (1000°F) and under pressures up to 3500 psi, the steam is piped to the *turbine* where it contacts a series of turbine blades and turns the turbine shaft. The turbine shaft is connected to the shaft of the generator, where magnets spin within wire coils to produce electricity. The steam is then drawn into a condenser which condenses the steam back into water so that it can be used over and over again in the plant. Millions of gallons of cooling water are pumped through a network of tubes that runs through the condenser, and after the steam is condensed, it is pumped to the boiler again to repeat the cycle.