Urban air pollution problems have existed for centuries and result from the burning of wood, vegetation, coal, natural gas, oil, gasoline, kerosene, diesel, waste, and chemicals. Two general types of urban-scale pollution were identified in the twentieth century: *London-type smog* and *photochemical smog*. The former results from the burning of coal and other raw materials in the presence of a fog or strong inversion, and the latter results from the emission of hydrocarbons and oxides of nitrogen in the presence of sunlight. In most places, urban pollution consists of a combination of the two. In this chapter, gas-phase urban air pollution is discussed in terms of its early history, early regulation, and chemistry.

4.1. HISTORY AND EARLY REGULATION OF URBAN AIR POLLUTION

Before the twentieth century, air pollution was not treated as a science but as a regulatory or legal problem. Because regulations were often weak or not enforced and health problems associated with air pollution were not well understood, pollution problems were rarely mitigated. In this section, a brief history of air pollution and its regulation until the 1940s is discussed.

4.1.1. Before 1200

In ancient Greece, town leaders were responsible for keeping sources of odors outside of town. In ancient Rome, air pollution resulted in civil lawsuits. The Roman poet Horace noted thousands of wood-burning fires (Hughes, 1994) and the blackening of buildings (Brimblecombe, 1999). Air pollution events caused by emissions under strong inversions in Rome were called *heavy heavens* (Hughes, 1994).

Another ancient source of pollution was copper smelting. The smelting of copper to produce coins near the Mediterranean Sea during Roman times and in China during the Song dynasty (960–1279) caused airborne copper concentrations to increase, as detected by Greenland ice-core measurements (Hong et al., 1996).

4.1.2. 1200–1700

In London in the Middle Ages, a major source of pollution was the heating of limestone [which contains $CaCO_3$(s), calcium carbonate] in kilns, using oak brushwood as an energy source, to produce quicklime [CaO(s), calcium oxide]. Quicklime was then mixed with water to produce a cement, slaked lime [$Ca(OH)_2$(s), calcium hydroxide], a building material. This process released organic gases, nitric oxide, carbon dioxide, and organic particulate matter into the air.

Sea coal was introduced into London as early as 1228 and gradually replaced the use of wood as a source of energy in lime kilns (and forges). Wood shortages may have led to a surge in the use of sea coal by the mid-1200s. The burning of sea coal resulted in the release of sulfur dioxide, carbon dioxide, nitric oxide, soot, and particulate organic matter. Coal merchants in London lived in Sea Coal Lane, and they would sell their coal to limeburners on nearby Limeburner's Lane (Brimblecombe, 1987). The quantity of coal burned per forge may have been only one-thousandth of that burned per lime kiln.

The pollution in London due to the burning of sea coal became so severe that, starting in 1285, a commission was set up to remedy the situation. The commission met for several years, and by 1306, King Edward I banned the use of coal in lime kilns. The punishment was "grievous ransom," which may have meant fines and furnace confiscation (Brimblecombe, 1987). By 1329, the ban had either been lifted or lost its effect.

Between the thirteenth and eighteenth centuries, the use of sea coal and charcoal increased in England. Coal was used not only in lime kilns and forges, but also in glass furnaces, brick furnaces, breweries, and home heating. One of the early writers on air pollution was **John Evelyn** (1620–1706), who wrote *Fumifugium, or The Inconveniencie of the Aer and the Smoake of London Dissipated* in 1661. He explained how smoke in London was responsible for the fouling of churches, palaces, clothes, furnishings, paintings, rain, dew, water, and plants. He blamed "Brewers, Diers, Limeburners, Salt and Sope-boylers" for the problems.

4.1.3. 1700–1840 – The Steam Engine

Air quality in Great Britain (the union of England, Scotland, and Wales) worsened in the eighteenth century due to the invention of the steam engine, a machine that burned coal to produce mechanical energy. The idea for the steam engine originated with the French-born English physicist **Denis Papin** (1647–1712), who invented the pressure cooker (1679) while working with Robert Boyle. In this device, water was boiled under a closed lid. The addition of steam (water vapor at high temperature) to the air in the cooker increased the total air pressure exerted on the cooker's lid. Papin noticed that the high pressure pushed the lid up. The phenomenon gave him the idea that steam could be used to push up a piston in a cylinder, and the movement of the cylinder could be used to do work. Although he designed such a cylinder-and-piston steam engine, Papin never built one.

Capitalizing on the idea of Papin, **Thomas Savery** (1650–1715), an English engineer, patented the first practical steam engine in 1698. The engine replaced horses as a source of energy for pumping water out of coal mines. Its main limitation was that it did not work well under high pressure. Following Savery, **Thomas Newcomen** (1663–1729), an English engineer, developed a modified steam engine in 1712 that overcame some of the problems in Savery's engine. Because Savery had a patent on the steam engine, Newcomen was forced to enter into partnership with Savery to market the Newcomen engine. Newcomen's engine was used to pump water out of mines and power waterwheels. Steam engines in the early eighteenth century were inefficient, capturing only 1 percent of their maximum possible energy (McNeill, 2000). Because coal mines were not located in cities, early steam engines did not contribute greatly to urban pollution.

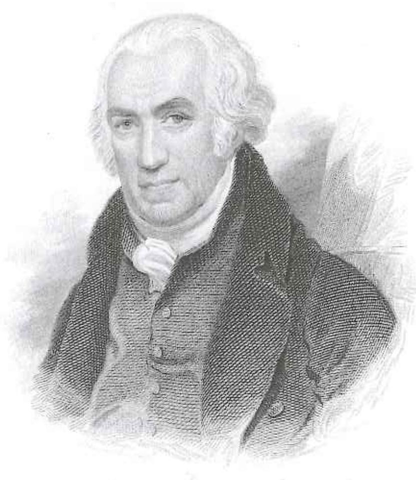

Figure 4.1. James Watt (1736–1819).

In 1763, Scottish engineer and inventor **James Watt** (1736–1819; Fig. 4.1) was given a Newcomen steam engine to repair. While fixing the engine, he realized that its efficiency could be improved. After years of work on the idea, he developed an engine that contained a separate chamber for condensing steam. In 1769, he received a patent for the revised steam engine. Watt made further modifications until 1800, including an engine in which the steam was supplied to both sides of the piston and an engine in which motions were circular instead of up and down. Watt's engines were used not only to pump water out of mines, but also to provide energy for paper mills, iron mills, flour mills, cotton mills, steel mills, distilleries, canals, waterworks, and locomotives. For many of these uses, steam engines were located in urban areas, increasing air pollution. Pollution became particularly severe because, although Watt had improved the steam engine, it still captured only 5 percent of the energy it used by 1800 (McNeill, 2000). Because the steam engine was a large, centralized source of energy, it was responsible for the shift from the artisan shop to the factory system of industrial production during the **Industrial Revolution** of 1750–1880 (Rosenberg and Birdzell, 1986).

In the nineteenth century, the steam engine was used not only in Great Britain, but also in many other countries, providing a new source of energy and pollution in those countries. The steam engine played a large part in a hundred-fold global increase in coal combustion between 1800 and 1900. Industries centered around coal combustion arose in the United States, Belgium, Germany, Russia, Japan, India, South Africa, and Australia, among other nations.

Pollution problems in Great Britain worsened not only because of steam-engine emissions, but also because of coal combustion in furnaces and boilers and chemical combustion in factories. Between 1800 and 1900, air pollution may have killed people in Great Britain at a rate four to seven times the rate it killed people worldwide (Clapp, 1994).

4.1.4. Regulation in the United Kingdom, 1840–1930

The severity of pollution in the United Kingdom (the 1803 union of Great Britain and Northern Ireland) was sufficient that, in 1843, a committee was set up in London to obtain information about pollution from furnaces and heated steam boilers. Bills were brought before Parliament in 1843 and 1845 to limit emissions, but they were defeated. A third bill was withdrawn in 1846. In 1845, the Railway Clauses Consolidated Act, which required railway engines to consume their own smoke, was enacted. In 1846, a public health bill passed with a clause discussing the reduction of smoke emissions from furnaces and boilers. The clause, was removed following pressure by industry. Additional bills failed in 1849 and 1850.

In 1851, an emission clause passed in a sewer bill for the city of London, and this clause was enforced through citations. In 1853, a Smoke Nuisance Abatement (Metropolis) Act also passed through Parliament. This law was enforced only after several years of delay. In 1863, Parliament passed the Alkali Act, which reduced emissions of hydrochloric acid gas formed during soap production. Air pollution legislation also appeared in the Sanitary Acts of 1858 and 1866, the Public Health Acts of 1875 and 1891, and the Smoke Abatement Act of 1926.

4.1.5. Early Regulation in the United States, 1869–1940

Most pollution in the United States in the nineteenth century resulted from the burning of coal for manufacturing, home heating, and transportation. Early pollution control was not carried out by state or national agencies, but delegated to municipalities. The first clean air law in the United States may have been an 1869 ordinance by the city of Pittsburgh outlawing the burning of soft coal in locomotives within the city limits. This law, was not enforced. In 1881, Cincinnati passed a law requiring smoke reductions and the appointment of a smoke inspector. Again, the ordinance was not enforced, although the three primary causes of death in Cincinnati in 1886 were lung-related: tuberculosis, pneumonia, and bronchitis (Stradling, 1999). In 1881, a smoke-reduction law passed in Chicago. Although this law had the support of the judiciary, it had little effect.

St. Louis may have been the first city to pass effective legislation. In 1893, the city council passed a law forbidding the emission of "dense black or thick gray smoke" and a second law creating a commission to appoint an inspector and examine smoke-related issues. The ordinance, was overturned by the Missouri State Supreme Court in 1897. The Court stated that the ordinance exceeded the "power of the city under its charter" and was "wholly unreasonable" (Stradling, 1999). Nevertheless, by 1920, air pollution ordinances existed in 175 municipalities; by 1940, this number increased to 200 (Heinsohn and Kabel, 1999).

In 1910, Massachusetts became the first state to regulate air pollution by enacting smoke-control laws for the city of Boston. The first federal involvement in air pollution was probably the creation of an Office of Air Pollution by the Department of Interior's Bureau of Mines in the early 1900s. The purpose of this office was to control emission of coal smoke. The office was relatively inactive and was eliminated shortly thereafter.

Although early regulations in the United Kingdom and the United States did not reduce pollution, they led to pollution-control technologies, such as technologies for recycling chlorine from soda-ash factory emissions and the electrostatic precipitator, used for reducing particle emissions from stacks. Inventions unrelated to air pollution relocated some pollution problems. The advent of the electric motor in the twentieth century, for example, centralized sources of combustion at electric utilities, reducing air pollution at individual factories that had relied on energy from the steam engine.

4.1.6. London-type Smog

In 1905, the term **smog** was introduced by **Harold Antoine Des Voeux**, a member of the Coal Smoke Abatement Society in London, to describe the combination of smoke and fog that was visible in several cities throughout Great Britain. The term spread after Des Voeux presented a report at the Manchester Conference of the Smoke Abatement League of Great Britain in 1911 describing smog events in the autumn of 1909 in Glasgow and Edinburgh, Scotland, that killed more than 1,000 people.

The smoke in smog at the time was due to emissions from the burning of coal and other raw materials. Coal was combusted to generate energy, and raw materials were burned to produce chemicals, particularly **soda ash** [$Na_2CO_3(s)$], used in consumable products, such as soap, detergents, cleansers, paper, glass, and dyes. To produce soda ash, many materials, including charcoal, elemental sulfur, potassium nitrate, sodium chloride, and calcium carbonate were burned, emitting soot, sulfuric acid, nitric acid, hydrochloric acid, calcium sulfide, and hydrogen sulfide, among other compounds.