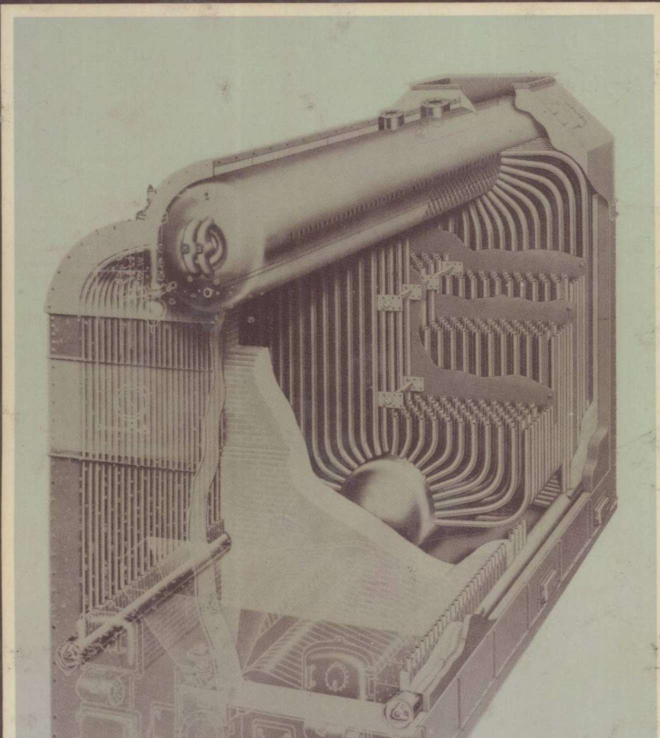
James J. Jackson

Steam Boiler Operation

Principles and Practice



Second Edition

Steam Boiler Operation: principles and practice

SECOND EDITION

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Preface to the First Edition

Steam Boiler Operation: Principles and Practice was written to fill a need for a practical text on effective power plant operation. Present literature is either very elementary or assumes a college education. This book will provide practical information for the professional or the lay person.

Based on over 35 years experience in the production and use of steam, this book attempts to pass along the essence of that experience.

Before the advent of the "energy crisis," the operation of steam-producing equipment and the ultimate use of steam, for any purpose, was of little concern to the general public. Whether they be apartment dwellers, or home owners who rely on a boiler man for heat and hot water, or the head of a large corporation who assumes that somebody is looking after the power house, consumers of steam power have only recently begun to appreciate the role of steam energy in their daily lives. It has now become apparent that energy-conversion equipment such as boilers and engines must be operated efficiently. This book, therefore, is prepared as a guide for persons whose daily work is energy conversion—whether they operate a small heating boiler or the largest power plants.

Conservative estimates suggest that if all steam-producing and using equipment in the United States were operated efficiently, an immediate reduction of energy consumption of 25% would be possible. Rising costs of fuel and the need for this country to become as energy-independent as possible demand that these savings be achieved. It is to specialists in the power plant field that this nation must look for energy conservation.

JAMES J. JACKSON

Preface to the Second Edition

The energy crisis of the past decade has made industrial, commercial, and domestic consumers of all forms of energy aware of the finite nature and high cost of nonrenewable fossil fuels. The failure of the nuclear power industry to establish itself as a viable alternative to fossil-fired plants assures, for the forseeable future, a reliance on coal, natural gas, and oil to fuel our power plants.

The basic laws of steam boiler operation remain valid, but in preparing the second edition, I have included the most widely used innovations that have been generated by the energy crisis. Due to the broad acceptance of the first edition, I have also had the benefit of suggestions from the academic world and power plant personnel, whose contributions have been incorporated in the revised text.

As in the past, it is the knowledge and skill of the watch engineer that will enable us to operate boilers efficiently to extract maximum value from all energy sources.

JAMES J. JACKSON

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1

A Brief History of Steam

Lord, send a man like Robbie Burns, to sing the song of steam.

Rudyard Kipling, "M' Andrews Hymn"

The dictionary defines steam as "the gas or vapor into which water is changed by boiling, especially when used under pressure as a source of energy." Man has been familiar with steam for thousands of years, but only in the last two centuries has he discovered how to utilize steam to his advantage.

The application of early technology in the ancient world was influenced by the socio-economic structure of the era. As long as thousands of slaves could be used to do heavy work and supply the needs of a minority, there was no incentive to seek mechanical substitutes for human toil. The great Greek and Roman engineers had a remarkable knowledge of the properties of steam and hot air but made no attempt to apply their knowledge.

Hero of Alexandria was able to open the temple gates at sunrise by an ingenious arrangement of lenses concentrating the sun's rays on a tank of water that expanded when heated and caused the gates to open. His "Whirling Aeolipile" (see Fig. 1-1) employed in its simplest form the principle of the reaction turbine and jet engine of today, but at the time was considered only an amusing toy.

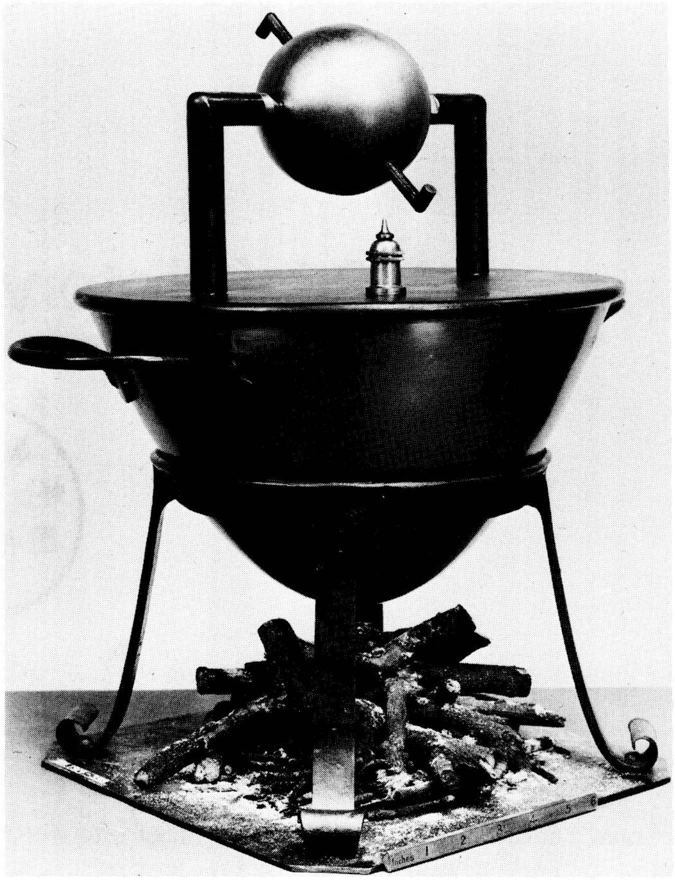

Figure 1-1. Hero's aeolipile, c. A.D. 50. *(Courtesy of British Crown Copyright, The Science Museum, London)*

After the Western Roman Empire collapsed in the fifth century A.D., Europe sank into the Dark Ages and no significant scientific inventions were produced for a thousand years.

The dawn of the Renaissance in the 15th century witnessed great progress in art, literature, and a wide range of learning, and set the stage for men to regard scientific inquiry and invention as essential for human progress. Many experiments were undertaken, which demonstrated a multitude of scientific principles.

In 1606, Giovanni Battista della Porta described two laboratory experiments that showed the power of steam to shift water by forcing the steam into a sealed tank of water. The steam built up pressure and forced out the water.

In della Porta's second experiment a flask with a long slender neck was filled with steam and the neck was inserted into a tank of water. The steam condensed, creating a vacuum and atmospheric pressure forced the water into the flask.

Soon after della Porta's experiments, Salomon de Caus, a Frenchman living in England, devised an ingenious use for steam pressure. de Caus, a noted landscape gardener, placed a spherical water tank over a fire, thus making a simple boiler. A pipe atop the sphere emitted a stream of water when the steam pressure was intensified by heat from the fire, thus creating a steam-powered fountain.

One of the great scientists of this era was Galileo, famous for his telescope, the pendulum, and his experiments with gravity. In 1641, he was consulted by the engineers of the Grand Duke of Tuscany after they had tried unsuccessfully to make a suction pump. The dukes' engineers were attempting to draw water from a depth of 50 feet. Galileo realized that pumps would draw water up from 28 feet and no deeper. He started experimenting to solve the problem, but died the following year.

One of his pupils, Evangelista Torricelli, continued Galileo's experiments and, in 1643, discovered that the pressure of the atmosphere would support a column of water 32 feet high if the upper end of the tube was sealed and all air pumped out. Torricelli and an associate, Vivani, went a step further and showed that atmospheric pressure would also support a column of mercury thirty inches high, thus demonstrating the principle of the simple barometer.

About this time, in the 1650's in Germany, Otto von Guericke was also experimenting with a vacuum and atmospheric pressure. He demonstrated the power of combining a vacuum with atmospheric pressure by filling a copper sphere with water and pumping it out. He created such a good vacuum that the atmospheric pressure crushed the sphere.

A later experiment by von Guericke was a valuable contribution towards development of the steam engine. He made a cylinder with a tight-fitting sliding piston. Twenty men hauled the piston to the top of the cylinder and the air was evacuated from the cylinder by connecting it to a vacuum sphere. The 20 men strained unsuccessfully to hold the piston at the top of the cylinder; but because of the atmospheric pressure above and the vacuum below, the piston slid down very easily.

It was now becoming clear that a powerful mechanical device could be built, if only a vacuum could be produced rapidly. della Porta had shown that water could be sucked up into a flask by the condensation of steam. Several inventors developed devices based on this principle.

Further work was carried out by Robert Boyle, an Irish chemist and Robert Hooke, his English assistant. Both men made significant contributions to the theory of heat engines, now known as thermodynamics.

Many experiments were being carried out at this time using steam pressure or atmospheric pressure combined with a vacuum. At the end of the 17th century a steam pump was built that effectively combined both sources of power. This was the work of Thomas Savery (Fig. 1-2) who, in 1698, patented an "engine for raising water by the impellant force of fire." A pump was positioned about halfway up a pipe between inlet and outlet. Steam from a boiler was piped to a closed tank until the tank was filled with the steam; then the supply was cut off and cold water was poured over the tank. The steam condensed, creating a vacuum which drew water up the suction pipe into the tank. A nonreturn valve in the suction pipe prevented the water from escaping back down the pipe. The steam cock was opened again and steam entered the tank, the pressure built up and forced the water through a second nonreturn valve to an outlet pipe. The cycle was then repeated.

There is no doubt that Savery's pumps worked, but they were little more than experimental prototypes. In 1699 he installed twin pumps working alternately on the banks of the Thames River in London. The necessary hand operation of the valves was a handicap, but the chief reason for his limited success was the inability of the pumps to lift water more than about 50 feet. The first stage, with a perfect vacuum, should have lifted the water 32 feet, but 20 to 25 feet was their limit and the pressure in the second stage was restricted by the boilers. Savery's boilers were dangerous, since they had no safety valves.

Savery's greatest contribution to the utilization of steam was probably his practical work improving valves and boilers. His predecessors had been experimental scientists and dreamers.

In 1663 the engineer Thomas Newcomen was born in Devonshire, England. He spent his early years in Devon and was apprenticed to a blacksmith and ironmonger. About 1685 he went into partnership with John Calley to supply Devonshire and Cornwall tin mines with needed tools and hardware.

Newcomen was acutely aware of the need to keep the mines free of water. Until this time, the mining of the tin had been basically

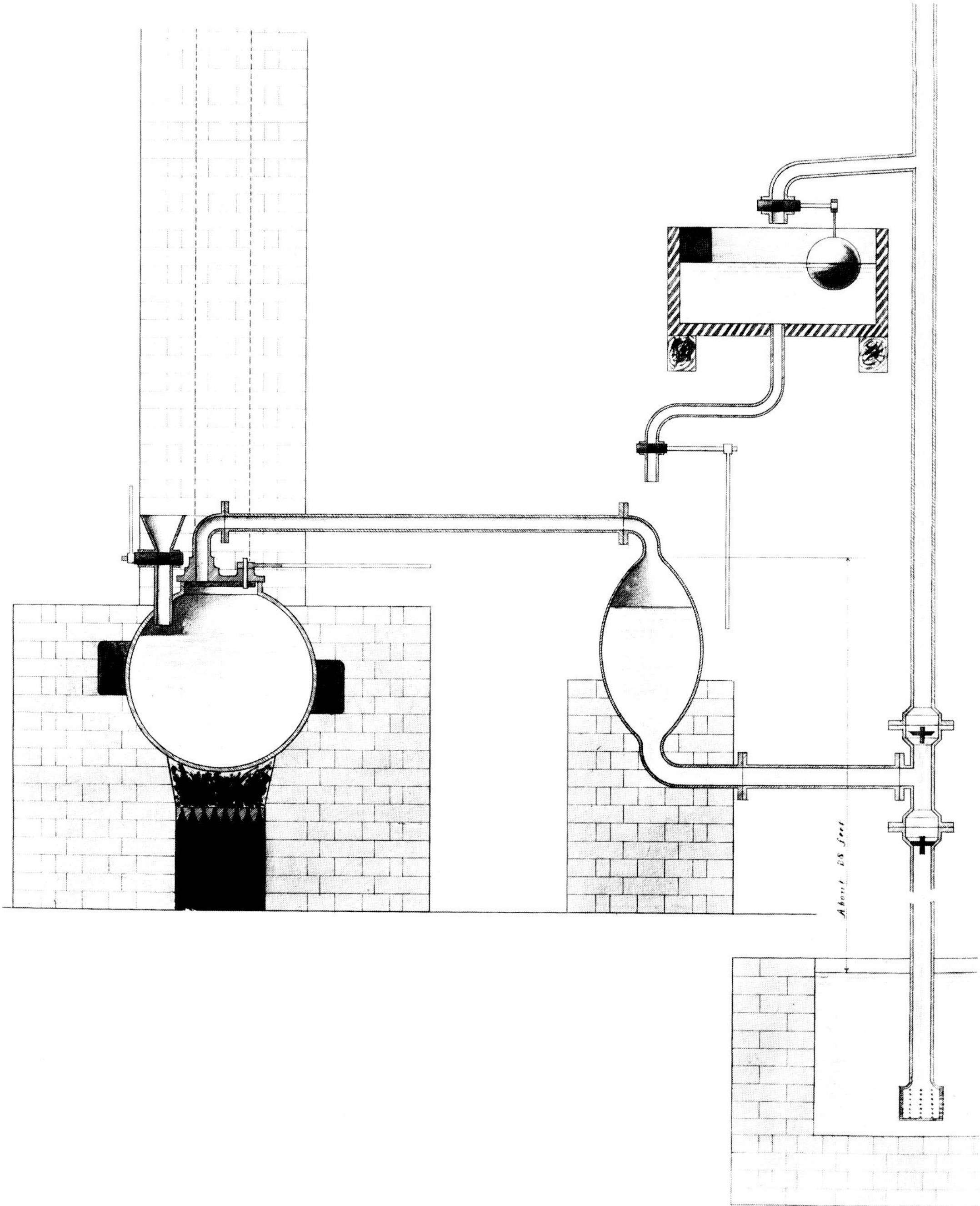

Figure 1-2. Savery's single pumping engine, c. 1699. *(Courtesy of British Crown Copyright, The Science Museum, London)*

surface mining, but with the surface deposits gone, shafts were being sunk to mine at subsurface levels. Being a metal worker, and familiar with all metals, he conducted experiments with power machinery at about the same time as Savery. In 1705, Newcomen and Calley entered into a partnership with Savery.

In 1712, after years of experimentation, Newcomen and Calley built their first successful steam-powered engine (see Fig. 1-3). It was a huge contraption some 30 feet high. Dominating the arrangement was a 25-foot-long oak beam, pivoted at the center, which rocked like a giant see-saw. The beam was used to transmit power from the engine's single cylinder to the water pump. It was, quite naturally, called a "beam engine."

The hand-operated mechanics of Newcomen's engine were based on Savery's original ideas. Under one end of the beam was a brass cylinder and beneath this a boiler. The water inside the boiler was heated from below by a coal fire. Inside the cylinder was a piston that moved up and down, a movement transmitted to the end of the beam by a chain. The other end of the beam was attached to rods that were, in turn, attached to a water pump. The pump end of the beam was made heavier so that the pump stopped in the "down" position and the cylinder end was in the "up" position with the piston at the top of its stroke. A valve was opened on the boiler, admitting steam to the cylinder. The cylinder filled with steam and the valve was then closed. A water-injection cock was opened, condensing the steam in the cylinder and creating a vacuum. Atmospheric pressure forced the piston down and the movement of the beam raised the pump, forcing water out of the mine. When the piston reached the bottom of the cylinder, the heavier end of the beam raised the piston, ready for the next working stroke. Steam was allowed into the cylinder on the upstroke and helped to drive out the water remaining from the condensed steam.

The valves and cocks on Newcomen's early engines were all operated by hand, usually by a boy who constantly had to tend the engine. Legend has it that an inventive young man named Humphrey Potter devised an automatic system of strings and cords to open and close the cocks, basing the device on the rocking movement of the beam. In fact the system of rods and levers later devised to open the cocks automatically was called the "Potter cord."

A "beam engine" therefore, is the basic mechanism that uses direct steam pressure or atmospheric pressure in conjunction with condensing steam. Condensation taking place within a cylinder using

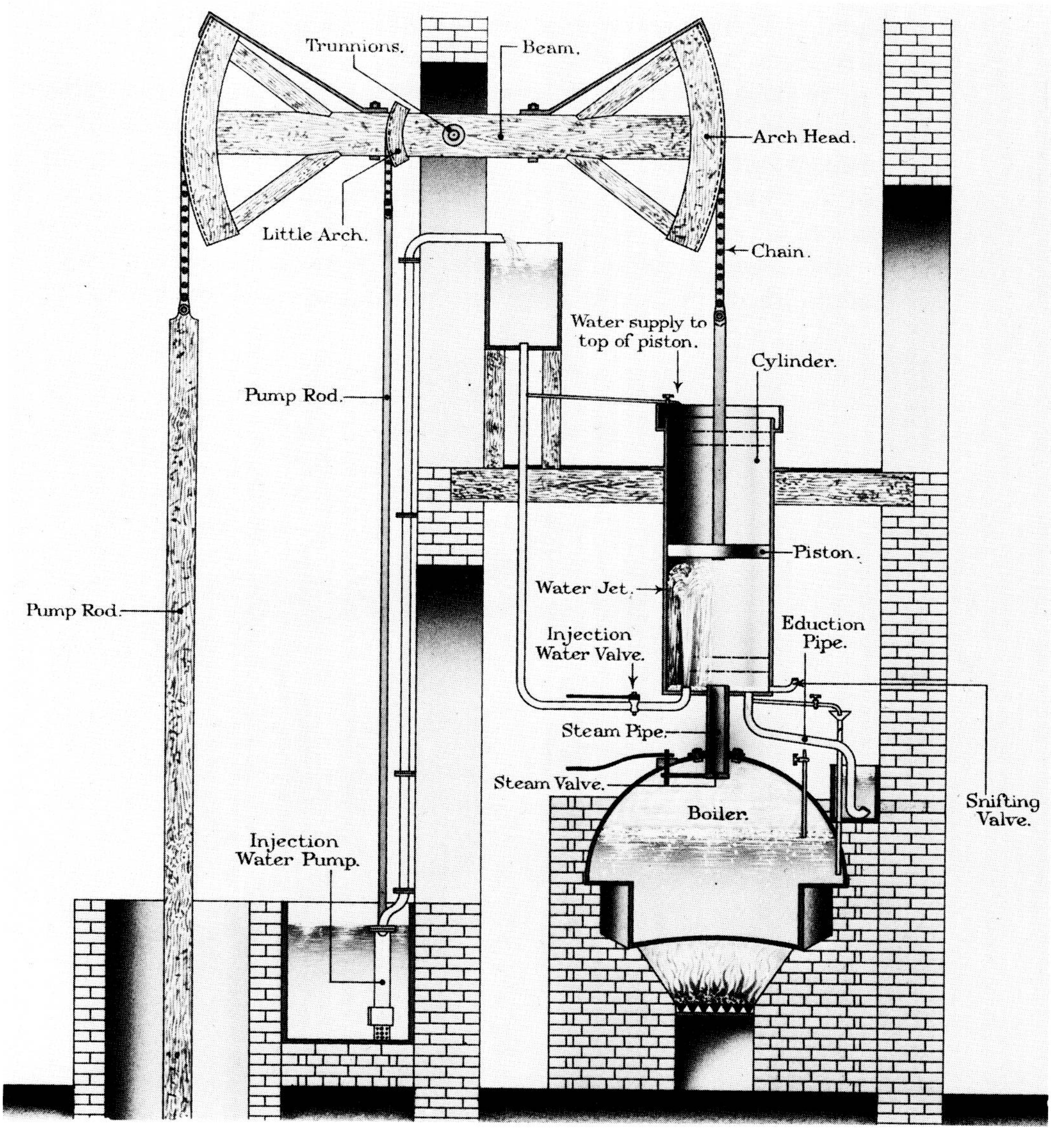

Figure 1-3. Newcomen's pumping engine, c. 1712. *(Courtesy of British Crown Copyright, The Science Museum, London)*

a water spray device was the main feature of what is called the Newcomen type engine. Some improvements were made by other engineers but the basic design remained the same for a century.

By 1725, the atmospheric pressure engine was firmly established and further progress awaited a more reliable boiler capable of sus-