Model Entry

Encyclopedia of the Industrial Revolution, 1750-2007

Steam Engine

As the decisive invention that ushered in the Industrial Revolution, the steam engine literally changed the world. Until the 1780s, humanity had relied on muscle, wind, or water flow for power. From the 1780s, beginning in Britain and then elsewhere in the world, steam engines drove machines to produce textiles, to mill foods, to turn lathes, and eventually to transport people and cargo. In all these applications, the use of steam power exponentially increased production and thus lowered prices. Mass production and therefore mass consumption of all sorts of goods became possible for the first time in history. Particularly steam engine design improvements invented by JAMES WATT in the 1780s thus enabled the Industrial Revolution, and ultimately a consumer revolution.

Within a few years of finding new industrial uses, steam engines also radically changed transport. First steam-driven ships then locomotives in the early 19th century "shrank" the world by cutting travel time, and increasing payloads. Both increases in production and better transportation in turn encouraged rapid urbanization for several reasons. Practical steam power made centralized factory production increasingly attractive and profitable. Unlike wind- or water-driven equipment which needed the right environmental conditions, steam-driven machines could be located anywhere the market demanded: at commercial cities, near easy transport, close to ports, close to fuel, anywhere that rationalized the production process. Concentrating production in advantageous places drew investors, suppliers, and workers to these same communities. These people were the pioneers of the urban industrial environment. Initiating the use of steam engines did not just solve technical issues of production; it reworked the very shape of whole societies.

In the mid-18th century, prior to the invention of the steam engine, production across entire fields of industry faced insurmountable limits because of the lack of reliable power. Earlier in the century, textile manufacturers had exceeded the constraints of human muscle and animal power by applying water power to industrial needs. Water-driven mechanical equipment like RICHARD ARKWRIGHT's WATER FRAME, the powered SPINNING MULE, SPINNING JENNY, and POWERED LOOMS all radically increased production capabilities for thread, yarn, and cloth. But water power imposed conditions that fostered other problems. Water-driven mills had to be located near sources of flowing water. Seasonal conditions affected the availability and flowing force of the water. And water power itself operated within physical limits of weight and gravity. The ultimate answer to such problems was the replacement of water-driven machinery with that driven by steam. The steam engine however, while it transformed basic industries like textiles, itself had a history and development not originally related to the problem of textile production.

Ideas for using steam as a power source existed far back in human history. The ancient Greeks conceived a spinning ball powered by steam escaping through directed pipe vents. The Romans also toyed with the idea of direct steam propulsion. There is no record of a practical application of such ideas, and for several centuries thereafter, no evidence exists of anyone using steam power. By the 1600s, this changed. In 1698, English inventor THOMAS SAVERY earned a patent for a steam pump designed to move water. Savery used heat expansion and cooling to create vacuum pressure to draw water. Although inefficient and using enormous amounts of wood or coal fuel, the engine was a tremendous advance over other pumping options of the day. Some years later, another English inventor, THOMAS NEWCOMEN, developed a remarkable improvement of Savery's idea. Where Savery had heated and cooled whole chambers to create differential pressures, Newcomen created a piston and cylinder design. In this model, a piston attached to a rod was driven up and down by changes in pressure created inside the cylinder by the introduction and then expulsion of steam. Unlike Savery's engine, the Newcomen model did not require tremendous pressure in the steam. Rather, the different cylinder pressures came about by the extreme temperature changes resulting from the introduction or the expulsion of the steam. Though Newcomen's engine evolved under improvements by subsequent engineers like JOHN SMEATON, the basic design dominated English steam engine production until roughly 1800. For the most part, people used the Newcomen engine to move water, whether out of coal mines or in water lifts or even to turn waterwheels where natural flow proved insufficient. A much better machine than Savery's, the Newcomen engine still suffered from a terrible inefficiency and high rate of fuel consumption.

Though Savery and Newcomen had solved important problems in steam power, the credit for the steam engine that drove the industrial revolution better belongs to JAMES WATT. In the 1760s, Watt was a mechanic and engineer in Glasgow, Scotland. While working to repair a Newcomen engine, he realized that efficiency would dramatically increase if the cylinder were kept hot instead of alternately heated and cooled. To this point, all steam engines were essentially pumps. They produced a simple up and down motion, directly related to the movement of the piston. Beginning in the 1780s, Watt patented a series of innovations that changed the delivery of steam engine power from simple stroke to rotary motion. James Pickard had secured a patent for attaching a rod to a flywheel in the same manner that foot treadles were already constructed. To avoid dealing with Pickard's claims, Watt invented the so-called "sun and planet gear." In this device, the rod from the engine attached to a fixed gear, which was stroked around another gear. The result was a spin on this second gear, which was attached to a fly wheel and drive shaft. The spinning driveshaft could power other equipment. Watt's rotary motion solution was a major step in the Industrial Revolution because water powered textile equipment was already designed for rotary power. Watt had supplied the means to deliver that power with a steam engine. Watt's decision to apply steam pressure to both sides of the piston, thus creating a "double action" engine, constituted his other major achievement of this decade. Now the engine delivered power from a "push-pull" effect. To this point, steam engines still operated mostly as pumps. By the 1780s, however, Watt had supplied engines for textile production. In 1794, he formed a business with MATTHEW BOULTON to manufacture commercial steam engines for various industrial uses. The partners prospered in their Birmingham firm, making their fortunes and vigorously prosecuting competitors for infringement of patent.

Subsequent development of the steam engine depended upon a technical understanding of thermodynamics. Through insight and experimentation, inventors like RICHARD TREVITHICK achieved increased performance by returning to the concept of high pressure steam, which Watt had abandoned as too likely to cause explosions. Trevithick rightly understood that high pressure steam would create greater power from smaller engines and thus make locomotion possible. Unfortunately, one of Trevithick's high pressure engines exploded in a fatal accident at Greenwich in 1803. Four attendants died and Boulton and Watt used the incident to turn the public against Trevithick's designs. Tragedies like the accident at Greenwich stemmed both from inexperienced operators of the new machines and from general ignorance of the science underlying steam power.

Rigorous scientific understanding of heat processes inherent to steam power came only with the work of French physicist Sadi Carnot and thermodynamic theorists Rudolf Clausius and William Thompson (later named Lord Kelvin). In the 1820s, Carnot first published the work containing the "Carnot Cycle," a description of the most efficient heat-power transfer possible. Not until after his death in the 1830s, however, did his writing earn any public recognition. The Carnot Cycle is the basis for the Second Law of Thermodynamics, which states that over time energy or temperature differences in a system will equalize. The equalization can power work, but never at perfect efficiency. About twenty years later, Clausius and Thompson, working separately, systematized and expanded our understanding of heat and energy transfer. These investigations are the foundation of modern thermodynamics.

In the nineteenth century, steam engines moved beyond just powering industrial equipment and began powering means of transportation. Trevithick built the first locomotive in 1801, but the most successful early model belonged to GEORGE STEPHENSON with his 1829 "Rocket." British engineer WILLIAM SYMINGTON first installed a steam engine to power a boat, but the American ROBERT FULTON created the first commercially successful steamer, which he ran on the Hudson River in 1807.

For the balance of the 1800s, continued improvements on the piston steam engine dominated its development. Only late in the century, SIR CHARLES PARSONS revolutionized steam power with his steam turbine engine. His basic design also benefited greatly in the 1890s from the work of CARL GUSTAF DE LAVAL. The turbine engine differs significantly from a piston engine. The piston engine delivers power by exerting alternating pressures on a piston situated inside a cylinder. The result is a lateral oscillation, or stroke, effect. The turbine engine delivers rotary power derived from rapidly turning blades driven by a flow, eliminating the need to translate reciprocal power to rotary. Turbines may be either impulse type, where the flowing steam strikes blades to move them, or reaction type, where escaping steam emitted from an outlet mounted on a drive shaft turns the whole apparatus. Impulse turbines operated on the same principle as a windmill. Reaction turbines operated on thrust analogous to a rocket. The design of steam turbines did not readily fit them for locomotives, but the turbine engine did make dramatic changes in ship engines and in generators. In 1897 Parsons's company built the first turbine-powered vessel, the *Turbinia,* which astonished British naval officials by achieving speeds over 30 knots, one-third faster than the fastest ships of the day. The Royal Navy decreed that after 1906 all naval vessels would boast turbine engines. In 1907, the Cunard liner *Mauretania* was fitted with turbine engines making it the fastest passenger ship of the day. In more recent times, the steam turbine engine works mostly in power generation. It is especially useful in nuclear power plants, wherein heat from the reactor creates steam used to drive the turbine. Turbine engines used to drive vehicles are now almost universally various gas turbine engines.

In many ways, the steam engine separates the modern, industrial era from the rest of human history. Beginning in the 1700s, creative inventors found ways to apply steam power to basic problems of machinery and transport. The resulting radical increase in output coupled with lowered prices generated mass markets that drove further change. For example, in Britain, cloth that sold for 11 shillings a yard in the 1780s, sold for only 1 shilling by the 1830s. Steam-powered textile equipment allowed one worker to produce as much thread as 200 hand workers. People of the middle and lower classes could now afford, and began to demand, consumer textile products. Steam-powered increases in productivity affected workers' wages. For example, by the 1840s, English textile worker families could collectively earn 30 shillings a week in the steam-powered mills. Such salaries would allow them luxuries like meat, extra clothes, and consumables that rural workers could not have. Steam-driven transport increased the power of rising wages by cutting shipping costs and thus lowering consumer prices. Later, railroads compounded the effect. Thus the application of steam engines to industry and transport not only solved longstanding technical problems, but also created an entirely new consumer economy.

See also: COAL, FACTORY; FACTORY SYSTEM; FLYING SHUTTLE; KAY, JOHN; LUDDITES; PRINTING PRESS, STEAM; PUFFING BILLY; RAILROADS; STEAM TURBINE; TEXTILE TNDUSTRY

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