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JAMES WATT AND THE INVENTION OF THE STEAM ENGINE¹

Born in Greenock, Scotland, James Watt (1736–1819) showed early signs of inventive ability and learned the trade of scientific instruments maker. In 1757, he took employment in this capacity at the University of Glasgow. At the university, he gained important practical knowledge from Joseph Black (1728–99), a professor of medicine whose discoveries laid the foundation for thermodynamics. Here was a striking example of both the high level of sociability among diverse professions—both intellectual and manual—and of the concern of intellectuals with applied science in the Western world. Using Black’s concept of latent heat (that heat does not increase the temperature of boiling water but simply produces more steam), Watt dramatically improved the efficiency of Thomas Newcomen’s (1663–1729) steam engine. The new engine was first patented in 1769. In 1775, the savvy entrepreneur Matthew Boulton (1728–1809) became his business partner. The firm of Boulton and Watt made them both wealthy men. Watt’s improvements to the engine played a fundamental role in the Industrial Revolution.

The following passage is a firsthand account of his experimentations with the steam engine. For a link to the original text click [here](#).

INVENTION OF THE STEAM ENGINE

My attention was first directed, in the year 1759, to the subject of steam-engines, by the late Dr. Robison, then a student in the University of Glasgow, and nearly of my own age. He at that time threw out an idea of applying the power of the steam engine to the moving of wheel carriages, and to other purposes, but the scheme was not matured, and was soon abandoned on his going abroad.

About the year 1761 or 1762 I tried some experiments on the force of steam in a Papin’s digester,² and formed a species of steam-engine by fixing upon it a syringe, one third of an inch diameter, with a solid piston, and furnished also with a cock to admit the steam from the digester, or shut it off at pleasure, as well as to open a communication from the inside of the syringe to the open air by which the steam contained in the syringe might escape. When the communication between the digester and the syringe was opened, the steam entered the syringe, and by its action upon the piston raised a considerable weight (15 lbs.) with which it was loaded. When this was raised as high as was thought proper, the communication with the digester was shut, and that with the atmosphere opened; the steam then made its escape, and the weight descended. The operations were repeated, and, though in this experiment the cock was turned by hand, it was easy to see how it could be done by the machine itself, and to make it work with perfect regularity. But I soon relinquished the idea of constructing an engine upon its principle, from being sensible it

¹ Oliver Thatcher, (Ed.), *The Library of Original Sources*, vol. 6 (New York: University Research Extension, 1907), 305-10, 311-12.

² High pressure cooker created by Denis Papin (1647–1712).

would be liable to some of the objects against Savery's³ engine, viz., the danger of bursting the boiler, and the difficulty of making the joints tight, and also that a great part of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston. I, however, described this engine in the fourth article of the specification of my patent of 1769; and again in the specification of another patent in the year 1784, together with a mode of applying it to the moving of wheel carriages.

The attention necessary to the avocations of business⁴ prevented me from then prosecuting the subject further, but in the winter of 1763-4, having occasion to repair a model of Newcomen's engine belonging to the Natural Philosophy class of the University of Glasgow, my mind was again directed to it. At that period my knowledge was derived principally from the Desaguliers,⁵ and partly from Belidor,⁶ I set about repairing it as a mere mechanism; and when that was done, and it was set to work, I was surprised to find that its boiler could not supply it with steam, though apparently quite large enough (the cylinder of the model being two inches in diameter, and six inches stroke, and the boiler about nine inches in diameter). By blowing the fire it was made to take a few strokes, but required an enormous quantity of injection water, though it was very lightly loaded by the column of water in the pump. It soon occurred that this was caused by the little cylinder exposing a greater surface to condense the steam, than the cylinders of larger engines did in this proportion to their respective contents. It was found that by shortening the column of water in the pump, the boiler could supply to cylinder with steam, and that the engine would work regularly with a moderate quantity of injection. It now appeared that the cylinder of the model, being of brass, would conduct heat much better than the cast iron cylinders of larger engines (generally covered on the inside with a stony crust) and that considerable advantage could be gained by making the cylinders of some substance that would receive and give out heat slowly. Of these wood seemed to be the most likely, provided it should prove sufficiently durable. A small engine was, therefore, constructed, with a cylinder six inches diameter, and twelve inches stroke, made of wood, soaked in linseed oil, and baked to dryness. With this engine many experiments were made, but it was soon found that the wooden cylinder was not likely to prove durable, and that the steam condensed in filling it still exceeded the proportion of that required for large engines, according to the statements of Desaguliers. It was also found that all attempts to produce a better exhaustion by throwing in more injection caused a disproportionate waste of steam. On reflection, the cause of this seemed to be the boiling of water in vacuo at low heats, a discovery lately made by Dr. Cullen⁷ and some other philosophers (below 100°, as I was then informed) and consequently, at greater heats, the water in the cylinder would produce a steam which would, in part, resist the pressure of the atmosphere.

By experiments which I then tried upon the heats at which water boils under several pressures greater than that of the atmosphere, it appeared that when the heats proceeded in an arithmetical, the elasticities proceeded in some geometrical ratio; and, by laying down a curve from my data, I ascertained the particular one near enough for my purpose. It also

³ A very early version of the steam engine invented in 1698 by Thomas Savery (1650–1715).

⁴ At this time Watt had found work as a surveyor.

⁵ A French-born natural philosopher who was also an inventor and a scientist (1683–1729).

⁶ A French engineer who was significant to the development of hydraulics (1698–1761).

⁷ William Cullen (1710–90) was a professor at the University of Edinburgh Medical School.

appeared that any approach to a vacuum could only be obtained by throwing in large quantities of injection, which would cool the cylinder so much as to require quantities of steam to heat it again, out of proportion to the power gained by the more perfect vacuum, and that the old engineers had acted wisely in contenting themselves with loading the engine with only six or seven pounds on each square inch of the area of the piston. It being evident that there was a great error in Dr. Desaguliers' calculations of Mr. Beighton's⁸ experiments on the bulk of steam, a Florence flask, capable of containing about a pound of water, had about one ounce of distilled water put into it; a glass tube was fitted into its mouth, and the joining made tight by lapping that part of the tube with pack thread, covered with glazier's putty. When the flask was set upright, the tube reached down near to the surface of the water, and in that position the whole was placed in a tin reflecting oven before a fire, until the water was wholly evaporated, which happened in about an hour, and might have been done sooner had I not wished the heat to exceed that of boiling water. As the air in the flask was heavier than the steam, the latter ascended to the top, and expelled the air through the tube. When the water was all evaporated, the oven and flask were removed from the fire, and a blast of cold air was directed against one side of the flask, to collect the condensed steam in one place. When all was cold, the tube was removed, the flask and its contents were weighted with care, and the flask being made hot, it was dried by blowing into it by bellows, and, when weighted again, was found to have lost rather more than 4 grains, estimated at $4\frac{1}{3}$ grains. When the flask was filled with water, it was found to contain about $17\frac{1}{2}$ ounces of avoirdupois of that fluid which gave about 1800 for the expansion of water converted into steam of the heat of boiling water.

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In repetitions of this experiment at a later date, I simplified the apparatus by omitting the tube and laying the flask upon its side in the oven, partly closing its mouth by a cork, having a notch on one side, and otherwise proceeding as has been mentioned.

I do not consider these experiments as extremely accurate, the only scale beam of a proper size which I had then at my command not being very sensible, and the bulk of the steam being liable to be influenced by the heat to which it is exposed, which in the way described is not easily regulated or ascertained; but, from my experience in actual practice, I esteem the expansion to be rather more than I have computed.

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On reflecting further I perceived that, in order to make the best use of steam, it was necessary first, that the cylinder should be maintained always as hot as the steam which entered it; and, secondly, that when the steam was condensed, the water of which it was composed, and the injection itself, should be cooled down to 100° , or lower, where that was possible. That means of accomplishing these points did not immediately present themselves, but early in 1765 it occurred to me, that if a communication were opened between a cylinder containing steam and another vessel which was exhausted air and other fluids, the steam, as an elastic fluid, would immediately rush into the empty vessel, and continue to do until it had established an equilibrium, and if that vessel were kept very cool by an injection, or otherwise, more steam would continue to enter until the whole was condensed. But both the vessels being exhausted, or nearly so, how were the injection water, the air which would enter with it, and the condensed steam, to be got out? This I

⁸ Henry Beighton (d. 1743) was an English engineer.

proposed, in my own mind, to perform in two ways. One was, by adapting to the second vessel a pipe, reaching downwards more than 34 feet, by which the water would descend (a column of that length overbalancing the atmosphere) and by extracting the air by mean of a pump.

The second method was by employing a pump, or pumps, to extract both the air and the water, which would be applicable in all places, and essential in those cases where there was no well or pit.

This latter method was the one I then preferred, and is the only one I afterwards continued to use.

In Newcomen's engine the piston is kept tight by water, which could not be applicable in this new method; as, if any of it entered into a partially exhausted and hot cylinder, it would boil, and prevent the production of a vacuum, and would also cool the cylinder by its evaporation during the descent of the piston. I proposed to remedy this defect by employing wax, tallow, or other grease, to lubricate and keep the piston tight. It next occurred to me that, the mouth of the cylinder being open, the air which opened to act on the piston would cool the cylinder being open, the air which opened to act on the piston would cool the cylinder, and condense some steam on again filling it. I therefore proposed to put an air-tight cover upon the cylinder, with a hole and stuffing-box for the piston to slide through, and to admit steam above the piston to act upon it, instead of the atmosphere. The piston-rod sliding through a stuffing-box was new in steam engines; it was not necessary in Newcomen's engine, as the mouth of the cylinder was open, and the piston rod was square and very clumsy. The fitting the piston-rod to the piston by a cone was an after improvement of mine (about 1774). There still remained another source of the destruction of steam, the cooling of the cylinder by the external air, which would produce an internal condensation whenever steam entered it, and which would be repeated every stroke; this I proposed to remedy by an external cylinder, containing steam, surrounded by another of wood, or of some other substance which would conduct heat slowly.

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The steam-pipe was adjusted to a small boiler. When the steam was produced, it was admitted into the cylinder, and soon issued through the perforation of the rod, and at the valve of the condenser. When it was judged that the air was expelled, the steam-cock was shut, and the air-pump piston-rod was drawn up, which leaving the small pipes of the condenser in a state of vacuum, the steam entered them and was condensed. The piston of the cylinder immediately rose, and lifted a weight of about 18 lbs., which was hung to the lower end of the piston-rod. The exhaustion-cock was shut, and the steam was readmitted into the cylinder, and the operation was repeated; the quantity of steam consumed, and the weights it could raise, were observed, and, excepting the non-application of the steam-case and external covering, the invention was complete, in so far as regarded the savings of steam and fuel. A large model, with an outer cylinder and wooden case, was immediately constructed, and the experiments made with it served to verify the expectations I had formed, and to place the advantage of the invention beyond the reach of doubt. It was found convenient afterwards to change the pipe-condenser for an empty vessel, generally of a cylindrical form, into which an injection played, and, in consequence there being more water and air to extract, to enlarge the air-pump.

The change was made because, in order to procure a surface sufficiently extensive to condense the steam of a large engine, the pipe-condenser would require to be very

voluminous, and because the bad water with which the engines are frequently supplied would crust over the thin plates, and prevent their conveying the heat sufficiently quick. The cylinders were also placed with their mouths upwards, and furnished with a working beam and other apparatus, as was usual in the ancient engines; the inversion of the cylinder, or rather of the piston rod, in the model, being only an expedient to try more easily the new invention, and being subject to many objections in large engines.

In 1768 I applied for letters patent for my “Methods of Lessening the Consumption of Steam, and, consequently, of Fuel, in Fire-Engines” which passed the seals in January, 1769; and my specification was enrolled in Chancery⁹ in April following.

⁹ The royal secretariat in its administrative role.