CHAPTER II.

THE STEAM-ENGINE AS A TRAIN OF MECHANISM.

"The introduction of new Inventions seemeth to be the very chief of all human Actions. The Benefits of new Inventions may extend to all Mankind universally; but the Good of political Achievements can respect but some particular Cantons of Men; these latter do not endure above a few Ages, the former forever. Inventions make all Men happy, without either Injury or Damage to any one single Person. Furthermore, new Inventions are, as it were, new Erections and Imitations of God's own Works."—Bacon.

The Modern Type, as Developed by Newcomen, Beighton, and Smeaton.

At the beginning of the eighteenth century every element of the modern type of steam-engine had been separately invented and practically applied. The character of atmospheric pressure, and of the pressure of gases, had become understood. The nature of a vacuum was known, and the method of obtaining it by the displacement of the air by steam, and by the condensation of the vapor, was understood. The importance of utilizing the power of steam, and the application of condensation in the removal of atmospheric pressure, was not only recognized, but had been actually and successfully attempted by Morland, Papin, and Savery.

Mechanicians had succeeded in making steam-boilers capable of sustaining any desired or any useful pressure, and Papin had shown how to make them comparatively safe by the attachment of the safety-valve. They had made steam-cylinders fitted with pistons, and had used such a combination in the development of power.

It now only remained for the engineer to combine known forms of mechanism in a practical machine which should be capable of economically and conveniently utilizing the power of steam through the application of now well-understood principles, and by the intelligent combination of physical phenomena already familiar to scientific investigators.

Every essential fact and every vital principle had been learned, and every one of the needed mechanical combinations had been successfully effected. It was only requisite that an inventor should appear, capable of perceiving that these known facts and combinations of mechanism, properly illustrated in a working machine, would present to the world its greatest physical blessing.

The defects of the simple engines constructed up to this time have been noted as each has been described. None of them could be depended upon for safe, economical, and continuous work. Savery's was the most successful of all. But the engine of Savery, even with the improvements of Desaguliers, was unsafe where most needed, because of the high pressures necessarily carried in its boilers when pumping from considerable depths ; it was uneconomical, in consequence of the great loss of heat in its forcing-cylinders when the hot steam was surrounded at its entrance by colder bodies ; it was slow in operation, of great first cost, and expensive in first cost and in repairs, as well as in its operation. It could not be relied upon to do its work uninterruptedly, and was thus in many respects a very unsatisfactory machine.

The man who finally effected a combination of the elements of the modern steam-engine, and produced a machine which is unmistakably a true engine—i. e., a train of mechanism consisting of several elementary pieces combined in a train capable of transmitting a force applied at one end and of communicating it to the resistance to be overcome at the other end—was THOMAS NEWCOMEN, an "iron-monger" and blacksmith of Dartmouth, England. The engine invented by him, and known as the "Atmospheric Steam-Engine," is the first of an entirely new type.

The old type of engine—the steam-engine as a simple machine—had been given as great a degree of perfection, by the successive improvements of Worcester, Savery, and Desaguliers, as it was probably capable of attaining by any modification of its details. The next step was necessarily a complete change of type; and to effect such a change, it was only necessary to combine devices already known and successfully tried.

But little is known of the personal history of Newcomen. His position in life was humble, and the inventor was not then looked upon as an individual of even possible importance in the community. He was considered as one of an eccentric class of schemers, and of an order which, concerning itself with mechanical matters, held the lowest position in the class.

It is supposed that Savery's engine was perfectly well known to Newcomen, and that the latter may have visited Savery at his home in Modbury, which was but fifteen miles from the residence of Newcomen. It is thought, by some biographers of these inventors, that Newcomen was employed by Savery in making the more intricate forgings of his engine. Harris, in his "Lexicon Technicum," states that drawings of the engine of Savery came into the hands of Newcomen, who made a model of the machine, set it up in his garden, and then attempted its improvement; but Switzer says that Newcomen "was as early in his invention as Mr. Savery was in his."

Newcomen was assisted in his experiments by John Calley, who, with him, took out the patent. It has been stated that a visit to Cornwall, where they witnessed the working of a Savery engine, first turned their attention to the subject; but a friend of Savery has stated that Newcomen was as early with his general plans as Savery.

After some discussion with Calley, Newcomen entered into correspondence with Dr. Hooke, proposing a steam-engine to consist of a *steam-cylinder containing a piston similar to that of Papin's, and to drive a separate pump*, similar to those generally in use where water was raised by horse or wind power. Dr. Hooke advised and argued strongly against their plan, but, fortunately, the obstinate belief of the unlearned mechanics was not overpowered by the disquisitions of their distinguished correspondent, and Newcomen and Calley attempted an engine on their peculiar plan. This succeeded so well as to induce them to continue their labors, and, in 1705, to patent,[1] in combination with Savery—who held the exclusive right to practise surface-condensation, and who induced them to allow him an interest with them—an engine combining a steam-cylinder and piston, surface-condensation, a separate boiler, and separate pumps.

In the atmospheric-engine, as first designed, the slow process of condensation by the application of the condensing water to the exterior of the cylinder, to produce the vacuum, caused the strokes of the engine to take place at very long intervals. An improvement was, however, soon effected, which immensely increased the rapidity of condensation. A jet of water was thrown directly *into* the cylinder, thus effecting for the Newcomen engine just what Desaguliers had done for the Savery engine previously. As thus improved, the Newcomen engine is shown in Fig. 19.

Here *b* is the boiler. Steam passes from it through the cock, *d*, and up into the cylinder, *a*, equilibrating the pressure of the atmosphere, and allowing the heavy pump-rod, *k*, to

[1] It has been denied that a patent was issued, but there is no doubt that Savery claimed and received an interest in the new engine.

fall, and, by the greater weight acting through the beam, *i i*, to raise the piston, *s*, to the position shown. The rod *m* carries a counterbalance, if needed. The cock *d* being shut, *f* is then opened, and a jet of water from the reservoir, *g*, enters the cylinder, producing a vacuum by the condensation of the steam. The pressure of the air above the piston now forces it down, again raising the pump-rods, and thus the engine works on indefinitely.

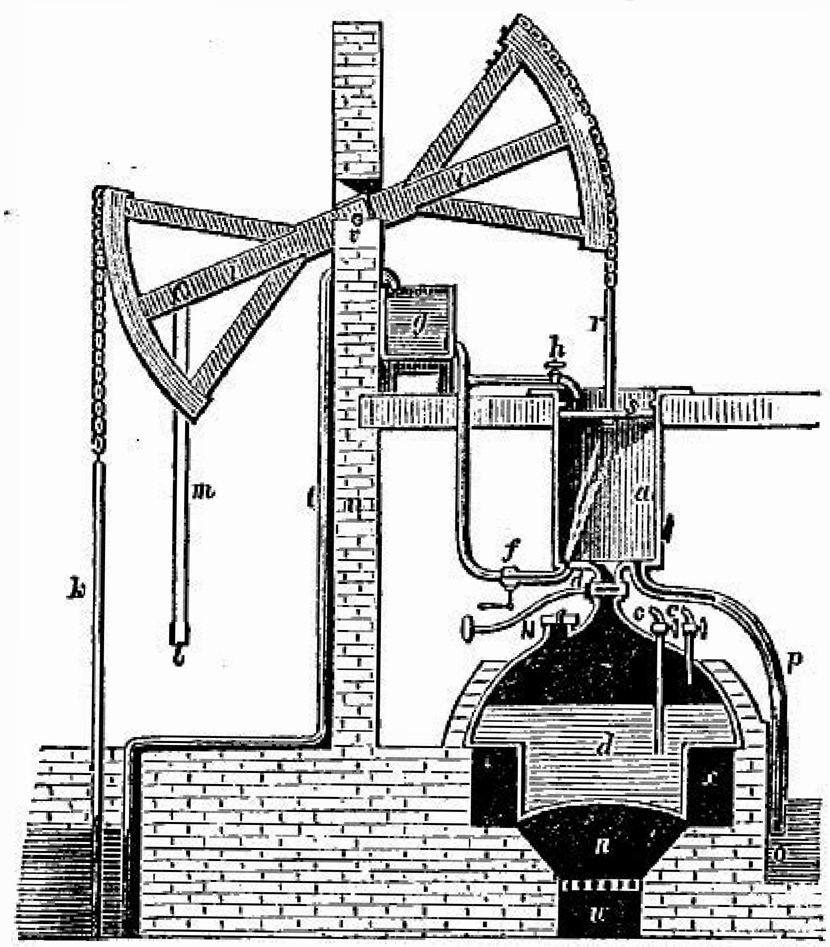

FIG. 19.—Newcomen's Engine, A. D. 1705.

The pipe *h* is used for the purpose of keeping the upper side of the piston covered with water, to prevent air-leaks—a device of Newcomen. Two gauge-cocks, *c c*, and a safety-valve, *N*, are represented in the figure, but it will be noticed that the latter is quite different from the now usual form. Here, the pressure used was hardly greater than that of the atmosphere, and the weight of the valve itself was ordinarily sufficient to keep it down. The condensing water, together with the water of condensation, flows off through the open pipe *p*. Newcomen's first engine made 6 or 8 strokes a minute; the later and improved engines made 10 or 12.

The steam-engine has now assumed a form that somewhat resembles the modern machine.

The Newcomen engine is seen at a glance to have been a combination of earlier ideas. It was the engine of Huyghens, with its cylinder and piston as improved by Papin, by the substitution of steam for the gases generated by the explosion of gunpowder; still further improved by Newcomen and Calley by the addition of the method of condensation used in the Savery engine. It was further modified, with the object of applying it directly to the working of the pumps of the mines by the introduction of the overhead beam, from which the piston was suspended at one end and the pump-rod at the other.

The advantages secured by this combination of inventions were many and manifest. The piston not only gave economy by interposing itself between the impelling and the resisting fluid, but, by affording opportunity to make the area of piston as large as desired, it enabled Newcomen to use any convenient pressure and any desired proportions for any proposed lift. The removal of the water to be lifted from the steam-engine proper and handling it with pumps, was an evident cause of very great economy of steam.

The disposal of the water to be raised in this way also permitted the operations of condensation of steam, and the renewal of pressure on the piston, to be made to succeed each other with rapidity, and enabled the inventor to choose, unhampered, the device for securing promptly the action of condensation.

Desaguliers, in his account of the introduction of the engine of Newcomen, says that, with his coadjutor Calley, he "made several experiments in private about the year 1710, and in the latter end of the year 1711 made proposals to drain the water of a colliery at Griff, in Warwickshire, where the proprietors employed 500 horses, at an expense of £900 a year; but, their invention not meeting with the reception they expected, in March following, through the acquaintance of Mr. Potter, of Bromsgrove, in Worcestershire, they bargained to draw water for Mr. Back, of Wolverhampton, where, after a great many laborious attempts, they did make the engine work; but, not being either philosophers to understand the reason, or mathematicians enough to calculate the powers and proportions of the parts, they very luckily, by accident, found what they sought for."

"They were at a loss about the pumps, but, being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they came, about 1712, to the method of making the pump-valves, clacks, and buckets, whereas they had but an imperfect notion of them before. One thing is very remarkable: as they were at first working, they were surprised to see the engine go several strokes, and very quick together, when, after a search, they found a hole in the piston, which let the cold water in to condense the steam in the inside of the cylinder, whereas, before, they had always done it on the outside. They used before to work with a buoy to the cylinder, inclosed in a pipe, which buoy rose when the steam was strong and opened the injection, and made a stroke; thereby they were only capable of giving 6, 8, or 10 strokes in a minute, till a boy, named Humphrey Potter, in 1713, who attended the engine, added (what he called a *scoggan*) a catch, that the beam always opened, and then it would go 15 or 16 strokes a minute. But, this being perplexed with catches and strings, Mr. Henry Beighton, in an engine he had built at Newcastle-upon-Tyne in 1718, took them all away but the beam itself, and supplied them in a much better manner."

In illustration of the application of the Newcomen engine to the drainage of mines, Farey describes a small machine, of which the pump is 8 inches in diameter, and the lift 162 feet. The column of water to be raised weighed 3,535 pounds. The steam-piston was made 2 feet in diameter, giving an area of 452 square inches. The net working-pressure was assumed at $10\frac{3}{4}$ pounds per square inch; the temperature of the water of condensation and of uncondensed vapor after the entrance of the injection-water being usually about 150° Fahr. This gave an excess of pressure on the steam-side of 1,324 pounds, the total pressure on the piston being 4,859 pounds. One-half of this excess is counterweighted by the pump-rods, and by weight on that end of the beam; and the weight, 662 pounds, acting on each side alternately as a surplus, produced the requisite rapidity of movement of the machine. This engine was said to make 15 strokes per minute, giving a speed of piston of 75 feet per minute, and the power exerted usefully was equivalent to 265,125 pounds raised one foot high per minute. As the horse-power is equivalent to 33,000 "foot-pounds" per minute, the engine was of $\frac{265125}{33000} = 8.034$—almost exactly 8 horse-power.

It is instructive to contrast this estimate with that made for a Savery engine doing the same work. The latter would have raised the water about 26 feet in its "suction-pipe," and would then have forced it, by the direct pressure of steam, the remaining distance of 136 feet; and the steam-pressure required would have been nearly 60 pounds per square inch. With this high temperature and pressure, the waste of steam by condensation in the forcing-vessels would have been so great that it would have compelled the adoption of two engines of considerable size, each lifting the water one-half the height, and using steam of about 25 pounds pressure. Potter's rude valve-gear was soon improved by Henry Beighton, in an engine which that talented engineer erected at Newcastle-upon-Tyne in 1718, and in which he substituted substantial materials for the cords, as in Fig. 20.

In this sketch, *r* is a plug-tree, plug-rod, or plug-frame, as it is variously called, suspended from the great beam, with which it rises and falls, bringing the pins *p* and *k*, at the proper moment, in contact with the handles *k k* and *n n* of the valves, moving them in the proper direction and to the proper extent. A lever safety-valve is here used, at

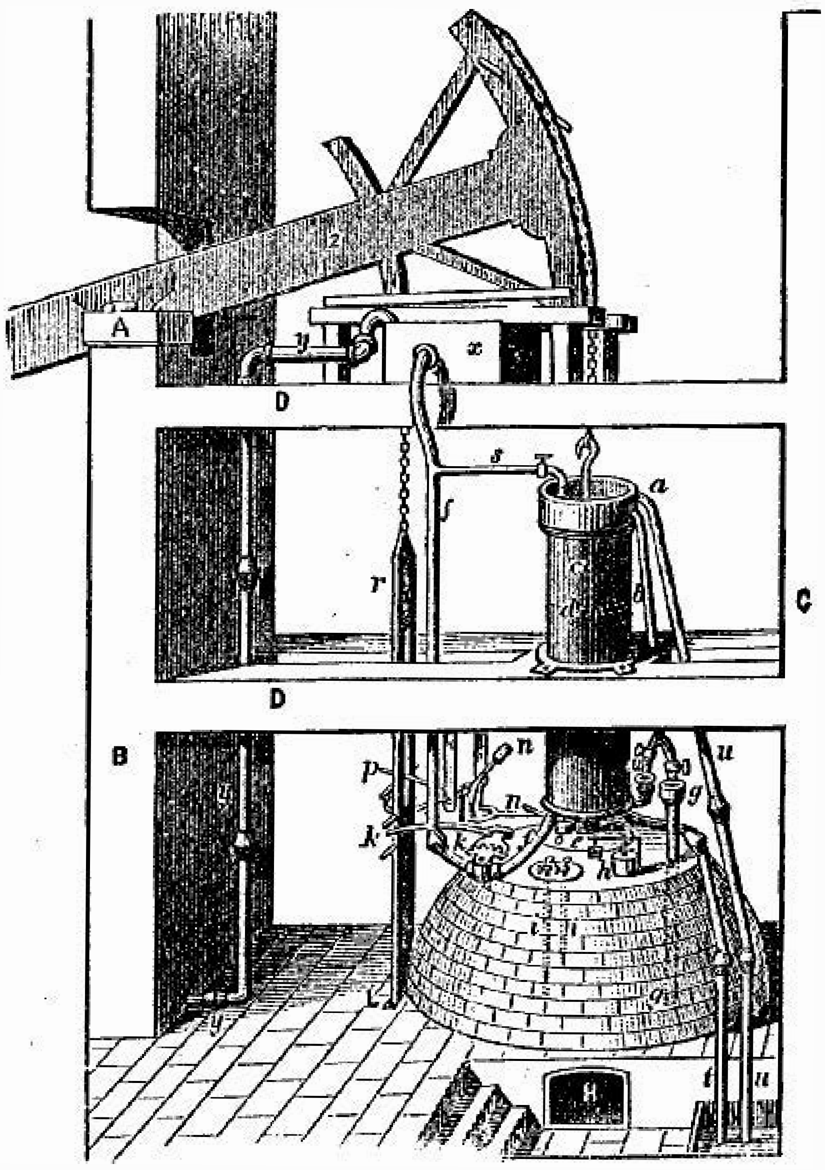

FIG. 20.—Beighton's Valve-Gear, A. D. 1718.

the suggestion, it is said, of Desaguliers. The piston was packed with leather or with rope, and lubricated with tallow.

After the death of Beighton, the atmospheric engine of Newcomen retained its then standard form for many years, and came into extensive use in all the mining districts, particularly in Cornwall, and was also applied occasionally to the drainage of wet lands, to the supply of water to towns, and it was even proposed by Hulls to be used for ship-propulsion.

The proportions of the engines had been determined in a hap-hazard way, and they were in many cases very unsafe. John Smeaton, the most distinguished engineer of his time, finally, in 1769, experimentally determined proper proportions, and built several of these engines of very considerable size. He built his engines with steam-cylinders of greater length of stroke than had been customary, and gave them such dimensions as, by giving a greater excess of pressure on the steam-side, enabled him to obtain a greatly-increased speed of piston. The first of his new style of engine was erected at Long Benton, near Newcastle-upon-Tyne, in 1774.

Fig. 21b illustrates its principal characteristic features. The boiler is not shown.

The steam is led to the engine through the pipe, *C*, and is regulated by turning the cock in the receiver, *D*, which connects with the steam-cylinder by the pipe, *E*, which latter pipe rises a little way above the bottom of the cylinder, *F*, in order that it may not drain off the injection-water into the steam-pipe and receiver.

The steam-cylinder, about ten feet in length, is fitted with a carefully-made piston, *G*, having a flanch rising four or five inches and extending completely around its circumference, and nearly in contact with the interior surface of the cylinder. Between this flanch and the cylinder is driven a "packing" of oakum, which is held in place by weights; this prevents the leakage of air, water, or steam, past the piston, as it rises and falls in the cylinder at each stroke of the engine. The chain and piston-rod connect the piston to the beam, *I I*. The arch-heads at each end of the beam keep the chains of the piston-rod and the pump-rods perpendicular and in line.

A "jack-head" pump, *N*, is driven by a small beam deriving its motion from the plug-rod at *g*, raises the water

[1] A fac-simile of a sketch in Galloway's "On the Steam-Engine," etc.

required for condensing the steam, and keeps the cistern, *O*, supplied. This "jack-head cistern" is sufficiently elevated to give the water entering the cylinder the velocity requisite

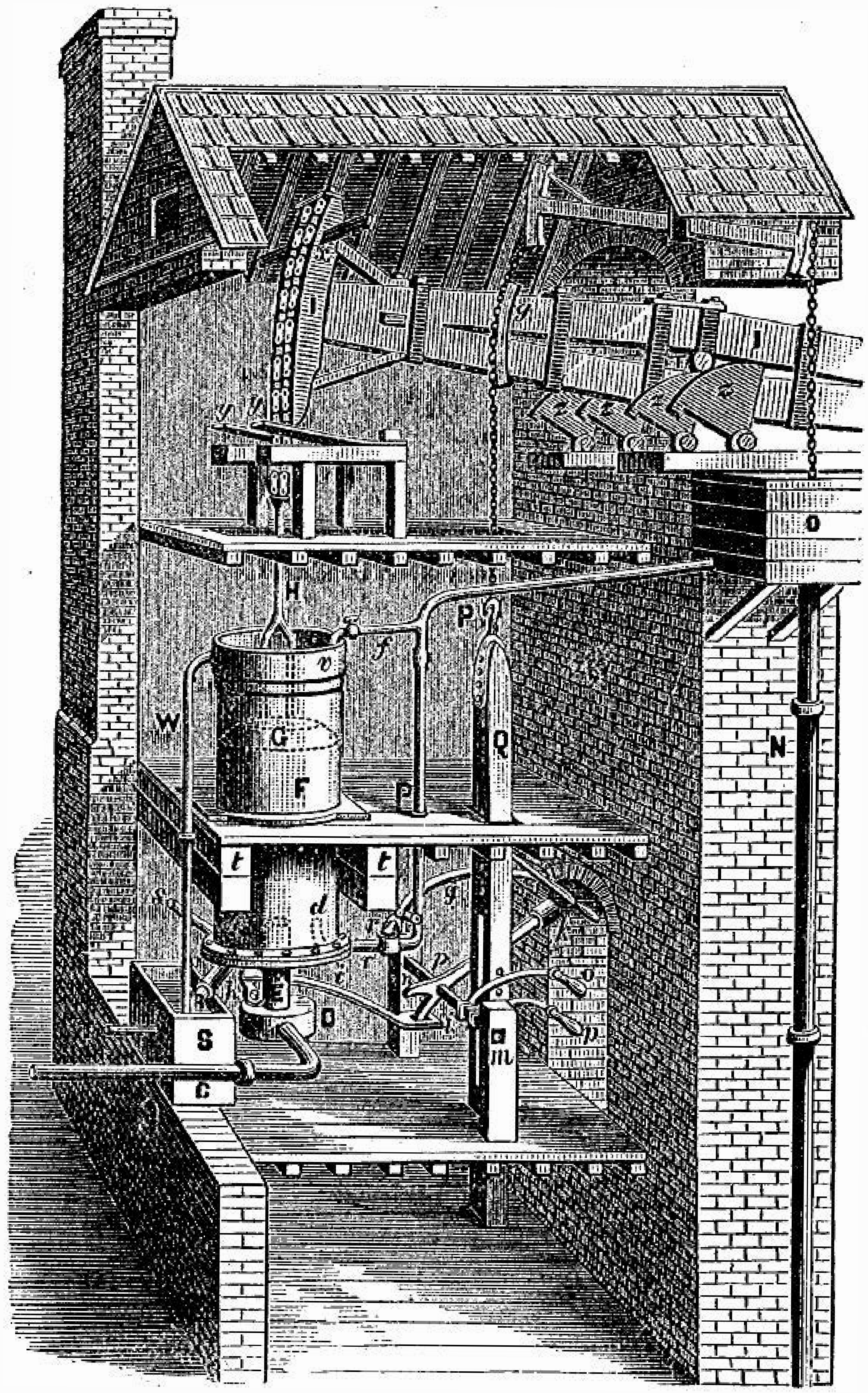

FIG. 21.—Smeaton's Newcomen Engine.

to secure prompt condensation. A waste-pipe carries away any surplus water. The injection-water is led from the cistern by the pipe, *P P*, which is two or three inches in diameter, and the flow of water is regulated by the injection-cock, *r*. The cap at the end, *d*, is pierced with several holes, and the stream thus divided rises in jets when admitted, and, striking the lower side of the piston, the spray thus produced very rapidly condenses the steam, and produces a vacuum beneath the piston. The valve, *e*, on the upper end of the injection-pipe, is a check-valve, to prevent leakage into the engine when the latter is not in operation. The little pipe, *f*, supplies water to the upper side of the piston, and, keeping it flooded, prevents the entrance of air when the packing is not perfectly tight.

The "working-plug," or plug-rod, *Q*, is a piece of timber slit vertically, and carrying pins which engage the handles of the valves, opening and closing them at the proper times. The steam-cock, or regulator, has a handle, *h*, by which it is moved. The iron rod, *i i*, or spanner, gives motion to the handle, *h*.

The vibrating lever, *k l*, called the *Y*, or the "tumbling-bob," moves on the pins, *m n*, and is worked by the levers, *o p*, which in turn are moved by the plug-tree. When *o* is depressed, the loaded end, *k*, is given the position seen in the sketch, and the leg *l* of the *Y* strikes the spanner, *i i*, and, opening the steam-valve, the piston at once rises as steam enters the cylinder, until another pin on the plug-rod raises the piece, *P*, and closes the regulator again. The lever, *q r*, connects with the injection-cock, and is moved, when, as the piston rises, the end, *q*, is struck by a pin on the plug-rod, and the cock is opened and a vacuum produced. The cock is closed on the descent of the plug-tree with the piston. An eduction-pipe, *R*, fitted with a clock, conveys away the water in the cylinder at the end of each down-stroke; the water thus removed is collected in the hot-well, *S*, and is used as feed-water for the boiler, to which it is conveyed by the pipe *T*. At each down-stroke, while the water passes out through *R*, the air which may have collected in the cylinder is driven out through the "snifting-valve," *s*. The steam-cylinder is supported on strong beams, *t t*; it has around its upper edge a guard, *v*, of lead, which prevents the overflow of the water on the top of the piston. The excess of this water flows away to the hot-well through the pipe *W*.

Catch-pins, *x*, are provided, to prevent the beam descending too far should the engine make too long a stroke; two wooden springs, *y y*, receive the blow. The great beam is carried on sectors, *z z*, to diminish losses by friction.

The boilers of Newcomen's earlier engines were made of copper where in contact with the products of combustion, and their upper parts were of lead. Subsequently, sheet-iron was substituted. The steam-space in the boiler was made of 8 or 10 times the capacity of the cylinder of the engine. Even in Smeaton's time, a chimney-damper was not used, and the supply of steam was consequently very variable. In the earlier engines, the cylinder was placed on the boiler; afterward, they were placed separately, and supported on a foundation of masonry. The injection or "jack-head" cistern was placed from 12 to 30 feet above the engine, the velocity due the greater altitude being found to give the most perfect distribution of the water and the promptest condensation.

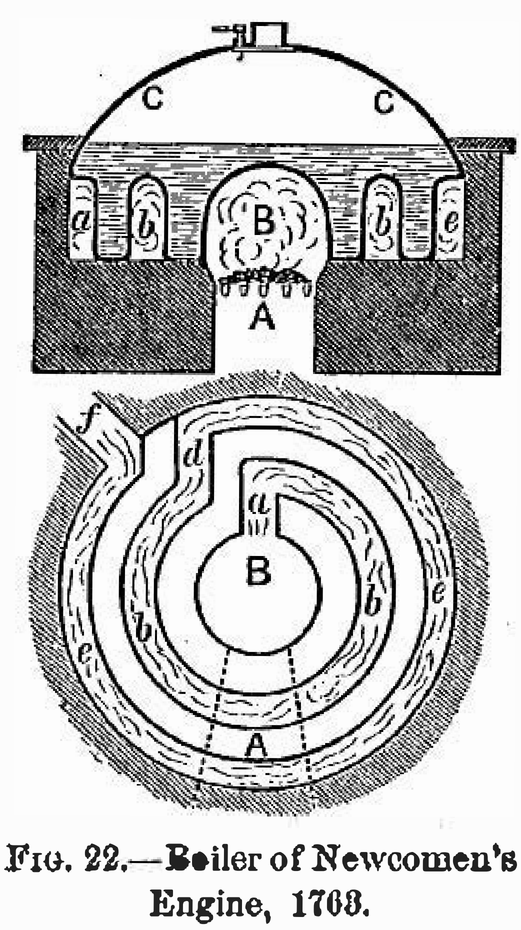

FIG. 22.—Boiler of Newcomen's Engine, 1763.

Smeaton covered the lower side of his steam-pistons with wooden plank about 2¼ inches thick, in order that it should absorb and waste less heat than when the iron was directly exposed to the steam. Mr. Beighton was the first to use the water of condensation for feeding the boiler, taking it directly from the eduction-pipe, or the "hot-well." Where only a sufficient amount of pure water could be obtained for feeding the boiler, and the injection-water was "hard," Mr. Smeaton applied a heater, immersed in the hot-well, through which the feed passed, absorbing heat from the water of condensation *en route* to the boiler. Farey first proposed the use of the "coil-heater"—a pipe, or "worm," which, forming a part of the feed-pipe, was set in the hot-well. As early as 1743, the metal used for the cylinders was cast-iron. The earlier engines had been fitted with brass cylinders. Desaguliers recommended the iron cylinders, as being smoother, thinner, and as having less capacity for heat than those of brass.

In a very few years after the invention of Newcomen's engine it had been introduced into nearly all large mines in Great Britain; and many new mines, which could not have been worked at all previously, were opened, when it was found that the new machine could be relied upon to raise the large quantities of water to be handled. The first engine in Scotland was erected in 1720 at Elphinstone, in Stirlingshire. One was put up in Hungary in 1723.

The first mine-engine, erected in 1712 at Griff, was 22 inches in diameter, and the second and third engines were of similar size. That erected at Ansthorpe was 23 inches in diameter of cylinder, and it was a long time before much larger engines were constructed. Smeaton and others finally made them as large as 6 feet in diameter.

In calculating the lifting-power of his engines, Newcomen's method was "to square the diameter of the cylinder in inches, and, cutting off the last figure, he called it 'long hundredweights;' then writing a cipher on the right hand, he called the number on that side 'odd pounds;' this he reckoned tolerably exact at a mean, or rather when the barometer was above 30 inches, and the air heavy." In allowing for frictional and other losses, he deducted from one-fourth to one-third. Desaguliers found the rule quite exact. The usual mean pressure resisting the motion of the piston averaged, in the best engines, about 8 pounds per square inch of its area. The speed of the piston was from 150 to 175 feet per minute. The temperature of the hot-well was from 145° to 175° Fahr.

Smeaton made a number of test-trials of Newcomen engines to determine their "duty"—i. e., to ascertain the expenditure of fuel required to raise a definite quantity of water to a stated height. He found an engine 10 inches in diameter of cylinder, and of 3 feet stroke, could do work equal to raising 2,919,017 pounds of water one foot high, with a bushel of coals weighing 84 pounds.

One of Smeaton's larger engines, erected at Long Benton, was 52 inches in diameter of cylinder and of 7 feet stroke of piston, and made 12 strokes per minute. Its load was equal to 7½ pounds per square inch of piston-area, and its effective capacity about 40 horse-power. Its duty was 9½ millions of pounds raised one foot high per bushel of coals. Its boiler evaporated 7.88 pounds of water per pound of fuel consumed. It had 35 square feet of grate-surface and 142 square feet of heating-surface beneath the boilers, and 317 square feet in the flues—a total of 459 square feet. The moving parts of this engine weighed 8½ tons.

Smeaton erected one of these engines at the Chasewater mine, in Cornwall, in 1775, which was of very considerable size. It was 6 feet in diameter of steam-cylinder, and had a maximum stroke of piston of 9½ feet. It usually worked 9 feet. The pumps were in three lifts of about 100 feet each, and were 16¾ inches in diameter. Nine strokes were made per minute. This engine replaced two others, of 64 and of 62 inches diameter of cylinder respectively, and both of 6 feet stroke. One engine at the lower lift supplied the second, which was set above it. The lower one had pumps 18½ inches in diameter, and raised the water 144 feet; the upper engine raised the water 156 feet, by pumps 17½ inches in diameter. The later engine replacing them exerted 76½ horse-power. There were three boilers, each 15 feet in diameter, and having each 23 square feet of grate-surface. The chimney was 22 feet high. The great beam, or "lever," of this engine was built up of 20 beams of fir in two sets, placed side by side, and ten deep, strongly bolted together. It was over 6 feet deep at the middle and 5 feet at the ends, and was 2 feet thick. The "main centres," or journals, on which it vibrated were 8½ inches in diameter and 8½ inches long. The cylinder weighed 6½ tons, and was paid for at the rate of 28 shillings per hundredweight.

By the end of the eighteenth century, therefore, the engine of Newcomen, perfected by the ingenuity of Potter and of Beighton, and by the systematic study and experimental research of Smeaton, had become a well-established form of steam-engine, and its application to raising water had become general. The coal-mines of Coventry and of Newcastle had adopted this method of drainage; and the tin and the copper mines of Cornwall had been deepened, using, for drainage, engines of the largest size.

Some engines had been set up in and about London, the scene of Worcester's struggles and disappointments, where they were used to supply water to large houses. Others were in use in other large cities of England, where water-works had been erected.

Some engines had also been erected to drive mills indirectly by raising water to turn water-wheels. This is said by Farey to have been first practised in 1752, at a mill near Bristol, and became common during the next quarter of a century. Many engines had been built in England and sent across the channel, to be applied to the drainage of mines on the Continent. Belidor[1] stated that the manufacture of these "fire-engines" was exclusively confined to England; and this remained true many years after his time. When used for the drainage of mines, the engine usually worked the ordinary lift or bucket pump; when employed

[1] "Architecture Hydraulique," 1734.

for water-supply to cities, the force or plunger pump was often employed, the engine being placed below the level of the reservoir. Dr. Rees states that this engine was in common use among the collieries of England as early as 1725.

The Edmonstone colliery was licensed, in 1725, to erect an engine, not to exceed 28 inches diameter of cylinder and 9 feet stroke of piston, paying a royalty of £80 per annum for eight years. This engine was built in Scotland, by workmen sent from England, and cost about £1,200. Its "great costð" is attributed to an extensive use of brass. The workmen were paid their expenses and 15*s.* per week as wages. The builders were John and Abraham Potter, of Durham. An engine built in 1775, having a steam-cylinder 48 inches in diameter and of 7 feet stroke, cost about £2,000.

Smeaton found 57 engines at work near Newcastle in 1767, ranging in size from 28 to 75 inches in diameter of cylinder, and of, collectively, about 1,200 horse-power. Fifteen of these engines gave an average of 98 square inches of piston to the horse-power, and the average duty was 5,590,000 pounds raised 1 foot high by 1 bushel (84 pounds) of coal. The highest duty noted was 7.44 millions; the lowest was 3.22 millions. The most efficient engine had a steam-cylinder 42 inches in diameter, the load was equivalent to 9¼ pounds per square inch of piston-area, and the horse-power developed was calculated to be 16.7.

Price, writing in 1778, says, in the Appendix to his "Mineralogia Cornubiensis:" "Mr. Newcomen's invention of the fire-engine enabled us to sink our mines to twice the depth we could formerly do by any other machinery. Since this invention was completed, most other attempts at its improvement have been very unsuccessful; but the vast consumption of fuel in these engines is an immense drawback on the profit of our mines, for every fire-engine of magnitude consumes £3,000 worth of coals per annum. This heavy tax amounts almost to a prohibition."

Smeaton was given thee description, in 1773, of a *stone* boiler, which was used with one of these engines at a copper mine at Camborne, in Cornwall. It containede three copper flues 22 inches in diameter. The gases were passed through these flues successively, finally passing off to the chimney. This boiler was cemented with hydraulic mortar. It was 20 feet long, 9 feet wide, and 8½ feet deep. It was heated by the waste heat from the roasting-furnaces. This was one of the earliest flue-boilers ever made.

In 1780, Smeaton had a list of 18 large engines working in Cornwall. The larger number of them were built by Jonathan Hornblower and John Nancarron. At this time, the largest and best-known pumping-engine for water-works was at York Buildings, in Villiers Street, Strand, London. It had been in operation since 1752, and was erected beside one of Savery's engines, built in 1710. It had a steam-cylinder 45 inches in diameter, and a stroke of piston of 8 feet, making 7½ strokes per minute, and developing 35½ horse-power. Its boiler was dome-shaped, of copper, and contained a large central fire-box and a spiral flue leading outward to the chimney. Another somewhat larger machine was built and placed beside this engine, some time previous to 1775. Its cylinder was 49 inches in diameter, and its stroke 9 feet. It raised water 102 feet. This engine was altered and improved by Smeaton in 1777, and continued in use until 1813.

Smeaton, as early as 1765, designed a *portable* engine,[1] in which he supported the machinery on a wooden frame mounted on short legs and strongly put together, so that the whole machine could be transported and set at work wherever convenient.

In place of the beam, a large pulley was used, over which a chain was carried, connecting the piston with the pump-rod, and the motion was similar to that given by the

[1] Smeaton's "Reports," vol. i., p. 223.

discarded beam. The wheel was supported on A-frames, resembling somewhat the "gallows-frames" still used with the beam-engines of American river-boats. The sills carrying the two A's supported the cylinder. The injection-cistern was supported above the great pulley-wheel. The valve-gearing and the injection-pump were worked by a smaller wheel, mounted on the same axis with the larger one. The boiler was placed apart from the engine, with which it was connected by a steam-pipe, in which was

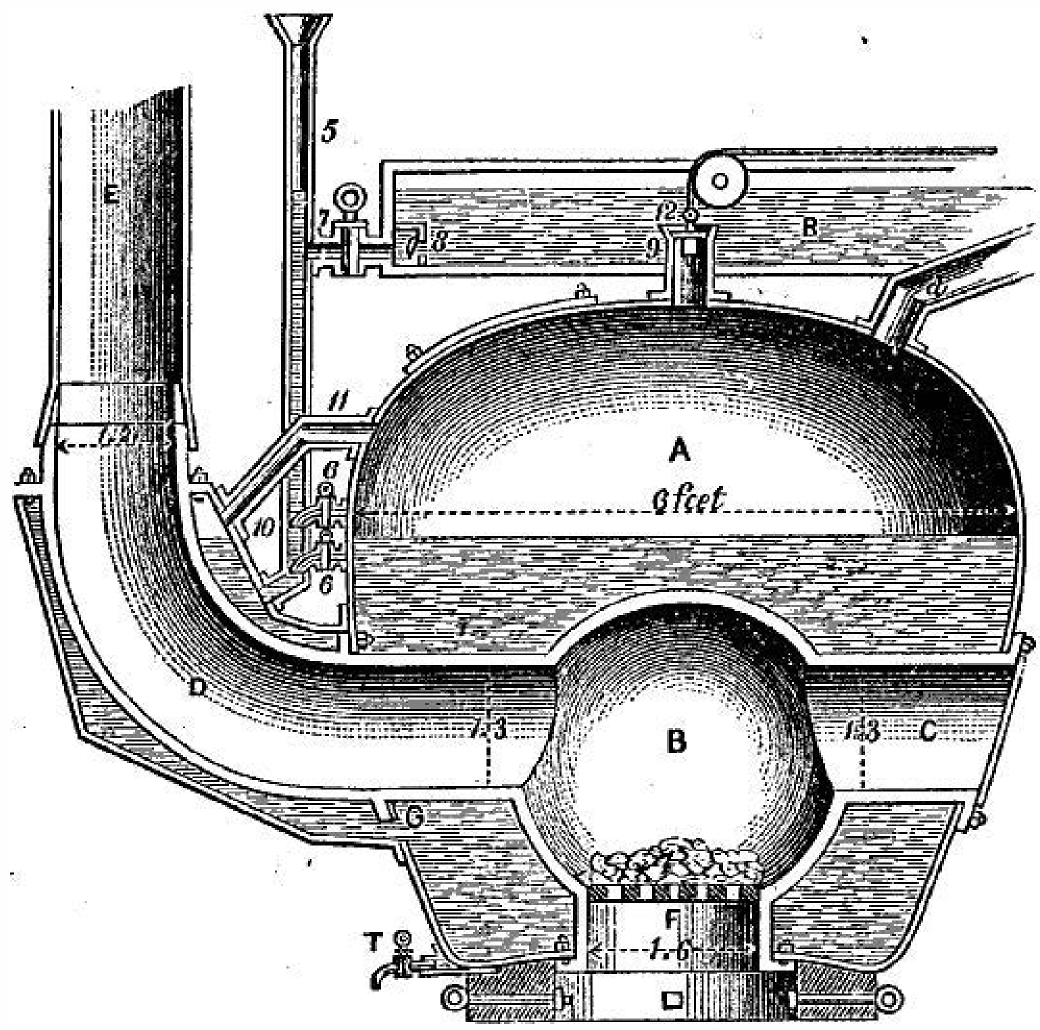

FIG. 23.—Smeaton's Portable-Engine Boiler, 1765.

placed the "regulator," or throttle-valve. The boiler (Fig. 23) "was shaped like a large tea-kettle," and contained a fire-box, *B*, or internal furnace, of which the sides were made of cast-iron. The fire-door, *C*, was placed on one side and opposite the flue, *D*, through which the products of combustion were led to the chimney, *E*; a short, large pipe, *F*, leading downward from the furnace to the outside of the boiler, was the ash-pit. The shell of the boiler, *A*, was made of iron plate one-quarter of an inch thick. The steam-cylinder of the engine was 18 inches in diameter, the stroke of piston 6 feet, the great wheel 6¼ feet in diameter, and the A-frames 9 feet high. The boiler was made 6 feet, the furnace 34 inches, and the grate 18 inches in diameter. The piston was intended to make 10 strokes per minute, and the engine to develop 4⅛ horse-power.

In 1773, Smeaton prepared plans for a pumping-engine to be set up at Cronstadt, the port of St. Petersburg, to empty the great dry dock constructed by Peter the Great and Catherine, his successor. This great dock was begun in 1719. It was large enough to dock ten of the ships of that time, and had previously been imperfectly drained by two greatwindmills 100 feet high. So imperfectly did they do their work, that a *year* was required to empty the dock, and it could therefore only be used once in each summer. The engine was built at the Carron Iron Works, in England. It had a cylinder 66 inches in diameter, and a stroke of piston of 8½ feet. The lift varied from 33 feet when the dock was full to 53 feet when it was cleared of water. The load on the engine averaged about 8⅛ pounds per square inch of piston-area. There were three boilers, each 10 feet in diameter, and 16 feet 4 inches high to the apex of its hemispherical dome. They contained internal fire-boxes with grates of 20 feet area, and were surrounded by flues helically traversing the masonry setting. The engine was started in 1777, and worked very successfully.

The lowlands of Holland were, before the time of Smeaton, drained by means of windmills. The uncertainty and inefficiency of this method precluded its application to anything like the extent to which steam-power has since been utilized. In 1440, there were 150 inland lakes, or "*meers*," in that country, of which nearly 100, having an extent of over 200,000 acres, have since been drained. The "Haarlemmer Meerd' alone covers nearly 50,000 acres, and forms the basin of a drainage-area of between 200,000 and 300,000 acres, receiving a rainfall of 54,000,000 tons, which must be raised 16 feet in discharging it. The beds of these lakes are from 10 to 20 feet lower than the water-level in the adjacent canals. In 1840, 12,000 windmills were still employed in this work. In the following year, William II., at the suggestion of a commission, decreed that only steam-engines should be employed to do this immense work. Up to this time the average consumption of fuel for the pumping-engines in use is said to have been 20 pounds per hour per horse-power.

The first engine used was erected in 1777 and 1778, on the Newcomen plan, to assist the 34 windmills employed to drain a lake near Rotterdam. This lake covered 7,000 acres, and its bed was 12 feet below the surface of the river Meuse, which passes it, and empties into the sea in the immediate neighborhood. The iron parts of the engine were built in England, and the machine was put together in Holland. The steam-cylinder was 52 inches in diameter, and the stroke of piston 9 feet. The boiler was 18 feet in diameter, and contained a double flue. The main beam was 27 feet long. The pumps were 6 in number, 3 cylindrical and 3 having a square cross-section; 3 were of 6 feet and 3 of 2½ feet stroke. Two pumps only were worked at high-tide, and the others were added one at a time, as the tide fell, until, at low-tide, all 6 were at work.

The size of this engine, and the magnitude of its work, seem insignificant when compared with the machinery installed 60 years later to drain the Haarlemmer Meer, and with the work done by the last. These engines are 12 feet in diameter of cylinder and 10 feet stroke of piston, and work—they are 3 in number—the one 11 pumps of 63 inches diameter and 10 feet stroke, the others 8 pumps of 73 inches diameter and of the same length of stroke. The modern engines do a "duty" of 75,000,000 to 87,000,000 with 94 pounds of coal, consuming 2¼ pounds of coal per hour and per horse-power.

The first steam-engine applied to working the blowingmachinery of a blast-furnace was erected at the Carron Iron-Works, in Scotland, near Falkirk, in 1765, and proved very unsatisfactory. Smeaton subsequently, in 1769 or 1770, introduced better machinery into these works and improved the old engine, and this use of the steam-engine soon became usual. This engine did its work indirectly, furnishing water, by pumping, to drive the water-wheels which worked the blowing-cylinders. Its steam-cylinder was 6 feet in diameter, and the pump-cylinder 52 inches. The stroke was 9 feet.

A direct-acting engine, used as a blowing-engine, was not constructed until about 1784, at which time a single-acting blowing-cylinder, or air-pump, was placed at the "out-board" end of the beam, where the pump-rod had been attached. The piston of the air-cylinder was loaded with the weights needed to force it down, expelling the air, and the engine did its work in raising the loaded piston, the air-cylinder filling as the piston rose. A large "accumulator" was used to equalize the pressure of the expelled air. This consisted of another air-cylinder, having a loaded piston which was left free to rise and fall. At each expulsion of air by the blowing-engine this cylinder was filled, the loaded piston rising to the top. While the piston of the former was returning, and the air-cylinder was taking in its charge of air, the accumulator would gradually discharge the stored air, the piston slowly falling under its load. This piston was called the "floating piston," or "fly-piston," and its action was, in effect, precisely that of the upper portion of the common blacksmith's bellows.

Dr. Robison, the author of "Mechanical Philosophy," one of the very few works even now existing deserving such a title, describes one of these engines[1] as working in Scotland in 1790. It had a steam-cylinder 40 or 44 inches in diameter, a blowing-cylinder 60 inches in diameter, and the

[1] "Encyclopædia Britannica," 1st edition.

stroke of piston was 6 feet. The air-pressure was 2.77 pounds per square inch as a maximum in the blowing-cylinder; and the floating piston in the regulating-cylinder was loaded with 2.63 pounds per square inch. Making 15 or 18 strokes per minute, this engine delivered about 1,600 cubic feet of air, or 120½ pounds in weight, per minute, and developed 20 horse-power.

At about the same date a change was made in the blowing-cylinder. The air entered at the bottom, as before, but was forced out at the top, the piston being fitted with valves, as in the common lifting-pump, and the engine thus being arranged to do the work of expulsion during the down-stroke of the steam-piston.

Four years later, the regulating-cylinder, or accumulator, was given up, and the now familiar "water-regulator" was substituted for it. This consists of a tank, usually of sheet-iron, set open-end downward in a large vessel containing water. The lower edge of the inner tank is supported on piers a few inches above the bottom of the large one. The pipe carrying air from the blowing-engine passes above this water-regulator, and a branch-pipe is led down into the inner tank. As the air-pressure varies, the level of the water within the inverted tank changes, rising as pressure falls at the slowing of the motion of the piston, and falling as the pressure rises again while the piston is moving with an accelerated velocity. The regulator, thus receiving surplus air to be delivered when needed, greatly assists in regulating the pressure. The larger the regulator, the more perfectly uniform the pressure. The water-level outside the inner tank is usually five or six feet higher than within it. This apparatus was found much more satisfactory than the previously-used regulator, and, with its introduction, the establishment of the steam-engine as a blowing-engine for iron-works and at blast-furnaces may be considered as having been fully established.

Thus, by the end of the third quarter of the eighteenth century, the steam-engine had become generally introduced, and had been applied to nearly all of the purposes for which a single-acting engine could be used. The path which had been opened by Worcester had been fairly laid out by Savery and his contemporaries, and the builders of the Newcomen engine, with such improvements as they had been able to effect, had followed it as far as they were able. The real and practical introduction of the steam-engine is as fairly attributable to Smeaton as to any one of the inventors whose names are more generally known in connection with it. As a mechanic, he was unrivaled; as an engineer, he was head and shoulders above any constructor of his time engaged in general practice. There were very few important public works built in Great Britain at that time in relation to which he was not consulted; and he was often visited by foreign engineers, who desired his advice with regard to works in progress on the Continent.