PUMPS & PUMPING MACHINERY 1500 BC-1960

Historical Development-1

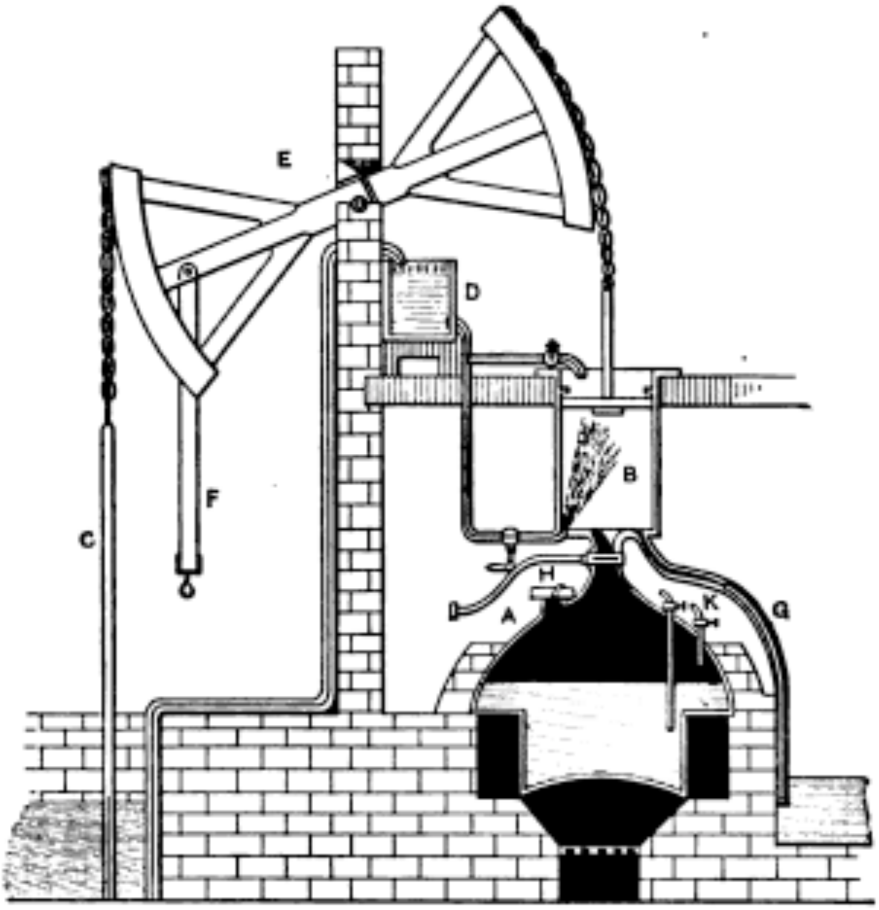

FIG. 31.—The Atmospheric Engine of Newcomen.

From PUMPING MACHINERY, 1919

PUMPING MACHINERY

A TREATISE ON THE

HISTORY, DESIGN, CONSTRUCTION AND OPERATION OF VARIOUS FORMS OF PUMPS

BY

ARTHUR M. GREENE, JR.

Professor of Mechanical Engineering, Russell Sage Foundation, Rensselaer Polytechnic Institute; Sometime Junior Dean, School of Engineering, University of Missouri

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PUMPING MACHINERY

CHAPTER I

HISTORICAL DEVELOPMENT

THE pump, considered as any apparatus used to raise water, is one of the oldest machines known to man. Long before the Christian Era, when man emerged from the age of the hunter into that of the shepherd, he found it necessary to raise water from wells for his flocks in places where there were no pure streams. Indeed, even before this age there must have been devices to raise water from low levels to supply the personal needs of the hunter and those dependent on him.

Following the age of the shepherd came that of the farmer, when the demand for an apparatus to raise water was greater than before. The shepherd no longer wandered over the country in search of pasture, but now he cared for a definite tract of land to furnish the food supply for his flocks, his herds, and his family. Unfortunately it became necessary for him to use lands on which there was not a sufficient natural supply of water for irrigation, and he was compelled to lift water from low streams to these fields, so as to increase the yield from his land.

The next age was that of townsman and manufacturer. For protection, mutual aid, and comfort, man began to live in towns and cities. This necessitated supplying water for the common use by gravity from some higher source to fountains, by means of hand pumps from wells, or by utilizing natural springs. These town fountains, pumps, or springs are still prominent objects in the cities of the Old World, and also in our own colonial towns. As the town developed the supply was carried into some of the houses. Finally, as the burgher became a manufacturer and was compelled to dig into the earth for his raw materials, it became necessary to clear his excavations of the surface and subsurface waters which filled them.

Modern civilization has demanded more and more as pumping machinery has been perfected, until to-day running water in unlimited supply is found not only in the houses of cities, large and small, but even the isolated farm often has its own water works, giving ample water to each room of its house, barn, and dairy. The latest demand is the supply, at a moment's notice, of large quantities of water, under great pressure, to the congested districts of trade in our large cities for fire protection.

Thus from earliest times may be traced a demand for some means of raising water for man; for his herds and lands; for the purpose of clearing his mines, and finally for his own personal convenience as well as the protection of his property. The pumping machine has developed from a very crude origin, it is true, yet its earliest types were so effective that they may be found in use to-day although in modified form.

The present work will not consider the sources of water supply, the gauging of the flow, the distribution of water, its analysis or purification, or any of the problems of hydraulics save those which are concerned with the raising of water from one level to another.

Two of the earliest forms of pumps are the **Shadoof** and the **Noria,** the former being common in Egypt, while the latter is found in China and along the Euphrates as well as on the Nile. The first of these is the ordinary well sweep seen on many old farms in this country. A leather, earthen, or woven bucket is attached to an arm by means of ropes or tree branches and ropes. This arm is tied to a crossbeam supported in crotches of tree trunks planted in the ground at the edge of some river or well. The arm supporting the bucket is counterweighted by a stone or a mud ball, so that there will be practically no

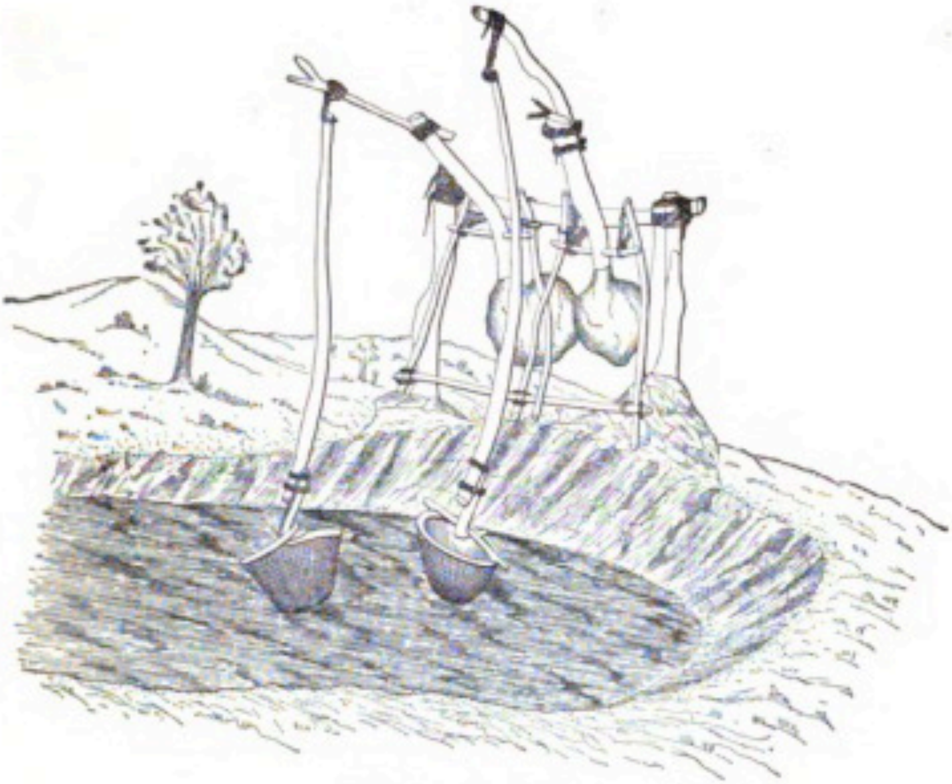

FIG. 1.—Shadoof.

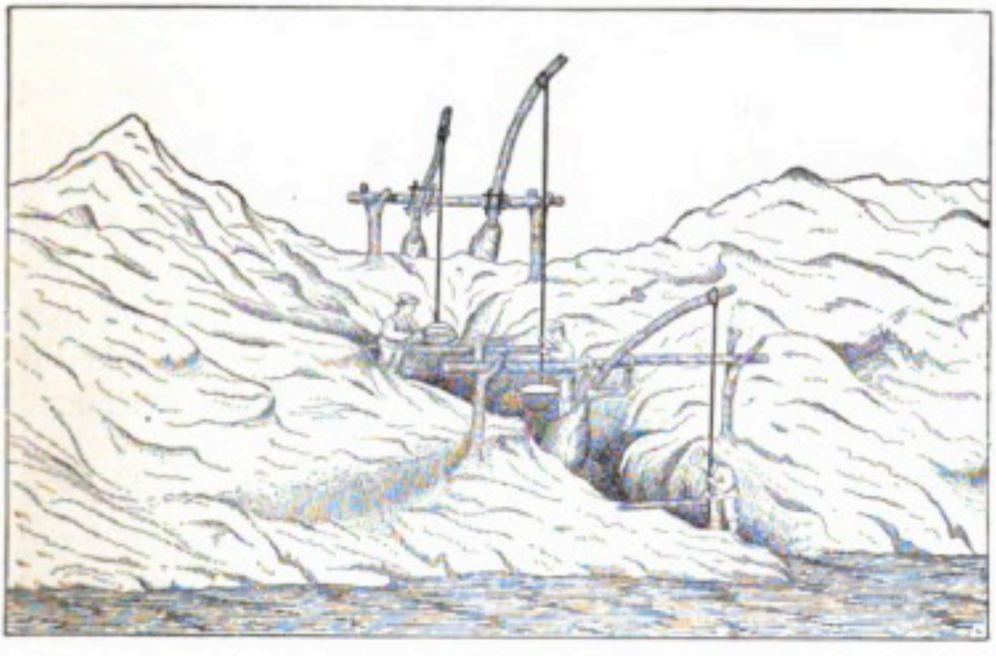

FIG. 2.—Shadoofs in Series.

weight to lift. A man then pulls on the bucket support, putting the bucket beneath the water, and then allows the counterweight to lift it to the proper level, where he empties the water into the canal or basin. From the canal it flows to the land which is to be irrigated. At times a series of these shadoofs is placed in line (Fig. 2), each shadoof raising the water a portion of the total lift which would be too great for any one machine. The shadoof is probably the oldest apparatus for raising water, although the simple bucket attached to a rope (Fig. 3) must have been used in early times. Wilson states that in India one or two men operate a *Paecottah* (the southern Indian name for the Egyptian shadoof), and lift from 1000 to 3000 cubic feet in from six to eight hours. The lift varies from 5 to 12 feet. This apparatus is known also as the *Swape* and in upper India it is called the *Lât.* Buckley states that the experiments of Wilson showed that two men could lift 57,600 cubic feet through a height of one foot in ten hours, while one man could lift 33,000 cubic feet.

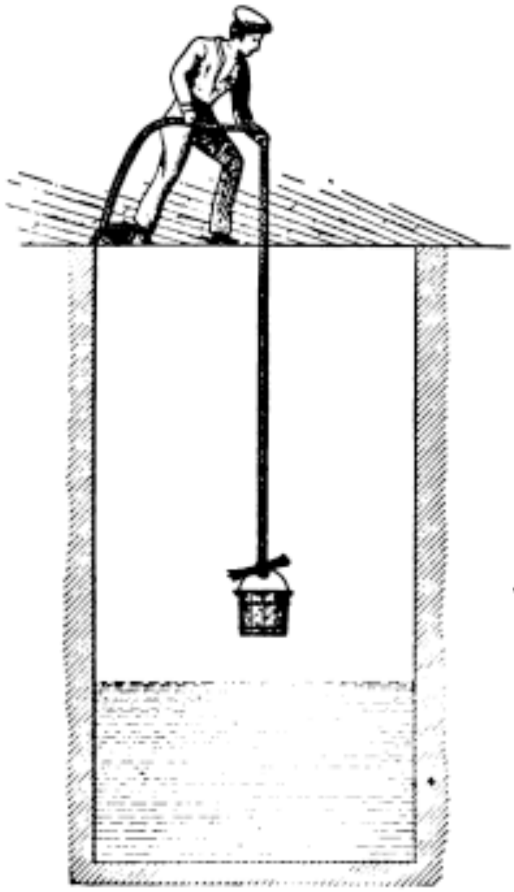

FIG. 3.—Bucket.

The Noria (Fig. 4) is a machine by which the water of a stream is raised in buckets attached to a wheel, the wheel being moved by the stream or in some cases by animal power. The Chinese claim to have used these as early as one thousand years before the Christian Era. One of them is described as consisting of eighteen or twenty arms with paddles, to the periphery of which is attached a number of buckets. At the lowest limit of the motion of the wheel these buckets dip below the water and are filled. The motion of the wheel thus raises the water to a higher level. In some wheels the impact of the stream on the buckets is sufficient to drive the wheel, while in other cases the wheel is provided with additional vanes to drive it. A simple Chinese wheel (Fig. 4) is formed of bamboo. The spokes of this wheel are attached to a central shaft and cross each other at two-thirds the distance to the periphery,

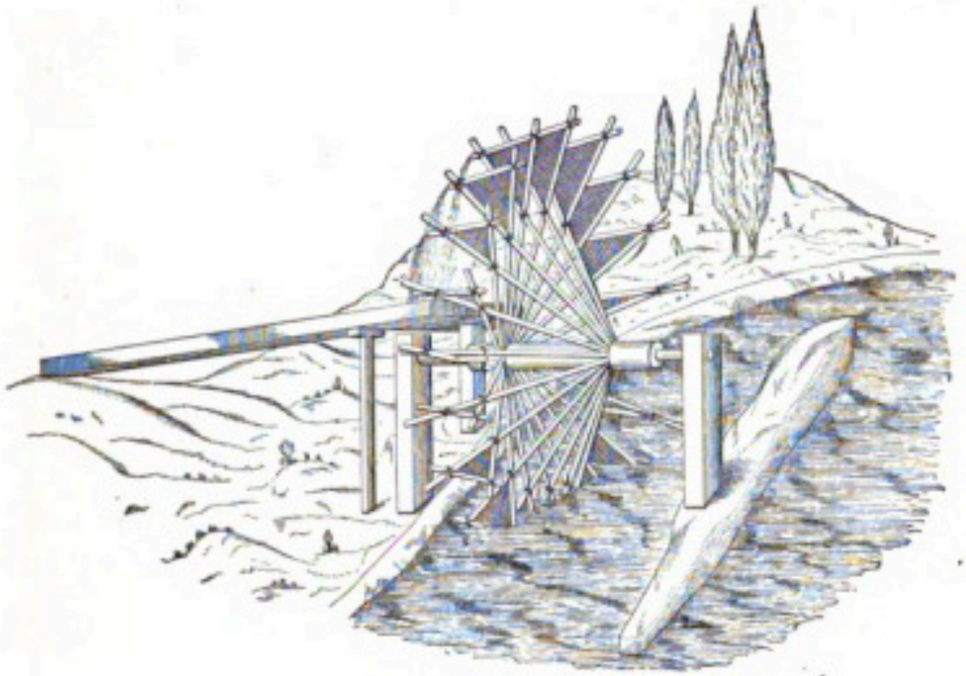

FIG. 4.—Noria.

where they are firmly lashed together, while at the end they are fastened to end pieces. These act as the buckets, the natural joint in the bamboo forming the bottom of the bucket. The triangle formed by the spokes and the end piece is filled with bamboo basket work, thus forming a paddle to drive the noria. The end tubes are cut and fastened at such an angle that when the vane is in a horizontal plane the end tube is inclined upward at an angle of twenty degrees so that the buckets will not discharge their contents until they pass the level of the axle. The buckets finally discharge into a trough which conducts the water to a canal or reservoir from which it can be used. The wheels are from 20 to 40 feet in diameter. In the case of a wheel 20 feet in diameter, containing twenty buckets 2 inches in diameter and 4 feet long, 70,000 gallons were raised in twenty-four hours when the wheel made four revolutions per minute.

These wheels were used throughout the East in Asia and Egypt. Colonel Chesney of the British army reports several of them in operation along the Euphrates as motors and pumps. Some of these were arranged so that their axles could be raised by means of stones in order that their depths of immersion

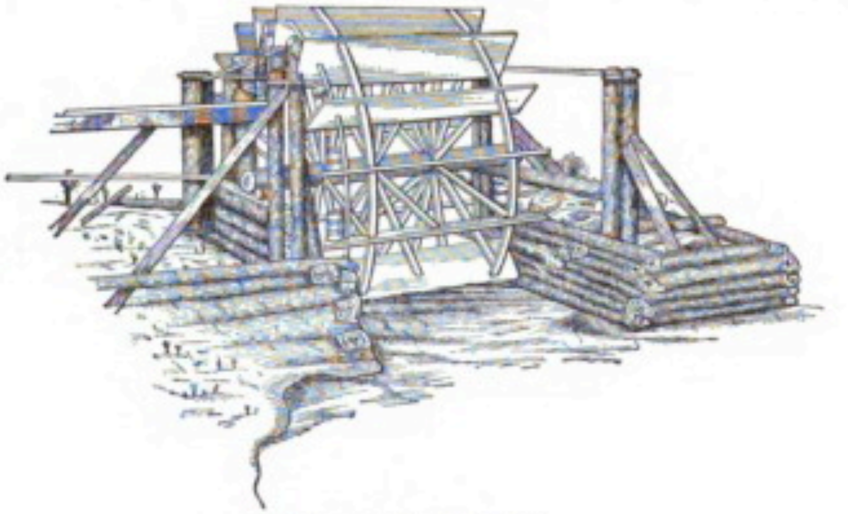

FIG. 5.—Modern Noria.

would be the same at different stages of the river. Along the river aqueducts are seen which carried the water away, and walls or dams are found which served to raise the water at the season of small flow and also served to direct the flow to the openings in the walls where the norias were placed. At the center of the river openings were left through which boats could pass.

An American wheel of modern application (Fig. 5) shows that the idea of centuries ago is still of value as the basis of an irrigating apparatus; as arranged here the full diameter is almost available for the lift. Such a machine is simple and very effective.

The name "noria" is also applied to a development of the older ancient machine, in which the buckets are attached to a chain or rope which, with its series of buckets or pitchers, is placed over the wheel and extends down to the water at considerable distance below. In this case, however, the wheel is driven by animal power. This form is known as the **Persian Wheel** (Fig. 6), while according to Buckley, the term *Sakias* is used for it in certain other places. To operate the Persian wheel a buffalo or camel is driven around a vertical axis, to an arm of which it is yoked. The axle contains a cog wheel (Figs. 6, 7, and 8) of crude form which engages with a second cog wheel mounted on a horizontal axis on which is placed the

FIG. 6.—Sakias.

band or chain wheel for the support of the bucket chain. The water is discharged from the buckets into a trough and flows to whatever fields are to be irrigated. It is stated that two bullocks will lift 2000 cubic feet of water per day and the heights of the lift will vary from 25 to 100 feet. The apparatus is common in the East, and in 1890 the American consul at Cairo reported 20,000 of these in use in the upper and lower Nile valleys.

A form in which the buckets are attached to the wheel as in the old noria, but in which the wheel is driven by animal power as in the Persian wheel, is still used at times, and is known as the *Sakias*. The term *Taboot* is applied to such an apparatus when the buckets are replaced by bags made of animal skins.

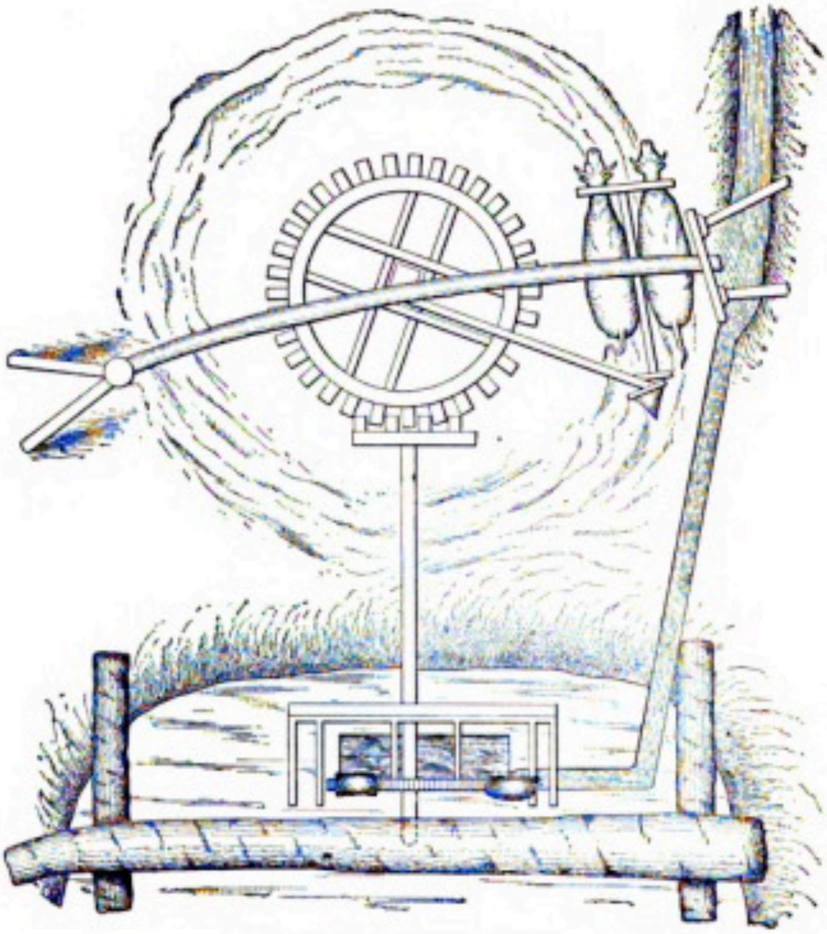

FIG. 7.—Persian Wheel.

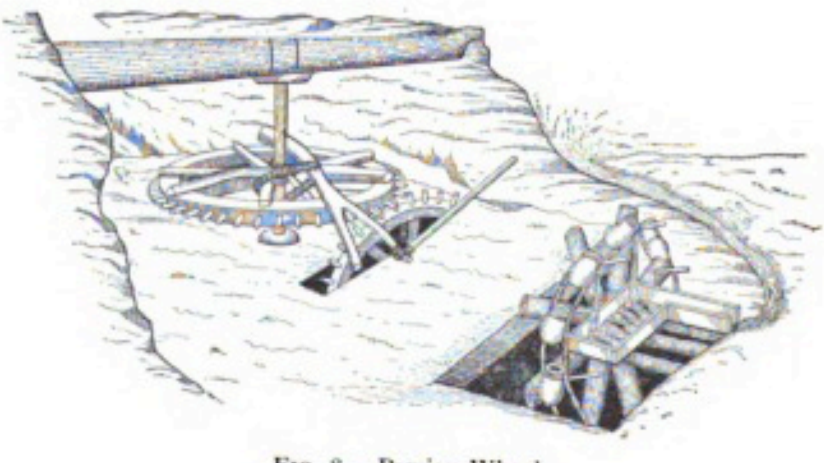

FIG. 8.—Persian Wheel.

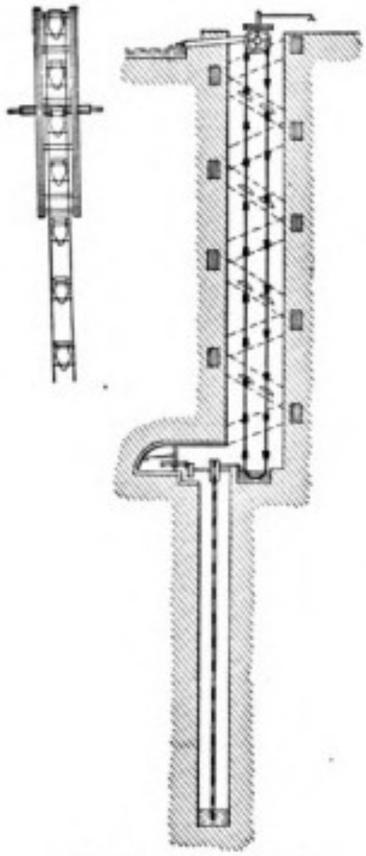

Fig. 9.—Joseph's Well.

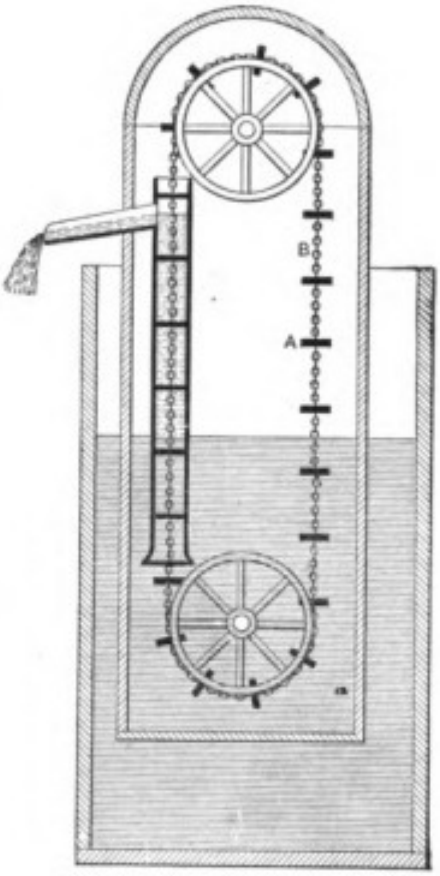

Fig. 10.—Chain Pump.

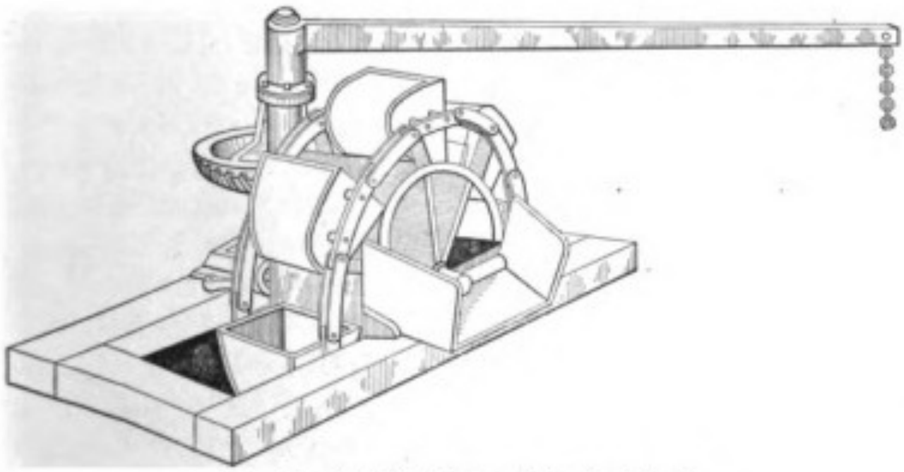

Fig. 11.—American Form of Persian Wheel.

An old Persian wheel whose date of construction is not known is located at Joseph's well at Cairo. This is shown in Fig. 9. The total depth is almost 300 feet, and this depth is divided into two lifts. The inclined passageway around the upper shaft enables the animals used for driving to be taken down to the lower driving wheel. The Romans built similar apparatus, calling them *Roman Buckets*. They were similar to our coal and grain elevators. Another development of this same apparatus consisted of a number of square discs mounted on a chain and fitted into a square pipe like small pistons. These chain discs, which have become the common chain

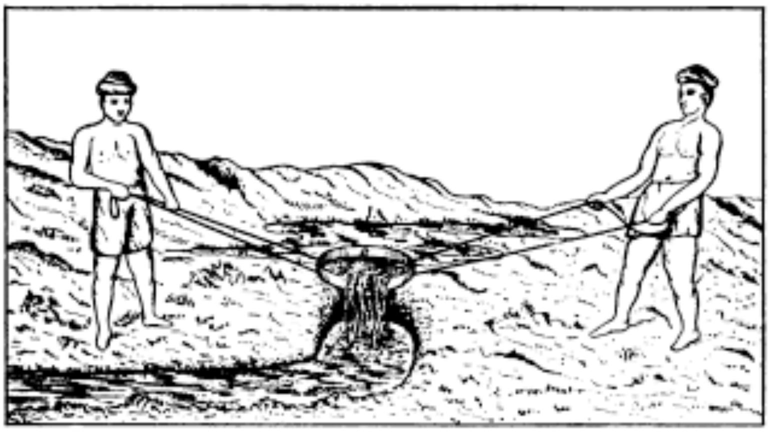

FIG. 12.—Mental.

pump of to-day, have been used in China from time immemorial. Fig. 10 shows the construction of this. The pallets or chaplets *AA* attached to the chain *B* are really loose-fitting pistons and in the application shown there is no suction.

The Persian wheel has been applied in America (Fig. 11); with it a horse is used and the crude gearing and buckets are replaced by metal parts. The principle, however, is the same as that of the old wheel. With such a machine a horse is said to lift 500 cubic feet per hour through a height of 20 feet.

The Mental, Katweh or **Latha** is a form of apparatus used in Egypt and India to-day (Fig. 12). It consists of a basket attached to two ropes in such a manner that two men may swing it into a stream when swinging it in one direction, while on the return swing the basket by a dextrous twist is discharged. In this manner two men may raise 20,000 cubic feet of water one foot in a day of ten hours.

The Doon (Fig. 13) consists of a long trough pivoted near one end and balanced by a stone attached to an overhead lever. The operator stands on the long counterbalanced end of the trough, overcoming the counterbalance and causing the outer end of the trough to dip into the water. On stepping from this, the weight lifts the trough and discharges the water into the ditch above the stream or pond.

Another primitive apparatus was the **Mot**, which consisted

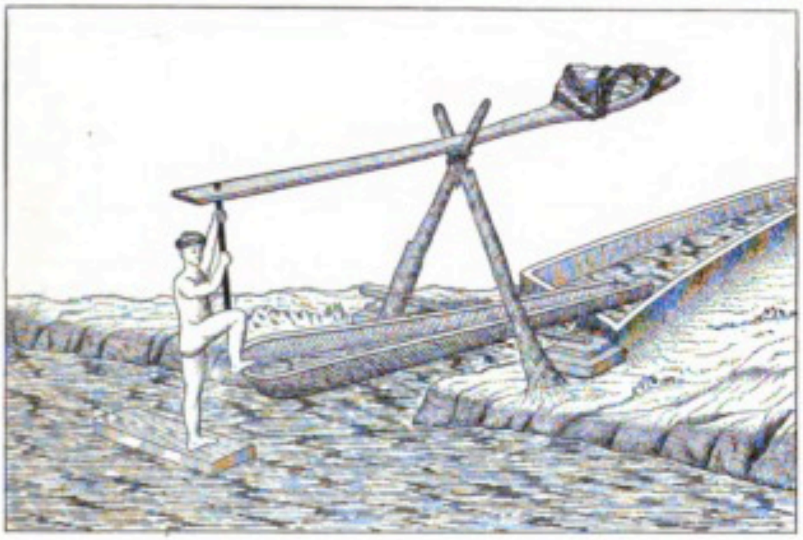

FIG. 13.—Doon.

of a bag of skin attached to a rope. The bag was raised to the surface by oxen, discharged, and then dropped back for another supply. This apparatus is effective, as two bullocks and a man can lift 79,000 cubic feet one foot in ten hours.

The double **Zig-Zag Balance** (Fig. 14) is shown by Mr. H. M. Wilson, as an apparatus used in Asia Minor and Egypt. Two men oscillate the frame and thus cause the water to flow past wooden valves at the intersection of the steps, and the water gradually passes from one step to the next. On each swing, water is lifted and gradually travels upward to the discharging trough.

Fig. 15 illustrates a method shown on certain Egyptian monuments. This should hardly be called a pumping appliance, but it serves to illustrate the great importance of irrigation when in ancient times such expensive methods were employed.

This brings one near the beginning of the Christian Era, and at this time there were several important applications of

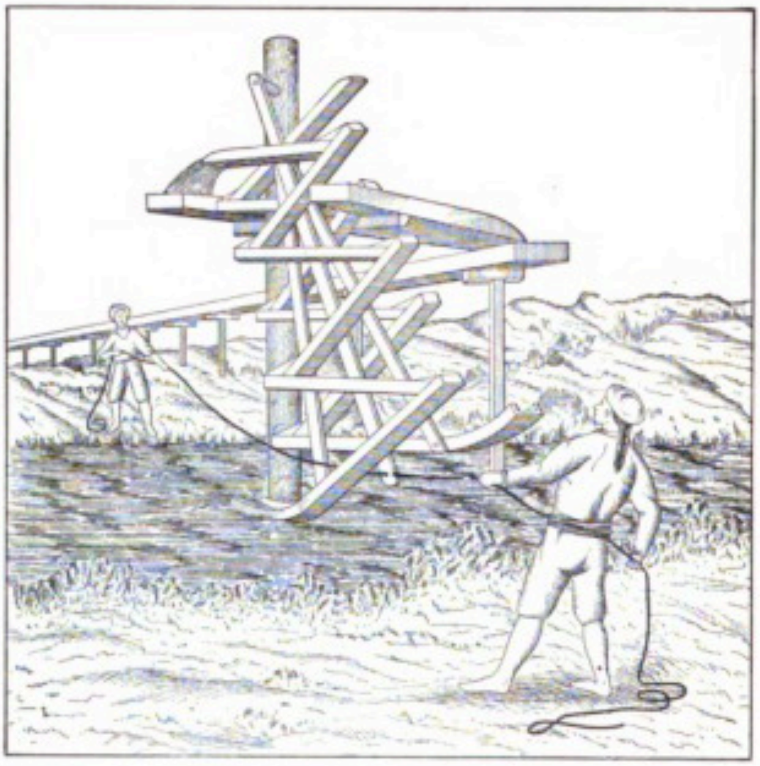

FIG. 14.—Zig-zag Balance.

mechanical principles to the raising of water. The use of suction to raise water was applied and valves were added to tubes carrying water while the movable diaphragm, partition or piston closely fitting the water vessel or tube was employed. The principle of the syphon was known at this time, and the syringe, which employed these various principles, was in use.

The principle of atmospheric pressure was not understood, although it was employed in the suction of water in early machines. It was not until the time of Torricelli, 1644, that this was fully comprehended.

Fig. 16 is known as a **Tympanum.** It was employed

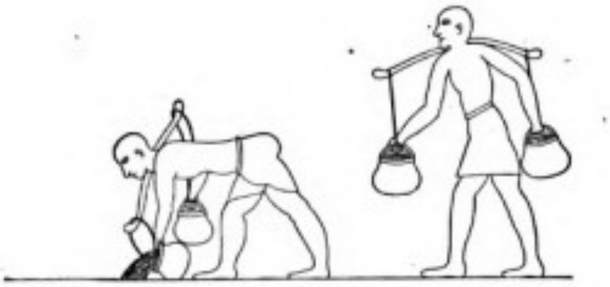

FIG. 15.—Egyptian Irrigation.

in Egypt. A spiral tube is attached to the face of the wheel, which is driven by the current. The end of the tube dips

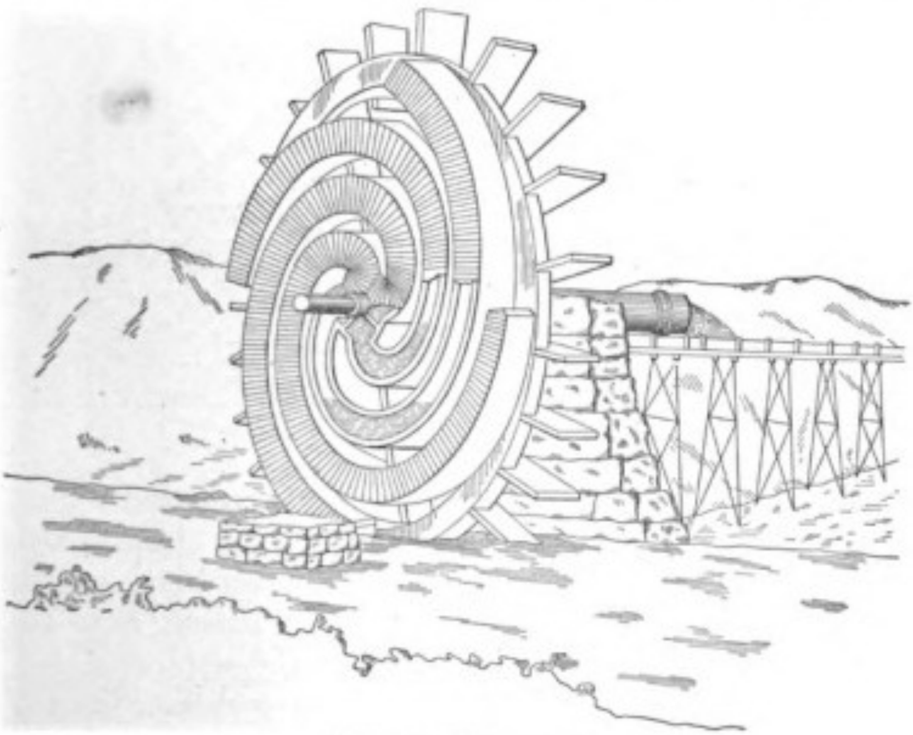

FIG. 16.—Tympanum.

beneath the stream, and as the wheel turns part of this water is caught within the tube and is gradually lifted to the hub of the wheel, where it is discharged into an irrigation flume.

The Archimedean Screw (Fig. 17) is one of the first combinations of a movable diaphragm in a tube. By turning the screw it is seen that the water is compelled to travel upward. The helical surface *A* on the axis *B* is rotated only, but the effect of it is that of axial movement.

The application of the principle of suction and one of the first uses of heat to lift water is described by Hero of Alexandria (*cir.* 120 B.C.) in his "Pneumatics." In this apparatus the heat from the burning sacrifice on the altar *A* (Fig. 18) is used to open the doors *B* of the temple. This was accomplished

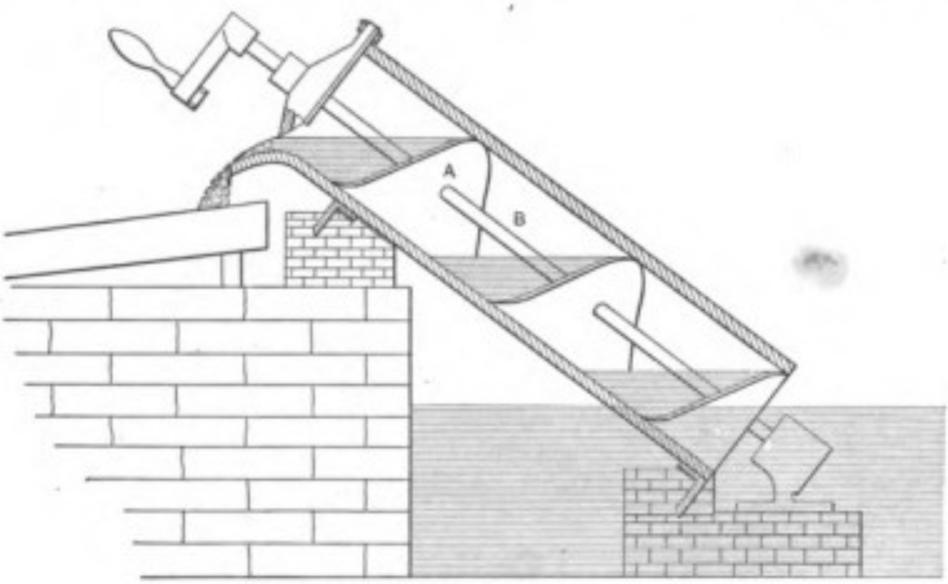

FIG. 17.—Archimedean Screw.

by the pressure produced on heating the air contained within the hollow altar *A*. The air was led into the top of the sphere *C* and its pressure drove the water into the bucket *D*, the weight of which acted on ropes attached to the trunnions *E* of the doors. When the sacrifice was burned the air contracted, producing a vacuum in *C*; the water was sucked back from *D* and the doors were closed by the weight *F*. In this apparatus it is important to notice the use of pressure to force water from one vessel to another, and of a vacuum or suction to draw water into a vessel.

From the description of Hero it is not possible to know whether he invented any of the devices described, but it is reasonable to suppose that many of them were the inventions of Ctesibius, who made several mechanical inventions. The

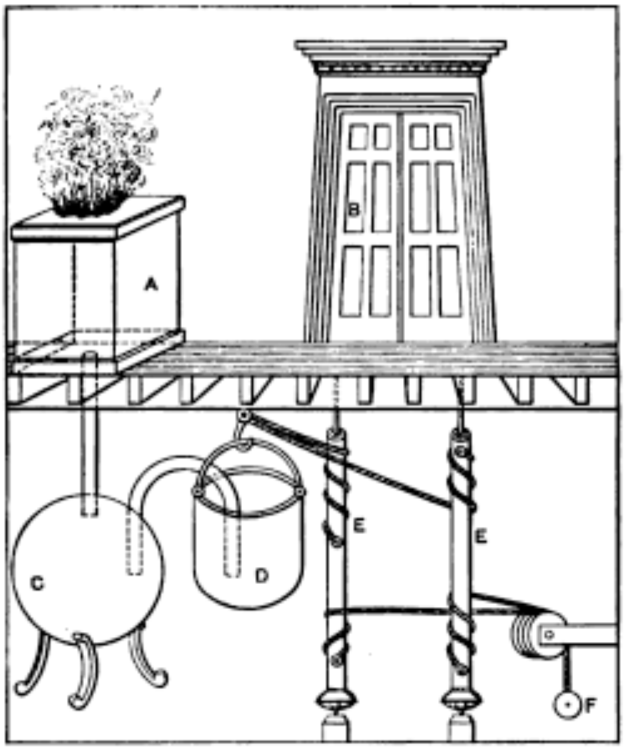

FIG. 18.—Temple Pump.

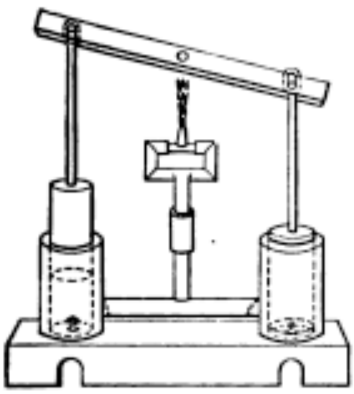

FIG. 19.—Force Pump.

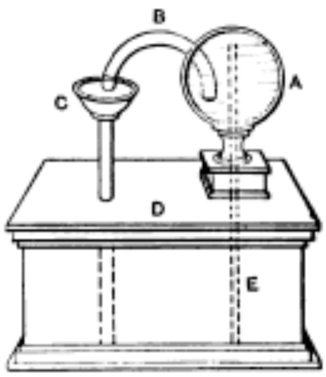

FIG. 20.—Sun Fountain.

Force Pump is ascribed to him and to Hero. This pump (Fig. 19) may have been suggested by the noria, in which valves were used at the bottom of the buckets to facilitate filling. There were two single-acting pistons, moved up and down by a cross rod or beam, and although the pumps were single acting the stream was continuous, owing to the arrangement of the pumps. It is to be noted that this was intended for a fire pump, and is the earliest fire engine of which there is record.

Another machine (Fig. 20) called a **Fountain** uses the expansive force of heated air to operate it Water is driven

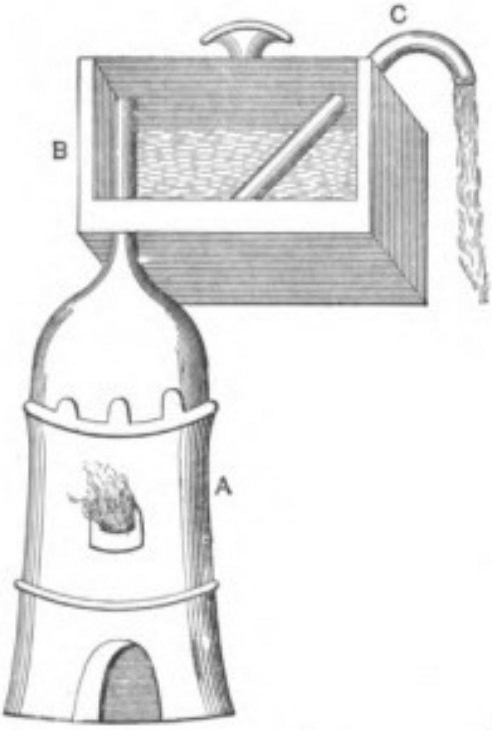

Fig. 21.—Steam Pump.

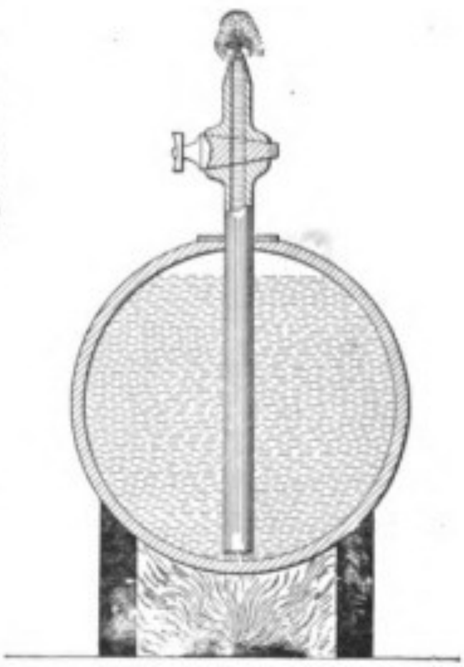

Fig. 22.—Fountain of de Caus.

from the vessel *A* through the syphon *B* by the expansion of the air in the top of *A* when exposed to the sun's rays. This water then falls into the box *D* and when the vessel *A* cools water is drawn up from *D* through the pipe *E*. Although Hero describes it in this manner, it is well to note that some form of valve must be placed in *C* and *E* to have the action proceed as described.

The use of steam pressure was suggested by Giovanni Baptista della Porta in 1601 in an apparatus (Fig. 21) in which steam is generated in a boiler *A*, from which it is discharged into the top of a vessel *B* filled with water. A pipe *C* reaches to the bottom of *B*, and when the steam pressure is exerted on the water in *B* it is forced from the discharge pipe *C*. The apparatus is the same as that of Hero, and della Porta suggests in his book, published in 1601, that the vacuum caused by the condensation of the steam be used for filling the vessel with water. Della Porta should have shown another pipe leading from the vessel *B* to the source of water supply. It is interesting that della Porta suggested the separation of the boiler and

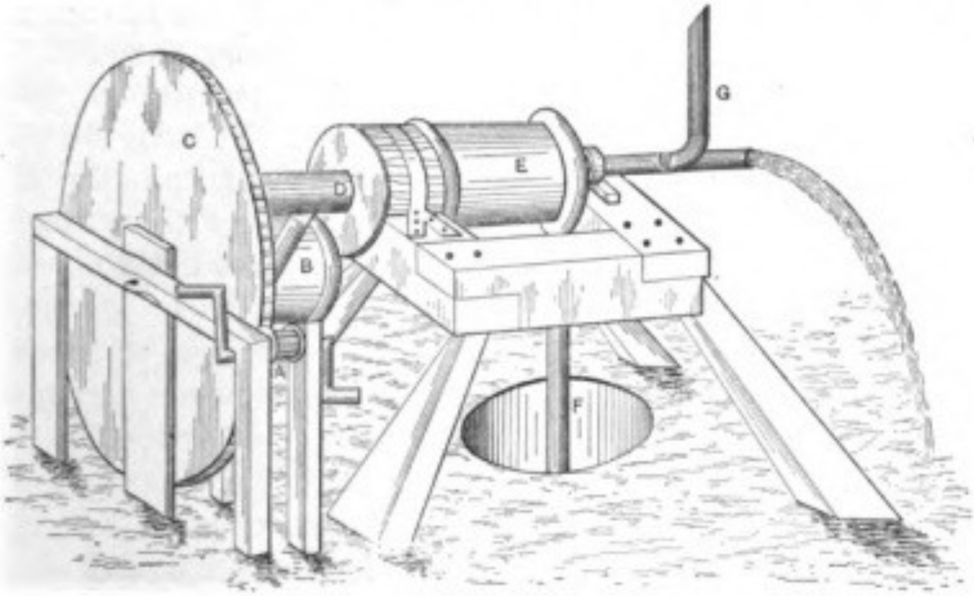

Fig. 23.—Pump of da Vinci.

the pump cylinder, a very valuable point, although in 1615 Solomon de Caus proposed to combine the two by placing the equivalent of the vessel *B* on the fire and heating the water in it for the purpose of driving the same by the pressure of the steam. (Fig. 22.)

Before this time, in the fifteenth century, Leonardo da Vinci suggested the pump shown in Fig. 23. The lantern wheel *A* was turned by two cranks and this motion was transmitted to a cylinder *B* through the toothed wheel *C*, and a helical groove in the cylinder *B* caused a piston rod *D* to travel back and forth by means of a pin on the rod which fitted into the helical groove. The movement of the solid piston of the cylinder *E* would then suck water from the well through the suction pipe *F* and discharge it through the discharge pipe *G*. Valves must have been employed here, although not shown, and the machine at once suggests the complete understanding of the action of the piston within a cylinder.

In 1630 a patent was granted to David Ramseye by the English king which covered two points: "to raise water from low pitts by fire," and "to raise water from low places and mynes and coal pits, by a new waie never yet in use."

There is no record of what he did, but this seems to be one of the first useful applications of heat to the raising of water.

While the use of heat for pumping was progressing, the application of water power and animal power was being developed extensively. In England there was the installation of the London Bridge Water Works in 1581, by which the current of the Thames was used, while in France Agostino Ramelli published a book describing his inventions, including pumps. This book was published in 1588, and the pumps described were operated by men and animals as well as by the currents of streams. According to an old account the application of the lift pump was made in 1581, "when Peter Morrys was given a grant by the Lord Mayor and Commonalty of the city of London for the term of 500 years for supplying and conveyance of water into houses by pipes from an artificial force from London Bridge on condition that he pay ten shillings annually into the chamber of London." He was authorized to use the first arch of London Bridge for this purpose.

In a paper before the American Water Works Association, Mr. T. W. Yardley quotes from a description published in 1633 as follows: "The present supply of good water for London is like to be very much enlarged by the great improvement of the water works of Peter Morrys before mentioned, who, being a Dutchman, in the twenty-third year of Queen Elizabeth, first gave assurance of his skill in raising Thames water so high as should supply the upper parts of London; for the Mayor and Aldermen came down to observe the experiment, and they saw him throw water over St. Magnus steeple, before which time no such thing was known in England as the raising of water." The success of this invention was such that Morrys obtained additional grants for two other arches under London Bridge. The second grant was for 2000 years and was finally secured by the New-River Water Company.

In 1731 Henry Beighton, the engineer, described the London Bridge water works in the "Philosophical Transactions," and accompanied his minute account by an engraving. It may be that the pumping apparatus had changed from the time of its first installation, but that is not known.

There were three water wheels (Fig. 24) at the time of this

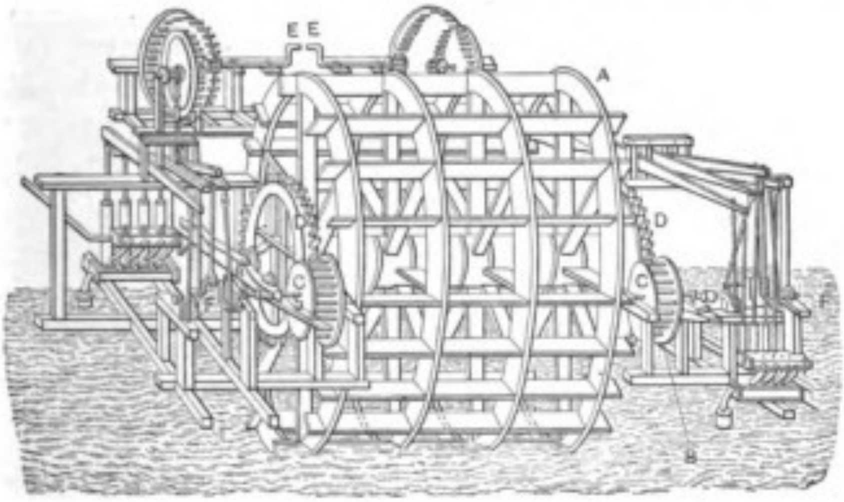

Fig. 24.—London Bridge Water Works.

description, each about 20 feet in diameter. These wheels *A* were carried on heavy frames *BB* and were raised and lowered with the tide. The frames *B* supporting the wheel *A* were pivoted at the axles of the lantern wheels *CC*, so that although the axle of the wheel *A* was raised and lowered the pin wheels *DD* attached to *A* on its axle were always in contact with the lantern wheels *CC*. The beams *BB* were supported at their outer ends by chains, which were raised or lowered by the cranks *EE* acting on a series of crown wheels and lantern wheels.

The axles of the lantern wheels *CC* were connected by a coupling to crank shafts *FF*, each provided with four cranks, which in turn were connected to a series of vibrating levers. These levers were connected to pump rods at each end, although in the figure one set of pumps is omitted for clearness. There were sixteen pumps to the wheel with cranks arranged so that four of them would work alternately. The pump cylinders were 4 feet 9 inches long and 7 inches in diameter; they were fixed to the top of an iron cistern which contained the proper foot valves, while the discharge valves were placed in another box.

According to the description of this pump the gears were so arranged that the crank turned 2⅛ times per turn of the main wheel. With the several wheels used in 1733, containing 52 forcers or cylinders in all, 1954 hogsheads were pumped per hour while the main wheels made six turns per minute. This would occur with full tide, and at that rate 46,896 hogsheads would be pumped per twenty-four hours.

Beighton states that the amount of leakage or "slip" in the pump amounted to from 20 to 25 per cent of its displacement. The reasons for this he gives: 1st, the amount of valve lift will cause leakage; 2d, no leather can be made strong enough for pistons. He states that loose leathers cause leakage while tight leathers cause excessive friction.

Such pumps excite admiration when the amount of experience possessed at that day and the state of the art of both machinists and millwrights is considered.

While the works of Peter Morrys were being constructed in England, a book appeared in Paris, 1588, by Captain Agostino Ramelli, an Italian engineer. An account of this book on the various machines of Ramelli is given by Mr. W. F. Durfee in *Cassier's Magazine* for June, 1895. Among the machines for pumping water given by Mr. Durfee three have been taken to illustrate methods described by Ramelli, and also to illustrate the state of the art at this time. A number of the machines show that Ramelli was familiar with the action of the piston and the rotary engine as well as with the principles of gearing to transmit power between shafts at an angle and not in the same plane; and for the purpose of obtaining reciprocating motion from continuous rotary motion.

In Fig. 25 a method is shown for draining an excavation or site beside a flowing stream. The wheel *A* is driven by the stream. Attached to its axle or shaft *B* is a series of cranks moving a set of levers *CC*, which cause the two shafts *D* to

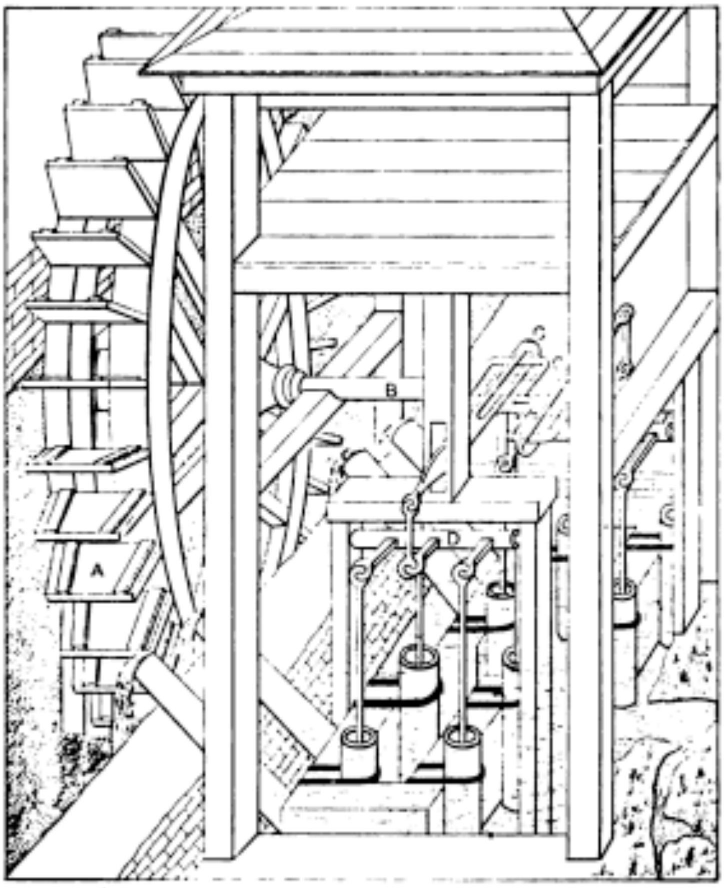

FIG. 25.—Ramelli's Pump.

oscillate. Each of the shafts *DD* has four arms which serve to drive the pump rods of four submerged pumps.

It is to be noted that in both this machine and that of Peter Morrys the crank and connecting rod are in evidence long before the time of James Watt. Here are also seen successful methods of securing reciprocating motion from rotary motion.

The wheel *A* of Fig. 26 was turned by a man walking on the inside, and in this the crank *B* gave a reciprocating motion to

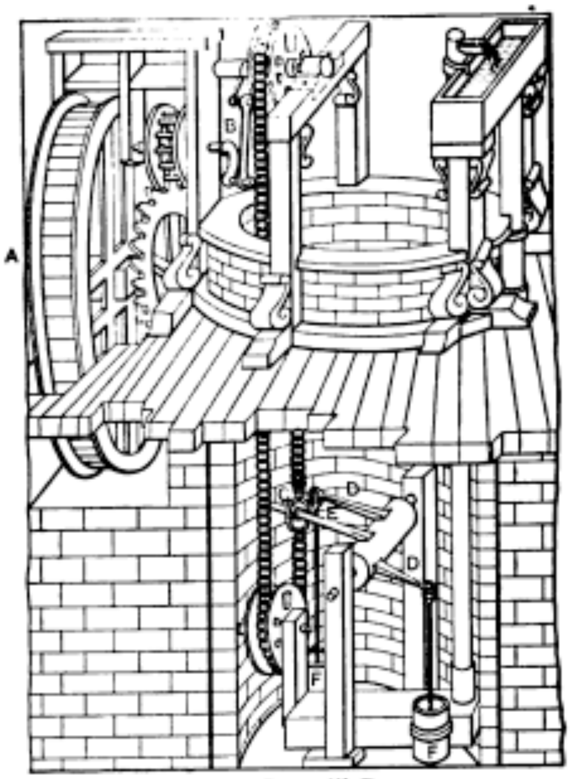

FIG. 26.—Ramelli Pump.

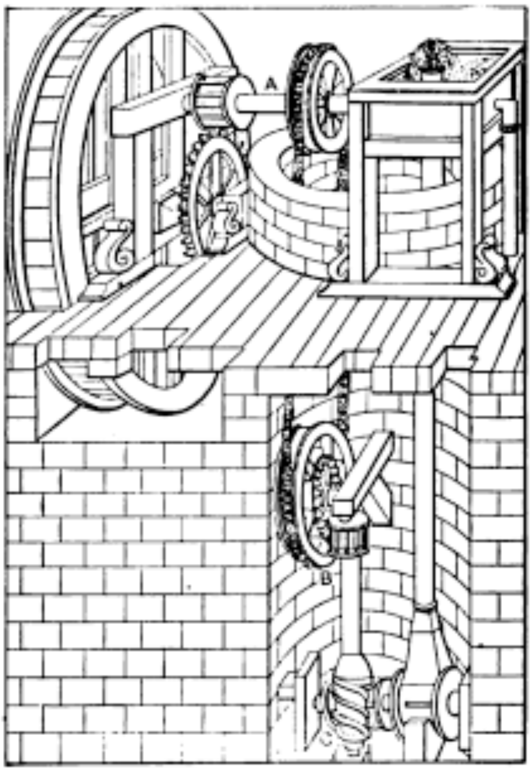

FIG. 27.—Ramelli's Rotary Pump.

the chain *CC*, which pulled in each direction on the arm *E*, driving the arms *DD* up and down and pumping on each stroke, one pump *F* forcing water on the up stroke of *E* and the other on the down stroke.

This not only shows the application of the crank and connecting rod, but there is much ingenuity displayed in arranging a chain to operate on both strokes.

The rotary pump (Fig. 27) of Ramelli is deserving of particular notice as a pump and also for the ingenious arrangement of its gears. For some reason the chain was not carried down to the axle of the pump. It may have been to keep this out of the water or for the purpose of getting a higher speed. The pin and lantern wheels at *A* and the crown and lantern wheels at *B* serve to increase the number of rotations, while the spiral gears at *C* serve only to change the direction of motion.

In 1628, two years before Ramseye secured his patent from King Charles for the use of fire, Edward Somerset, Marquis of Worcester, is thought to have installed an apparatus for raising water at Raglan Castle. He did not secure a patent on this until 1663, however, and there were no drawings nor even a model with his patent. From the description of the apparatus in his patent and from the grooves in the walls of Raglan Castle, an idea of the construction and operation of the machine may be formed, although it is not certain that this is correct in every detail.

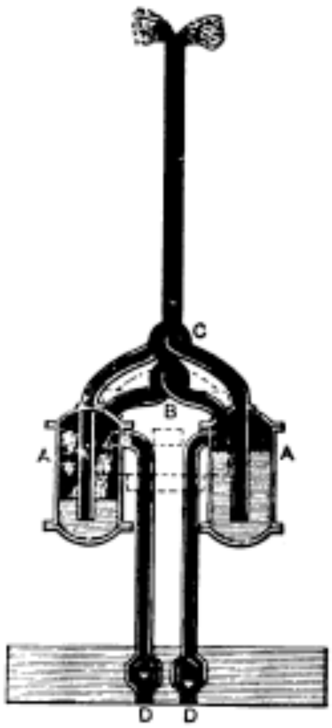

FIG. 28.—Worcester's Pump.

Two vessels *AA* (Fig. 28) are connected to a boiler through a valve *B*. In the figure the connection to the boiler is made to the right-hand vessel and the steam from the boiler presses on top of the water in *A* and forces it out through the valve *C*. During this action the right-hand foot valve *D* is held down on its seat. The water is driven to a height corresponding to the steam pressure, and for that reason high steam pressure was required for great heads. While the right-hand vessel *A* is discharging, the condensation of steam in the left-hand vessel produces a vacuum in the vessel and water is drawn up through the foot valve *D*.

On the reversal of the valves *B* and *C* the operation just described is repeated with opposite vessels and so the operation became continuous.

Worcester introduced this for the water supply at Vauxhall near the old city of London. Upon examination it is seen that apart from the useful application of the invention there is nothing new in this apparatus, as the elements are all found in della Porta's work.

In 1683 Sir Samuel Moreland, the master mechanic of the laboratory of Charles II, published a book from Paris on "The Elevation of Water by All Sorts of Machines." He had been sent to Paris by Charles on business relating to the water works which the king had erected. In his book Moreland speaks of the expansion of steam and its pressure, showing that a good idea of the pressure and volume of saturated steam was common in that day. He also refers to the duty of his pumping engines, using the term as it is used to-day—the amount of work per hundred weight of coal. The question of the application of steam to the raising of water was one which not only occupied Moreland, but many other mechanicians, on account of the difficulty which was then experienced in clearing the shafts of the English mines from the vast quantities of water which collected therein from the underground flow. Many mines had to be abandoned because of the cost of carrying the mines deeper when this expense of draining was too great. The work was mostly done by animal power and the cost was rather startling when compared with the steam pump of even the early days.

It is to be noted that Moreland introduced and invented the plunger type of pump in 1675. This type of pump was one in which an enlarged end of a rod was forced into a chamber, displacing the water. This was followed shortly afterward by a bucket pump, in which the water passed through valves in the piston on the down stroke, as was the case in the later engines of Simpson used at Thames-Ditton.

In 1698 Thomas Savery patented the design of an engine

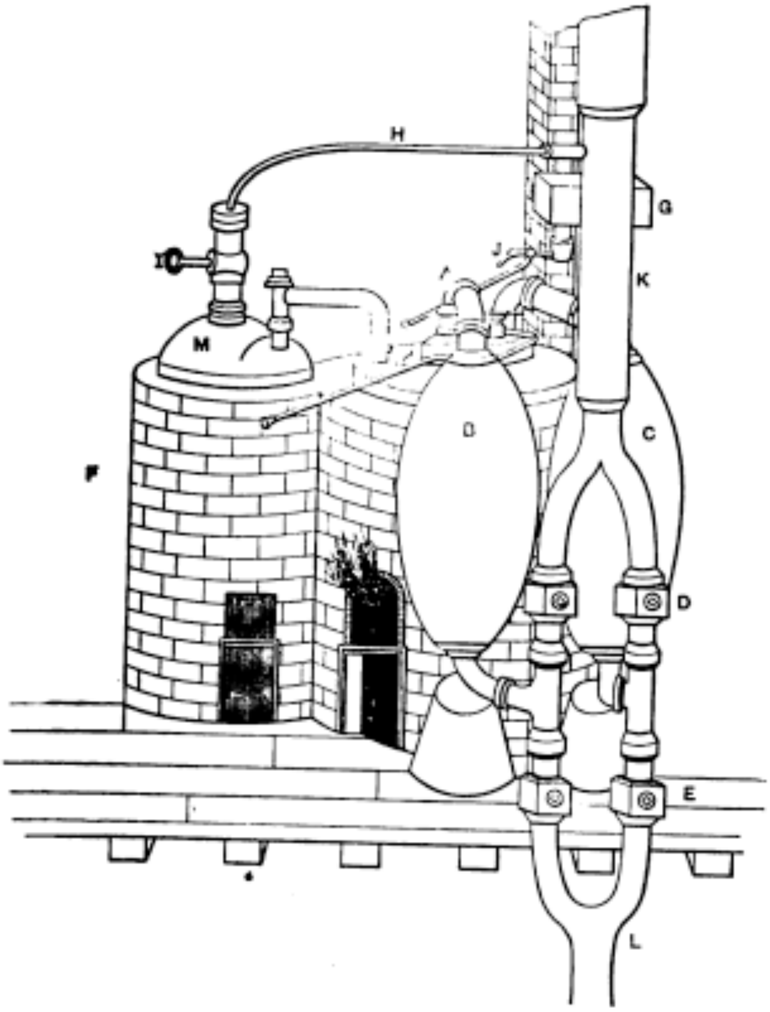

FIG. 29.—Savery's Pump of 1702.

for freeing the mines of Cornwall from water. It was the first steam apparatus applied to this kind of work. In 1699 he submitted a model to the Royal Society of London and successful experiments were made with it. A model fire engine was exbihited before King William III at Hampton Court in 1698, and the success of this led to the granting of the patent which

Continued in Part-2