PUMPS & PUMPING MACHINERY
1500 BC-1960

Introduction

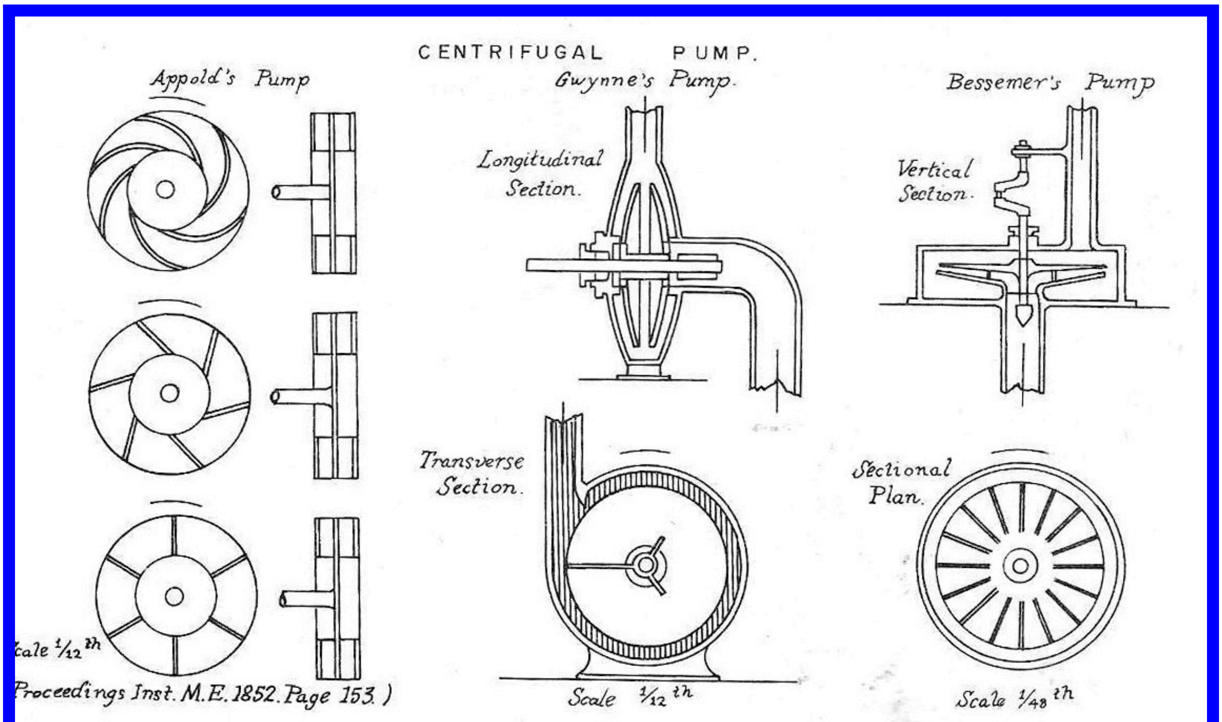


Fig. 8.9. The three pumps at the 1851 Exhibition (by Appold, Gwynne and Bessemer).

This outline of the development of water pumping devices from early civilisations until mid-20th century has been taken from the book:

BUILDING SERVICES HERITAGE:
A REVIEW OF ITS DEVELOPMENT
Neville S Billington & Brian M Roberts,
Pergamon Press, Oxford, 1982

8.4 PUMPS

8.4.1 The first pumps and water-moving devices

Primitive methods of raising water from one level to another relied on the use of buckets, or various forms of the well sweep (swape) — an early application of the lever. The most famous version of the well sweep is the Egyptian "shaduf" which dates from around 1550 B.C. (Fig. 8.2). Another version found in India was the "picotab". These were intermittent methods, but later it was possible to raise water continuously by the screw or snell, commonly ascribed to Archimedes (287-212 B.C.) and by the chain of pots (both still in use in some parts of the world).(4)(7)(8)(9)

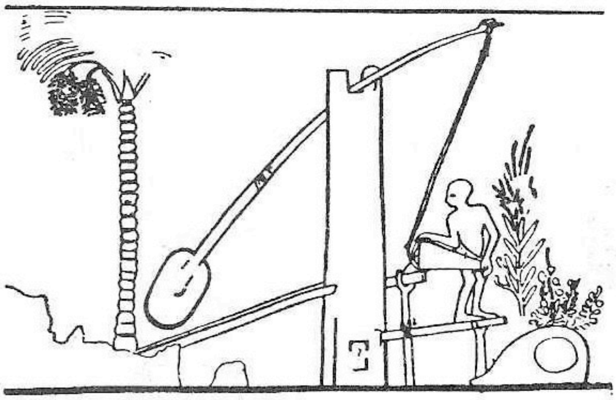


Fig. 8.2. Shaduf, 1500 B.C.

The Archimedean water screw, in its simplest form, consists of a coil or pipe that is rotated with its axis slightly inclined to the horizontal while the lower end is below water level (Fig. 8.3).

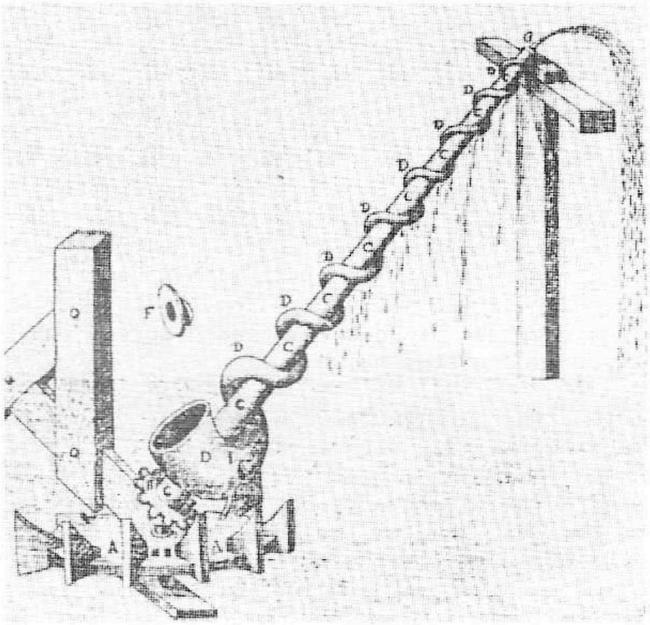


Fig. 8.3. Archimedes' spiral screw (*c*. 230 B.C.).

The chain of pots, or Persian wheel, had a horizontal axis and carried a rope chain to which earthenware pots were attached at regular intervals.

A similar device, the square pallet chain pump, was used in China in the 1st century A.D. Its Western prototype, the "chain and rag" pump, did not appear until about the 15th century. In these pumps, one side of the chain passed up through a vertical conduit and the water was drawn up the conduit by the pallets or rags sealing it as they entered at the bottom.

In early classical times, the Persian wheel and the screw were used extensively in Egypt, but the Roman saw the development of the Noria or Egyptian wheel. This was a large wooden wheel with a horizontal axis arranged so that its lower extremity dipped below the water surface. Buckets were attached to the rim of the wheel which was rotated by a treadmill or by animal power through gearing.(15)

The first pump using a piston and cylinder combination may have been the fire pump described in Hero's *Spiritalia* around the 2nd century B.C., but force pumps were also used for domestic purposes, of which the best known is probably the Ctesebian suction and force pump (1st century B.C.) illustrated in the treatise of Philo of Byzantium.

Roman plunger pumps were discovered at Silchester (Fig. 8.4) and the British Museum has similar bronze pumps found at Etruria and Bolsena. Pumps have also been discovered at Metz, and at Saint-Germain-en-Laye. In each case the finds consist of a heavy wood block with portions of lead piping.

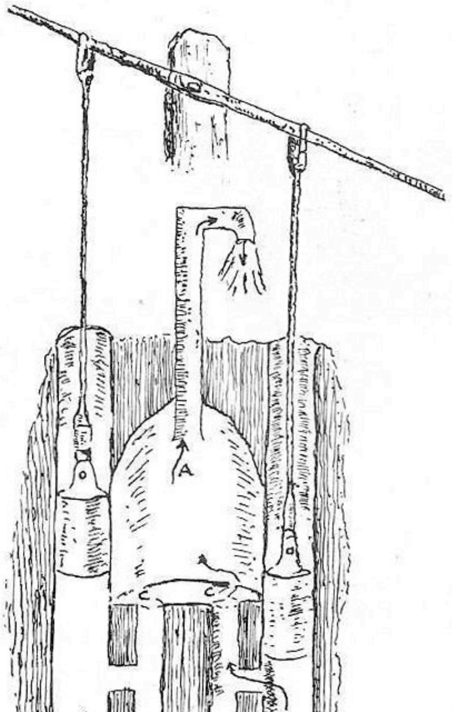


Fig. 8.4. Roman Force Pump, Silchester.
(Courtesy, Reading Museum)

Similar types of piston pumps were used by the Greeks and Romans for pumping air which was used to operate Greek toys and other spectacular devices used in temples and places of amusement.

During the period of the Dark Ages and the Renaissance (A.D. 400-1500) water wheels of various types were developed and were in widespread use. While it appears that there was not very much interest in water pumps during this period, it is believed that considerable use was made of piston pumps of various kinds during the Middle Ages. The bilge or burr pump which had one valve in the bottom and a conical leather piston which would collapse and open out on successive strokes of the piston, was used extensively on board ships. A bellows type of water pump was also in use.

From 1500 onwards and up to the beginning of the Industrial Revolution, ways of achieving the successful pumping of water occupied the minds of both scientists and constructors, as demonstrated in publications of Agricola (1556) and Ramelli (1588) (Fig. 8.5). Agricola describes the rag and chain pump which had then been developed for lifts up to 60 m and which could handle very large quantities of water.

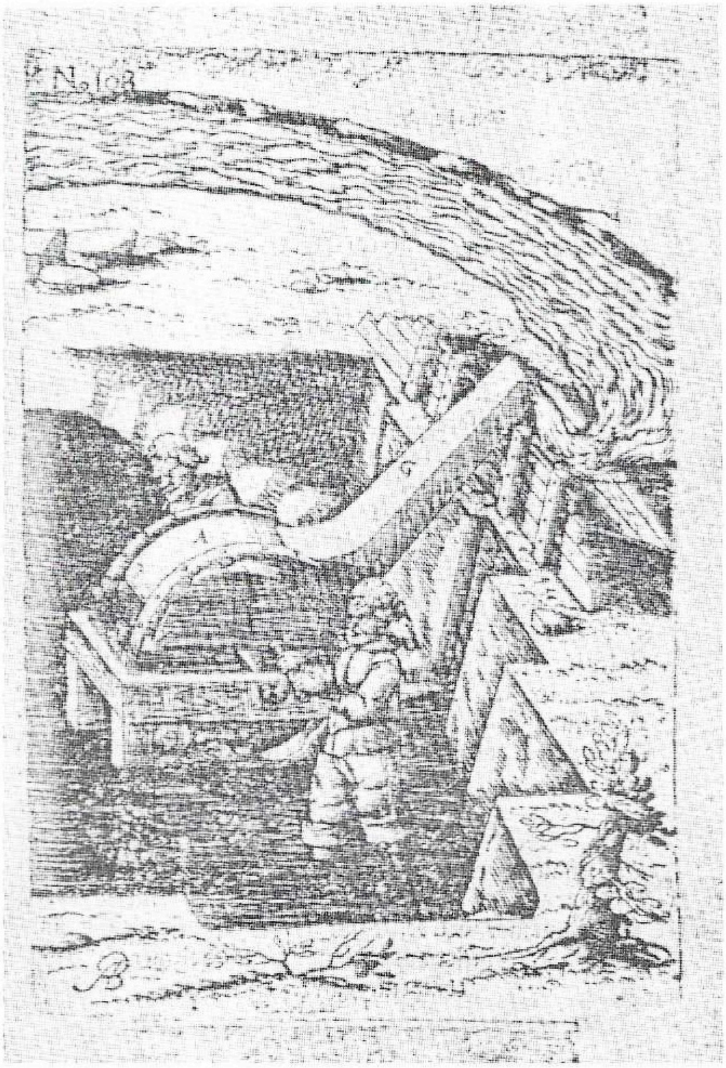


Fig. 8.5. Rotary displacement pump (from Ramelli, 1588).

He also describes one pump as being the most ingenious, durable and useful of all — a multiple lifting pump:(1)

> "... composed of several pumps... the lower one lifts the water out of the sump and pours it into the first tank; the second pump lifts again from that tank into a second tank, and the third pump lifts it into the drain of the tunnel. A wheel fifteen feet (4.5 m) high raises the piston-rods of all these pumps at the same time and carries them to drop together."

Ramelli described more than 100 different types of pumps and the illustrations show a number of rotary pumps, including a vane type of positive rotary pump.

8.4.2 Papin and Le Demour(11)

Back in 1500, Leonardo da Vinci had sketched a device for raising water by centrifugal force but his drawing did not indicate the essential features of the centrifugal pump, which are fluid entry near the axis of the rotor with discharge arranged on the circumference. Both of these principles were embodied in Papin's "Hessian" pump, which meets these requirements although having only two moving blades.

In 1688, Denis Papin was appointed Professor of Mathematics at Marburg, in Prussia. Soon after he became involved with the work of his patron, the Landgrave of Hesse, in cutting a canal through water-logged land. The pumps then available were unable to keep the works dry, and so Papin developed his centrifugal pump.

This first pump of Papin's was largely experimental (he may have obtained his inspiration from the earlier design of rotary pump evolved by Johan Jordan) (Fig. 8.6). Papin's centrifugal pump had two blades rotating in a circular casing. Defects included the absence of a stuffing box where the shaft passed through the casing, and an undersized discharge outlet. By 1705, Papin had effected considerable improvements, including a multi-bladed impeller and a spiral casing. In his communication, in June of the same year, to the Royal Society, Papin stated that his design "may be applied for Wind as well as for Water". Papin realised the importance of the spiral casing in minimising turbulence.

However, Papin was obviously also fully aware of the practical difficulties of developing the centrifugal pump, for a year earlier, in 1704, he had written to Leibnitz:

> "The machine which operates by centrifugal force is excellent in Theory; but, Monsieur, I find in it a great inconvenience in practice, for where it is used to raise water to some considerable height, it is necessary to impart to it a high speed and one always uniform."

Papin is perhaps best remembered for his achievements with the digester, the air pump, and his "fire-engine" for raising water. The undoubted constructional difficulties and the lack of a suitable prime mover caused his concept of a centrifugal pump to lapse into obscurity until Le Demour's work in 1732. Although several patents were granted for centrifugal pumps it was to be another century before the centrifugal pump found widespread use.

Extensive use continued to be made of piston pumps worked by water wheels in mines and in water works, and the development that took place can be studied by examining the various installations at the London Bridge Water Works. The most elaborate machine constructed for raising water was the famous one at Marly-la-Machine on the Seine, near Paris, built in 1682 for operating the fountains at Versailles.

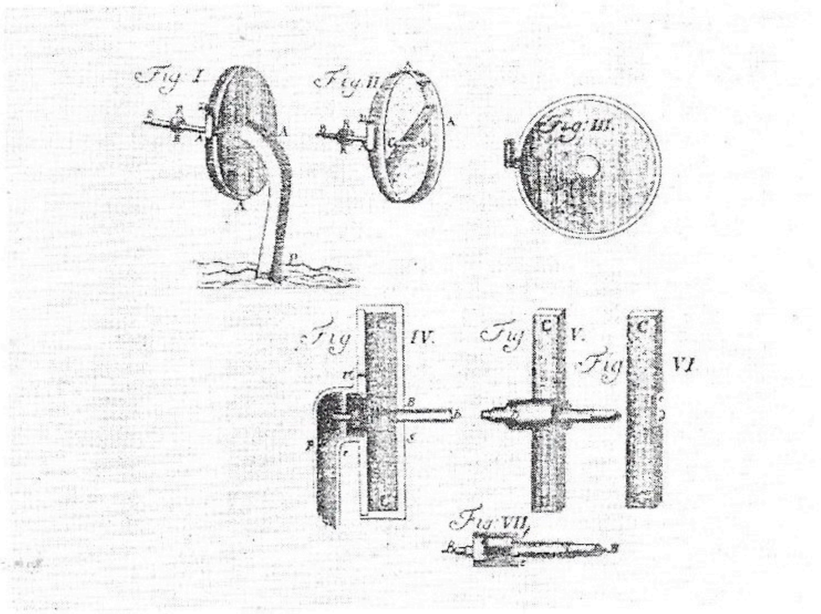


Fig. 8.6. Papin's "Rotatilis Suctor et Pressor Hassiacus" (1689).

However, the two outstanding mechanical engineering achievements of this period were Savery's pulsometer pump of 1689 and the Newcomen atmospheric engine of 1712. Captain Thomas Savery was granted a master patent in 1698 for "an engine for raising water by the impellant force of fire" although this may have been achieved some 30 years earlier by the Marquis of Worcester with his "water commanding engine":

> "Steam from a boiler was admitted to a closed vessel and there condensed by cold water poured on the outside. The resulting vacuum drew water up the suction pipe through a non-return valve in the bottom of the vessel. When steam was again admitted, the water was driven out of the vessel through a second non-return valve and up the delivery pipe. The steam and cold water valves were worked by hand".

In 1702, he introduced an improved pump with two vessels, which discharged alternately to give a continuous flow.

Savery's steam pump was built in considerable numbers and became known as "the Miner's friend" until superseded by Newcomen's invention, which was the first to use steam energy to work a piston within a cylinder.

Another pump developed at the turn of the century was the plunger pump, an invention attributed to Samuel Moreland on the basis of his patent of 1675. The specification of the pump is not set out in the patent, but is supposedly similar to the pump installed at York Buildings in London (*ca.* 1710), and described by Usher:(20)

> "The feature of this pump that proved to be significant for the future was the gland and stuffing box through which the plunger operates. Two thickness of cupped leather are bolted to the top of the pump cylinder and held in place by an outer plate... . In the plunger pump the prime mover lifts the plunger, whereas the water is raised by the descent of the plunger, which must, in some cases, be weighted with lead disks proportionate to the height to which the water is to be raised."

It was in 1732 that Kernelien Le Demour published in Paris his description of a "Machine pour élever de l'eau". The illustration of his machine was described by Harris as "showing a very crude appliance — it cannot with justice be called a pump — designed to raise water by centrifugal force". Le Demour's description is as follows:(11)

> "AB is a receptacle in the centre of which is placed a vertical shaft CD which can be turned freely by means of the crank M fitted to it, on this shaft are fitted arms, on the extremities of these arms the pipe GFE is fixed at an inclined position... . This pipe turns with the shaft CD and by the centrifugal force which is communicated to it by the power which rotates the crank M, the water rises in the pipe and is discharged at the extremity G."

Tests carried out by the Académie des Sciences reported that Demour's machine "made 34 revolutions in as many seconds and has raised about 120 l of water to a height of 2 m. The pipe was inclined at 50 degrees". This machine cannot be regarded as making any improvement on Papin's centrifugal pump, but it did reawaken interest in the development of centrifugal-type pumps.

8.4.3 From Euler to Appold(11)

In 1751, Leonhard Euler, the Swiss mathematician, analysed Le Demour's device, and proposed a more advanced machine:

> "The Machine will have the form of a hollow funnel of which the interior surface is a parabolic cone formed by the revolution of a parabola around the axis. The exterior surface is a cone generally similar but greater, forming with the interior surface, the cavity in which the water can rise. And to hold the two surfaces together, the cavity is divided from top to bottom by diaphragms... . To operate the machine it is immersed into water... so that the cylindrical portion is below the water, the height of the cylinder being regulated accordingly."

While Euler's proposals did not lead to any practical advance in the development of the centrifugal pump, his theory was not replaced until Unwin's paper of 1877, and some of his work is still used in centrifugal pump calculations.

In 1785 John Skeys patented "A Pump on a new Construction" (British Patent No. 1506) which foreshadowed the vertical axial flow type of pump. But it was not until 1818 that really practical development of the centrifugal pump took place (Fig. 8.7). This breakthrough took place in America. As Harris(11) relates:

> "The year 1818 saw the introduction in America of what is now known as the "Massachusetts Pump", from the name of its place of employment, the name of the designer having been lost. In spite of its semi-anonymity, the Massachusetts Pump is of considerably more importance than is usually appreciated, because it showed a return to the original conception of Denis Papin with the creation of a forced vortex within a circular, or spiral, casing by means of blades, as opposed to all the other devices which had been tried in the intervening century. The principle of the forced vortex is fundamental to the general principle of all modern centrifugal pumps, and it will be appreciated that the design of the Massachusetts pump had much in common with present-day design. From 1818 onwards, though there may have been minor departures from this fundamental design, the development of the centrifugal pump has proceeded along a well-defined line."

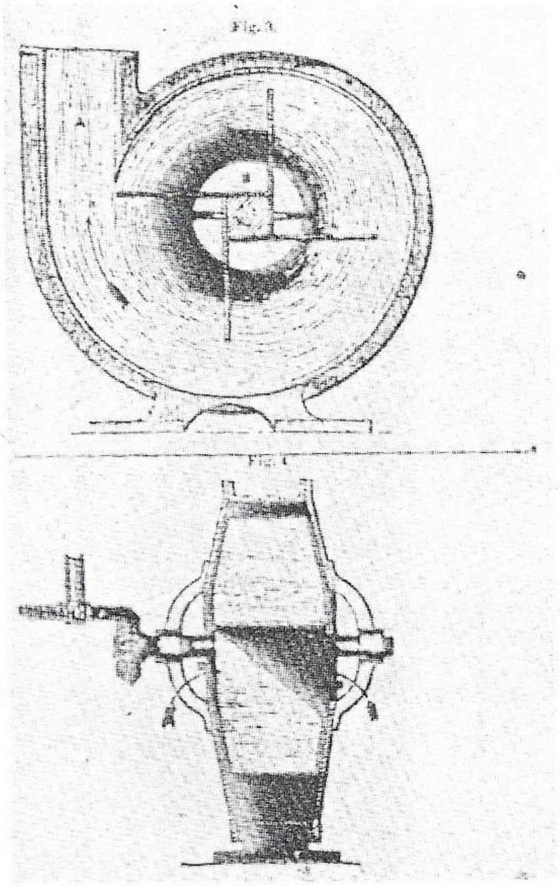


Fig. 8.7. The Massachusetts Pump (1818).

It is recorded that by 1830 an improved Massachusetts pump was working in New York, while in 1831 Messrs. Blake of Connecticut brought out a "centrifugal disc pump", incorporating a semi-shrouded impeller (Fig. 8.8). In 1839 W. D. Andrews was granted the first US patent for a centrifugal pump (this pump incorporated a form of volute discharge chamber). In Russia, a centrifugal pump was built by Sablukow some time prior to 1836. In France, in 1838, M. Combes presented his paper "Sur Les Roues de Reaction" in which he discussed the centrifugal pump. Combes also investigated the effect of curved blades and went on in 1843, to establish various principles and formulae which he developed from the early ideas of Segner and Euler. In March 1846, Andrews received a further US patent for an improved version of his pump, which incorporated the first double shrouded impeller. Meanwhile, an Englishman, James Stuart Gwynne began his centrifugal pump experiments in America, acquiring the patent rights of Andrews' 1846 design, and in 1851 acquiring his own US patent for his "Direct Acting Balanced Pressure Centrifugal Pump". Somewhat surprisingly Gwynne's pump only employed one blade.

Meanwhile, on this side of the Atlantic, the centrifugal pump was also being developed independently by both Appold and Bessemer. Prior to the Great Exhibition of 1851 much controversy raged between Appold, Bessemer and Gwynne over the merits of their respective pumps (Fig. 8.9). The argument was conclusively settled by the tests conducted by the Jury of the Exhibition, which gave the following results:(7)

Make	Water quantity (1/s)	Head (m)	Speed (rev/min)	Efficiency (%)
Appold	94	5.9	788	68
Bessemer	64	1.0	60	22.5
Gwynne	22	4.2	670	19

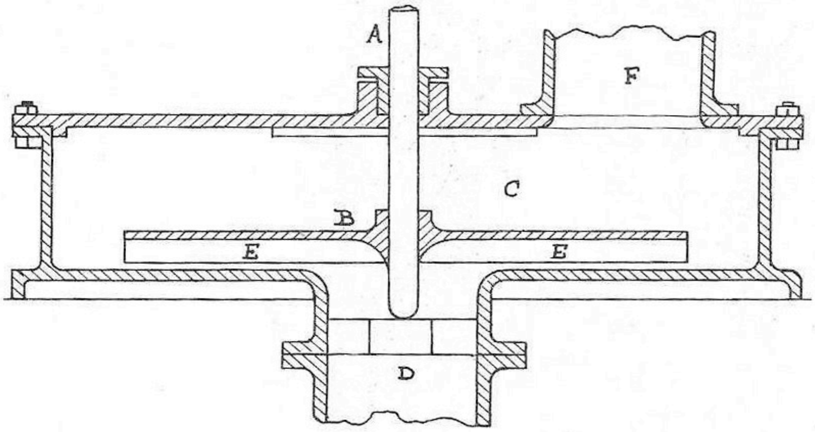
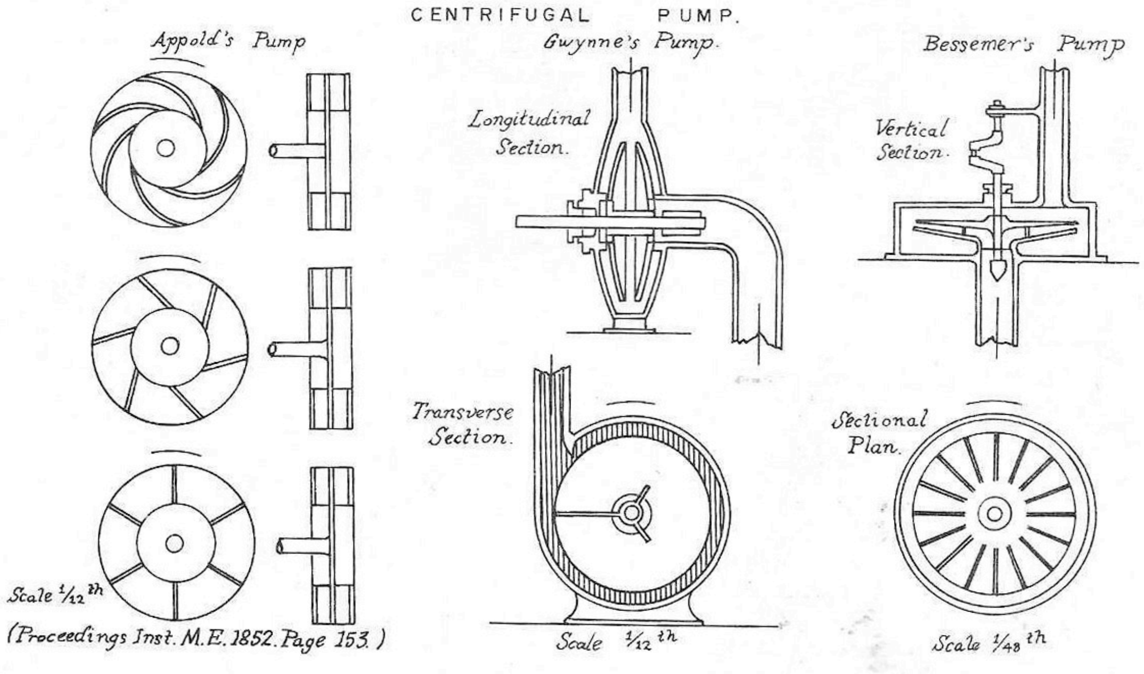


Fig. 8.8. Blake's vertical "disc" pump (1831).



(Proceedings Inst. M.E. 1852. Page 153.)

Fig. 8.9. The three pumps at the 1851 Exhibition (by Appold, Gwynne and Bessemer).

Gwynne's pump was handicapped by its small size and having only one blade. Bessemer's model suffered due to its very slow speed and its radial bladed design. The superiority of the Appold pump is apparent, due to its high speed and the curved vanes on the impeller.

Osborne Reynolds, best known for his analyses of fluid motion and for the "Reynolds Number", was responsible for making important improvements to the design of centrifugal pumps. He patented the multi-stage centrifugal pump in 1875 and subsequently introduced guide vanes to enable fluid kinetic energy to be converted to pressure head within the pump, with a resulting improvement in efficiency.

8.4.4 Pumps in the 20th century

The earliest IHVE paper on pumps was that presented by Barker in 1922. Barker, a Past-President of the IHVE, and a brilliant engineer who contributed much to the knowledge of the heating industry, took, at this time, what might now be regarded as a rather surprising attitude to pumps for heating installations:(2)

> "There is a strong tendency to misuse the centrifugal pump in heating installations. A large number of installations in these modern times are being put in with pumps which ought to be put in to work by natural gravity if the interests of the client were properly considered."

In fairness, Barker recognised that centrifugal pumps were here to stay. He recommended that a Centrifugal Pump Standardisation Committee should be set up, and left the pump manufacturing industry in no doubt as to the type of pump required:

> "The centrifugal pump suitable for our purposes should be designed essentially to have a high efficiency at a low head. No makers seem to have attended to this matter, or, at any rate, the efficiency of most of the pumps which are on the market at the present time for very low heads is exceedingly low.
>
> A range of ¾ in, 1 in, 1½ in, 2 in, and 4 in, (18-100 mm) having impellers varying in diameter from 4 in to 7 in (100-175 mm), and having capacities from 2000 lbs to 200,000 lbs (900-90,000 kg) per hour, would cover practically all the heating installations in this country of which I have any knowledge."

By 1927, Pullen was able to summarise developments in centrifugal pumping as follows:(13)

> "Until about thirty years ago, centrifugal pumps were only used for very low heads, say, up to 9 m and where economy was of secondary consideration, but with the improvements in design and construction of today, it is possible to build highly efficient and economical centrifugal pumps up to 90 m per stage.
>
> The development of the modern centrifugal pump dates from the introduction of the electric motor and steam turbine, which provide high-speed prime movers admirably adapted for driving what is essentially a relatively high-speed machine, and the centrifugal is replacing, for nearly all conditions of use, the reciprocating pump."

At this time, there were two kinds of pump impeller in use. The "open" impeller consisted of a series of radial vanes on a central hub, and revolved between fixed side plates in the casing. The clearance required between these plates in the impeller produced leakage or "slip" with a consequent loss of pump efficiency. One modification of this design employed a stiffening web on one side, usually extending from the centre to the periphery (and permitting the impeller vanes to be made thinner.)

The alternative impeller was the "closed" (or "shrouded") type, consisting of two circular discs with the vanes in between. This arrangement formed closed passages for the water from the suction inlet to the periphery — the only point of possible leakage being back into the suction, which was reduced to a minimum by making the hub or wearing rings on the impeller a running fit in the suction cover. The frictional loss of the enclosed impeller is much less than the open type.

The other requirement to obtain a high pump efficiency was the shape of the pump casing, and this was usually of a volute or spiral form, designed to gradually reduce the velocity of the water as it flows from the impeller to the discharge outlet. Apparently, some pumps of this period employed a circular case with the impeller fitted concentrically. The only advantage was cheaper construction costs, mainly because the same case could be used for a large number of sizes of impeller.

By 1935, emphasis in the heating industry had shifted away from the theory and design of pumps to the more practical aspects of their selection and installation. Thus, papers in that year by Jones(12) and by Brookes Ward(6) were concerned with pump characteristics, with the complexities of parallel and series pumping operations, with selection of motor and drives, and how to locate and install pumps to prevent noise and vibration problems. However, some constructional problems were still not yet always adequately resolved:(12)

> "The impeller should be dynamically and hydraulically balanced to ensure perfectly true running, the shaft being supported by at least two bearings in addition to the stuffing box and wearing rings, one bearing being near the impeller, the other in an outer bracket and so designed to take up surplus end thrust in either direction. A source of trouble with pumps used as accelerators is leakage of water from the gland, especially in high buildings where the static head may be anything up to 275 kPa."

Pumps for building engineering services have been steadily improved and developed since World War II, but the event having most impact on the general public has been the introduction of low-cost reliable small circulating pumps for domestic heating systems (Fig. 8.10). In recent domestic pumps, the head developed can be adjusted to suit the specific installation.

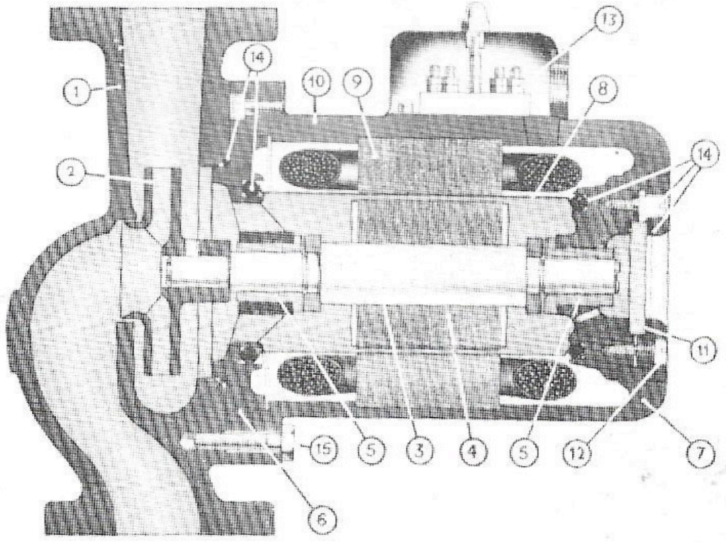


Fig. 8.10. Domestic central heating pump (1955).

REFERENCES

1. Agricola (1941) *De Re Metallica* (Basle 1556), trans. Hoover, Stanford U.P.
2. Barker, A. H. (1922) The use of centrifugal pumps in heating installations, *Proc. IHVE,* 21, 277.
3. Bennett, S. B. (1910) *Manual of Technical Plumbing and Sanitary Science,* Batsford.
4. Bernal, J. D. (1969) *Science in History,* Pelican.
5. Björling, P. R. (1902) *Pipes and Tubes,* Whittaker, London.
6. Brookes Ward, W. (1935) Pumps for heating installations, *JIHVE,* 3, 151.
7. Burstall, A. F. (1965) *A History of Mechanical Engineering,* Faber & Faber.
8. Derry, T. K. and Williams, T. I. (1960) *A Short History of Technology,* O.U.P.
9. Forbes, R. J. (1958) *Man the Maker,* Constable, London.
10. Hadfield, R. A. (1923) History of Metallurgical Science, Lecture to Birmingham University Metallurgical Society.
11. Harris, L. E. (1951) Some factors in the early development of the centrifugal pump, *Trans. Newcomen Soc.,* 28.
12. Jones, P. F. (1935) Hints on pump selection and installation, *JIHVE,* 3, 47.
13. Pullen, C. A. (1927) Notes on the selection of pumps, *Proc. IHVE,* 26, 75.
14. Raynes, F. W. (1909) *Domestic Sanitary Engineering and Plumbing,* Longman.
15. Robins, F. W. (1946) *The Story of Water Supply,* O.U.P.
16. Rosser and Russell Ltd. (1975) *The First 200 Years,* Privately published.
17. Rowntree, N. (1976) Water engineering - 100 years of evolution, *Proc. I Mech. E,* 190, 65-76.
18. Sullivan, R. W. (1970) The valve industry - its history and future, *J.ASHRAE* (July).
19. Tomalin, E. F. J. (1959) The use of plastics in heating and ventilating equipment, *JIHVE,* 27, 59.
20. Usher, U. P. (1954) *A History of Mechanical Inventions,* Harvard U.P.