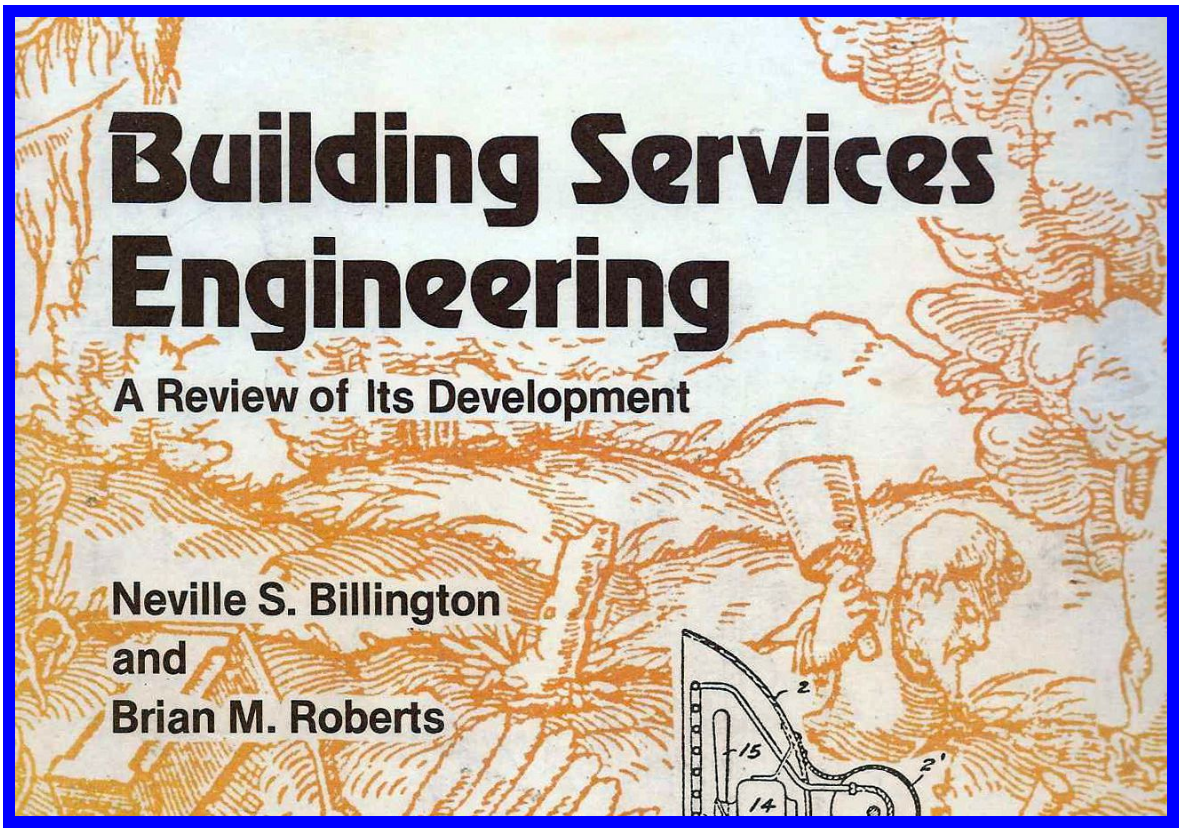
STEAM & HOT WATER BOILERS
1840-1930



FROM UK HISTORY 1982

3.8 BOILERS

3.8.1 Early boilers[39][61][65]

The very first boiler was probably that made by Hero of Alexandria in about 130 B.C. It was spherical in shape, and designed to produce steam, probably as an engine. There seem to be no further records until 1663, when, in a book entitled *A Century of Inventions*, the Marquis of Worcester described a spherical boiler used for raising water to a height of 12 m. This was followed in 1698 by Savery's boiler (used for the same purpose): this was in the shape of a cauldron with a flat top, and could generate steam at 170 kPa. It was constructed from hammered copper, the flat top being of lead.

Newcomen and Cawley's boiler of 1705 was designed to drive Newcomen's beam engine. The boiler itself resembled a circular haystack in form, and was some 3 m in diameter. It was constructed of iron plates rivetted together, and set in brick-work, which formed the flueways for the combustion gases from the furnace beneath the boiler. It seems to have been uneconomical and unsuitable for raising large quantities of steam, and it was superseded by the cylindrical "waggon" boiler which had an internal firebox, and sometimes a smoke flue. Both the haystack and waggon boilers were in common use by 1725, and held their place for 70 years or so. Brindley, and Watt, manufactured furnace-tube boilers in about 1800.

Rumford experimented with boilers, and concluded that they should be as large as possible, to minimise the heat loss per unit weight of water. He and Leslie recommended that boiler plates should be thin, again to aid heat transfer. At that time, boiler pressures did not exceed 25 kPa. In Rumford's setting, the flue gases leaving the back of the combustion chamber were returned to the front end, and finally led to the chimney stack through flueways running alongside the furnace chamber beneath the boiler.

Thomas Tredgold gave a lengthy dissertation on the design and operation of boilers. He preferred the spherical boiler because of the low surface to volume ratio which minimised heat loss. He deprecated the waggon boiler, because it was structurally weak. With Rumford, Tredgold recommended thin plates for the bottom part of the boiler, not only because of the better heat conduction, but also because the metal would be less liable to overheating. The boiler, he said, should be about half filled with water, and the steam space should be equal in volume to that of the pipes etc., using the steam. The optimum water surface area was said to be 2 m^2. The length of cylindrical or waggon boilers should be about $2\frac{1}{2}$ times the diameter, and should not be so great that the gases were cooled below 100°C.(90)

Tredgold thought the additional complication of taking a return flue through the boiler was not worthwhile. The grate area was to be one-quarter of the heating surface: 0.1 m^2 of grate will burn 5 kg of coal per hour, and evaporate 35 kg of water.

A decree was published in Paris (loi de 12 juillet 1828) prescribing a formula for calculating the required thickness of sheet iron or copper for steam boilers. There was a minimum of 30 mm, and a maximum of 150 mm, with a limit on the pressure, because metal quality could not be assured in large thicknesses. The decree also required a fusible plug, to melt at 10 to 20°C above the normal working pressure.(68)

3.8.2 Smoke reduction

Smoke pollution was, even then, felt to be a nuisance, as the following extracts from Chambers' Information for the People (1842) show.(3) In them, a number of plans for reducing smoke emission are described.

> "A plan for reducing smoke was devised by Mr Ivison of Edinburgh. In it, he projects a jet of steam into the space between the fire and the boiler. The theory is that the steam is decomposed by the heat and its oxygen unites with the carbon of the smoke."

"Mr Greenway employs two boilers and two furnaces. The furnaces are supplied with dampers so that their communication with their respective flues can be cut off and a communication between the two fires opened by an intermediate flue. When fresh coals are put on one fire, the damper of that fire is shut, and the intermediate flue opened, so that the smoke is obliged to descend through the bars and ascend through the burning fuel of the other fire."

"Williams' proposal was described in 1841. A long boiler is supposed, and the grate is placed at one end having its ashpit below as usual. The fumes of the coal pass onward under the boiler, towards a chimney at the opposite extremity. Under the centre of the boiler, and quite separate from the ashpit, there is a square chamber having a flue by which air can be admitted from without. Three short vertical tubes project upwards from it into the space beneath the boiler along which the fumes pass. These tubes are perforated all round the sides and tops. At every charge of fresh coal, the first product is a very large body of impure coal gas, the unconsumed portion of which as it passes the bridge and meeting the air, mingles with it and is instantly inflamed. The saving of fuel is said to be about 25%."

3.8.3 Cornish and Lancashire boilers

Early boiler designs were governed by their use as steam generators, and by the methods then available for construction (casting or rivetting). Designs were simple, and the only heating surface was that which could be licked by the flames and hot gases. External furnaces were necessarily inefficient, since much of the combustion products never came into contact with the water-backed surfaces.

The Cornish and Lancashire boilers with their internal flues marked the first advance towards increased heating surface; the Economic boiler with its secondary (indirect) passes was the final stage along this road.

The Cornish boiler seems to have been due to Richard Trevithick, and comprises a cylindrical shell inside which runs a cylindrical flue.* Moorhouse gives the date as about 1800; Simpson and Gunn make it 10 years later. Trevithick eventually raised the steam pressure to 1 MPa, this being accomplished even with such imperfect methods of construction as hammering the plates to shape by hand, punching and drifting the rivet holes into rough alignment, whilst it was customary to lay in the joint a piece of rope yarn before rivetting up, to ensure steam tightness.

The growth of the cotton industry in Lancashire led to demands for larger engines of greater power. Mr Fairbairn (later Sir William) modified the Cornish boiler in 1855 by making it longer and of larger diameter, and by introducing two furnace tubes: this became known as the Lancashire boiler. Both patterns were essentially the same as present-day designs.

An 1853 patent by Pearce was the forerunner of the Economic boiler; Thomson (1866) devised the three-pass Economic boiler. The "wet-back" or Scotch marine boiler was devised by Dagleish during this same period.

A typical low-pressure steam boiler of the period, working at 500 kPa, would have 1.7 m^2 heating surface per horse-power, and could evaporate 7 kg of water per kg of coal: the coal consumption was 5 kg per horse-power-hour. Boilers were commonly fitted with water-level indicator, pressure gauge, and thermometer.

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*According to Woolrich, the inventor of the Cornish boiler was Oliver Evans of Philadelphia, in 1800. In this version, Evans is said to have given the name "Cornish" in recognition of help received from Trevithick in their correspondence.

Box reports the results of tests on various boilers, including Government trials on Cornish boilers.[17] The efficiencies ranged between 50 and 70%. Box demonstrated that forced draught and excess air both reduced the efficiency. The boiler length was critical: an increase of 50% above normal gave a mere 3% increase in efficiency, and thereafter the greater losses caused the efficiency to fall.

*3.8.4 Tubular boilers**

As metal-working techniques improved, the multi-tubular boiler (either fire-tube or water-tube) became possible. It gave greatly increased heating surface, and because of the higher gas or water velocities, there was also a greater rate of heat transfer. The construction of the water tube boiler also permitted higher pressures to be used. The tubes imposed some restriction on water flow within the boiler, and gravity circulation was insufficient to prevent local boiling. Forced circulation became necessary. (This was less of a problem in hot-water boilers, since the external circuit ensured a circulation within the boiler.)

Seguin (French patent of 1827) invented a vertical multi-tubular fire-tube boiler, and used fan draught to overcome the resistance of the fire-tubes. Péclet illustrates the Holcroft and Hoyle boiler (BP of 1854), which comprised an upper cylinder and two lower cylinders containing fire-tubes (Fig. 3.18). The use of fire-tube boilers was then increasing, particularly in England. Cater's patent tubular boiler had a furnace beneath the shell, and the gases passed along a bottom external flue, and then through two passes of fire-tubes within the shell.[17]

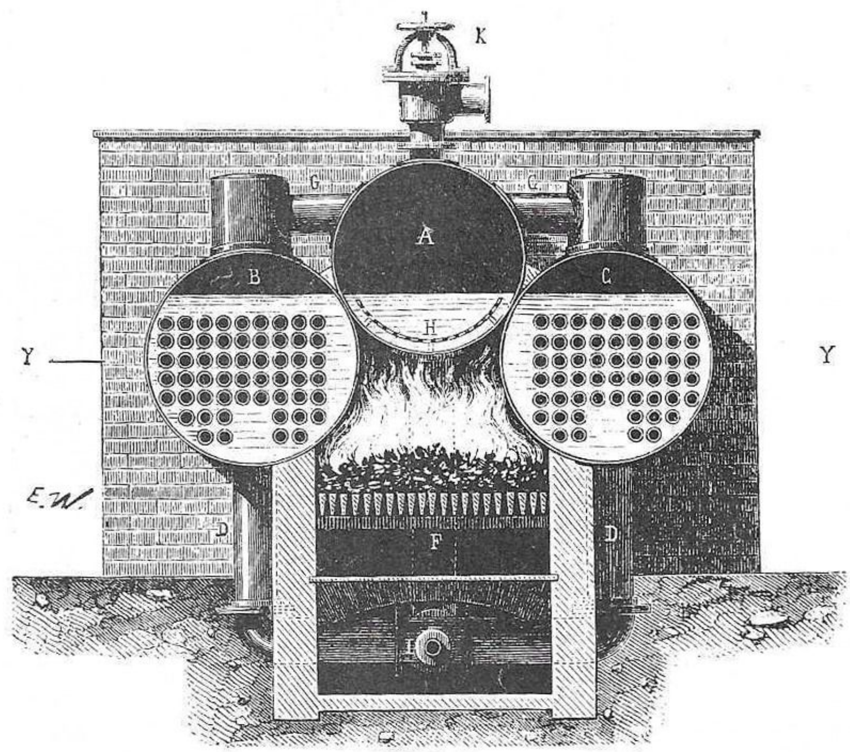

Fig. 3.18. Holcroft and Hoyle's steam boiler (1854).[66]

*An excellent account of the development of steam boilers is given by Powles.[97]

The first water-tube boiler was built by William Blakey in 1766. A water-tube boiler, used in the Cornish mines, was patented by Woolf in 1803. Another was patented by Moore in 1824, and a third by Alban in 1840.* Inglis' patent of 1868 was important. There was a horizontal drum, with headers at each end, and the tubes between the headers were slightly inclined. The boiler was externally fired, the grate being below the front end of the water tubes.

All these early boilers relied upon gravity circulation: forced circulation was a later introduction.

In the early years of the 20th century, several models of water-tube boilers for steam-raising were designed. The Root and Hogan boilers illustrated by Carpenter, and used in the USA around 1910, are typical.[23] The Root boiler appears very similar to the Belleville model described by Picard; the Hogan boiler resembles modern steam boilers.

Modern water-tube boilers differ only in the form and arrangement of the tubes and the position of the feed-water connection. All have a steam drum and a bottom water header. In an endeavour to permit small water-tube boilers to be used with low-quality feed water, Fraser and Fraser introduced a dual circulation boiler in 1954. The water circuits are arranged so that the impurities are concentrated in the cooler water circuit, and only relatively pure water passes through the hottest tubes. A divided steam and water drum, with a spill-over baffle, effects the separation of the two circuits.[8]

Before this, Jones (1904), Carpenter (1910) and Dye (1917) all remarked on the importance of extending the water space below the grate level, to allow the accumulation of sludge without causing incrustation and consequent damage.

3.8.5 *Boiler draught*

According to Brownlie,[20] a Mr Tindell of Scarborough used forced draught in 1814. Seguin's use has already been mentioned, and in 1855, Beaufume used a fan driven by a small steam engine in a furnace which was essentially a producer-gas generator.

By 1904, three methods of assisting boiler draught were in use, viz. steam jet, forced draught and induced draught. The two latter were obtained by steam-driven fans, of which the speed could be automatically increased when the steam pressure fell.

The use of secondary air to aid combustion was first employed by Watt (his patent of 1785) but, according to Tredgold, it was re-invented several times. Robertson patented the idea in 1791. Darcet in France introduced the air at the rear of the grate (1814), and in 1820, Parkes obtained a similar patent in Britain. Chapman of Whitby used pre-heated secondary air, introduced at the back of the grate.

3.8.6 *Water treatment*

The effect of scale on boiler performance was studied by Cousté (*Ann. des Mines*, 1854).[66] To avoid scaling:

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*The water-tube boiler was able to work at greater pressure, while at the same time using metal of lesser thickness.

"At first, potatoes were used. The gummy substance which is formed mixes with the deposits and prevents their adherence."

Bran was also used, and in 1836 Chaix had proposed clay, while in 1845 Neron and Kurtz successfully used logwood at the rate of 1 kg/hp, the action being due to the dyestuff leached out by the water. Péclet considered it was better to precipitate the calcium salts from the feed water, though he lists various other water treatments to combat corrosion — spanish white, lime, sodium carbonate, ammoniacal liquor from gas works, and zinc anodes in the water.

There were, too, patents for preventing incrustation in boilers (Davies, BP 3051 (1867); West BP 365 (1863) — both of which were for compositions of oil or oil, lime, soap etc. — and Jones and Powell, BP 3483 (1867), who attempted to use static electricity generated by steam from the boiler).

3.8.7 Heating boilers

Boilers for heating water instead of steam-raising were smaller and cruder than the steam boilers. Moorhouse says:

"It is reported that Mr Braithwaite of Kendal warmed part of his house, in 1812, by a small rectangular boiler having its furnace included in a rectangular cast-iron case, which had the appearance of a chest placed against the wall. From the boiler a small pipe led to a copper vessel under a double writing desk."(61)

The Marquis de Chabannes designed a wrought iron rivetted cylindrical boiler with a moveable fire grate. The saddle boiler — originally of rivetted wrought plates, but later of cast iron — was developed shortly afterwards. In 1854, Samuel Cook discovered a method of joining wrought plates by "fire-welding". His first designs were saddle and cylindrical boilers, and by 1863 he had established the Premier Works at Halifax.

"So was born a new industry which soon spread, especially in the north, whilst new and improved designs were quickly forthcoming when experience and skill warranted them."(61)

Many early designs of fire-welded boilers were brick-set. Fox notes that these early boilers, some of which incorporated a waterway bar and secondary flues, were in no essential way different from the cast-iron sectional designs of his own period.(39) The water-cooled grate bar had been introduced in England in 1843 by Kyher and Leighton.

There followed a period of great activity in boiler design and manufacture. In 1867, Robert Foster of Beeston patented a cast-iron saddle boiler with a terminal-end waterway (Fig. 3.19) — an advance made possible by improving foundry practice — and this enabled the gases to traverse the boiler a second time.(65) Bouillon and Muller's boiler was a double cylinder, cast in one piece, over a grate, and enclosed within a brickwork setting (Fig. 3.20). The flue gases washed both inner and outer surfaces of the cylinder.(68)

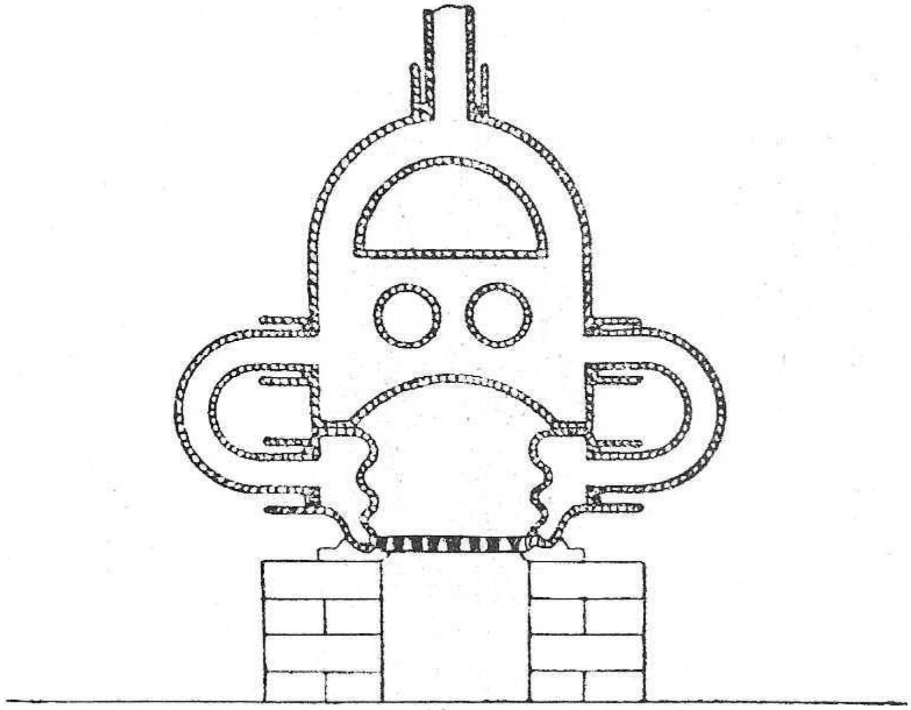

Fig. 3.19. Foster's patent terminal end saddle (1867).[65] (Courtesy, CIBS)

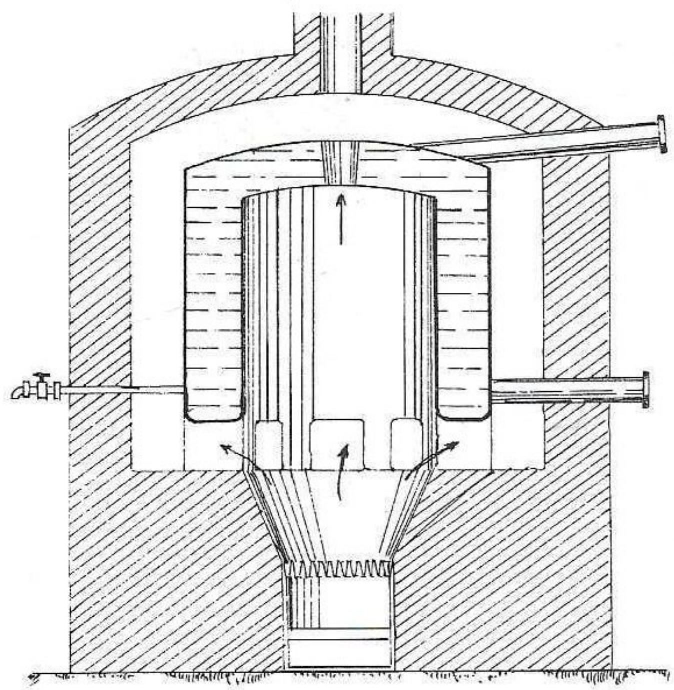

Fig. 3.20. Brick-set annuler boiler by Bouillan and Muller.[68]

Another welded boiler was patented by Evans in 1869 (BP 1679), and a year later the first fire-welded wrought iron independent boiler (i.e. it did not need a setting) was made. Russell's cast iron vertical tubular boiler, having wrought plates, angles and channels for its frame-work, was also built in 1870. The use of corrugated flues and tubes was patented in 1871. Edward Compton designed the Cochran boiler — a vertical cross-tube boiler — which was shown at the Bristol Agricultural Show in July, 1878.

In 1870, Joseph Russell invented his double pendant tubes (BP 2771) to ensure that circulation was maintained within the boiler system.

> "These tubes which are double are attached as to the outer one to the crown of the fire chamber or flue, as usual, the inner tube being suspended from a horizontal plate by which the water heater is divided into two distinct compartments. The upper compartment received the cold water, whence it passes down through the inner circulating tubes and up through the outer tubes to the hot water compartment, the water being heated in its passage."[76]

Wright's "Flame-impact" boiler was perhaps the first cast-iron sectional boiler to be made (1870) (Fig. 3.21).[65] The joints between the sections were made tight by means of india-rubber rings. Four years later, Wagstaff introduced a horizontal cast-iron sectional boiler, similar to the older saddle boiler. Again rubber rings were used to make the joints (Fig. 3.22). In 1875, Keith's "Challenge" boiler — another vertical sectional model — was introduced, but this design had the disadvantage that the grate area was the same, whatever the number of sections (Fig. 3.23).

Cast iron boilers were first used in Germany in about 1890. Rudolf Otto Meyer took out a patent for Strebel's boiler, in which the sections were circular annuli. Buderus began production of cast iron boilers in about 1895.

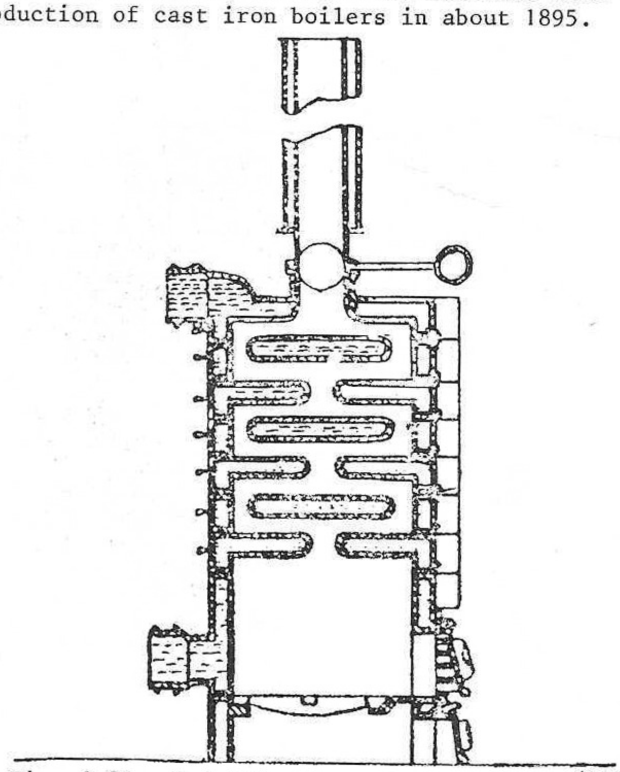

Fig. 3.21. Wright's flame impact (1870).[65]
(Courtesy, CIBS)

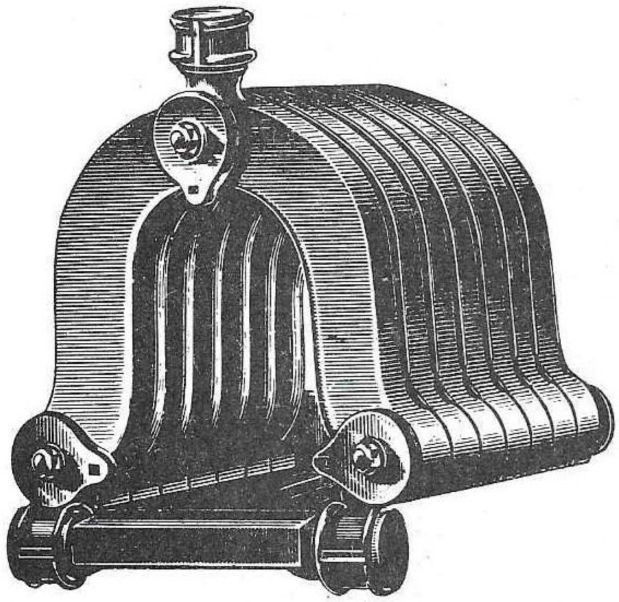

Fig. 3.22. Wagstaff's sectional saddle boiler, patented 1874.

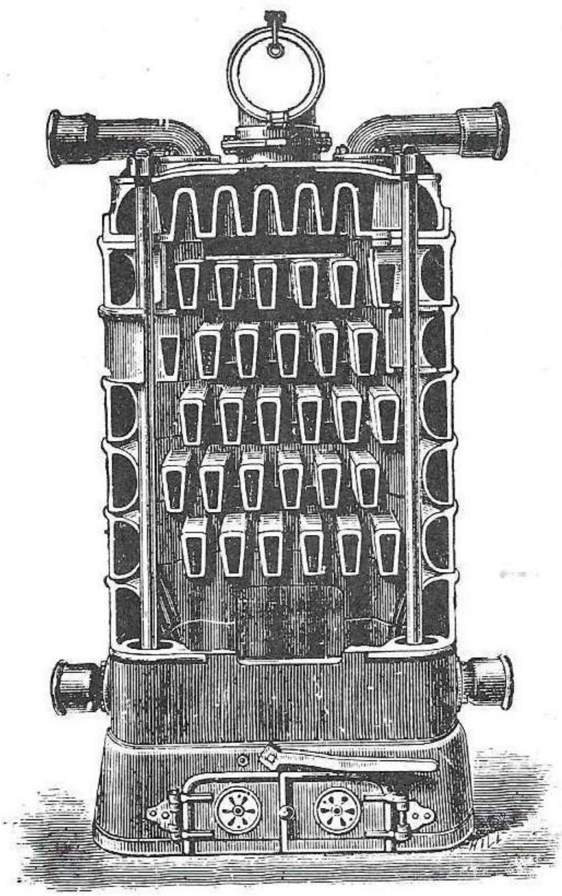

Fig. 3.23. Keith's 'Challenge' vertical sectional boiler.

By 1880, improvements in the working of malleable iron led to the manufacture of welded and rivetted saddle boilers. Wrought boilers of English manufacture began to supersede cast iron boilers in Switzerland. By 1890, more ambitious types of independent wrought iron boilers were being attempted. The "Severn" boiler was recognised as being particularly efficient.

Hartley and Sugden produced a wrought iron sectional boiler (the "European") in 1902. It had cross-tubes in each section, and flow and return headers.

Nevertheless, between 1895 and 1900, large numbers of cast-iron sectional boilers were being imported into Britain from America. The foreign makes apparently showed superior foundry practice, and they used taper nipples instead of rubber rings for jointing.[61] But by 1903, cast-iron horizontal sectional boilers, with taper nipples, were in full manufacture in Britain. The "Robin Hood" was one of the first.

Baldwin states (1889) that two types of boiler – the coil and the sectional – were normally used in the USA at that time.[10] The coil boiler used either a continuous spiral tube (as in the Perkins system) or a box coil with water tubes between the headers. James Nason was the first US maker of spiral coil boilers, in wrought iron. This type has a high resistance to water flow. Nason also introduced the box coil boiler. Pascal Ironworks made a box coil model with waterway grate bars, and later models had a baffled flue way. All were soon obsolete.

The Mills and Clogston boilers had the sections separately connected to the headers. The Gold boiler was similar, but had a 3-pass flue and a shaking grate. Hitchings, of New York, made a cast-iron conical boiler in 1844, probably the first of its kind (Fig. 3.24). The Gurney vertical sectional boiler had a magazine feed.

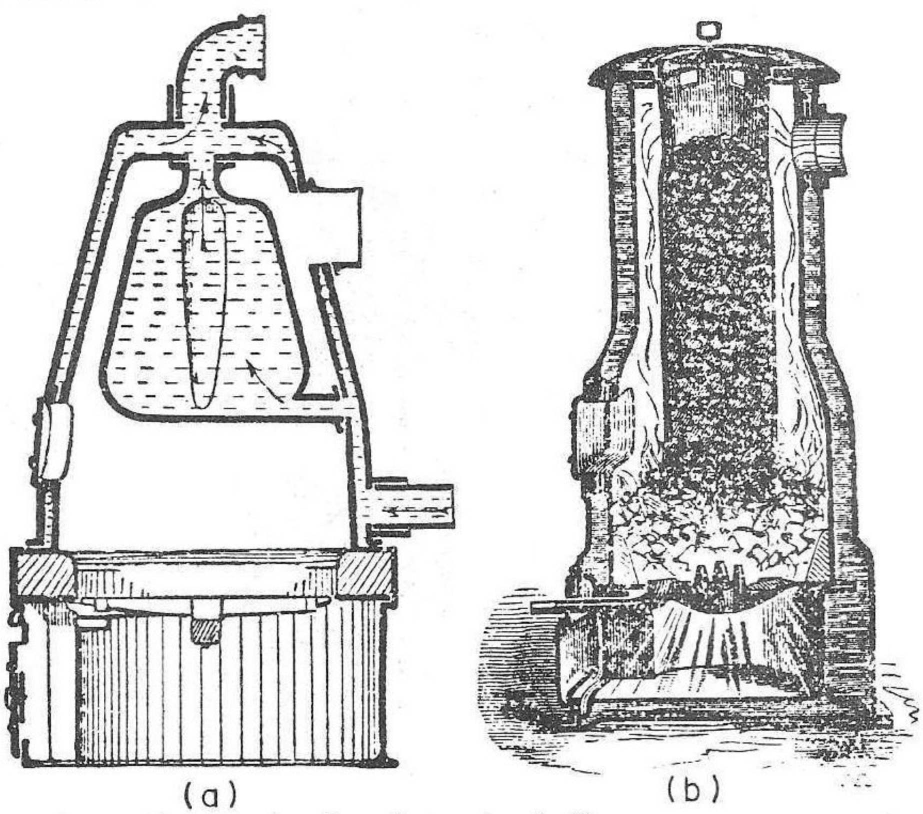

Fig. 3.24. Two American hot-water boilers.
(a) Hitchings conical boiler, 1844.
(b) Hitchings magazine boiler.

There seems to have been little significant advance in boiler design between about 1905 and 1930 but manufacturing techniques improved.

During the Great War, oxy-acetylene and electric arc welding made great advances, and many boiler makers (in the UK) learned much of the arts of pressing and welding. It became possible to make mild steel boilers in sections, capable of withstanding higher pressures than cast-iron boilers, and in sizes up to 1½ MW. (Fox notes that a steel sectional boiler, fire-welded, was made in 1902, but it was only a simple box boiler with cross tubes. It was costly to produce and the sections were a poor fit.) In 1931, Binns and Speight were making welded mild steel sectional boilers, for either oil or solid fuel. No nipples were used, the sections being independent, and connected to external flow and return headers. Sizes up to 1 MW were available, the largest size costing £825. In 1937, Lumby's were marketing steel sectional boilers. An automatic boiler for burning anthracite peas, with fan draught controlled by an immersion thermostat, and rated at 0.4 MW was on sale at £462. The price had risen to £951 in 1953, and to £1090 in 1960. A pressed-steel sectional boiler, for solid fuel or oil firing, was available up to 0.7 MW. The all-welded steel package boiler was introduced to the UK in 1953, from America.

The first corner-tube boiler in the UK was built by Saunders and Taylor, and installed at Metro-Vick (Sheffield) in 1959 . Large-diameter tubes at the corners connected by distributor tubes and collectors (headers) permit thermosiphon circulation within the boiler itself. This self-balances the water flow through the water tubes of the boiler, preventing burn-out by blockage in the hottest tubes. It also reduces the flow resistance and requires less pump head than conventional forced-circulation boilers (Fig. 3.25).

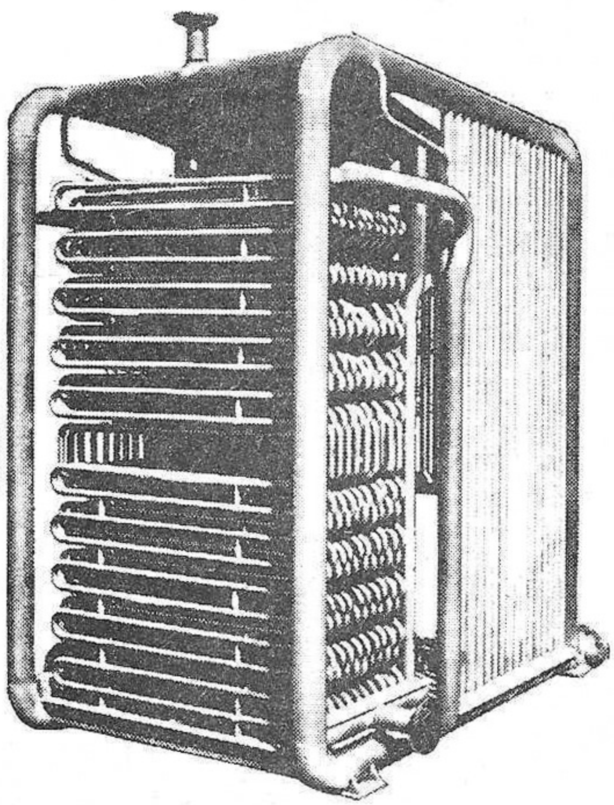

Fig. 3.25. Edwin Danks' new corner tube boiler (1958).

The smaller Earlymill boiler, of similar design, would burn unattended for 24 hours, and was intended for domestic use.

In hopper-fed boilers, the fuel is contained in an external hopper, from which it falls by gravity on to the front end of the grate. Picard illustrates a number of then current designs, many showing great ingenuity. Hopper feeding requires that the fuel be moved along the grate either by hand or automatically.

An embryonic stoker was used in Watt's smoke-preventing furnace (BP 1485 of 1785). It embodied two-stage firing – the front grate to coke the fuel and the rear grate to consume the residual coke – as an aid to smoke reduction. The principle of the underfeed stoker was invented by Hawkins and Dowson of London in 1816. Brunton (a member of the Watt-Boulton-Murdoch group) made a flat revolving-grate stoker in 1819, and in 1822 he patented a travelling grate with peristaltic motion (BP 4685), which is the basis of almost all modern coking and sprinkler stokers. A sprinkler stoker was invented by Stanley at about the same date.

Bodmer patented a travelling grate with continuous forward motion (BP 6617 of 1834), some years before Juckes' patent chain grate of 1841 (Fig. 3.27). This was followed by Taylor's patent 3371 (1868) for a chain grate stoker applied to a shell boiler.[20]

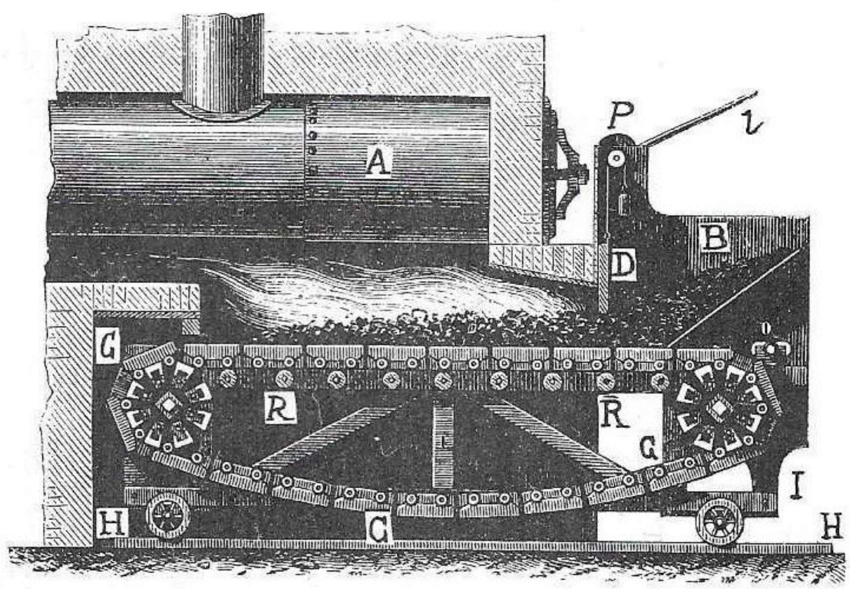

Fig. 3.27. Juckes' chain grate stoker (mid nineteenth century).

Automatic stokers were in limited use at the beginning of the 20th century, though neither Carpenter (1910) nor Barker (1912) mention their use in heating work. For the smaller heating boiler, the underfeed screw stoker was introduced *ca.* 1930 (Fig. 3.28). The coal was transported by the screw from the base of the fuel hopper to the combustion chamber of the boiler. No grate was used, and the device was suitable only for relatively short cast iron sectional boilers. It was claimed to reduce fuel consumption by 25% or even 50%, compared with hand-firing. The motion of the screw was controlled thermostatically to regulate the firing rate.

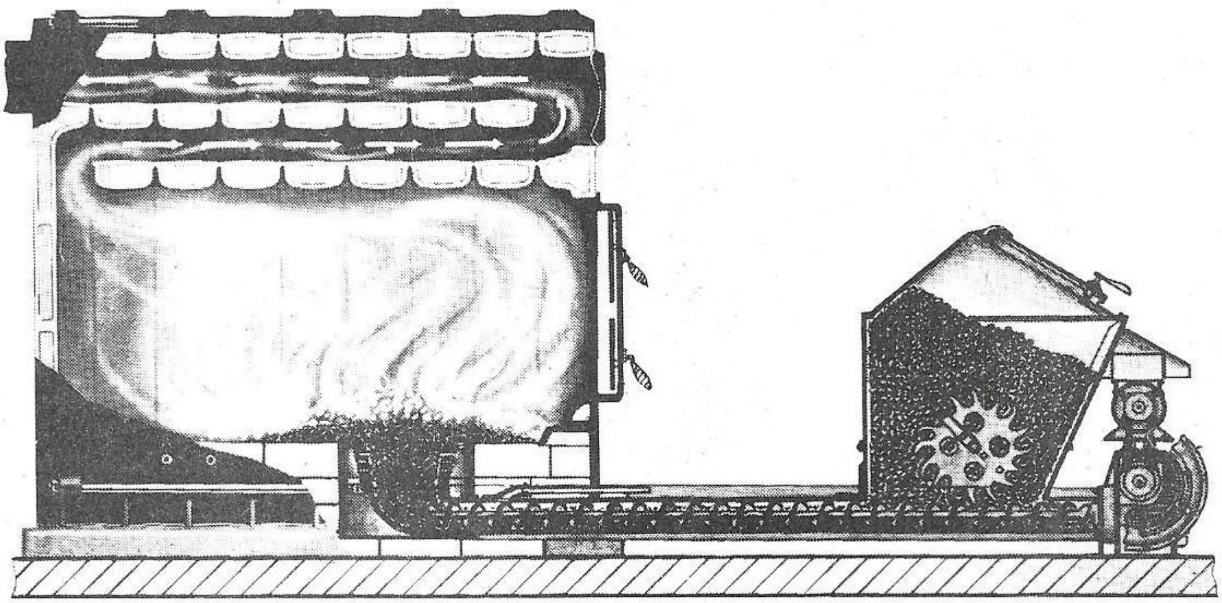

Fig. 3.28. Automatic screw stoker (*ca.* 1937).
(Courtesy, Crane Ltd.)

A modified sprinkler stoker — the Velos — was introduced in 1959. In this, the coal was transported by screw from the hopper to a water-cooled pre-combustion chamber, the fuel being sprinkled into this chamber. The gases are led into the combustion tube of the boiler (which may be either fire-tube or water-tube). Automatic control of the fuel supply and combustion air ensures a constant fuel/air ratio, and yields a CO_2 content of the flue gases of 14–16%.

In attempts to revive the market for coal, the National Coal Board is undertaking research into fluidised bed combustion, particularly for shell boilers.

About the turn of the century, Barker advocated the use of producer gas as an aid to smokeless combustion: it seems clear that examples already existed. Certainly Siemens had used a gas producer in 1862, though he did not apply it to boilers.(61) In 1908, Wollaston used a producer beneath a vertical boiler (Fig. 3.29).

*3.8.14 Oil firing**

Round about 1860, soon after the discovery of oil in America, Aydon, an Englishman, realised that if high burning rates were to be achieved, the fuel would have to be atomised. He proposed to inject the oil into superheated steam. The Russian, Schpakofsky, obtained a British patent in 1865 for the use of compressed air, while in 1868, F. Cook got an American patent for a rotating-cup atomiser. This device was little used and was not fully practicable until it was revived in 1900–10. Koerting used a pressure jet to atomise the spray: this has been credited to the year 1902, though his German patent of 1882 seems to describe the invention.

*A detailed account of early burners is given by Lew.(98)