BABCOCK BOILER DESIGN RATIONALE

GENERAL

This design of boiler was widely used in “full size” steam ships and derivatives were offered by Savery and Simpson Strickland for use in steam launches.

The book “Marine Steam” published by The Babcock & Wilcox Co 1901, is free of copyright restrictions and has been placed on the internet by the Cornell University Library.
Link is http://www.archive.org/details/cu31924098338373

It is strongly recommended that this is downloaded and carefully read, as it will clarify the design philosophy of this type of boiler and the advantages claimed.

Before the advent of modern sealing methods and CNC machining this design had serious disadvantages in that the headers consisted of a set of complex steel castings, and the boiler was unavoidably expensive to produce, particularly in small sizes.
Drawings of the Savery boiler are presented in the Appendix, and show the complexity of the boiler before modern methods enabled it to be simplified.

The logic of this boiler design, as re-worked for 21st Century production techniques, is that all the complexity and most of the man-hours are in the production of the two headers and cover plates.

Whilst it may be possible to produce these using manual means it is logical to use a CNC mill, thus ensuring overall accuracy and a smooth transition from the straights to the radii for the ‘0’-ring groove. It is assumed that for most builders of the boiler this part will be sub-contracted to a specialist machine shop.

The CNC milling costs will consist of a one-off cost for writing the software, then for each batch produced there will then be a set-up cost, and for each assembly there will be a machine time cost.

Once the headers have been produced the remainder of the boiler is much simpler than the norm. All tubes are straight, and there are only 3 or 4 sets of equal length tubes, (depending on the size of boiler). There is complete access for the tube expanding process without the need for special tools.

As the steam drum incorporates removable end caps, and the headers have bolted plate covers all of the boiler is accessible for close examination or cleaning.

DESIGN CONSIDERATIONS

The main feature of the design is the use of flat plate headers to take the ends of the generating tubes. This enables the use of only a steam drum, the mud drum(s) of other designs being eliminated.
The Babcock book together with the Savery drawings will show the layout and proportions, which are very consistent over a wide range of boiler sizes.

In the design of a high performance water tube boiler we can identify various ratios which have clear significance, and you should ignore at your peril.

These are summarised below,

$$\frac{\text{Heating surface}}{\text{Grate area}}$$

$$\frac{\text{CSA through generating tubes}}{\text{CSA through return tubes}}$$

Steam drum diameter relative to heating surface

$$\frac{\text{Clear area through the tube stack}}{\text{Clear area of the flue}}$$

Conjectural evaporation rate for natural and forced draught.

For the smaller boiler it was possible to adopt only one size of tube, (12mm OD) for supply, generating, and return tubes, whilst still maintaining the normal values of the ratios described above.

In the case of the larger boiler we use two sizes of tube, (20mm OD and 12mm OD) which is more closely copying the prototype boilers.

GRATE AREA, FIREBOX VOLUME, AND COMPLETE CONMBUSTION.

Contemporary literature on boiler design always highlights the requirement for a sufficient combustion chamber volume to ensure complete combustion of the gasses before they enter the tube stack. As the gases enter the generating area the heat is rapidly extracted by heating the boiler contents, until their temperature falls below the temperature of combustion. If complete combustion has not occurred before this point two highly detrimental factors prevail.

The increased cost of additional firing is totally wasted as non burnt fuel is sent to the atmosphere.

The partly burnt gases will deposit soot, tar etc in the tube stack to the detriment of heat transfer.

In an attempt to design a compact, low profile boiler the temptation is always to reduce the height between the fire bed and the generating section. Adherence to the proportions established by our forebears is the easy answer.

ECONOMISER

The boiler may be constructed either with or without an economiser.
The benefit of the economiser is increased for a higher working pressure and more particularly if forced draught is employed.

The designer has considered the benefits of feed water heating, and this was published as a letter in the SBA “Funnel” magazine.

It will be seen that in a high efficiency boiler of this type, the inclusion of an economiser of 7 ft^2 heating surface gives more benefit than would be the case or an increase in the heating surface of the generating section by the same amount. This is because the flue gases at the top of the boiler will be relatively cold, and a greater temperature gradient will prevail in an economiser where the contents are at a rather lower temperature than the temperature of the boiler contents.

FORCED DRAUGHT

Forced draught was more widely used by our forebears than it is today. Published information indicates that a pressure of between 1.3” and 2” water gauge at the grate will result in the capability of doubling the quantity of coal burnt. On the face of it one might assume that the evaporative capacity of the boiler would also be doubled, in line with the doubling of the heat energy produced by the fire. If the boiler geometry is unchanged the more intense fire will result in an increased furnace temperature, and this will carry on throughout the tube stack, resulting in higher temperatures in the smoke box and funnel.

In this case the economiser is a solution as the temperature gradient increases markedly and the efficiency of the economiser increases.

With forced draught more water will be evaporated, but this is likely to be of the order of 1.5 x the natural draught output, but this will be associated with a doubling of the quantity of fuel consumed.

STEAM COLLECTION ARRANGEMENTS / ABOVE AND BELOW WATER LEVEL DISCHARGE FROM THE GENERATING TUBES

Marine boilers seldom used the dome arrangement favoured in land based designs. In this context one must appreciate the consequences of above and below water level discharge of the boiler generating tubes. This is epitomised by the Thornycroft / Yarrow argument which was raging at the turn of the 19th century.

The rival 3-drum boiler designs were not dissimilar in general outline and proportions, but the fundamental difference was the use of bent tubes discharging above the water level in the Thornycroft design, as opposed to straight tubes discharging below the water level for the Yarrow design.
To obtain circulation the Thornycroft boiler required large, unheated, downcomers to supply water to the mud drums. In contrast the Yarrow boiler established an intimate circulation with the water descending in the tubes furthest away from the fire and ascending in the tubes closest to the fire.

In the event the spray generated in the steam drum with above water discharge in the Thornycroft boiler was a significant negative feature. By the 1920's virtually all watertube boilers in RN service were either Yarrow or Babcock. (see Ref 5).

In general a configuration with above water discharge requires more steam drum volume to allow for the collection of dry steam. This can be seen in the LIFU type 3-drum boilers, and the vertical centre drum "Lune Valley" type.

Yarrow had to make a glass model of his boiler configuration to convince the sceptics that it did work as he said. It is interesting to note that the Babcock boiler suffered similar questioning, and its critics again questioned the straight tubes and, more pertinently, the fact that the cross sectional area of the return tubes was less than the cross sectional area through the generating tubes.

The objection to straight tubes was easily overcome, and in this respect it is worth quoting verbatim from Reference 2. *…straight tubes do expand and bend when the boiler is steaming, and without doubt they do not always resume their absolutely straight form after cooling down…..if the stresses put upon the straight tubes are not greater than the metal and the joints are calculated to bear easily, the objection of not making allowance for expansion and contraction does not count for much.*

The Babcock boiler was fitted with glass observation portholes and tested at a very high output. It was seen that separation of water and steam was occurring in the steam side header, and what was being discharged into the steam drum from the return tubes was water for the lower part of the tubes, and steam for the upper part of the tubes.

To further ensure lack of priming it will be noted that a simple baffle plate is also fitted to deflect the flow downwards.

USE OF 'O'-RINGS AND DOWTY SEALS

Our forebears had rather more limited options for sealing arrangements than we have. Without modern methods the sealing of the large flat cover plates would have been problematical.

Details of the 'O'-ring groove are shown on the drawings. The 'O'-ring is 3mm diameter cord in viton material, which is suitable for working temperatures up to 200˚C continuous and 250˚C intermittent. An alternative material is "Atlas"

Tetrofluoroethylene/ propylene copolymers (FEPM), which is suitable for steam duties up to 260˚C.
On assembly the ‘O’ rings are to be lightly coated with James Walker’s Copper Anti-Seize compound, or equivalent.

Dowty seals are used at the 12mm bolts in the headers and at the 20mm dia tie bars in the steam drum.
These are to be temperature rated to a minimum of 200˚C continuous duty.

TUBES - DRILLING AND EXPANSION

12mm OD x 0.7 wall and 20mmOD x 1.0 wall generating tubes are to be a close sliding fit in the drilled holes. The tube from Dorset Tubes Ltd is produced to very close tolerances, and Tony Dunn has had no trouble fitting it to 12mm reamered holes.

Cu-Ni-Fe MATERIAL - PROPERTIES

For 90/10 tube published data gives a permissible working pressure of 50.9 bar for 20mm OD x 1.0 wall, and 61.3 bar for 12 OD x 0.7 wall, at a temperature of 250˚C. For a superheater application the temperature will exceed this and a permissible pressure of 60.1 Bar applies for a temperature of 300˚C. All these permissible working pressures are greatly in excess of our design pressure of 17.24 bar g.

In our design the superheater is of the radiant type, and the decision was made to make this as a fabrication in stainless steel 316.

HEADERS PRODUCTION

There are two options for the production of the headers, and the choice of which method to employ will depend on the facilities available.

It is possible to order a sufficient quantity of boiler plate in 30mm, 20mm, 16mm and 10mm thicknesses to produce all the machined items, flame cutting them “from the rough”, then carrying out all the machining operations.

The alternative is to purchase accurate profiles flash ground to the finished thickness from a specialist supplier such as Precision Profiles of Bristol.
Both surfaces should be ground. Flash grinding adds minimal cost to the blank, but provides a truly flat surface for setup and removes the surface hard layers.

If this is not done there is a likelihood that the headers will end up slightly bowed.

The table below gives the material requirements for the machined items of the larger boiler.

Item	No off	Raw plate t	Finished plate t	Profile dimensions
Headers	2	30	28	Rectangle 490 x 246.3
Header covers	2	10	8	Rectangle 487 x 243.3 with 45.5 radius corners
Economiser headers	2	16	14	Oval 286 x 102
Economiser covers	2	16	14	Oval 286 x 102
Steam drum ends	2	20	Supply raw	Circle. 232 diameter

FABRICATION SEQUENCE

1) Produce the machined items, consisting of, water side header, water side cover plate, steam side header, steam side cover plate, 2 x steam drum end plates, steam drum with holes for water and steam tubes.

2) The boiler can be produced as a “weldless” design. This means that there is no welding of the pressure parts, requiring the establishment of qualified welding procedures and NDE of the completed weldments. In spite of the attraction of this there is some merit in considering the use of a dome to ensure that the steam collector pipe will not prime in a seaway, particularly in a beam sea where the roll response can be significant with an athwartships steam drum.

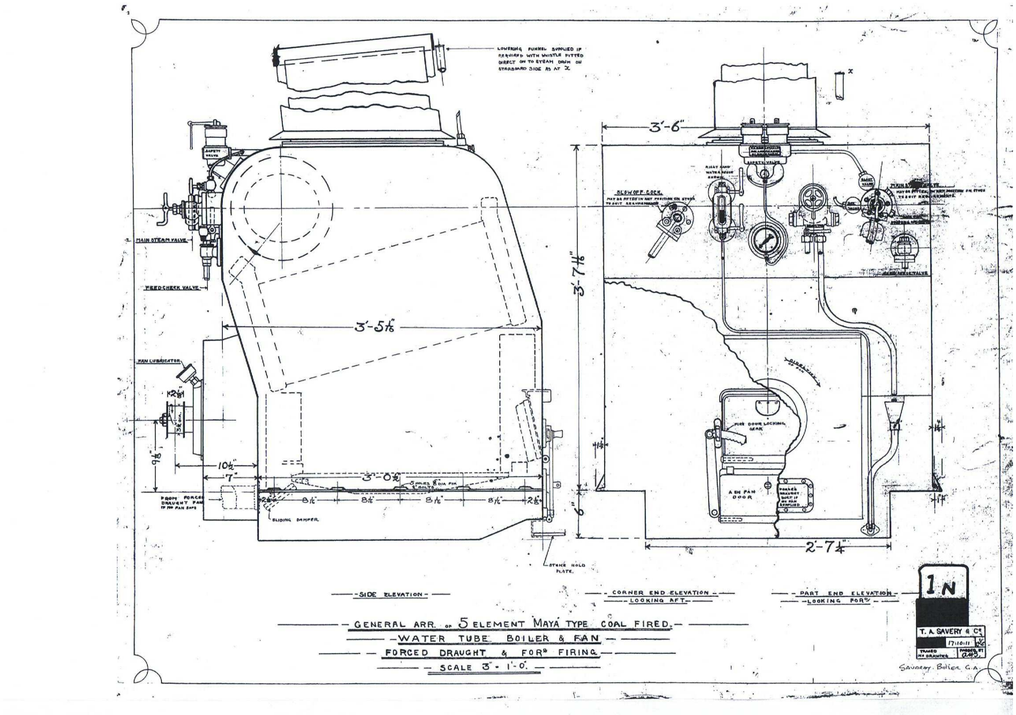
If a dome is to be employed this should be completed now.

3) The pressure parts are now incorporated into the boiler casing. It will be seen that the upper part of the boiler casing sides have a strength function, forming the framework for the relative positioning of the drum and headers. They are welded to the drum and header sides.

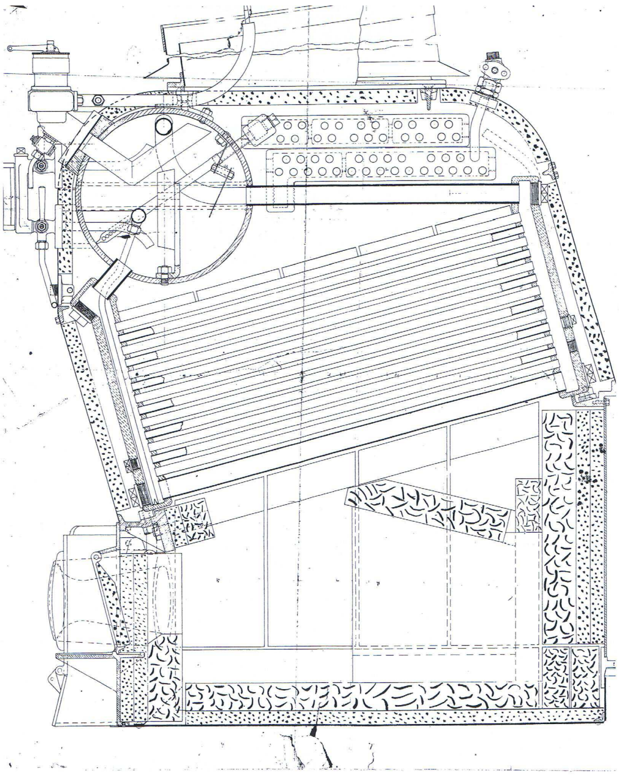
4) Insert and expand all the tubes. At this point a hydraulic test can be carried out.

5) Complete the remainder of the casing and ashpan.

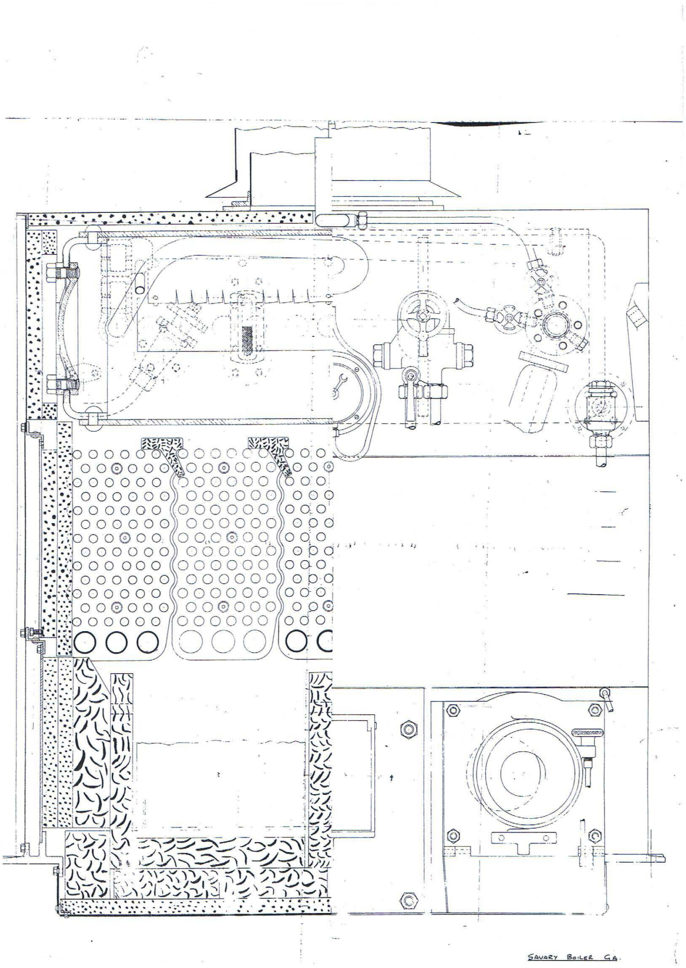
APPENDICES



GA of the Savery Boiler



Sectional Elevation of the Savery Launch Boiler



Sections through the Savery Launch boiler

REFERENCES

1 “Marine Steam. Forged Steel Water-tube Marine Boilers manufactured by The Babcock and Wilcox Co”
First Edition 1901

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Dixon Kemp Third Edition 1897

3 “Boilers Types and Design”
International Correspondence Schools 1907

4 “The Marine Steam Engine” R Sennet and H J Oram, New Impression 1917

5 Two papers “Present Position of Marine Steam Boilers” and “Naval Water-Tube Boilers”.
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6 Lloyds Register “Rules and Regulations for the Classification of Ships Part 5 Main and Auxiliary Machinery. Chapter 10 Steam Raising Plant and Associated Pressure Vessels”