# The Case for Boiler Water Treatment

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**WATER** as a substance can vary from the pure (distilled) to putrid (highly contaminated). Beech Hurst town main water is a relatively pure but "hard" water containing:

- Pure Water + Permanent Hardness + Temporary Hardness + Other Mineral Salts

Consider the composition of each of these constituents and what happens to them when water is boiled and turned into steam in a locomotive boiler.

Pure Water comprises $H_2O$, which when boiled produces pure steam which leaves the boiler via the steam pipes, performs useful work (we hope) delights all beholders, and does no harm to the boiler.

Permanent Hardness comprises Calcium and Magnesium Sulphates plus silicates (sand) plus chlorides (mainly Sodium Chloride, i.e. salt), which when pure water is boiled away as steam remain "in solution" in the boiler water space thus increasing the concentration of dissolved solids and sludge; they leave the boiler via valves and plugs during blowdown or wash-out times. They do not do much harm to the boiler unless the sludge builds up sufficiently to keep water away from the copper surface, or dissolved solids should reach a high enough concentration to cause corrosion of the boiler surfaces. (All car owners are no doubt aware of the corrosive properties of salt water). They can also cause "priming" by reducing the surface tension of the water. However with the quantities present in Beech Hurst water a great deal of steam would have to be evaporated to produce these effects. For example to make the boiler water as salty as sea water, 500 times the boiler capacity would have to be evaporated into steam. Also at sufficiently high concentrations calcium sulphate can cause scale, but again this concentration in unlikely to be reached at Beech Hurst between blowdowns or wash-outs.

Temporary Hardness comprises Calcium Bicarbonate which when boiled produces $CO_2$ (Carbon Dioxide) and Calcium Carbonate scale. The $CO_2$ leaves the boiler as a gas, mixed with the steam through the steam pipes; but the scale deposits itself on the water surfaces of the boiler copper. The $CO_2$ can cause corrosion but in small quantities provided it escapes freely with the steam it will be relatively harmless. Not so, however, the calcium Carbonate scale, this is the really harmful constituent of the water, this scale which is similar to "furring" in a domestic kettle etc. is a good heat insulator and so causes considerable harm to the boiler, as explained later.

Other Mineral Salts are of only insignificant quantities and so have no effect except to slightly increase the concentration of sludge and dissolved solids in the water.

So town main boiler feed can be summarised thus:

| Constituent | Comprising | When Boiled Becomes |
|---|---|---|
| Pure Water | $H_2O$ | Steam |
| Permanent Hardness | Calcium and Magnesium Sulphates + Silicates + Chlorides | Concentrated solution + sludge |
| Temporary Hardness | Calcium Bicarbonate | Carbon Dioxide + Scale |

**THE EFFECT OF SCALE** in the boiler is to act as a heat insulating film between the water which is to be boiled and the fire which is producing the heat to boil it. If we consider a clean boiler as shown below in fig 1, then when the water is boiling it will have the same temperature as the steam, i.e. saturated steam temperature $t_s$ corresponding to boiler pressure. The rate of steam production requires a heat transfer of 'x' B Th Us to be passed from the fire to the water through the copper. To produce this heat transfer there must be a difference in temperature, hence the water/steam surface of the copper must be at higher temperatures $t_1$ and $t_4$ than $t_s$ and the fire surface temperatures $t_2$ and $t_5$ of the copper must be higher than the water/steam surface. As the water boils it turns into steam and goes away to the "engine" being replaced by fresh water which again takes away the heat from the copper, hence the water and steam act as a "coolant" on the copper.

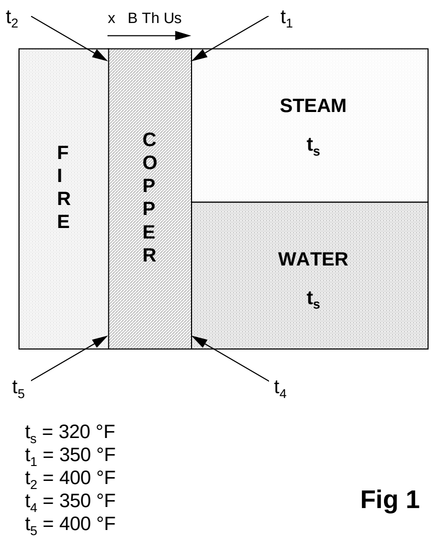


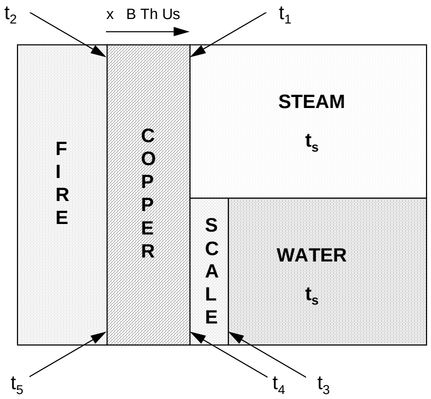

Fig 1

For a 90lb/sq in pressure locomotive working reasonably hard the sort of temperatures I would expect to require about 30°F for heat transfer from copper to water and about 50°F for heat transfer across copper hence:

water boiling/steam saturation temperature $t_s$ = 320°F actual

As copper in both steam and water spaces is in contact with steam or water at 320°F then the whole of steam/water surface of copper will be at same temperature hence $t_1 = t_4$ = 350°F estimated, and whole of fire surface of copper will be at same temperature hence $t_2 = t_5$ = 400°F estimated.

Now consider what happens with a coating of scale on the water surface of the same boiler at the same rate of steaming as shown in fig 2 below:




| | |
|---|---|
| $t_s$ = 320 °F | saturated steam at 90 lb/sq in |
| $t_1$ = 350 °F | (estimated) |
| $t_2$ = 400 °F | (estimated) |
| $t_3$ = 350 °F | (estimated) |
| $t_4$ = 530 °F | (estimated) |
| $t_5$ = 630 °F | (estimated) |

**Fig 2**

This scale is a poor conductor of heat, so there will be a fair temperature gradient across it. The water/steam temperature $t_s$ remains the same, so opposite the steam space the temperatures $t_1$ and $t_2$ either side of the copper remain the same as for the clean boiler. But opposite the water space there is now a layer of scale and the water side surface temperature $t_3$ of this scale will correspond to the copper steam side temperature $t_1$ and the copper water (scale) side temperature $t_4$ will have risen by the considerable temperature gradient required across the scale to give the required heat transfer. In view of the rise in $t_4$ the temperature $t_5$ on the fire side of the water space copper will have risen by something more than the scale temperature gradient due to the higher working temperatures involved. A fairly thin (10/15 thou) hard scale, or about twice this in porous scale will probably require a temperature gradient of 180°F, so estimated temperatures become $t_3$ = 350°F, $t_4$ = 530°F, $t_5$ = 630°F.

So due to scale the boiler copper is now subjected to a higher working temperature than necessary, also because the copper/fire or gas temperature difference is reduced less heat can be extracted from the fire and gases hence higher exhaust gas temperature and increased rate of firing for steam output.

Referring again to fig 2 it can be seen that the scale formation is only below water level because calcium carbonate is only formed in the boiling water not in the steam. This introduces a further problem for the boiler, namely a local stress line caused by the different copper temperatures opposite steam and water spaces i.e. $t_1$ to $t_4$ and $t_2$ to $t_5$. Fortunately in loco boilers the scale edge will be more of a slope than square, as fig 3, due to the distance between high and low water levels, but even so a temperature difference of 200°F approximately in the level of a gauge glass is not conducive to a long boiler life.

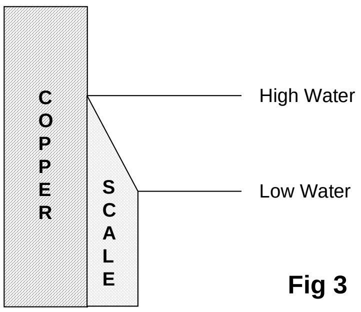



**Fig 3**

This effect also occurs round the edges of any patch of scale in a clean boiler, or any clean patch in a completely scaled boiler.

Figs 4 and 5 show actual temperatures recorded in scaled and non-scaled tubes of a 900/900 boiler. As can be seen a 10 thou film of scale can cause a very considerable increase of working metal temperatures. These figures were obtained by means of thermocouples attached to the surfaces so if any Model Engineer can manage to produce some actual figures for a model locomotive boiler I should be very interested to see them.

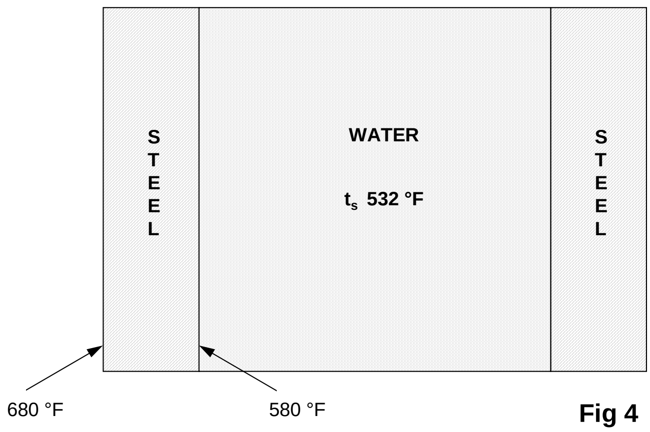



**Fig 4**

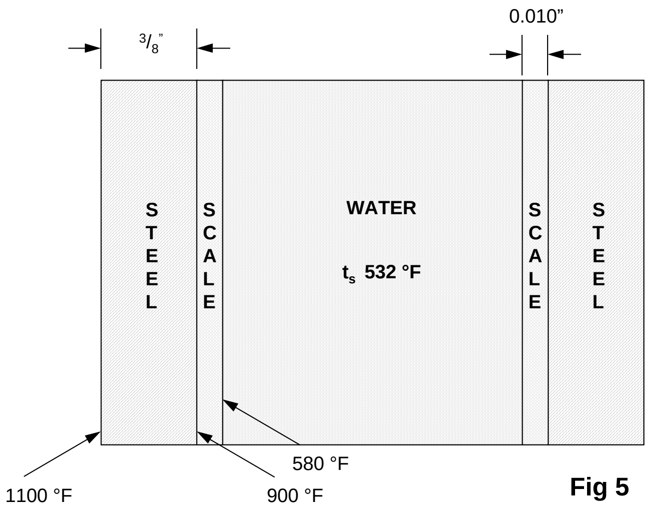



**Fig 5**

From the foregoing it can be seen that scale considerably increases the wear and tear on a boiler in service, as the copper working temperature is considerably increased, higher firing rates increase the gas velocity through the tubes, temperature stress points are created, thus reducing the life of the boiler, and where it is thick enough to limit the heat transfer the loco may be short of steam. Hence the need for boiler water treatment to prevent it.

**TREATMENT** of the raw town main can be carried out to prevent the calcium carbonate turning into scale.  There are two basic methods of doing this, namely precipitation and sequestration.

In the Precipitation process the calcium carbonate is turned into a sludge which remains in the boiler water space along with any "permanent hardness" sludge until removed by blowdown or wash-out.

In the Sequestration process the calcium carbonate is turned into an inert solution. For example a sodium based sequestric when fed to the boiler will have molecules with a sodium centre Na as fig 6, these work on the calcium carbonate molecules until their sodium centre comes out and is replaced by the calcium Ca as in fig 7, and this temporary hardness is then kept locked up in these molecules whilst in the boiler water space until removed by blowdown or wash-out.

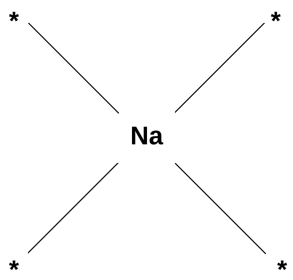



Fig 6

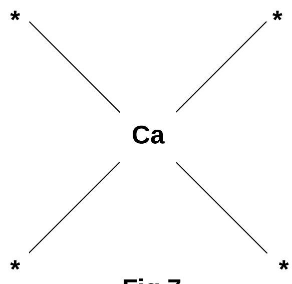



Fig 7

**TREATMENT IN PRACTICE on "Henry"**

During "Henry's" first season of running untreated water was used and after each run two gauge glass levels were blown down and the boiler washed out twice during the season.  By the end of the season both backhead blowdown valves (screw type) were seized solid, front firebox sliding disc type remaining operable.  Both backhead blowdowns were removed during annual overhaul and were found to be solid with scale round valve seats and threads to such an extent that the phosphor bronze spindle sheared before the valves turned.  An inspection of the water surfaces showed a thin film of hard white scale on the copper surfaces.

Consequently to save making new blowdown valves each year and a new boiler sooner than necessary it was decided to try to prevent further scaling by means of boiler water treatment from the start of the second season.

First method tried was precipitation using Calgon as an additive, this certainly prevented further scale formation, and also by heavy dosing removed the existing scale.  Unfortunately this form of treatment had two disadvantages, one priming when the engine was worked hard due to the sludge concentration combining with the loose scale particles from the first seasons scale being removed; two, fouling of injector cones due to priming and also injector steam being at a high enough temperature to cause Calgon to separate out and adhere to the metal surfaces of the cones. So Calgon treatment was abandoned, boiler and tender washed out, then refilled with town main.

Second method tried was Sequestration using sequestric acid disodium salt (SADS). Prior to the loco going into steam 10cc's of a saturated solution were put into the tender for each expected 2 hours running. The quantity does not have to be very accurate provided "too much" and not "too little" is used as it will remain in solution in the boiler water and if insufficient calcium bicarbonate arrives to use it all up during the running time the surplus will merely be wasted at blowdown.

This method caused no priming or injector fouling and during subsequent annual overhauls the backhead blowdown valves, which remained quite free, have been removed and the water space found to be clean except for a thin film of loose grey powdered sludge, left when the boiler was blown empty at the end of the running season, this can be wiped away to show bare copper so is quite harmless, and could no doubt be "washed out" with cold water, but as this would leave the boiler surfaces wet I prefer a little powdered sludge left by a hot "blown out" boiler for standing during the winter.

**TESTS** of samples of boiler water taken and analysed during the first seasons treatment are shown below:

Figures for 5 April and 28 June show composition of town main as supplied to boiler during filling.

Figures for 30 April are whilst using Calgon.

Figures from 9 July onwards are whilst using Sequestric acid disodium salt.

The dionic is a measure of the "conductivity" of the water and is the quickest and easiest means of checking dissolved solids in the water, but does not determine what they are.

The temporary hardness figure drops because boiling removes calcium carbonate.

The salt/permanent hardness ratio is approximately constant so increase in salt is a measure of the amount of water used between blowdowns. So if we look at the salt figures for say 15 October before blowdown we find it is 5.45 times town main, so with 60ppm calcium bicarbonate in town main 60 x 5.45 = 327ppm have been delivered to the boiler. But only 40ppm remain, hence 287ppm have been sequested (we hope) or formed scale.

Note: When calcium carbonate is "locked up" in SADS it cannot do harm, neither can it be determined by normal analysis.

| Date | Dionic 1/MΩ | Temp Hardness ppm | Total Hardness | | Salt | | Remarks |
|---|---|---|---|---|---|---|---|
| | | | ppm | ratio | ppm | ratio | |
| 5 Apr 69 | 320 | 60 | 124 | - | 55 | - | Filled Calgon |
| 30 Apr 69 | 1080 | 30 | 363 | 2.94 | 250 | 4.55 | |
| 28 Jun 69 | 320 | 60 | 124 | - | 55 | - | Filled SADS |
| 9 Jul 69 | 830 | 30 | 250 | 2.01 | 211 | 3.84 | |
| 10 Sep 69 | 1430 | 64 | 650 | 5.24 | 450 | 8.20 | Before Blowdown |
| 10 Sep 69 | 680 | 38 | 24 0 | 1.94 | 128 | 2.33 | After Blowdown |
| 15 Oct 69 | 1370 | 40 | 740 | 5.97 | 300 | 5.45 | Before Blowdown |
| 15 Oct 69 | 640 | 35 | 220 | 1.77 | 120 | 2.18 | After Blowdown |
| 11 Nov 69 | 1290 | 55 | 710 | 5.72 | 340 | 6.18 | Before Blowdown |
| 11 Nov 69 | 635 | 34 | 210 | 1.70 | 117 | 2.13 | After Blowdown |

Having found from the above series of readings and visual inspection in the following winter that this treatment plus blowdowns was achieving the desired results, subsequent running seasons have only required occasional "dionics" checks to prove that all is well.

One further "spin off" advantage is that SADS slightly increases the pH value of the boiler water which also assists to prevent the water becoming acidic at boiler pressure, although at Beech Hurst pressures this is only a marginal gain.

I hope that the above has shown that water treatment is worth while to stop the boiler "enemy" scale from forming, as even if a "scaled Boiler" can still produce sufficient steam to supply the requirements of its engine its life will be considerably shorter than that of a clean boiler producing the same amount of steam.  After all if you want an excuse to build another boiler why not build another loco?