

# Selection of Papers

by

**L.D. Porta**

**Volume 4**

- Special Edition -

## **Locomotive Boiler Water**

*covering*

**Water Treatment, Feedwater Heating and  
Boiler Water Behaviour**



*including papers by*

**Ing. Livio Dante Porta, Martyn Bane, Nigel Day, Shaun McMahon,  
Joachim Robrade, William Richardson and Friedrich Witte**

**Compiled and Edited by**

**Martyn Bane**

**On behalf of the Advanced Steam Traction Trust**





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## **- Special Edition - Locomotive Boiler Water**

### **Water Treatment, Feedwater Heating and Boiler Water Behaviour**

Papers covering water treatment, feedwater heating and boiler water behaviour from Livio Dante Porta, Martyn Bane, Nigel Day, Shaun McMahon, Joachim Robrade, William Richardson and Friedrich Witte

- Part 1 – Overview and Setting the Scene
- Part 2 – Ing. Livio Dante Porta Papers and Extracts
- Part 3 – Two German Papers
- Part 4 – Applying Porta
- Part 5 – Glossary, References and Index

**Edited by**

**Martyn Bane**

**Transcriptions and Translations by**

**Martyn Bane and Chris Newman**

**Series Editor**

**Chris Newman**

On behalf of the Advanced Steam Traction Trust.

***“What counts is what one has in the boiler, not what one feeds into it.”***

Ing. L.D.Porta's simple statement outlines, in just a few words, what became his approach to boiler water treatment. It seems at odds with accepted thinking on the topic, what did he mean by this? Very simply, if the boiler water chemistry is within a defined range the nature of the feedwater is of no concern.

It has been known since the 1970s with certainty, but for a few decades previously less clearly, that with a certain boiler water chemistry it is possible, in a practical sense, to prevent scale formation, corrosion and caustic embrittlement<sup>1</sup>. The use of Porta's system also ensures fully mobile, non-adherent sludge formation and the production of technically pure steam, foaming and boiler water swelling are controlled.

The boiler water chemistry is controlled through the addition of chemicals dosed at a defined rate, whilst the locomotive is in service, regardless of feedwater conditions. Naturally, the testing of boiler water samples needs to be undertaken to ensure success. The test results indicate if extra alkalinity needs to be added or if a boiler blowdown is required. Boiler water alkalinity and dissolved solids concentration are the two factors that are controllable conditions.

The implications of this are clear.

Feedwater constantly varies at and between watering points. There is nothing which can be done to change this unless a form of external treatment is applied, which the above suggests is not necessary. Therefore why be concerned by feedwater variation? Trying to accommodate any variations through adapting treatment dosing is always going to be, at best, difficult and inadequate. History has shown this to be the case, but it remains a common approach.

This volume contains much information supporting Porta's statement and approach.

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<sup>1</sup> The concept of absolutely zero scaling, corrosion etc is not achievable, but that which does occur is so limited to be of little concern.

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Page numbers at the top of each page represent those of this combined volume of papers.

Page numbers at the bottom of each page represent those of the individual papers.



ASH & Martyn Bane 2024

## **Part 1**

# **Overview and Setting the Scene**

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FCAF No.3 stands waiting for its next duty during the celebration of the line's tenth anniversary. This line, at the southern tip of Argentina, remains the best place in the world to see 'Porta Treatment' in use. 11 October 2004 © Martyn Bane

# Railway Locomotive Water Treatment

## An Overview of Carbonate and Tannin Based Internal Treatments



Issue 2.  
Martyn Bane. November 2013 and July 2023.

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## 1 INTRODUCTION

This document has been written as a non-technical overview of water treatment based on sodium carbonate<sup>1</sup> and tannin as applied to railway locomotives, primarily as an introduction to 'Porta Treatment'. It is written for a readership of people generally knowledgeable about steam locomotives and overall concepts of water treatment but not necessarily any detailed knowledge. It is not intended to be an exhaustive summary of the subject, or the specific internal treatments covered, rather it "opens the door" for those wishing to learn more on the topic. It is written from an international perspective but with an emphasis on UK practice. The references drawn upon, listed at the end of this document, are considerable in number and are generally of a technical nature. These references are shown as required in the text with the reference number in square brackets.

The arguments for and against internal or external treatments are not covered in detail but many of the arguments are implicit in this document. Internal treatments are those which see the addition of chemicals to the feedwater on the locomotive, concentrating in the boiler water to render effective treatment. External treatments, such as ion exchange or reverse osmosis, are those which alter the chemical nature of the feedwater before its addition to a locomotive's tanks. External treatments may be used in conjunction with internal treatments if required<sup>2</sup>.

The scope of this document covers locomotive type firetube boilers operating at up to 350psi. However, that does not mean the approaches and technical details outlined do not apply to other types of boilers or applications.

## 2 AN HISTORICAL SUMMARY

The problems associated with making steam by boiling water in a metal vessel have long been recognised, technical references available from the 19<sup>th</sup> century outline some of the early attempts to combat scale formation and corrosion [44]. Corrosion, through the thinning of materials, reduces their safe and useful life whilst scale can lead to the overheating of components, again shortening their life. Scale can also enable corrosion to develop unseen beneath it. The overall thermal efficiency of the boiler will be reduced by the presence of scale (fouling). The insulative effect of scale leads to a marked reduction in heat transfer rates and, thus, overall boiler efficiency. These problems all contribute negatively to the productivity and economics of operations.

The modern age of water treatment for railway locomotives started in the first couple of decades of the 20<sup>th</sup> century with the gradual development and adoption of treatment regimes based on various types of both internal and external treatments. The most successful internal treatment regimes were based on sodium carbonate<sup>3</sup> and tannin.

Sodium carbonate has several synonyms including 'soda ash' and 'washing soda'. Sodium carbonate readily dissolves in water, creating an alkaline solution. Tannin is the name given to a plant extract, the source of which is usually from trees. There are many different types of tannin, and they are put to many uses, such as the colouring of leather. Suitably processed tannin will readily dissolve in cold water, forming a mildly acidic solution.

The UK was almost unique in retaining boilers of arsenical copper (simply "copper" hereon) and steel construction on most its mainline locomotive fleet until steam traction was withdrawn. Elsewhere in the world, the move, to all-steel boilers was practically universal by the end of the 1930s, often due to cost. However, it was found that all-steel boilers needed an effective water treatment if they were to have a reasonable economic service life. Notably, moves towards all-

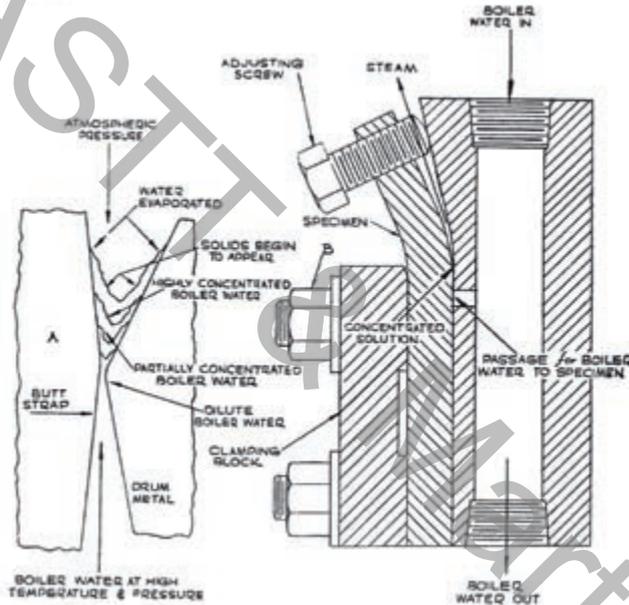
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<sup>1</sup> Herein used as shorthand for alkalinity derived from compounds of sodium – sodium bicarbonate, sodium carbonate and sodium hydroxide.

<sup>2</sup> The internal treatment sometimes being referred to as "after treatment", the external treatment being applied first.

<sup>3</sup> CAS No. 497-19-8.

ion concentration and caustic embrittlement, but it is not the sole cause [28]. A 50 ppm concentration of hydroxide ions can be conceived of occurring naturally with some feedwaters. The USBM/ASME study showed that the nature of the feedwater was the crucial factor in the occurrence, or otherwise, of caustic embrittlement. Certain waters contain natural inhibitors, a fact that would seem to apply to UK waters in general. When natural inhibitors are not present, embrittlement can occur. The American study showed that in addition to the nature of the feedwater, caustic embrittlement could only occur if two further factors were present, these being a very small leak in a high stress area, and extremely high levels of localised concentration of hydroxide ions caused by the evaporation of the boiler water at the leak. If any one or more of these three factors are missing caustic embrittlement does not occur [1][3][20][21][29].



**Fig. 4 – The Schroeder Embrittlement Detector used during the USBM/ASME study of embrittlement to simulate the conditions required to cause it. Boiler water ‘leaks’ out behind a strip of steel under high stress. The result is the deposition of hydroxide ions as the boiler water boils off. If the leakage rate is high, the hydroxide ions would be washed away; careful regulation of the leakage rate is essential. To the left is a representation of the conditions the detector seeks to replicate [8]. Also see US Patents 2,283,954, 2,283,955 and ASTM D807-2009.**

One solution to prevent embrittlement could be to limit the potential for the accumulation of hydroxide ions in boiler water. However, as USBM/ASME showed, if 50 ppm of hydroxide can be enough for caustic embrittlement to occur, prevention of this type would seem very difficult, especially on railway locomotives which take water from numerous differing sources. The more practical alternative is to use an embrittlement inhibitor. The North American testing programme showed that nitrates were excellent inhibitors, as were tannins. It was found that different tannins, and even different forms of the same tannin, had different inhibiting properties. The most effective tannin was found to be from the South American hardwood quebracho in what is described as a “crude” form [8][29]. Research, in the UK, further corroborated the evidence in support of the use of quebracho tannin [49]. The USBM/ASME study only tested tannins which were then in common use so, there is no data available for some now widely used tannins such as Mimosa or Eucalyptus. It is suggested quebracho tannin should be employed unless there are compelling reasons against its use. It is fortunate that quebracho is also a highly efficient absorber of dissolved oxygen [36].

## 4 PORTA’S CONTRIBUTION

The late Ing.<sup>11</sup> L.D. Porta started his development work on water treatment in 1969 due to severe problems operating steam-hauled services on the metre gauge Ferrocarril Nacional General Belgrano (FCGB) of Argentina. The water types encountered on this extensive system were very varied. They included some extremely hard water types, which would not traditionally be considered good boiler water. Many watering points employed base exchange external water

<sup>11</sup> Ing is short for Ingeniero, Spanish for Engineer. As in many non-English speaking countries, in Argentina Engineer is a formal professional title in the way Doctor is.

softening, but boiler conditions remained very poor<sup>12</sup> with heavy scaling, corrosion and serious problems with water carryover occurring after just a few days in service. One area of operation was known locally as a 'boiler cemetery', very heavy boiler repairs being generally undertaken on a 2 year cycle [1][42].

At this time, Porta was employed by the Argentine State Industrial Technology Institute (INTI) as the Head of the Thermodynamics department. He was well placed to lead the development programme from this position, which gave him access to all the necessary expertise contained within INTI.

As would be expected from a development engineer, Porta first undertook a review of international practice. Unsurprisingly, he found that TIA was then the most widely recognised and perhaps successful internal water treatment regime to date. It should be noted that Argentina also had its own home-grown sodium carbonate and tannin water treatment regime. It was this that Porta took as the basis for his work but with TIA as the standard to equal or better. The UK based 1950s work undertaken by J.A. Gray, E.F. Thurston and J. Furnival significantly influenced the path of this work [1]. A strict criterion was that the treatment had to be as applicable to developing countries as it would be to developed countries. The chemicals had to be safe to handle, easy to obtain and relatively inexpensive, whilst the boiler water had to be as safe to handle and dispose of as reasonably practicable [1].

Perhaps his biggest contribution to boiler water treatment was the realisation that by the use of a suitable antifoam, at all times, it really did become possible to successfully treat all feedwaters. He showed that by allowing the boiler water to reach traditionally high levels of both alkalinity and TDS a chemical buffer to incoming feedwater variation was created. As explained above, he had no reason to fear that the resultant high alkalinity would create caustic embrittlement whilst the antifoam in use guaranteed the boiler water would stay in the boiler by controlling the foaming.

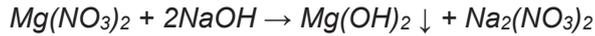
The high alkalinity had the positive effect of creating and ensuring the continued presence of magnetite on all water-facing steel surfaces. Magnetite is a corrosion product of iron, but unlike many oxygen-corrosion products, it is highly stable under the correct conditions, very hard and largely impermeable. It acts as an effective barrier to any attack on the underlying metal. However, it will only remain in place if the boiler water chemistry remains alkaline [1].

Scaling was also brought under full control, but so too was the problem of adherent sludge. Sludge, which is formed by the precipitation of material which could otherwise form scale, can often be sticky and adherent with a nature somewhat akin to scale – it has a significant insulative effect. Porta showed that, by ensuring the correct boiler water chemistry, all sludge formed was mobile and non-adherent, the slightest water circulation being sufficient to see it move.

The use of a polyamide antifoam had an unexpected positive effect. Rather than being a total defoamer, in part due to the high TDS, the selected antifoam acts as a foam control agent. It acts throughout the boiler water, altering the steam bubble formation at the heating surface and what happens to these bubbles once they have detached from the heating surface. A layer of dense foam develops on the surface of the boiler water which leads to a perhaps unexpected but very welcome phenomenon – the production of 'pure steam'. That is to say, the steam in the steam space is not contaminated with water or solids from the boiler water attached to the steam bubbles as they break into the steam space. The thick layer of foam acts as a large sieve. Problems associated with impure steam were left largely unaddressed by steam engineers and chemists, with a few exceptions, prior to Porta's work [1][14][55]. Impure steam, which is the norm, is the cause of much premature failure of items such as superheaters, valve and piston rings and various auxiliaries etc [57]. Deposits, the constituents of which vary depending on the material contaminating the steam, build up in various places which should remain clean. In severe cases, such deposits can act as a fine grinding paste in conjunction with lubricating oils [1][54]. In the field of steam turbines, high steam purity is essential. Delicate turbine blades can

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<sup>12</sup> Maintaining the external treatment plants in very remote parts of Argentina was a significant problem. Had the plants been working at all times things may have been different. This experience highlights a weakness of external treatment regimes.

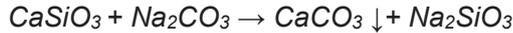


*magnesium nitrate + sodium hydroxide gives magnesium hydroxide (precipitated)  
+ sodium nitrate*

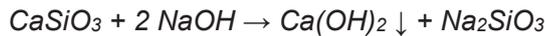
The examples above also indicate that if sodium hydroxide is added to water tanks, it can give rise to the precipitation of calcium carbonate in the tanks, which is generally to be avoided.

### C.2.2.3 Silica Hardness

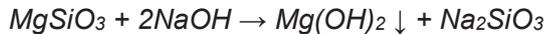
Silica compounds can be treated as in the examples below:



*calcium silicate + sodium carbonate gives calcium carbonate (precipitated)  
+ sodium metasilicate (water glass)*



*calcium silicate + sodium hydroxide gives calcium hydroxide (precipitated)  
+ sodium metasilicate (water glass)*



*magnesium metasilicate + sodium hydroxide gives magnesium hydroxide (precipitated) + sodium metasilicate (water glass)*

The solubility of certain compounds created by softening decreases as the temperature increases and the solubility of others increases as the temperature does. Examples of compounds with a decreasing solubility include:

- Calcium carbonate  $\text{CaCO}_3$ <sup>25</sup>.
- Calcium sulphate  $\text{CaSO}_4$ .
- Calcium hydroxide  $\text{Ca}(\text{OH})_2$ .
- Calcium silicate  $\text{CaSiO}_3$ .
- Magnesium hydroxide  $\text{Mg}(\text{OH})_2$ .

An example of a compound which becomes increasingly soluble as the temperature increases is:

- Calcium phosphate  $\text{Ca}_3(\text{PO}_4)_2$ .

It must be emphasised that the above is not a complete picture of the reactions which occur in a boiler; there are many more which are dependent on the precise chemical contents of the water.

### C.3 Other Problems

The internal softening of boiler water by sodium carbonate gives rise to what might be described as "after problems". However, it is true to say some, or all of these could have occurred anyway, such as:

1. Fouling of injectors, in pipes and feedwater heaters.
2. Immobile Sludge
3. Steam contamination through several mechanisms. In extreme cases resulting in water carryover (often called priming) into the steam circuit.
4. Caustic Embrittlement.
5. Acidic condensate.

Solutions exist for all of these 'after problems' but are not always practised. These are discussed in the papers contained in this volume but are briefly covered below for clarity. Addressing these problems takes any internal treatment to the next stage of complexity.

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<sup>25</sup> A controversial topic.

## E2 Ammonia in Boiler Water from EBS – Worked Example

The work undertaken included several chemical and numerical calculations to provide evidence to support the above points; one of these is presented below.

The following calculations were based on a typical daily water consumption for locomotive No.6024 'King Edward I' operating a 'Torbay Express' railtour from Bristol Temple Meads to Kingswear and back (in the UK), a then typical duty for this preserved steam locomotive. The antifoam in use in this example is that specified by Porta, ethylene bis stearamide (EBS).

This calculation is rather rough-and-ready but sufficiently accurate for current purposes. A pessimistic view is taken to give a worst-case scenario.

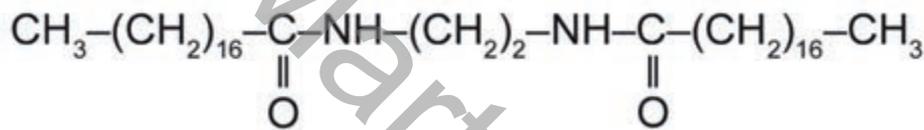
Assumptions:

- EBS dose in tender water – 0.4 ppm.
- Locomotive water consumption – 14,000 gallons of water per day.
- Locomotive Boiler Volume – 2,000 gallons<sup>33</sup>.
- Ammonia concentration required to corrode copper – 10 ppm.
- Ammonia does not corrode steel.

The calculation which follows is presented to show the theoretical maximum concentration of ammonia which could form and accumulate from the decomposition of EBS in the boiler.

As can be seen from the representation of an EBS molecule shown below, it contains two NH groups. On decomposition, these could form ammonia or compounds of ammonia.

EBS Formula – C<sub>38</sub>H<sub>76</sub>N<sub>2</sub>O<sub>2</sub>



The molecular weight of EBS can be determined by calculating the weight of its constituents leading to a calculation of the potential for ammonia or compounds of ammonia to be formed.

Molecular weight of C <sub>38</sub> H <sub>76</sub> N <sub>2</sub> O <sub>2</sub>					
	Element	Atoms	Molecular Weight	Method	g/mol
{1}	Carbon	38	12.01	38 x 12.01	456.38
{2}	Hydrogen	76	1.01	76 x 1.01	76.76
{3}	Nitrogen	2	14.01	2 x 14.01	28.02
{4}	Oxygen	2	16	2 x 16	32
{5}				<b>Total</b> = {1} + {2} + {3} + {4}	593.16

Molecular weight of ammonia forming NH groups in EBS					
{6}	Ammonia-forming NH groups in one molecule of EBS		<b>Number</b>	2	
	Element	Atoms	Molecular Weight	Method	g/mol
{7}	Hydrogen	2	1.01	2 x 1.01	2.02
{8}	Nitrogen	2	14.01	2 x 14.01	28.02
{9}	Molecular weight of NH groups			= {6} + {7}	30.04
{10}	Percentage of NH groups in EBS molecule			= ({5}/{8})/100	5.0644 %

EBS dose		Units	Method	Amount
{11}	EBS dose	ppm	Ref [1]	0.4
(11a)	EBS dose per litre	mg/l		0.4

<sup>33</sup> At 2½" of water showing in the gauge glass (¾ of a glass of water).

# It Shouldn't Happen to a Boiler

## A Photographic Illustration of Avoidable Boiler Problems

Martyn Bane and Nigel Day  
March 2021 and July 2023

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## INTRODUCTION

The photographs in this paper illustrate just some of the problems which can be found in boilers, problems which could be prevented entirely or the seriousness of which could be significantly reduced if a comprehensive water treatment system had been in use. The following photographs are not a record of all the types of problems which could be found but do illustrate many of the conditions referred to throughout this volume, problems which are all too commonly found. These problems are often simply accepted as a 'fact of life' when operating steam boilers. That is not, or perhaps should not, be the case.

### 1. FOULING AND CORROSION



**Fig. 1 – A narrow gauge locomotive boiler showing a scene which is not untypical. A liberal coating of scale nearly everywhere, including in the steam space, and a pile of scale dislodged from the boiler tubes as they were removed. Under the scale, largely unseen, is corrosion, scale being no cure to this problem. The fouling and corrosion are entirely avoidable.**

© Martyn Bane



**Fig. 18 – A badly necked stay which has no life left in it. Necking as shown has a thermomechanical cause (poor design) which cannot be cured by water treatment. However, it has been shown that a comprehensive water treatment can significantly retard the rates at which similar problems occur. © Nigel A.H. Day**



**Fig. 19 – A section of boiler plate wasted to below the accepted minimum thickness for safe operation. Also, note the wastage where the stays enter the plate and their poor general condition. The corrosion of the plate and stays shown can easily be avoided. © Nigel A.H. Day**

# Report on Water Treatment Practices on Locomotive and Industrial Boilers in Argentina

William Ridgway Richardson  
British Railways Board  
Buenos Aires, 19<sup>th</sup> of November, 1971

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**Ing. L.D. Porta, and an assistant, with locomotive No.1802 at Metán depot in 1972. The locomotive's steam sampling apparatus can be seen on the rear side of the steam dome, along with other modifications, but not as many as can be seen in other photographs in this volume.**

**© James Atkinsons, courtesy Richard Campbell [Editor]**

# Informe Estudios Tratamiento Aguas Locomotoras FCGB –

[Report Relating to Studies of Water Treatment  
on FCGB Locomotives]

## Translated Extracts

Buenos Aires, enero 1972

INTI-CID

368

Y

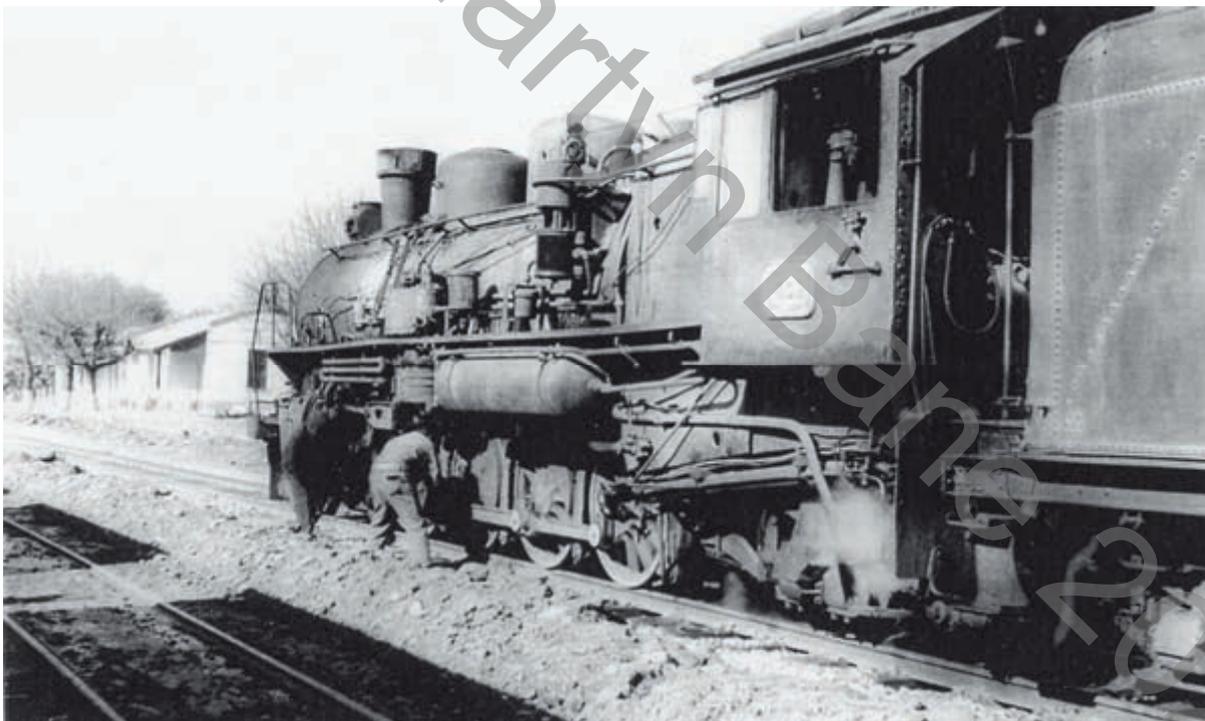
## SUMMARY

This report describes the aims of the work and successes achieved in 1971 (the first year of a three-year plan) relating to the studies and resolution of the boiler water problems of the FCGB. Starting out from a review of the considerable amount of modern bibliographic information, which shows that the subject has undergone profound change from the classic approach, the fundamental principles have been reviewed and adapted to railway needs, with particular attention to the methods and difficulties specific to the FCGB.

In effect: the practical problems of discipline, difficulty in communications, geographic extent of the railway, scarcity of supervisory staff with higher education, seniority, staff accommodation etc., require a very distinct effort to adapt and apply a technology that it is hard to find a parallel with elsewhere. It goes without saying that any increase in personnel or expenditure is not possible.

It must be noted that the achievement of many correct principles in practice has, in the past, been seriously hindered by factors such as those mentioned above. In addition, the Achilles' heel of the current treatment scheme lies in the dilution of responsibilities of application. This situation, in the past, has had its parallel on the French and British railways: hence it is regarded as essential that command must be concentrated in one single hand and with determined support from higher authority.

The development locomotive No.1802<sup>1</sup> has been used to confirm the accuracy of the fundamental principles and served to verify them in practice, it being expected to achieve 300,000km<sup>2</sup> in service without the need for a general overhaul. In service, it also confirmed the efficacy of the antifoam chosen in the 1969 tests. This tallies with the fact that difficulties in maintaining the timetable disappeared from running reports two years ago.



**FCGB Class C16 No.1802 during water treatment trials. 15 July 1971. © Richard Campbell  
[Editor]**

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<sup>1</sup> Baldwin built, metre gauge, FCGB Class C16 4-8-2. [Editor]

<sup>2</sup> 186,411 miles. [Editor]

## **Part 2**

# **Ing. Livio Dante Porta Papers and Extracts**

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# Steam Locomotive Boiler Water Treatment

Issued: Buenos Aires 1975.  
Revised: July 1977  
Reviewed: June 1987  
March 1992

L. D. PORTA Consulting Engineer.  
F. Inst Energy, M.I. Mech. E.  
Soc. Ben. CAI

Azara 1557 Banfield (1828)  
Argentina  
Tel 54-242 3533

(d) **Caustic embrittlement** produces cracks in a variety of appliances: bolts, flanges, etc., not to mention boiler plates. Three conditions must be simultaneously present to induce caustic embrittlement:

- a water leak small enough to be evaporated to a concentrated solution;
- high stresses at the point where there is a concentrated solution, and
- the kind of water that causes the embrittlement.

In the past, various kinds of disasters resulted from cracks caused by caustic embrittlement, the riveted joints being prone to be affected because they offered two of the above-mentioned conditions, namely small (concentrating) leaks and high stresses.

### 3 CARBONATE INTERNAL BOILER WATER TREATMENT

#### 3.1 Minimum Carbonate Content

The physicochemical phenomena leading to the formation of scale have been and are constantly studied. The names of HALL and STRAUB ([2] through [10]) are well known for their pioneering investigations in the field. THURSTON and GRAY [11][12] also made important contributions serving as a basis for the form of treatment evolved by the author. The latter authors showed that if a minimum of 200 to 300 ppm of  $\text{Na}_2\text{CO}_3$  was maintained at all times in the boiler water, no scaling occurred, and no corrosion developed. Since normally some 50% of the total alkalinity is decomposed, this means that about 600 ppm of total alkalinity (as  $\text{CaCO}_3$ ) must be carried at all times as an absolute minimum [11], or its equivalent of approx 450 ppm of phenolphthalein alkalinity. These relationships are somewhat different in the case of natural waters having excess alkalinity (bicarbonate waters) because the higher partial pressure of the  $\text{CO}_2$  in the system shifts the equilibrium towards a lesser carbonate decomposition [13].

Attention should be drawn to the fact that the classical phenolphthalein-heliantine<sup>6</sup> test gives false results in boiler waters, especially in the carbonate content (SCHWEDER and FELLOWS, [14]). In other words, what is reported as carbonate is not the actual boiler water carbonate, but it is a way of speaking.

One point much stressed by the above authors [11][12] was the requirement that the calcium carbonate sludge showed to be entirely mobile and easily redispersed after prolonged settlement. GRAY [11] established that more than 75% moisture in the sludge after two days settlement seemed to correlate well with adequate sludge mobility. In this connection, the presence of magnesium hardness was found to be essential, so much so that they did not hesitate to recommend the addition of magnesium hardness if required. The amount necessary is given by:

$$X_s = \frac{100}{\text{CaO}} (0.46 \text{ MgO} - 0.62 \text{ SiO}_2) \geq 7$$

(the quantities are to be calculated as mass percentages).

A value of  $X_s = 4$  should be an absolute minimum. In practice, most natural waters contain Mg and therefore no addition should be required. However, it seems that the aggregate of tannin and sodium hexametaphosphate (according to the author's experience) allows the index  $X_s$  to be lowered. The resulting sludge is then characterized by the fact that it settles rapidly into a fluffy mass. Even when evaporated to dryness, it is easily redispersed.

#### 3.2 The Need for Antifoam

Unlike stationary boilers, locomotive boilers do not take water of constant composition, nor is it possible to have a close chemical control. Therefore, there is no alternative but to allow the water alkalinity to play within wide limits well above the absolute minimum of 300 ppm of carbonate so as to have a reserve bulk to absorb any variation in the hardness content of the incoming water. This also entails an increased content of the TDS (Total Dissolved Solids) and

<sup>6</sup> Methyl orange. [Editor]

## 4 STEAM CONTAMINATION

Contrary to common belief in locomotive circles, the water in a locomotive boiler boils vigorously as in a kettle over the fire. The author has seen this by the simple expedient of putting two lubricator bulls-eye glasses as shown in Fig 2, one serving for illumination, the other for observation with the naked eye.

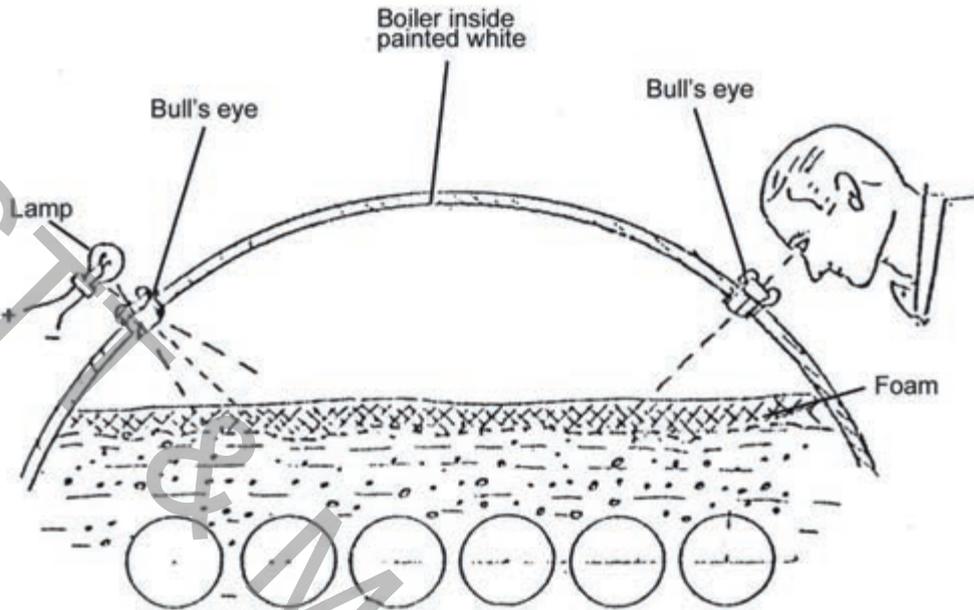


Fig. 2 – Elementary arrangement permitting observation inside the boiler while water is boiling.

### 4.1 Foaming

Normally there is a foam layer over the surface; its thickness may become high enough to reach the steam take off, this resulting in moisture entrainment and solid carryover, the latter both in the form of salts dissolved in the moisture and as suspended matter. Since (except when fresh water has been filled after a washout) there is always a fairly concentrated solution in the water space, the steam produced is slightly superheated: (RAOULT law, 17). When "clean" water is boiled, wet steam results (SENIFF [25]), containing about 2% moisture, which is a classical figure (see for example Ref [24]). But the mechanism of the entrainment is different when there is foaming. In the case of clean water, tiny drops are expelled from the water surface as seen in a glass of soda [25]. As will be shown later, very pure steam results when good antifoams are used, and therefore the above figure becomes zero. The engineer should be aware of these facts affecting the heat balance of different parts of the steam generator, particularly in connection with the interpretation of boiler test results and heat transfer calculations.

When a foam layer is present, but not too thick a one, no matter how high the steaming rate may be, very pure steam is produced. Repeated experiments, also including stationary boilers, showed that with a good antifoam, a TDS up to 35,000 ppm could be carried with a contamination below 2 ppm (this figure was the threshold of the method of measurement). This was repeatedly consistent with any concentration of suspended matter (including clay suspended in the feedwater), organic matter, oil, etc. Of course, this showed brilliantly in actual service in the form of perfectly lubricated piston rods, little piston and valve ring wear, immaculate insides of superheater elements, a clean, transparent water showing in the glass, no whiteness around the various minor steam leaks, etc.

The formation of foam starts from the production of steam bubbles at the heating surface. These bubbles may (or may not) coalesce into fewer and larger ones during their upward path to the surface of the water, and their persistence there is due to a multitude of causes not very well understood as yet ([26] through [36]). The fact is that a good antifoam produced the above-mentioned results. Its action is fourfold:

	Max	Min	Average
Ca <sup>++</sup>	82 ppm	8 ppm	44 ppm
Mg <sup>++</sup>	61 ppm	1 ppm	15 ppm
Na <sup>+</sup> + K <sup>+</sup>	635 ppm	16 ppm	171 ppm
Cl <sup>-</sup>	426 ppm	7 ppm	89 ppm
SO <sub>4</sub> <sup>=</sup>	509 ppm	29 ppm	156 ppm
CO <sub>3</sub> <sup>=</sup>	0 ppm	0 ppm	0 ppm
CO <sub>3</sub> H <sup>-</sup>	732 ppm	146 ppm	309 ppm
SiO <sub>2</sub>	35 ppm	10 ppm	22 ppm
Rest at 105°C	2,053 ppm	236 ppm	649 ppm
Total alkalinity	350 ppm	120 ppm	256 ppm (as CaCO <sub>3</sub> )
Total hardness	35°f	4°f	17.6°f
Permanent hardness	8°f	0°f	0.9°f



FCGB No.1802 engaged in shunting at Tucumán. Numerous alterations to this C16 4-8-2 are visible. The most prominent being the exhaust deflectors and Lempor exhaust ejector fitted with a sacrificial extension piece (the parallel section at the top of the chimney's diffuser) which, on more than one occasion, was destroyed in service. Other modifications visible include an extra gauge glass arranged on the rear section of the boiler barrel (as on a rack locomotive) and the steam sampling steam from the (rear) dome. 1973. © John A. Kirchner  
 [Editor]

# Boiler Foam Height Monitor

## SUMMARY

The system consists of an electric circuit (fed from the locomotive's 32V) which is closed when the top of the foam layer touches the tip of electrodes mounted in the steam space. Thus, lamps are lit up in sight of the crew. The electrodes are made out of electromotive spark plugs.

**Note:** This paper contains matter subject to intellectual property and patents.  
All rights reserved.

Issued: Nov 3, 1984

L.D.Porta  
American Coal Enterprises

**IN NO CASE IS THE SYSTEM TO BE CONNECTED TO OTHER APPARATUS OR ITS INDICATIONS TO BE RELATED TO SAFETY.**

## 4 OPERATION

The system is permanently connected. Before commencing a trip, or at any convenient time, the check key 8 is actuated. A proper foam condition will show by a clear lighting of the lamps; a glow indicates poor foam conditions as per (ii) in Section 1. Normally, only lamp 5 is lit (or not) depending on the water level showing in the glass. Higher water levels lead to successive lighting of lamps 6 and 7.

## 5 CONCLUDING REMARKS AND RECOMMENDATIONS

The system is based on the SIGNAL FOAM METER developed circa 1940 by the DEARBORN Chemical Company. This writer has applied it during the last 30 years, including in stationary boilers; he considers it as an **ESSENTIAL** whatever water treatment is adopted. Practical experience proves that, after becoming used to it, enginemen realise its full value when it is taken out of service. Even very experienced engineers (drivers), able to "see" the inside of the boiler without looking at it, find its indications of considerable help. Coupled with antifoams, it is a tool to make superheater elements last 20, or perhaps 30, years.

## APPENDIX – BOILER FOAM HEIGHT MONITOR FITTED TO FCAF NO.2 'ING. L.D.PORTA'

This appendix has been added to show the application of a foam height meter to a locomotive in the 21<sup>st</sup> century. The photographs are of the monitor fitted FCAF Garratt 0-4-0+0-4-0 No.2 'Ing L.D.Porta', with one exception. The electrodes were fitted ahead of the dome rather than the preferred location behind it due to the presence of the throttle (regulator) rod in the boiler.

[Editor]



**Fig. A1 – The spark plug electrodes as made and ready for installation.  
16 October 2003 © Shaun McMahon [Editor]**

# **A Feedwater Heating System suitable for SGS and TG Steam Locomotives**

Livio Dante PORTA of INTI  
M.I.Mech.E; F.I.Fuel; C.A.I.

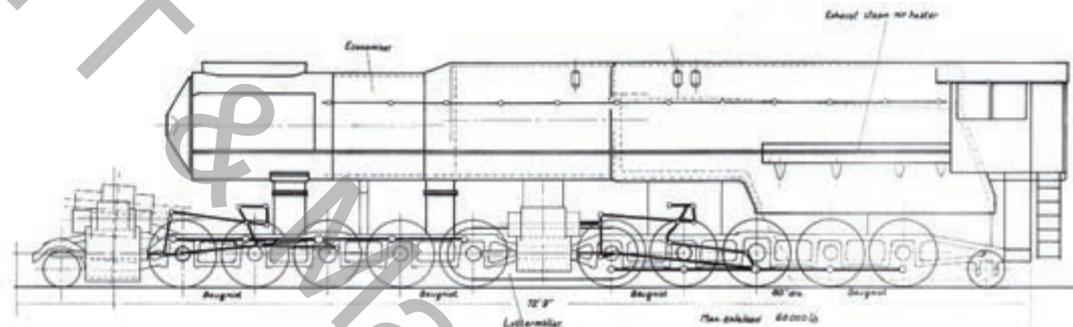
Issued: Buenos Aires Sept 1978

Revised: Feb 1979

## 1 INTRODUCTION

This paper is the latest development<sup>1</sup> of the author's feedwater heating system. It embodies two distinct advances, namely:

- It works on the idea of utilizing the tender as the place where internal water treatment chemical reactions occur, hence avoiding any scaling on exhaust steam surface heaters and on the economizer.
- The whole of the tender space is made to serve as a very large hot water reservoir, hence extending the benefits of feedwater heating when the regulator is shut, this being of special interest in the case of shunting engines.
- The essentials are the same as the system described in Ref [1], but in this case more details have been included with special consideration of the now-starting design of the 2-12-12-0 locomotives for the Río Turbio Railway (Argentina). When this is achieved, it is hoped to incorporate further details and also the experimental results.



An early side elevation of the then proposed 2-12-12-2, 75cm gauge, Mallet for Río Turbio. [Editor]



Artist's impression of Porta's later proposal, an 180 tonne 3,000kW 2-12-12-0 for the 75cm gauge Rio Turbio Railway. Note the differences in layout to the side elevation above, this altered layout being Porta's later preference. This locomotive would have incorporated the technology discussed in this paper.

Painting by Robin Barnes [Transcriber]

<sup>1</sup> In May 1978 Porta wrote a paper titled "A note on a new approach to steam locomotive boiler water treatment" which focussed feedwater preheating and treatment, focussing on shunting locomotives. He developed his ideas over the next few months before writing this paper. [Editor]

# **Steam Locomotive Boiler Water Circulation**

## **A First Semi-Quantitative Approach**

By

L.D.PORTA, C.Eng,  
F.Inst.F; M.I.Mech.E.; CAI,  
Chief, Dept. Thermodynamics, INTI  
ARGENTINA

Issued: Buenos Aires, April 1979.

Revised: Buenos Aires, June 1981.

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## SUMMARY

While water circulation is a most important issue in water tube boilers (where it is quantitatively mastered), it has been a matter of myth, vagaries and conjecture in the case of locomotive and other firetube boilers.

Some measurements carried out during water treatment tests for the FCGB (Argentina), coupled to elementary reasoning and knowledge of boiling heat transfer phenomena now available, have permitted the author to scheme out a reasonable picture of what life is like inside the boiler.

TGS (Advanced, Third Generation, Steam locomotive technology), intended to keep to the Stephensonian boiler, working at 60 atm<sup>1</sup> pressure, imposes the need to clear up circulation parameters. It is believed that the present paper represents the first step on a long (and happy) ladder leading to better boilers in the future, as required to operate in an energy starving world.

## FIGURES

Fig. 1 Boiler circulation in a locomotive boiler provided with NICHOLSON thermic syphons.

Fig. 2 Circulation flow pattern.

Fig. 3 Schematic view of the variation of steam-water proportions with height.

Fig. 4 A simplified scheme of water circulation.

Fig. 4A Porta's experimental 4 cylinder compound 4-8-0. [Editor]

Fig. 5 Guiding vanes placed to streamline circulation flow.

Fig. 5A Ferrocarril General Roca Class 8C 2-6-2T No.3477. [Editor]

Fig. 5B The metre gauge Class C16 4-8-2, No.1802. [Editor]

Fig. 6 Water gauge readings.

Fig. A2-1 The shape of the back water jump according to American 1920 tests.

Fig. A2-2 Tubes as Water Level Indicators on Locomotive Boilers.

Fig. A2-3 Arrangement of Lamp and Sight Glasses.

Fig. A3-1 Elementary Boiling Circuit.

Fig. A4-1 Bubbly Flow.

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<sup>1</sup> 882 psi. [Editor]

It is probable that the height of the water near the front tubeplate remains unchanged when the boiler steams, i.e. no swelling obtains there because most of it is concentrated at the back end. This should be carefully considered in the case of the author's boiler designs in which the tubes are just covered by some 30 to 50 mm of water only. The danger of burning because of water starvation there is not very great, but an inequality in the circumferential distribution of heat may lead to a collapse as pointed out by Tross [10]. This danger is, of course, greater at higher pressures.

#### 4 A TYPICAL BOILER BEHAVIOUR

The present analysis refers to a typical boiler of American design which is very familiar to the author. It corresponds to a metre gauge, 4-8-2 engine, class C16, FCGB (Argentina). The necessary particulars are as follows:

Builder	{1}	-	Baldwin
Year built	{2}	year	1948
Steam pressure, nominal =	{3}	atm	14
Current working steam pressure =	{4}	atm	13.5
Fuel	{5}	-	Oil
Grate area =	{6}	m <sup>2</sup>	4.1
Firebox heating surface including two syphons	{7}	m <sup>2</sup>	17
Large tubes heating surface, fire side =	{8}	m <sup>2</sup>	67
Small tubes heating surface, fire side =	{9}	m <sup>2</sup>	140
Total evaporative heating surface, fire side = {7} + {8} + {9} =	{10}	m <sup>2</sup>	224
Superheater surface, fire side =	{11}	m <sup>2</sup>	68
Water feed system	{12}	Injector, clack valve	
Firebox volume =	{13}	m <sup>3</sup>	≈ 7.5
Maximum evaporation in current service =	{14}	kg h <sup>-1</sup>	12,000
Max evaporation reached on test, (Engine No. 1802, RS burner)	{15}	kg h <sup>-1</sup>	16,000
Water volume at lowest glass indication (measured) =	{16}	m <sup>3</sup>	6
Steam chamber volume at lowest water level (measured) =	{17}	m <sup>3</sup>	3
Steam temp at max current steam production {14} (measured)	{18}	°C	380
Smokebox temperature at {14} (measured), =	{19}	°C	380
Heat to steam at pressure {4} = {14} x ({20d}-{20a})	{20}	Gcal h <sup>-1</sup>	9.0
Enthalpy of water at 15°C (from Steam Tables) =	{20a}	kJ/kg	62.98
		kcal/kg	15
Enthalpy of liquid water at 13.5 bar, temp 193°C (from Steam Tables) =	{20b}	kJ/kg	822
		kcal/kg	196
Enthalpy of saturated steam 13.5 bar, temp 193°C (from Steam Tables) =	{20c}	kJ/kg	2,787
		kcal/kg	666
Enthalpy of superheated steam at 13.5 atm and 380°C (from Steam Tables) =	{20d}	kJ/kg	3,215
		kcal/kg	768
<b>Heat {20} is made up as follows:</b>			
Heat to warm up the incoming water from 15°C to 193°C = {14} x ({20b}-{20a})	{21}	Gcal h <sup>-1</sup>	2.2
Heat to evaporate the water and raise pressure to 13.5 bar at 193°C = {14} x ({20c}-{20b})	{22}	Gcal h <sup>-1</sup>	5.6
Heat to superheat steam at 13.5 bar = {14} x ({20d}-{20c})	{23}	Gcal h <sup>-1</sup>	1.2
<b>Heat {20} is transferred as follows in different heating surfaces:</b>			
To firebox (HUDSON-ORROK – Ref [14]) =	{24}	Gcal h <sup>-1</sup>	3.5
	{25}		39%
To Superheater =	{26}	Gcal h <sup>-1</sup>	1.2
	{27}		13%
To small tubes =	{28}	Gcal h <sup>-1</sup>	2.9
	{29}		32%

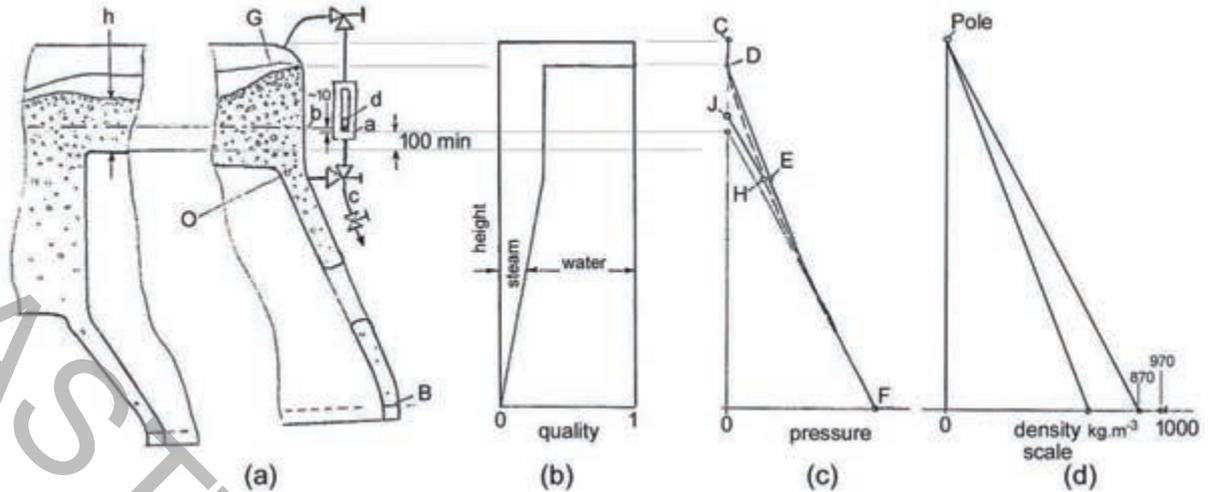


Fig. 6 – Water Gauge Readings

## 6 SOME PERTINENT QUESTIONS

There is little doubt that the picture described here is different from the one obtaining in the old, scaled, “not-antifoam-using” boiler. In the latter, bubbles are smaller (because the antifoam leads to fewer, easily coalescing, larger ones), hence with a smaller relative “slip” with respect to water.<sup>20</sup> Flow encountered higher resistances and reduced passage widths owing to scale, all contributing to a larger swelling volume. Certainly, the foam layer completely filled the steam space at the boiler back and probably reached the front end too. Circulation was not the best.

A different scheme of bubble evolution obtains when, for any reason, the steam pressure drops at a significant rate. Bubbles no longer originate only at the heating surface, but also over the whole water mass of the boiler. Those at the back of the boiler probably coalesce with the ones originating on heating surfaces, but those originating inside the barrel – which, as it was seen, is filled mostly with subcooled water – reduce the density there, hence tending to establish an upward flow where it should be downwards or horizontal. This upsets the fundamental circulation scheme, and for some seconds the various flow-paths “do not know which way to go”. The result is an increased swelling of the water, the whole mass of it becoming a froth filling the whole steam space, filling the dry pipe, etc. This is the familiar priming of “mechanical” origin. It arises when a sudden and prolonged slipping occurs, or when the fire has not been prepared to instantaneously liberate the necessary amount of heat required to produce such instantaneous steam demand. It is well known that, on handling a locomotive having foaming water, the steam pressure must be at its maximum and the fire absolutely fit to get an instantaneous response to boiler load changes so that circulation is not upset. This circulation instability is particularly noticeable in stationary water tube boilers in which, if steam is produced in the downcomers, the result is disastrous. In locomotive practice, it is frequently seen in shed movements and shunting.

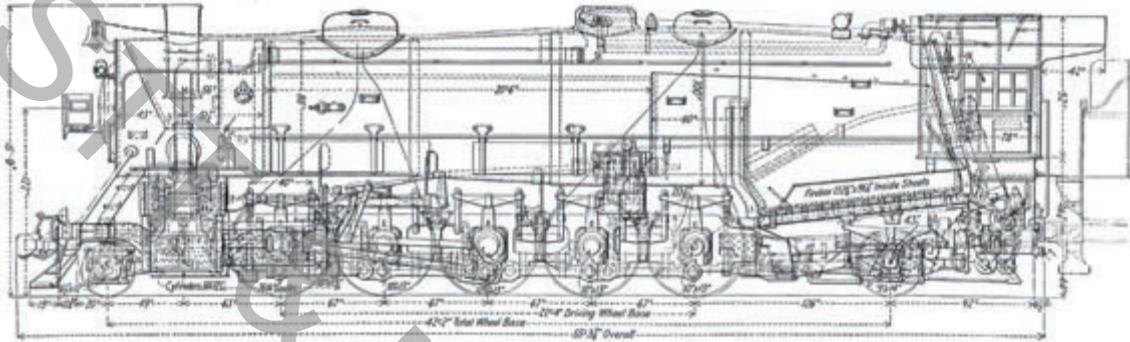
Operating boilers at pressures lower than the maximum also led to inconveniences because, for a given steam production, the volume of the steam that is generated is increased thereby leading to higher swelling. This is also well known from footplate experience.

<sup>20</sup> As explained elsewhere, Porta uses a “slip correction factor” to calculate the velocity of water flow, taking into account the relative speed of bubbles and water, the water flowing slower than the bubbles contained within it. [Transcriber]

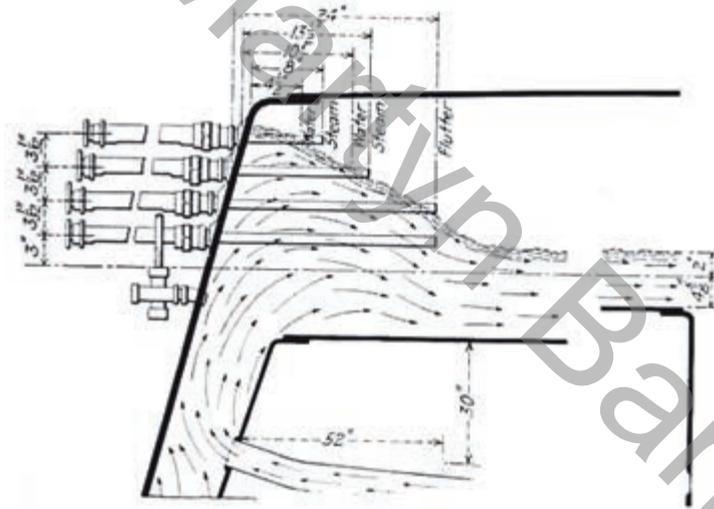
### Fifth Series of Tests

To further determine the approximate outline and proportions of the water conditions existing at the back boiler head, while the locomotive is being operated with heavy throttle, or when steam is being rapidly generated and simultaneously escaping from the boiler, tests were made with appliances shown by Fig. A5-6, covering a distance of 808 miles, in bad-water districts, on approximately level track and while handling regular tonnage.

The locomotive on which these tests were made was of the heavy 2-8-2 type, equipped with superheater and Duplex stoker, using bituminous coal for fuel, shown by Fig. A5-5. The boiler had a sloping back head, with firebox equipped with brick arch supported by four 3-inch arch tubes, the brick arch extending to within 52 in. of the door sheet and 30 in. of the crown sheet.



**Fig. A5-5 – USRA Heavy Santa Fe as used in the fifth series of tests.** Public Domain image, originally published in '1922 Locomotive Cyclopedic of American Practice'. [Editor]



**Fig. A5-6 – Water Indicating Devices Used in the Fifth Series of Tests**

The apparatus shown by Fig. A5-6 consisted of four gage cocks applied directly in the back head near the knuckle, one water column to which three gage cocks and one water glass were attached, one water glass with a 9-inch reading, standard application, with both top and bottom cocks entering boiler back head direct, one water glass applied for experimental purposes with the bottom cock entering the boiler back head on back knuckle and one entering 13 in. back head on back knuckle<sup>34</sup> and one entering 13 inches ahead of the back knuckle, and four exploration tubes or sliding gage cocks.

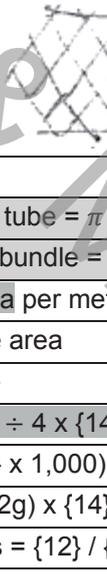
Fig. A5-6 shows a side elevation of these exploration tubes or sliding gage cocks entering the back head parallel to the horizontal axis of the boiler through suitable stuffing boxes, with a vertical pitch of 3½ in., giving a total vertical reading of 10½ in. with a horizontal adjustment of 24 in. Gradations were marked on these tubes so that accurate readings could be taken and

<sup>34</sup> The lack of clarity reflects the original report. [Editor]

# Surface Feedwater Heater for 3450

L.D. PORTA  
Undated but presumably c1980

## SINGLE PASS FEEDWATER HEATER

Feedwater flow assumed =	{1}	kg h <sup>-1</sup>	30,000	30,000
Ditto	{2}	kg s <sup>-1</sup>	8.33	8.33
Tube size	{3}	mm	18	25
Tube thickness	{3a}	mm	2.0	2.5
Inside diameter = {3} - 2 x {3a}	{4}	mm	14.0	20.0
Minimum bridge thickness for expanded tubes (Wärmeatlas) <sup>1</sup>	{5}	mm	5.5	6.5
Tubeplate bore (WA) [presumably from Wärmeatlas]	{6}	mm	18.5	25.5
Minimum centre-to-centre distance (32 minimum for 25mm tubes; 33mm chosen)	{7}	mm	24	33
Outside shell diameter	{8}	mm	267	267
Outside shell thickness	{8a}	mm	6.5	6.5
Tube arrangement type:				
Number of tubes	{9}	-	85	40
Internal perimeter of each tube = $\pi \times \{4\}$	{9a}	mm	44.0	62.8
Internal perimeter of tube bundle = {9} x {9a}	{9b}	mm	3,738	2,513
Water heating surface area per metre = {9b} x 1,000	{10}	m <sup>2</sup> m <sup>-1</sup>	3.74	2.51
Estimated heating surface area	{11}	m <sup>2</sup>	25.0	16.9
Heater length = {11} / {10}	{12}	m	6.68	6.73
Water flow area = $\pi \times \{4\}^2 \div 4 \times \{14\} \times 10^{-6}$	{13}	m <sup>2</sup>	0.0131	0.0126
Water velocity = {2} / ({13} x 1,000)	{14}	m s <sup>-1</sup>	0.636	0.661
Dynamic pressure = $1 \div (2g) \times \{14\}^2 \times 1,000 \text{ kgf} \cdot 10^{-3}$	{15}	kgf m <sup>-2</sup>	20.6	22.3
Length / diameter of tubes = {12} / {4}	{16}	-	477	337
Assumed friction factor	{17}	-	0.03	0.03
Tube pressure drop = {15} x {16} x {17}	{18}	kgf m <sup>-2</sup>	295	225
{18} in atm $\approx \{18\} / 10,000$	{19}	atm	0.0295	0.0225
Hence the heater can work simultaneously with the pump and the injector				
Approx final water temperature	{20}	°C	140	140
Approx steam temperature	{21}	°C	150	150
Approx mean water temperature	{22}	°C	100	106
From the Wärmeatlas, heat transfer coefficient (waterside only)	{23}	kcal m <sup>-2</sup> h <sup>-1</sup> K <sup>-1</sup>	6,000	5,000
Heat to be transferred = {1} x 1 kcal kg <sup>-1</sup> K <sup>-1</sup> x ({20} - 15°C)	{24}	Gcal h <sup>-1</sup>	3.75	3.75
Necessary mean temperature difference = {24} / ({11} x {23}) x 10 <sup>6</sup>	{25}	K	25.0	44.4
Final temperature difference [?]	{26}	K		~9
Mean steam / water temperature = ({20} + {21}) / 2	{26a}	°C		145.00

<sup>1</sup> "VDI-Wärmeatlas" or "VDI Heat Atlas" 1963, more recently republished by Springer Verlag. [Transcriber]

amount of dissolved solids. In fact, suspended solids are absolutely not harmful provided that particles are wetted, in which case they behave as if they were, say, minute solid balls in the water.

In the present system, the turbine exhaust cannot be sent to the heater so as to gain advantage by warming up the feed when the regulator is closed. This is because in the heater there is a high back pressure (as high as possible so as to get the maximum temperature on the feed), a condition for which the turbine is not designed (this would not be the case of a reciprocating pump). The best solution is to send the turbine exhaust to the ashpan, thereby reducing the amount of steam extracted from the exhaust going to the blast pipe. The same applies to the electric turbine. So far, the best way to avoid feeding the boiler with unheated water is to have airtight dampers and prescribing that fire cleaning is to be carried out on shed WHEN THE LOCOMOTIVE IS GOING TO GET OUT TO THE ROAD. Perfectly tight steam glands also contribute to the general engine economy to an unexpected degree, not to mention steam-tight valves.

There is still an interesting extra to be added: tender engines usually run uphill chimney first. On a 2.5 % grade, this means that some 10% tender capacity is lost because the front part of the tender is higher than the back.

Therefore, the suggestion is to place the water take-off for the injectors and the pump at the back of the tender provided of course that adequate piping is arranged (39) & (40). Experience tells that this is perfectly possible with full reliability.

An interesting improvement to the system can be achieved taking advantage of the ability of the feed pump to work with water at probably 10 K from the boiling point (Fig. 7). Instead of making the condensate discharge into the pump suction, it is discharged at the back of the tender where, as explained above, the pump suction should be located - item (42). The tender filling opening (43) is located at the front part so that water is made to reach the suction point along a zig-zag path (44). The back of the tender is always full of hot water near the boiling point. An automatic changeover valve (45), actuated by the regulator, allows the extraction of that hot water from the very back of the tender to feed the boiler with it during periods when no exhaust steam is available. The injector is as usual supplied from the cold water partition (46).

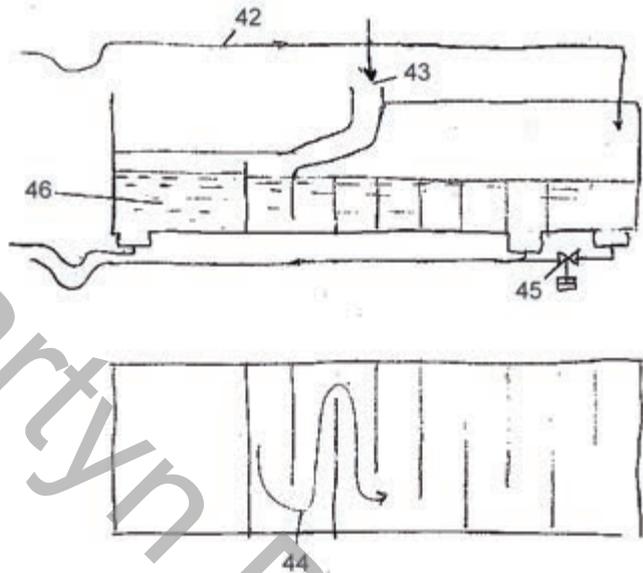


Fig. 7

It is clear that many alternatives are possible on the above arrangements, their usefulness depending on the possibility of adding up ALL the claimed advantages so as to make a grand total. It may be that they can reach a very large amount, so as to achieve a major improvement, say, like suppressing a watering stop. In that case, the traffic producing ability of the engine is considerably enhanced.

# **A List of some 500 Possible Improvements to Existing Steam Locomotive Power**

## **Extracts**

### **Section 4 – Water Treatment**

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July 1983 Edition

L.D. Porta  
Vice President  
Research & Development  
American Coal Enterprises, Inc.

Issued:

Revised:

TO: W.B. Benson  
FROM: L.D.Porta  
DATE: June 20, 1983

**SUBJECT: "A List of Some 500 Improvements to Existing Steam Locomotive Power"**

Attached you will find the paper of the subject heading. It has been written bearing in mind Turkish Railways as potential customers, and also as an ACE reminder.

The quoted references show through their dates, that many of the improvements have been developed by the undersigned over a number of years before joining ACE. Many of them are patentable, and if not, what is patentable is the combination into rebuilt or new locomotives.

This combination does not result from the simple adding-up of the various devices, but from an harmonious interrelationship. For example, better piston and valve rings lead to a reduced boiler demand, "as does a good insulation, etc. thus leading to a smaller boiler and dispensing with one or two carrying axles." By the same token, said better rings contribute to solve the problem of a small grate in an existing design to be rebuilt.

Concerning confidentiality, one should note that the risk of other people taking advantage of the list (for it is no more than a list) is, in the undersigned's opinion, very small. For what is essential is the ability to integrate each one of the items into a single package, and this is to be supported by a kind of scientific and engineering knowledge which is not as yet apparent in the railway scene. On the other hand, Turkish steam engineers will probably be impressed by the list which would mean to them that at least ACE has a solution to propose to their existing problems or to improve the performance of their steam power. The undersigned's experience is that people trying to copy get a poor replica!

The paper is a first edition only. It will be incremented with many items coming to the undersigned's memory and also from his written notes included in his soon-to-be-mailed papers. It has also to be complemented with a card index; also, complementary describing literature, figures, etc. are to be added.

A second paper dealing with the example of a rebuilt Turkish 2-10-0 ex-German 44<sup>1</sup> engine is underway showing the gains in power and thermal efficiency. Two similar ones should refer to the Indian WG class and the Chinese 2-10-2, this leading to firm business based on actual guaranteed figures and not to simple wording.

It is suggested to send a copy of the present paper to Mr. Ross ROWLAND, Chairman of ACE. It contains a comprehensive review of what has been the writer's past work, and what can be a significant field of future business for ACE. In any case, it is thought that it will add to his better understanding of the subjects on hand.



L. D. Porta  
Vice President  
Research & Development

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<sup>1</sup> Readers are directed to Locomotives International Issue 91, August/September 2014 for information on this proposal. Also reproduced by ASTT in "A Compendium of Articles and Papers celebrating the Centenary of the birth of the eminent Argentinian Locomotive Engineer Livio Dante Porta 1922 – 2003 Volume 2." [Editor]

**Part 3**  
**Two German Papers**

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## SECTION INTRODUCTION

Why is it relevant to discuss the internal water treatment practices of Deutsche Bundesbahn (DB) – German Federal Railways, the West German state railway operator – in a publication covering advanced steam technology? Is it not a little strange to do so? Not really, DB's approach to internal treatment was advanced for its time making it both very interesting and informative. It is also well recorded in technical publications, perhaps at a level of detail rarely achieved elsewhere. The approach taken grabbed Porta's attention leading to his writing a short set of comments on one technical article written by Joachim Robrade. Porta's comments are to be found in this section.

It was this set of comments which first started the editor's investigations into German water treatment practice. The full paper Porta commented on was obtained and translated, it being of great interest and seemingly describing a very similar approach that that taken by Porta. It too is included in this section. However, in trying to gain a deeper understanding of German practice whilst researching for this book, other articles and papers were uncovered giving a somewhat different view of the success achieved. One of these articles, by Friedrich Witte, follows that of Robrade.

On analysis, DB's treatment cannot be said to be the best post-World War II and pre-Porta internal treatment, despite initial appearances. That accolade belongs, perhaps, to the BR/ICI treatment described by A.J. Parsons, in his paper "*Some Aspects of Locomotive Boiler Feed Water Treatment*", published in the Journal of the Institution of Locomotive Engineers, volume 47, No.257, May 1957. Nonetheless, the well-recorded problems DB experienced provide an excellent basis for a 21<sup>st</sup> century analysis of what was done which, in turn, highlights some problems not caused by the internal water treatment but very much identified because of it. These, once again, underline that no chain is stronger than its weakest link. The analysis made is instructive to both students and users of internal boiler water treatment.

It is important to record my thanks to Roland Foschi and Fritz Goebel, both in Austria, for the very significant amount of help provided in sourcing papers and assisting with their technical translation. Only one of these appears in this section, but others are quoted from. Without them, the analysis and other comments made would be far less well-informed, but they are not claimed to be definitive.

# **Internal Treatment of Locomotive Feedwater on Steam Locomotives of Deutsche Bundesbahn**

Dipl.-Ing. Joachim Robrade, Minden (Westf.)

First published, in German, in  
Eisenbahntechnische Rundschau, May 1956.

DK 621.133.712

Treatment of locomotive feedwater is of great importance for the maintenance, performance and life of boilers. It is to an ever-increasing degree performed as "internal treatment" on the locomotive. The author, one of the officials responsible for the introduction, development and control of the new system on Deutsche Bundesbahn, describes its features and the successes achieved.

## A. THE SCOPE OF INTERNAL TREATMENT

The chemical treatment of feedwater in the locomotive boiler itself, the so-called 'internal treatment', has become very important on the Deutsche Bundesbahn (German Federal Railways) in recent years. This internal treatment was used on 178 locomotives on 1<sup>st</sup> May 1952, 1906 on 1<sup>st</sup> August 1953, 3650 on 1<sup>st</sup> August 1954 and 4585 on 1<sup>st</sup> December 1955.

How is this rapid expansion explained? Firstly, by the fact that it is inexpensive to start an application of the treatment:

- The equipment required on the locomotive only consists of two containers for the chemicals and two measuring cups used for dosing when taking water.
- At the locomotive depot, a dry storage room is required to store the chemicals and a small laboratory area is needed for routine testing of boiler and tender water samples (fig. 1).

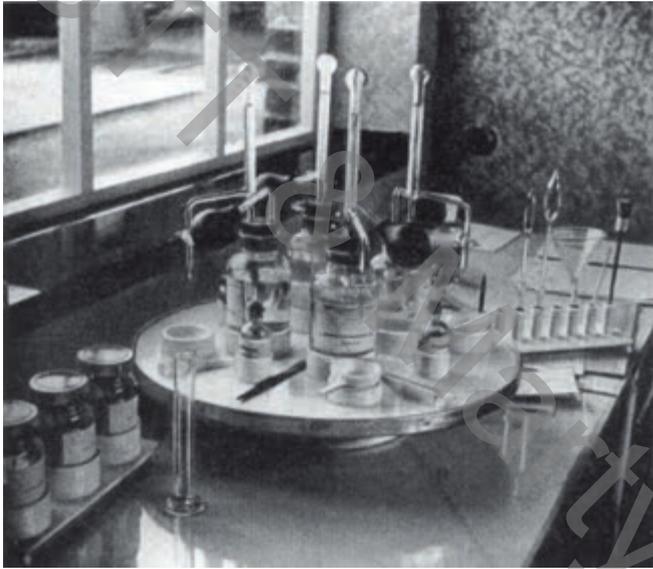


Fig. 1 – A locomotive depot water laboratory equipped with a rotary table.

These are all resources that a locomotive depot can muster. The results are clean, scale-free boilers, washout intervals are at least twice their previous length and savings on boiler work at depots and workshops testify to its considerable success.

## B. THE CHEMICAL CONDITIONS

The internal treatment of feedwater comprises of two parts, the chemical and procedural. The chemical side has been developed over the last two decades by Nalco<sup>2</sup> in Chicago, Lambro<sup>3</sup> in Milan, Tannin Developments Ltd<sup>4</sup> in England and solved by Société nationale des chemins de fer français (SNCF)<sup>5</sup> in France. All these methods precipitate the hardness in the water primarily by the action of sodium carbonate and sodium bicarbonate. The amount of these chemicals used per cubic meter of water is proportional to the permanent (non-carbonate) hardness. When softened, the hardness in the water becomes an insoluble sludge in the boiler; water-soluble salts, carbonic acid and water are also created. What is different with the internal treatment now being used is that, in addition to sodium carbonate and sodium bicarbonate, one of several special additives are added to the tender water, namely Nalco 8N, Diskro 310, a Tannin-Polyamide mixture or Traitement Intégral Armand (TIA) system compounds that contain substances which control both the sludge and the dissolved solids. The organic substances in

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Represented in the Federal Republic of Germany by:

<sup>2</sup> Lurgi, Gesellschaft für Chemotodinik, Frankfurt a. M. [Robrade]

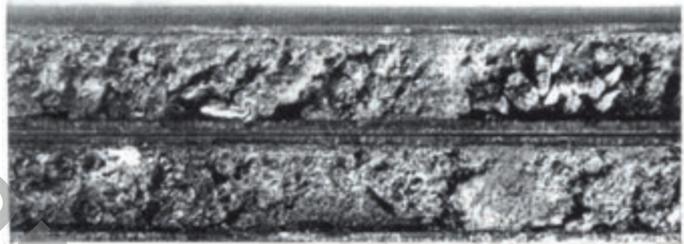
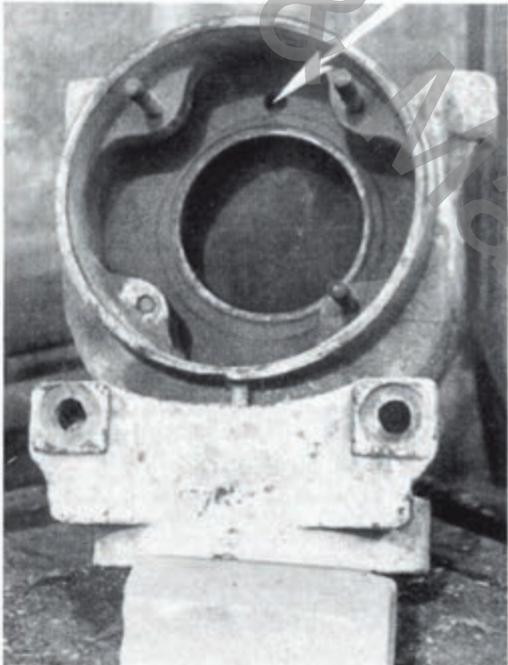
<sup>3</sup> Marquart AG, Beuel/Rh. [Robrade]

<sup>4</sup> Rheinische Gerbstoff-Extract-Fabrik, Karlsruhe. [Robrade]

<sup>5</sup> Krauß-Maffei AG, Munich-Allach. [Robrade]

advantage of using the internal treatment is that around half of the deposits found in the superheater elements consisted of sodium carbonate and thus are soluble in water. These can be removed by flushing the superheater elements through. More recent practice has been to weld a fire hose coupling into the steam pipe from the superheater to the cylinders, (see fig. 18). The hose from the washout pump is connected to it so that the boiler cooling water passes through the superheater. With this flushing process, the superheater elements have been kept clean on several Deutsche Bundesbahn divisions for a number of years.

Recently, an extremely heavily contaminated superheater element was found; fig. 19 shows a longitudinally sliced section of it. The deposit has no layered structure, but it gives the impression that a large quantity of boiler water sludge had reached the superheater. Therefore, a leak was suspected in the boiler. A detailed inspection inside the boiler showed that a drain hole existed in the regulator housing (fig. 20). These drain holes have been plugged by main workshops since 1943; obviously there are still locomotives in operation retaining these holes. When the regulator was open boiler water was drawn through the drain hole, especially when the water level was high, causing the damage shown. On the same locomotive, it was found that the regulator valve had not been completely shut during the cooling phase of the washout procedure. When the boiler was full, water contaminated with sludge had also filled the superheater elements. After these two causes were identified and eliminated, contamination of the superheater elements ceased at the depot in question.



**Fig. 19 (above) – Deposits in the superheater elements of a Class 01 locomotive.**

**Fig. 20 (left) – Drain hole in the regulator housing.**

A similar incident happened with the contamination of the train heating system. At the beginning of 1955, it was found that the hand washing water in new coaches, where the water is mixed with condensate from the train heating system, was in an extraordinarily dirty and unusable state. Analysis showed that the train heating condensate contained a very high proportion of boiler water which had somehow reached the train heating system. Confirmation and subsequent investigation of the locomotive used to haul the train in question showed that the steam pipe inside the boiler had a plug type connection; the boiler water could penetrate this at the average water level. In addition, the train heating pipes inside the boilers of other locomotives still contained drain holes that were at the normal boiler water level. Experimental installation of internal train heating pipes with screwed connections, as is common practice in the construction of new boilers, brought about success. The train heating condensate system is now working without problem. Similarly, steam used to operate locomotive auxiliaries such as air pumps and generators, are completely free of alkalinity or boiler sludge if the corresponding steam pipe joints inside the boiler are free from leaks, the water level is kept within the normal range, and the internal treatment is applied as specified by the staff. This has been confirmed by multiple measurements of steam purity. The internal treatment was thought to have caused damage to

# **Where there is Light, there must be Shadow**

**Critical remarks on the internal boiler water treatment**

First published, in German, in  
Die Lokomotivtechnik, May/June 1962.

Dipl.-Ing. Friedrich Witte, Minden

changes in staffing, etc., make it difficult to maintain a constant level of development. All our efforts have not been able to control, for example, the much more frequent water carryover. It is not always easy to control how often water carryover occurs during a journey. In addition to foaming of the entire boiler water, which is clearly visible in the superheated steam temperature, which has then usually already caused more serious damage, there is also a constant, creeping, water carryover. However, for statistical tracking, there are, at best, the cases indicated as the reason for exceeding section timings, i.e. late running, others are not recorded at all. This makes it all the more difficult to provide absolute proof of the damage caused by water carryover. However, in most cases, other causes cannot be proven, so that indirect evidence must be provided.

As internally clean as boilers have become, it is all the more difficult to keep upstream and downstream components clean, such as pumps, regulators, superheaters, feedwater heaters, valves, cylinders, the train heating system, etc. The various suggested flushing out methods are intended to eliminate the consequences because clogged superheater elements (Fig. 1) inevitably burn if there is no cooling by the steam in the element. Since the first section of an element clogs up first, the entire remaining element is then exposed to damage because cooling from the steam side is missing. The element then usually burns through in the area of the second return end, because here (Fig. 2) char deposits usually form on the outside as well. If water washes over running surfaces, the important oil film is removed. If water gets into the cylinders, the all too well-known deformed wheels, bent axles, crosshead and cylinder cover damage, and fracturing of cylinder blocks can occur, which have increased to such an extent that they cannot be overlooked following the introduction of internal treatment.



**Fig. 1 – A superheater return end filled with boiler water sludge.**



**Fig. 2 – Blocked and subsequently burnt superheater element.**

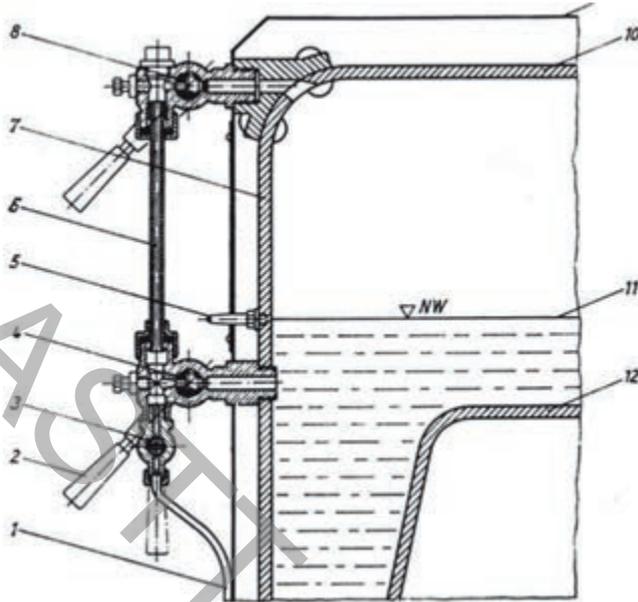
The effects of water cylinders are many and varied. The frictional resistance in the valve chest instantaneously increases very considerably, resulting in damage to the valve, the valve gear and increased wear of the liners. Thermal shock can cause cracks in the valve chest. Especially 'impressive' was the wear of cast iron gland bushes and rings of the piston rod stuffing boxes. These components have proved their worth over decades and there were justifiably strict instructions to maintain uniformity and standards. No changes of any kind, be it to the design or the materials used have been allowed, none of the alternatives ever offered were economic, be they from within DB or outside industry. The increasing number of locomotives using the internal feedwater treatment caused the demand for replacement parts to suddenly increase. It was found that the components were worn out well before the expected life of 60,000 to 80,000 km.

Other factors may also play a role, such as industry's declining interest in the supply of steam locomotive parts due to structural change and thus the shrinking number of experienced specialist manufacturers, low prices achieved in recent years, job changes, economic boom, etc. With the addition of the effects of the internal treatment, the service life of the components decreased to such an extent that it was hardly possible to keep up with demand. A remedy is now being tested, i.e. a modification to the existing design which addresses the changed conditions. Since the self-lubricating properties of the cast iron are obviously no longer sufficient,

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# **An Analysis of Internal Boiler Water Treatment Practices on Deutsche Bundesbahn in the 1950s and 60s**

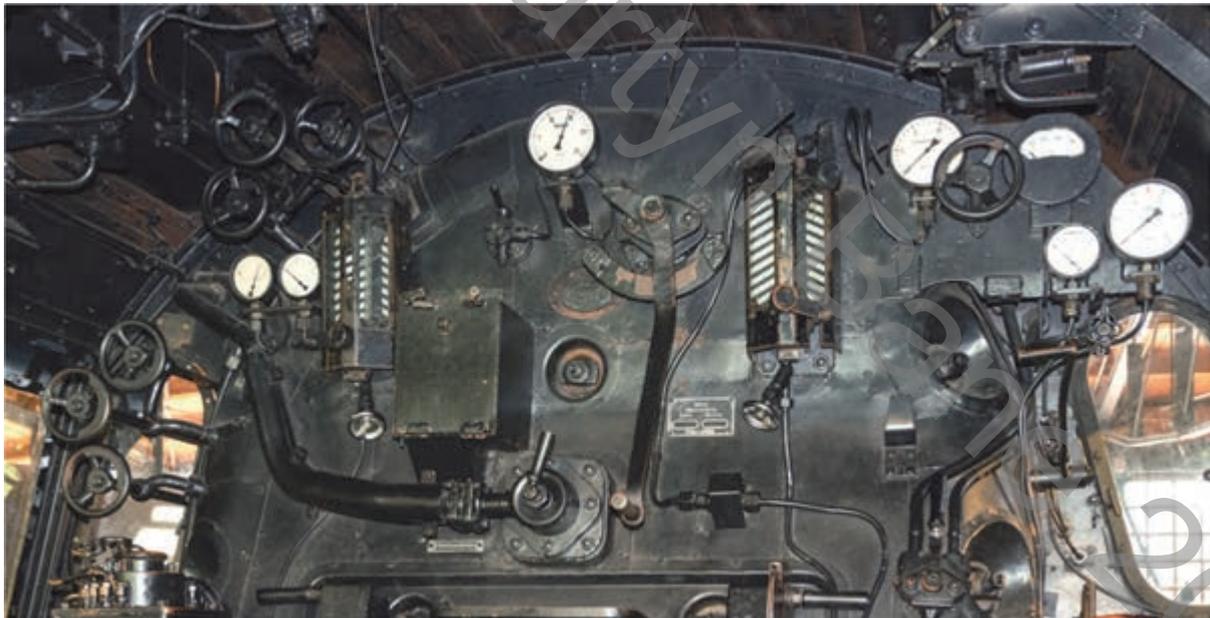
Martyn Bane  
March 2024



**Fig. 6 – The standard German gauge frame arrangement. The top connection to the boiler, whilst marginally better than one a little lower, is still susceptible to the circulation hump at the rear of the firebox. Combined with the use of a round-top firebox and with swelling boiler water due, in part, to ineffective antifoam, it is of no surprise DB locomotive suffered from false-high water level indications [49].**

Note: Item 5 shows the NW marker.

The US tests were not undertaken on locomotives with a boiler water chemistry similar to either DB's or Porta's norms<sup>9</sup>. However, that does not invalidate their results. The effect of high total dissolved solids (TDS) is to create conditions that can give rise to greater water swelling and potential for false high water level indication compared to boiler waters with lower TDS levels, but this does not have to be the case. An effective antifoam changes the behaviour of steam bubble formation. Larger, and consequently fewer, bubbles form, reducing the boiler water's tendency to swell. A less effective antifoam will not have such a marked effect, but it should at least have some [4][8].



**Fig. 7 – The footplate of DRG 50 001 on display at the Deutsches Technikmuseum Berlin. The position of the gauge glass top fittings, on the knuckle of the round-topped firebox, is prone to giving false water level indications. On this class of locomotive, the gauge glass was 305 mm tall [22]. The pyrometer can be seen on the top row of gauges and furthest to the right.**

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It is probable the use of Nalco-8N exacerbated DB's problems. As outlined in section 3.4.2, it is suspected that the performance of the antifoam was not all that it needed to be. This implies

<sup>9</sup> DB: 8,000 - 10,000 ppm total dissolved solids, Porta: 10,000 - 20,000 ppm total dissolved solids.

the normal operating range [34]. This sludge will have become baked into position, presumably over repeated incidents. The dissolved solids in the water carried over will, of course, have played a part in the clogging of the valves, but much can be expected to have been ejected into the atmosphere when the safety valves were open. Suspended solids were almost certainly more important in this case.

Any thoughts that the safety valves were clogged by water treatment chemicals, that is in their raw form and effectively undissolved in boiler water, can be dismissed.



Fig. 8 – Safety valve components clogged with boiler water sludge as shown in Witte’s paper.

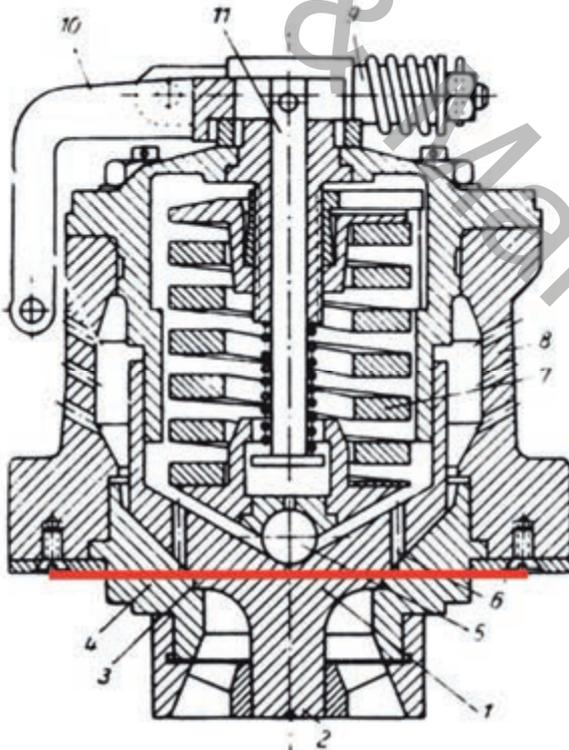


Fig. 9 – A cross-section view of the standard type of safety valve used by DB, the ‘Ackerman’ type. The clogged section shown in Fig. 8 is below the red line. [49].

Witte’s suggestion that the solution was the regular operation of the safety valves seems as naïve to the likely causes of the problem as Robrade’s opposite suggestion (not lifting the safety valves) was to the realities of footplate work. Robrade makes no comment on problems with the clogging of safety valves, but was his comment on not allowing them to lift a reference to this problem and perhaps an understanding of the cause?

What was the clogging of safety valves a symptom of? The likely factors are boiler water level, antifoam performance (boiler water swelling/foaming), and safety valve positioning. Unless caused by a sudden surge in boiler water (heavy braking, etc), the safety valves must have, if only for a short time, syphoned water from the boiler. If the boiler’s foam layer was at the level of the safety valves (poor antifoam performance or an over-full boiler), this syphoning would have started more easily, but it would not be essential. The lifting of a safety valve will lead to a localized pressure drop, the water level in that area will rise giving the potential for water to be syphoned. It is not entirely unhelpful to picture the action of a tornado in this regard. The

**Part 4**  
**Applying Porta**

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**COMMENTS by L.D. PORTA on  
the NTSB Report of Findings in  
the Gettysburg Accident**

Nov 1997

ALL textbooks and instructions issued say. But since BERNOULLI's time, it is well known that said law is valid only when the liquid is at rest. But in the boiler, the water circulates at velocities on the order of 3 to 6 ft/second, hence having a dynamic head of, say, 8 inches or more, thus making invalid such a principle, as proven by the BUREAU's tests. The world did not care too much about experiments carried out by "crazy Americans for their particular problems". The only reference to these experiments, to the best of the writer's knowledge, appeared in Germany ca. 1920 in the Zeitschrift Vereins Deutsche Ingenieure (ZVDI). But of course, nobody in German Railway at that time took ANY care to incorporate such ideas to the picture of water behaviour in the boiler<sup>3 4</sup>. The actual circulation in the boiler is much different from that depicted in the report. In the figure, it is seen that the pattern is very much like that depicted in the familiar advertisement of NICHOLSON's.

But the circulation is not created by density differences originated in temperature differences because the water becomes warmer, but (as the general theory of water circulation for water tube boilers states) on the greater or lesser amount of bubbles both resulting from the heat transfer (especially in the firebox area) and the auto-evaporation resulting from the diminishing pressure obtaining when the flow goes upwards. Thus, at point A, the volume fraction occupied by steam is roughly 40%, and the velocity in the order 3 to 5 ft/sec. This leads to the formation of the jump B which the ICC Inspectorate measured.

By the sides, there is also a jump because the water is also ascending by the firebox lateral passages. The whole circuit, as measured by the present writer, is run in some 5 to 10 seconds, and the overall mass flow about ... 500 times the steam production. Thus, the top surface of the water is far from being a plane as depicted in ALL textbooks. Besides, the upper part of the flow is a mixture of steam bubbles and water and there is a foam layer; there is a gradual transition towards "pure" steam much like occurs when boiling milk. But this has been Olympically IGNORED by railway people, even as it was clearly established ca. 1920. As the report states on page 20: "while the gage cocks may indicate PLENTY of water, in reality there may be little or no water over the crown sheet." NO engineer has ever been told that so as not to use cocks as attached to the back sheet. On the third paragraph on page 19, it is stated:

"This arrangement ensures that the water glass (located on the column) and the gage cocks indicate the same and true water level."

ABSOLUTELY FALSE: there is no such a "level" but an irregular "surface" which at best contains a foamy material on top or even reaches the top of the steam space. So, THERE IS NOT SUCH A THING AS WATER LEVEL. Thus, the picture given in Fig. 15 is basically wrong.

British boiler gages have cock controls which clearly show when their position is fully open or not. This is not the case for American type control valves, which therefore should be checked by the crew just when they put their feet on the footplate for the first time; it is not surprising that explosions occurred as reported on page 21. This writer knows about serious accidents due to partially opened top cocks.

The CMO of the Valley Railroad at Essex, Conn. reported that . . . "the turret valve of the injector was shut off". UNBELIEVABLE!!! The engineer responsible for it should be sent to jail!

After a very extensive series of tests carried out ca. 1970 by INTI (Instituto Nacional de Tecnología Industrial, Argentina) as requested by the Belgrano Ry., Argentina, and until a better evidence is offered to him, the writer proposes to ENFORCE the use of Polyamide antifoams for ALL locomotives just to ensure pure steam (contamination less than 2 ppm) and minimal foam disturbing the top water surface.

A molten current fuse plug DOES NOT SERVE AS EFFECTIVE PROTECTION because it does not die out (*kill*) the fire as he has witnessed. Maybe that NATHAN plugs are effective if applied as one plug for every 400 square inches of grate surface area. But NATHAN plugs must be confectioned according to strict procedures otherwise they will drop (at times) even with a full

<sup>3</sup> Take for example "Die Dampflokomotive", TRANSPRESS reprint. 1993, Berlin. "Nach der gesetz der komunizierenden Rohren stellt sich daher stets gleicher Wassenstand wie im Kessel ein." (P.262). [Porta]

<sup>4</sup> Also see: Witte, F.; "Where there is Light, there is Shadow. Critical remarks on the Internal Boiler Water Treatment" in this volume outlining the consequences of this failure. [Editor]

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ASST  
THE PRACTICAL APPLICATION  
OF 'PORTA TREATMENT'  
- AN ADVANCED INTERNAL  
BOILER WATER  
TREATMENT SYSTEM -  
ON STEAM LOCOMOTIVES OF  
THE FERROCARRIL AUSTRAL  
FUEGUINO, REP. ARGENTINA

Note: This paper contains matter subject to intellectual property, all rights reserved.

S. T. McMahon  
Ushuaia  
Tierra del Fuego  
Rep. Argentina  
18th March 2003



Fig. 10 – Draining the boiler down on FCAF No.3 for a washout. The water was just off the boil, the oil firing having been run to get the water hot enough to start the washout procedure. The sludge was extremely free flowing. 17 January 2004. © Martyn Bane [Editor]

Fig. 11 – Washing out the remaining sludge and loose scale gave a very different colour to the “brown” normally associated with washouts. 17 January 2004. © Martyn Bane [Editor]



Fig. 12 – Four samples were taken as the boiler was drained showing the variation in content which occurred. The first sample, taken as soon as the draining of the boiler started, is on the left. The fourth sample shows virtually no sediment. On the right, under a cover, is a boiler water sample taken before the draining commenced. 17 January 2004. © Martyn Bane [Editor]



Fig. 13 – No.3's throttle valve showing its low position, see note 13. The brass ‘false’ dome cover and the actual dome were removed to assist with fully washing out the boiler. 17 January 2004. © Martyn Bane [Editor]



Fig. 17 – FCAF No.2 'Ing L.D.Porta' stands at La Macarena station with its train into the Tierra del Fuego National Park. 16 January 2004. © Martyn Bane [Editor]

### 3 COMMENTS AND CONCLUSIONS

The writer was first made aware of the PT during 1992 and made several attempts to implement such in its entirety as a preventative measure against a predicted 'boiler epidemic' in the UK. It was realised by Porta, and others, that it was impossible to advance steam traction beyond first generation levels without the perfection of internal boiler water conditions. The RFIRT in southern Argentina proved to be a good testing ground for internal boiler water treatment and resulted in the boilers of the railway's Santa Fe class locomotives working for extended periods of time without having to remove such for heavy repair work.

During 1969 the Argentine State Railways called upon Instituto Nacional de Tecnología Industrial<sup>38</sup> to solve the widespread epidemic of water carryover and severe corrosion problems that its locomotives were suffering in the north of the country. C16 class 4-8-2 locomotive No.1802 was set up as a test engine and worked between Salta and Socompa<sup>39</sup> (a northern section of the FC Belgrano system). A regular crew was allocated to No.1802<sup>40</sup> accompanied by Porta for most of the in-service testing. Boilers in that region were fed with very hard water and these areas had become known as 'boiler cemeteries'. Locomotive boilers had to be washed out every couple of weeks and tubes replaced every 2 years due to severe scaling of the internal surfaces. We should remember that the results of a corrective system are not gained overnight, however by 1974 locomotive No.1802, and others of the railways fleet in the same area that had been put on to the corrective system, required washing out only twice a year. This state of affairs represented incredible savings in terms of labour and infrastructure costs, not to mention ease of operation for the crews themselves.

timescale. In this state the FCAF locomotive boilers are still in saturated rather than superheated state therefore the full benefits of modification have yet to be reaped at Ushuaia. Stage 2 modifications, again at minimal financial outlay, are planned for both steamers and design work for such is well in hand. The focal point of this work is the heavy rebuild of No.2's original boiler and No.3's existing boiler. In the case of No.2, it is convenient to prepare the original boiler (removed 2001) before stage 2 work commences on the locomotive itself thus not having to withdraw such from traffic at a premature point in time (i.e. revenue earning capacity will not diminish relative to time in service). Boiler work will consist of designing and manufacturing a new Belpaire type firebox with rounded corners and replacement of the rigid stays by the flexible Tross type. The foundation ring of such will be of the 'U' Tross design and the auxiliary manifold will be moved outside the cab in order to improve crew comfort and satisfy safety requirements. The design of the longitudinal stays will be improved as well as mounting on the carrying cradle. The boiler will be superheated, some 75% of the tubeplate will be occupied by superheater flues whilst the remaining smoke tubes will be fitted with a 'superheater booster'. The fitting of a superheater header and feedwater heater will require the existing smokebox to be lengthened positioning the exhaust system directly in between the 2 components parts (the exhaust system may need some alterations to be carried out as a result of the boiler gas flow



**Fig. 24 – Gauge frame components from FCAF No.2 'Ing L.D. Porta' showing copper extension pipes added to ensure correct boiler water level indication<sup>a</sup>. © Martyn Bane [Editor]**

cross section area being altered during superheating). The boiler of locomotive No.3 will receive similar treatment as to that of No.2 however in addition will receive a new oil firing combustion system and therefore the volume of the firebox will alter accordingly. Both boilers will receive combustion primary air pre-heating and feedwater pumps. The position of No.3's rebuilt boiler will be slightly higher than as fitted at the moment, yet it is not planned to dramatically alter the overall shape of this very aesthetically pleasing and popular locomotive. This particular area of design has often been overlooked by many and it should be remembered that it is not necessary to alter the overall 'form' of something in order to improve it when a little reshaping of component parts can achieve the same result.<sup>b</sup>

<sup>a</sup> See Porta L.D.: 'Steam Locomotive Boiler Water Circulation A First Semi-Quantitative Approach' to understand why the extension tubes were fitted. [Editor]

<sup>b</sup> Sadly, the stage 2 work described did not happen. A second Garratt was supplied to the railway in 2005 but was considerably less advanced than the locomotive concept described. [Editor]

# Does it Work? 'Porta Treatment' in the UK



Martyn Bane  
March 2024

been shown to be inaccurate. If the Chemical Abstracts Service (CAS) number of the antifoam chemical had been quoted from the start, confusion and time wasting could have been prevented. It is also true to say if, earlier in life, I had taken my formal education in chemistry to a higher level I would probably have known how and where to look sooner than I figured it out. I consider not being a professional chemist both an advantage and hindrance to what I did with 'Porta Treatment'.

It has been suggested that Porta left out key information in his papers to make those trying to apply his ideas think and thus gain a fuller understanding of what they were doing [12]. Not an entirely bad idea - you do not learn very much if all the answers are given at the start. However, from my efforts, I can say it has proved fairly unhelpful at times! Perhaps that says as much about me as it does about Porta's approach?

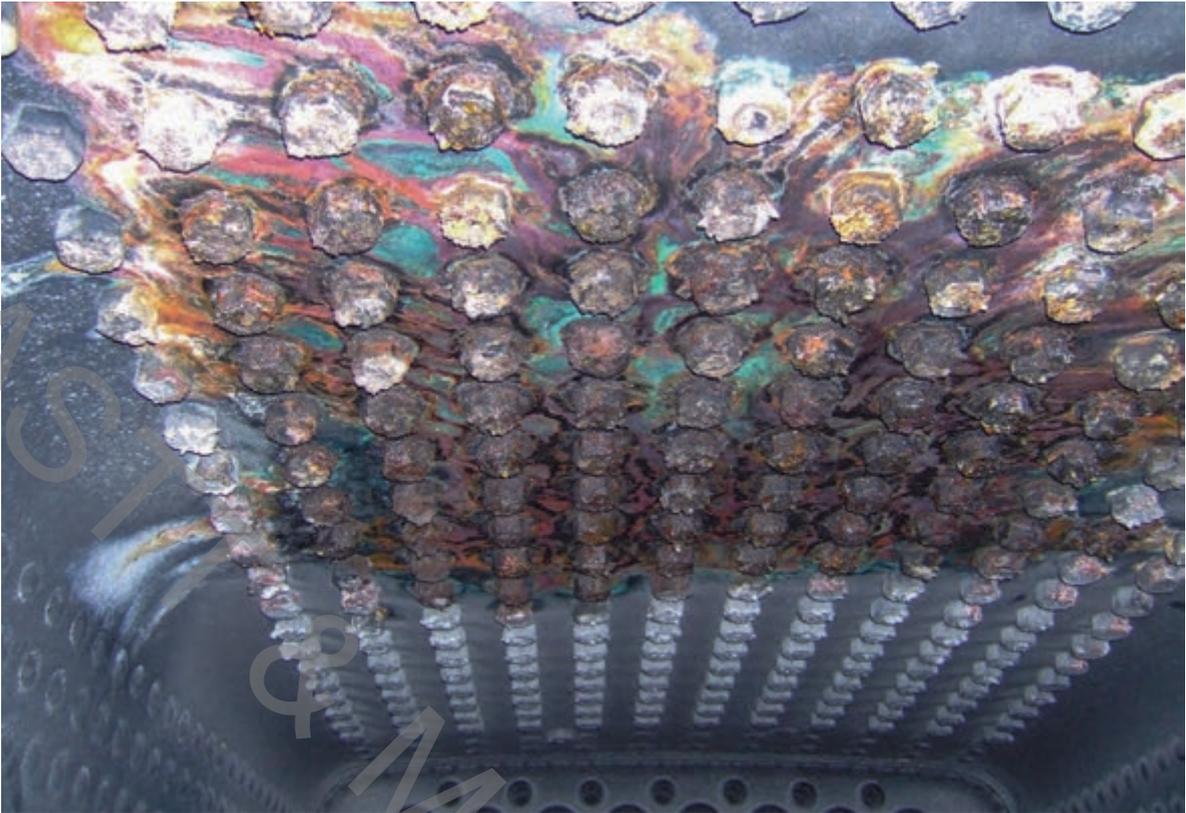
In the comments which follow, I do not propose to give a blow by blow account of my water treatment work, it would be immensely dull if I were to do so. Rather, I outline what I did and why, pick out a few of my more instructive experiences and provide pointers for anyone who wishes to pick up the baton and try to make Porta's water treatment regime actually work as it ought.

## 2 FIRST STEPS



**Fig. 1 – End of the day checks, driver Parrott inspects FCAF No.3 'Camila'. In the background is the line's heavily rebuilt Garratt No.2 'Ing. L.D. Porta'. 14 January 2004**

I first took a serious interest in the treatment around 2002, a chance meeting early that year led to a copy of Porta's paper being passed to me. I continued to pursue its application for over a decade and a half. In that time, I achieved much success, had a few serious problems, conducted both ad hoc and controlled antifoam/steam purity testing and entirely failed to achieve antifoam performance in line with Porta's specifications. I appeared to see it in Argentina in 2004, but the failure of the water testing meters at Ferrocarril Austral Fueguino (FCAF) meant I was never entirely sure what I was witnessing. All I saw was pH testing with test papers and no measurement of dissolved solids - not ideal. That is not to suggest any sleight of hand was at work, I do not believe it was, rather that I simply never saw concrete proof of the boiler water



**Fig. 5 – More serious trouble with No.6024. Leakage from the steel crown stays took a while to start, but when it did it really did start! It continued for several months, during a busy period for the locomotive with several mainline trips a month which ended with a stint on a preserved railway. Whilst manageable, just, it was not ideal. The leaks *seemed* far more evident when the boiler was cold. However, on one memorable day, whilst prepping the in-steam locomotive for a mainline trip, doing not much more than functional testing stood on the spot, around 1,000 gallons (4,546 litres) of water over and above the normal amount for a prep day was consumed. This was not sustainable and led to concerns over water consumption when running but, thankfully, was a one off. The trip itself passed off without incident or high water consumption. In the way things can happen, just as the locomotive was to be ‘stopped’ so that the crown stay leakage could be attended to, it promptly ceased without any work being undertaken. There was never even a hint of trouble again. 16 August 2006**

### **3 STANDARD APPROACH AND PRACTICE**

#### **3.1 Guiding Principle**

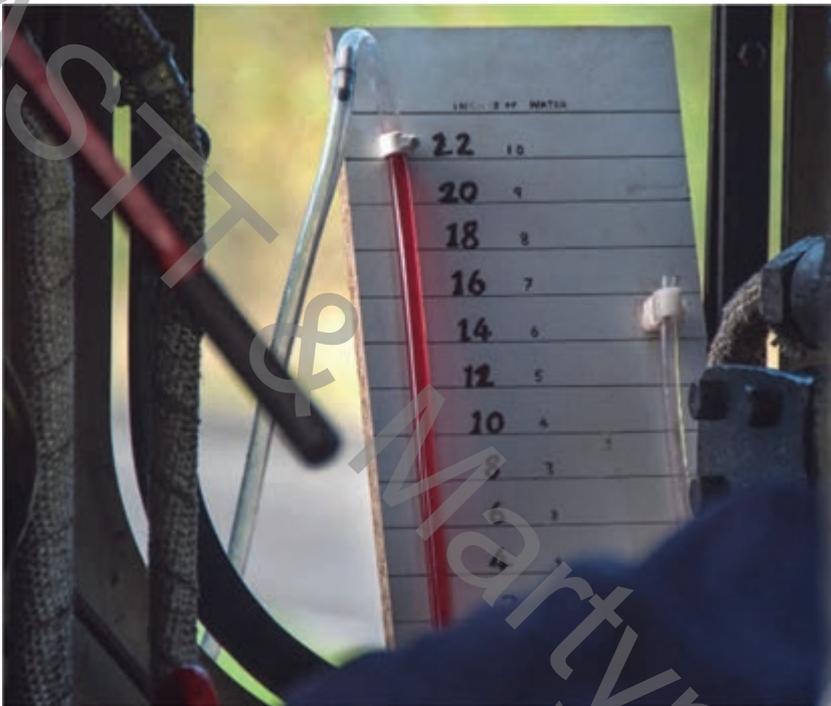
Early on I set some standards which I used to guide what I was doing. My guiding principle was to follow Porta’s instructions unless there were strong reasons to do something different.

The nature of No.6024’s use was irregular and occasional, with no more than a handful of days in steam at a time. The locomotive was not in daily use for weeks on end. This very much influenced how I dosed the boiler, gave me more scope to do what I wanted and generally made my job easier, but not all of the time.

The results I achieved meant I felt little need to vary my underlying dosing plan over time; within the restrictions I was working, the dosing worked. It did evolve a little, but not much, as dictated by changed circumstances. Occasionally, as my confidence grew, I strayed from it to see what would happen. However, the thinking behind the dosing never changed.

## 6.2 Testing Days

The testing days were fairly straightforward. Having set the correct boiler water conditions (based mainly on TDS) the 'antifoam of the day' and salt were added to the locomotive's tanks and off we went from Llanfair each morning. Things were taken gently to Welshpool to allow the antifoam to reach the boiler and simply to see how things went<sup>27</sup>. The first day was planned as testing of the testing techniques, to assist with this steam samples were taken on the outward climb to Castle Caereinion. Sampling on this section was repeated, as required, at other times during the testing programme, but more out of interest to see what was going on, to see if our 'noses' were right, rather than to acquire any especially valid results.



**Fig. 13 – The smokebox manometer with measurements in inches of water. The higher figures were added after experience showed them to be necessary. The engine was being worked extremely hard! 16 October 2012**

At Welshpool, any final tweaks were made, and conditions were recorded before a formal test run was attempted. The factors recorded included the boiler water conditions, it being vital to know what was going on internally.

It was gratifying that at the start of the programme, we did not need to use all of the "learning" trips written into the plan to get things working as we wanted. A test run generally entailed getting away from Welshpool fairly gently to let the loco warm up, then after the 5 mph restriction across the New Drive level crossing, the serious business started. Once the prescribed smokebox vacuum level had been reached, and if other conditions (primarily water level/injector use and boiler pressure) had reached a steady state, the water sampling valve was opened and allowed to run for several minutes to ensure samples were fresh<sup>28</sup>. Then a number of samples were taken for later analysis. Generally, four samples were taken on each test trip. It was possible to hand each sealed sample bottle back to a colleague via the opening in the cab backsheet across the gap to the very conveniently positioned balcony of the leading coach, a very nice MAV bogie vehicle. This arrangement also enabled others to observe and offer advice and comments, generally of a helpful nature!

At Sylfaen, where the locomotive ran-round the four coach test train, a boiler water sample was taken and the temperature of the water in the tanks was checked. There is a significant climb

<sup>27</sup> On the first morning of testing the driver predicted precisely where the locomotive might "pick up the water". He was not wrong!

<sup>28</sup> When the system was in use a 10 - 11 seconds delay was noted between altering the regulator setting etc and the sample water changing characteristics.

away from Sylfaen back towards Welshpool, and this short section was used for further sample collection if felt helpful which, more often than not, it was.

It had been proposed to test samples when running back to Welshpool and at other times and places as needed, but with the staff available, this proved optimistic. It became the norm to test samples on the move back to Llanfair after test running for the day had been concluded. Further work was undertaken each evening, back at Llanfair.



**Fig. 14 – The mobile testing bench in one of the WLLR’s very nice Hungarian (MAV) bogie coaches. Visible in this view are numerous samples from the day, some very obviously contaminated, various electronic test meters for TDS and pH, turbidity and, back right, the equipment and chemicals for the silver nitrate testing. 09 October 2012**

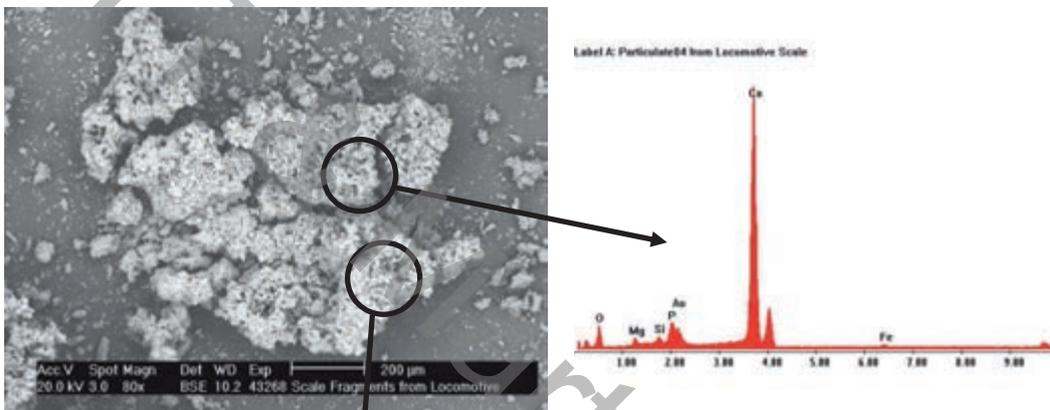


**Fig. 15 – Testing samples when back at Llanfair after a rather damp day’s work. 11 October 2012**

or less for treatments made up of comparable chemicals [20]. Readers are invited to compare various treatments they may be familiar with to the quantities for 'Porta Treatment' quoted in this volume.

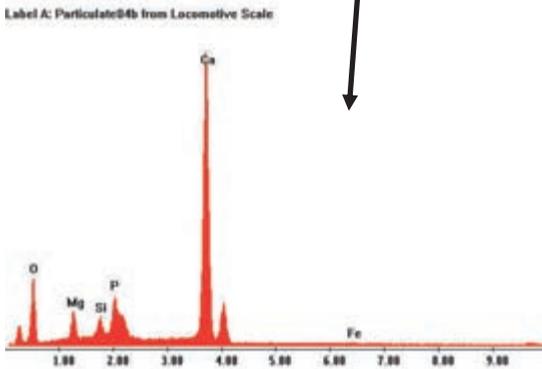
An often-repeated view, within the above view, is that there is far too much tannin (again with the above caveats.) Quebracho, the tannin used, is a very strongly coloured tannin when dissolved in water. Perhaps this leads to confusion. I have been told on several occasions that this "too much" tannin creates deposits in boilers, even when quebracho has not been used. Readers are reminded Porta's recommended dose is 13 ppm [15], Richardson quotes British Railways as using 30 ppm as standard [20].

Two instances stick in my mind, both when samples of deposits were presented to me as 'evidence' of tannin deposition. In both cases, no analysis had been made but as they were brown in colour it was tannin, had to be, could not be anything else. My answer in both cases was straightforward, get it independently analysed. I had a good idea of what both samples were, but not possessing eyes equipped to undertake chemical analysis I preferred to reserve final judgement until the conclusion of a scientific analysis.



SEM image of large particle (optical image 2).

EDX spectrum of upper circle site (slightly darker optically)



EDX spectrum of lower circle site, more oxygen, magnesium silicon and phosphorous present

**Fig. 20 – An example of the results of an analysis of deposits collected from the feedwater delivery trays of No.6024. [10]**

**Note: SEM: Scanning Electron Microscopy.  
EDX: Energy Dispersive X-Ray Spectroscopy.**

Independent professional analysis showed neither sample contained tannin let alone either being a solid tannin deposit. The samples were, in conversational terms, 'scale' [10]. In one of the samples the brown colouration was identified as, to put it crudely, 'rust' (fig. 20). No surprise considering the sample was taken from a heavily corroded steel feedwater delivery tray. The moral of these two incidents is simple, even if you think you know what a deposit is made of and it is important to be sure, have it professionally analysed. It could change your thinking - it did in at least one of these quoted instances.

## **Part 5**

# **Glossary, References and Index**

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## GLOSSARY

The definitions provided are specific to steam locomotive technology, associated boiler water treatment and other terms used in this volume. Other definitions, more relevant to other technologies, may exist.

<b>A</b>	
AAR	See Association of American Railroads.
ABMA	See American Boiler Manufacturers Association.
Absorption	A chemical or physical process in which one substance takes in another.
ACE	See American Coal Enterprises.
ACE internal water treatment	Initially INTI Water Treatment, now 'Porta Treatment'. Advanced internal boiler water treatment regime developed 1969 - 1974 in Argentina under the direction of Ing. L.D. Porta.
ACR	See Alfred County Railway.
Adherent sludge/mud	See sludge.
Adsorption	The process of one substance becoming attached to the surface of another.
After treatment	The addition of chemicals to feedwater already subjected to a form of external treatment.
AgCl	See silver chloride.
AgNO <sub>3</sub>	See silver nitrate.
Alfloc	Trade name of a British water treatment company later taken over by ICI. Well known for supplying both external and internal water treatment systems.
Alfred County Railway	A now (2024) closed 76 mile (122 km) 2 ft (610 mm) gauge railway in South Africa. It ran from Port Shepstone to Harding. Formally a South African Railways route, run by a private company from 1998 which adopted modern steam technology including 'Porta Treatment'.
Alkali	A base that dissolves in water. A solution of a soluble base has a pH greater than 7.0.
Alkaline	A solution which has a pH greater than 7.0.
Alkaline corrosion	Corrosion of a metal due to the presence of an alkaline solution, i.e.: alkaline boiler water.
Alkaline hardness	See temporary hardness.
Alkalinity	The capacity of a solution to resist changes in pH making the solution more acidic. It is not a measure of pH. Can be measured by titration of a sample with acid and an indicator solution. Three types of alkalinity exist: Bicarbonate, Carbonate, and Hydroxide.
Alloy	A metal made by combining two or more metallic elements.
Aliphatic	A form of hydrocarbon.

Priming	Working water. Water as a more or less continuous stream entering the steam circuit for reasons other than chemistry; mechanical reasons and operator error, such as running with too high a water level or poor driving techniques, being the normal reasons. Dissolved and suspended solids in the boiler water can be expected to accompany this carried over water in a quantity related to their concentration in the boiler water. Can be seen and heard "at the chimney". Not the same as water carryover or steam contamination, although priming shares and amplifies many of their qualitative characteristics.
psi	Pounds per square inch. A measure of pressure. 1 psi = 0.06804596 atm or 0.06894757 bar.
Pure steam	Technically pure steam, in Ing. L.D. Porta's context, which has a measurable contamination by solids of less than 2 ppm.
Pyrometer	A high temperature thermometer, used to measure superheated steam temperature.
<b>Q</b>	
Qualitative	The quality or qualities of something rather than its measured quantity or quantities.
Quantitative	The quantity or quantities of something rather than its quality or qualities.
Quebracho	A South American hardwood tree, the timber and bark are a rich source of tannin. Name derived from the word quiebrahacha meaning "Axe breaker". In the context of water treatment, it is one of the principal tannins used.
<b>R</b>	
Radial-stayed	The pattern of crown stays fitted to a round-top firebox. The stays are not perpendicular to the inner firebox crown, rather they are laid out in a radial pattern based on the shape of the firebox wrapper.
Ramal C14	The FCGB route from Salta to Socompa which crosses the Andes.
Ramal Ferro Industrial de Río Turbio	Also Red Ferro Industrial de Río Turbio. 75 cm/2'5½" gauge coal railway from Río Turbio to Río Gallegos (later Punta Loyola) in the Patagonian province of Santa Cruz, Argentina. Best known for Ing. L.D. Porta's work on the railway modernising its fleet of 2-10-2 locomotives. The line has also been known by other names, including being named in honour of Evita Perón for a short period.
Reactive exhaust	A steam locomotive exhaust system that responds instantaneously and in line with the demand on a boiler. It limits the delay, when starting, on the maintenance of boiler pressure and water level whilst, conversely, imparts a reduction in demand on the locomotive as a whole. A traditional exhaust may rapidly fall off in performance at high output; a reactive one does not tail off at any output.
Reagent	A mixture of chemicals which promote chemical reactions.

## REFERENCES

The references listed below constitute a complete list of all paper or electronic documents and one video that I used during my water treatment work. It is in no way meant to be a complete or definitive list of *all* water treatment reference materials. Those presented herein are intended to enable the interested reader to get a “head start” at any research he or she may choose to undertake. Porta’s reference list in ‘Steam Locomotive Boiler Water Treatment’ is, necessarily, concise, this list is not. I believe to understand water treatment as fully as possible it is necessary to read around the topic; this list is at least a start in that direction. No comment is made on the quality or usefulness of the documents listed.

A number of the references listed are unpublished but, where legally possible, can be supplied on request.

My thanks are due to the many people who helped me to amass this considerable volume of reference material.

Martyn Bane  
November 2023

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# Locomotive Boiler Water

In this fascinating volume of papers written by the late Ing. L.D. Porta solutions are offered to the perennial problems associated with water usage by steam locomotives. Underlining Porta's holistic view of steam locomotive engineering, papers are presented on feedwater treatment, advanced feedwater heating and boiler water circulation and behaviour, amongst others, which show how they are inseparable from each other.

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*Ing. Livio Dante Porta*

Livio Dante Porta (1922-2003) remains an unsung hero in the long history of steam locomotive development. Following in the footsteps of André Chapelon, he rebuilt numerous locomotives in Argentina and elsewhere, and designed several revolutionary locomotives, both large and small. Only one of his designs was built and most of his rebuilds have been lost to scrap merchants. He has however left a rich legacy in the form of several hundred technical papers covering a wide range of topics. This, the fourth in the Advanced Steam Traction Trust's volumes of Porta's writing, is published with the permission of the Porta Family Foundation.

