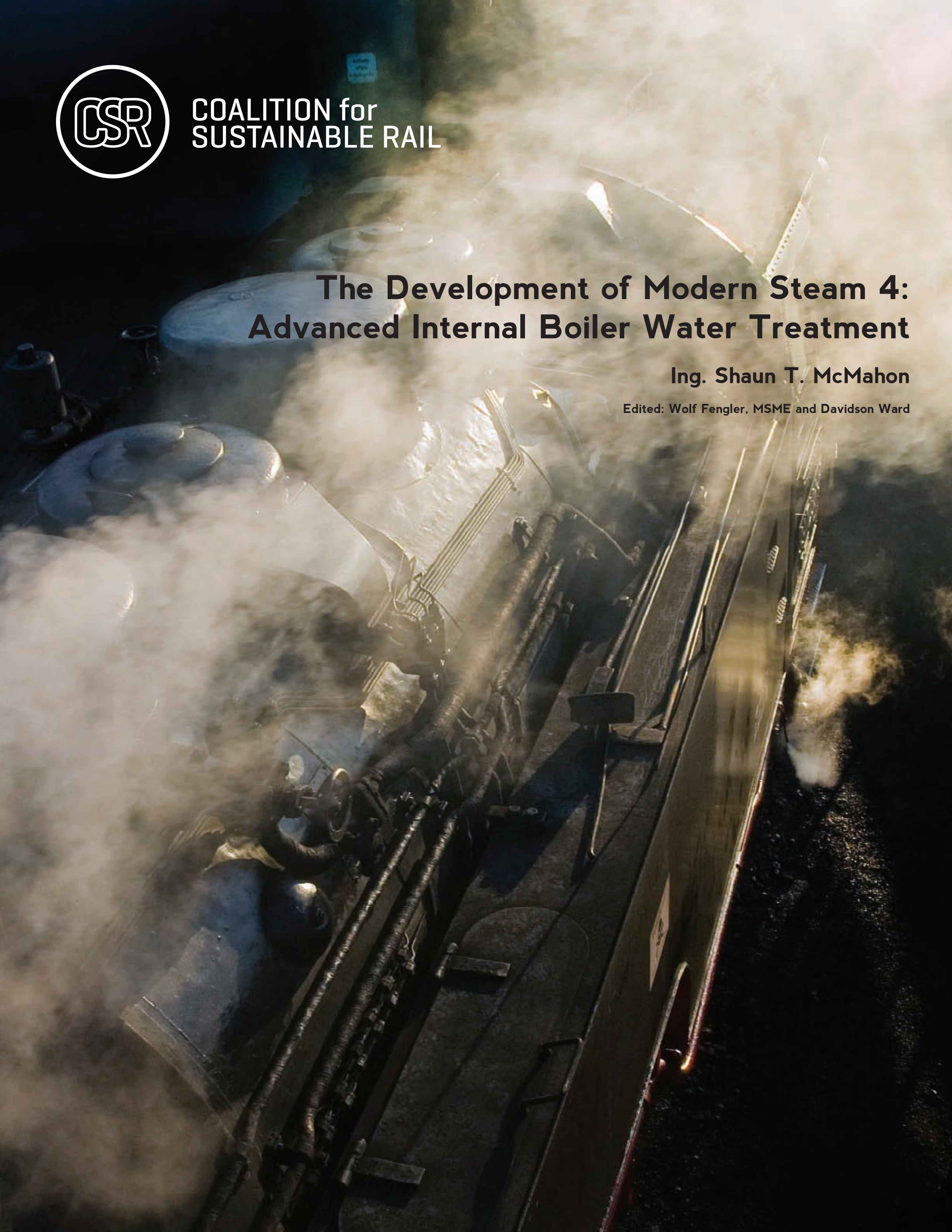
COALITION for SUSTAINABLE RAIL



# The Development of Modern Steam 4: Advanced Internal Boiler Water Treatment

Ing. Shaun T. McMahon

Edited: Wolf Fengler, MSME and Davidson Ward

## About the Coalition for Sustainable Rail

The Coalition for Sustainable Rail (CSR) is dedicated to the advancement of modern steam technologies, research and development of biofuels, and educational outreach. CSR is a 501c(3) research and development non-profit organization whose mission is to support and advance sustainable modern steam, fuel, energy, and transportation technologies; to promote the safe and efficient operation and preservation of historic rail equipment; and to conduct informational activities to increase awareness of sustainable and historical technologies. It maintains formal research relationships with multiple institutes at the University of Minnesota, including the Natural Resources Research Institute, a leader in the development of advanced, modern biofuels.

## About CSR's White Paper Program

Working in conjunction with the University of Minnesota, the Porta Family Foundation, and other not-for-profit rail and biomass research organizations, CSR's White Paper Program brings works pertinent to biofuel, steam locomotive and transportation research into the public discourse.

**Cover Image -** *Pure steam wafts past the boiler of a Harz Narrow Gauge Railways (HSB) 2-10-2T No. 99 7236 as it is steamed up in Wernigerode, Germany. The locomotive was built in 1955 by 'Lokomotivbau Karl Marx,' in East Germany. Today it and 16 other identical locomotives, known as the 'Neubau' or "New Build" locomotives, designating their design and construction post WWII, serve as the backbone of the HSB operation.*

# The Development of Modern Steam 4: Advanced Internal Boiler Water Treatment

**Ing. Shaun T. McMahon**

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## Foreword

Dear Reader:

The core of this White Paper dates back to the year 2000 when David Morgan, MBE. TD. of the U.K. made his first visit to the *Ferrocarril Austral Fueguino* (FCAF) in Ushuaia, Argentina, as part of the preparations for a planned international rail conference that had opted to dedicate part of the proceedings to modern steam development at the start of the 21st Century. Amazed by the results being achieved up to that date by my application of the INTI Internal Boiler Water Treatment (as it was known up until mid 2001), Mr. Morgan took the news back to the U.K., at the same time inviting me to present details of the application of the treatment at the conference in 2003.

In reading through the paper some 13 years later, I feel a gratifying pride which of course must be shared with those mentioned in the References and Special Thanks To: Section, not to mention my late mentor L.D. Porta, who read and approved the paper just two months prior to his death in 2003.

This paper is aimed at providing a background on the technology and an exemplary test case. The application of PT to historic and first generation steam locomotives is a crucial step in keeping historic equipment operating safely and efficiently, and it is a must for any future development of second and third generation steam. As a matter of course, attention is focused on application of the treatment in countries such as Argentina and the developing world.

Throughout the paper, the reader will discover that considerable progress in this particular field has been made by the simple application of lessons learned from practical experience as well as horse-sense engineering. The reader will see that a step by step approach to the application of the treatment is essential for its success, and accepting that early trials have to be seen as a 'step in the right direction approach' until the whole system is up and running on an internal basis.

It cannot be over emphasized that IT IS NOT WHAT IS PUT INTO THE BOILER THAT COUNTS, BUT WHAT ONE ALREADY HAS IN THE BOILER. PT is an internal treatment system and therefore relies on what is built up inside the boiler, not what is fed into such. This MUST be remembered at all times during the application of the treatment. It will be evident to the reader that the emphasis has shifted nowadays away from chemical laboratory testing to a much more focused approach at running shed levels as was the case at the Alfred Country Railway, *Ferrocarril Austral Fueguino, Ferroclub Argentino,* etc.

As one reviews this paper, it may seem that some inconclusive statements are found in the text, but it should be remembered that this is quite normal when the subject is under practical application development stages. By no means should the numerous recommendations be dismissed whose ultimate goals are to drastically reduce overall costs associated with boiler maintenance and repair.

This paper deals deliberately with a given case of the practical and successful application of 'Porta Treatment' in one of the most technically hostile and geographically isolated steam railroad operations in the modern world. This in itself is proof that, if applying the treatment can occur in the developing world, then the problem is not associated with the product but the person attempting to apply it.

Enjoy your read,

**Shaun McMahon**

*Board Officer and Director of Engineering*

## 1. Brief Description of Steam Locomotive Boiler Water Treatment

A continual problem since the development of the first steam locomotive has been treatment of the boiler water. Water contains impurities (minerals, metals, etc.) which can lead to problems in boilers. Since the vast majority of steam locomotives are non-condensing (i.e. water is used once and exhausted out of the chimney), locomotive water treatment is more difficult to control than on ships and stationary power plants whose closed systems condense steam to water for reuse.

In a steam locomotive, water is boiled and pure steam is collected for propulsion. As this pure steam is drawn off of the boiler, the impurities present in the feedwater are left in the boiler, creating ever-increasing levels of concentration. Over a period of time, these impurities precipitate out of the solution and onto the internal surfaces of the boiler. This process is called fouling. These materials can slow down the transfer of heat from the fuel to the water and decrease the locomotive's efficiency and power. Such fouling can also accelerate corrosion of the internal surfaces of the boiler, thus increasing maintenance requirements and decreasing the life of boiler components.

Steam is generated in bubbles which burst at the surface of the water, but if the level of impurities in the boiler water are too high in the boiler, the bubble action can create 'foam,' which can be sucked into the drypipe and beyond, causing damage to machinery and making normal operation of the locomotive difficult. Operators in the past attempted to minimize foaming by reducing the concentrations of impurities by 'blowing down' the boiler, or removing small amounts of water and sediment from the low points of the boiler while the locomotive was under steam. If this had to be done very often, a great deal of fuel and water was wasted. Certain geographical areas have much worse water than do others, therefore whilst this phenomena was a nuisance for all railways, it became a tremendous problem for some.

Normal practice on steam locomotives was to 'wash out' the boiler at least monthly. The locomotive is taken out of service, has its fire extinguished and the boiler is left to cool down (cooling down of the boiler was not U.S. practice, more on that later). Boiler plugs are then removed and washing out of the boiler internals begins. This consists of directing a high-pressure jet of water through the spaces provided by the absence of the boiler plugs and follows a systematic course to sweep debris down and back to the mudring. Undesirable matter is flushed out during this operation. Once flushing out is complete, the plugs are refitted. This process could take several hours, not to mention the time taken to gently re-warm the boiler from cold (again not US practice). All of this represented a significant amount of labor accompanied by lack of 'availability' of the locomotive to haul trains.

A more serious problem was that fouling materials often hardened onto boiler surfaces and could not be removed by using normal washout methods. If fouling becomes sufficiently severe, it can actually cause the temperature of parts of the boiler, such as firebox surfaces and tubes, to become so great that they could be permanently damaged.

The whole issue of boiler water condition was another


***Often quite dramatic,*** *blowing down the boiler removes sediment from the lowest reaches of the system, where it tends to settle. This image shows Iowa Interstate QJ locomotive 7081 blowing down its boiler in Rock Island, Illinois on July 29, 2011. Photograph by Scott Lothes and courtesy of the Center for Railroad Photography and Art - railphoto-art.org.*

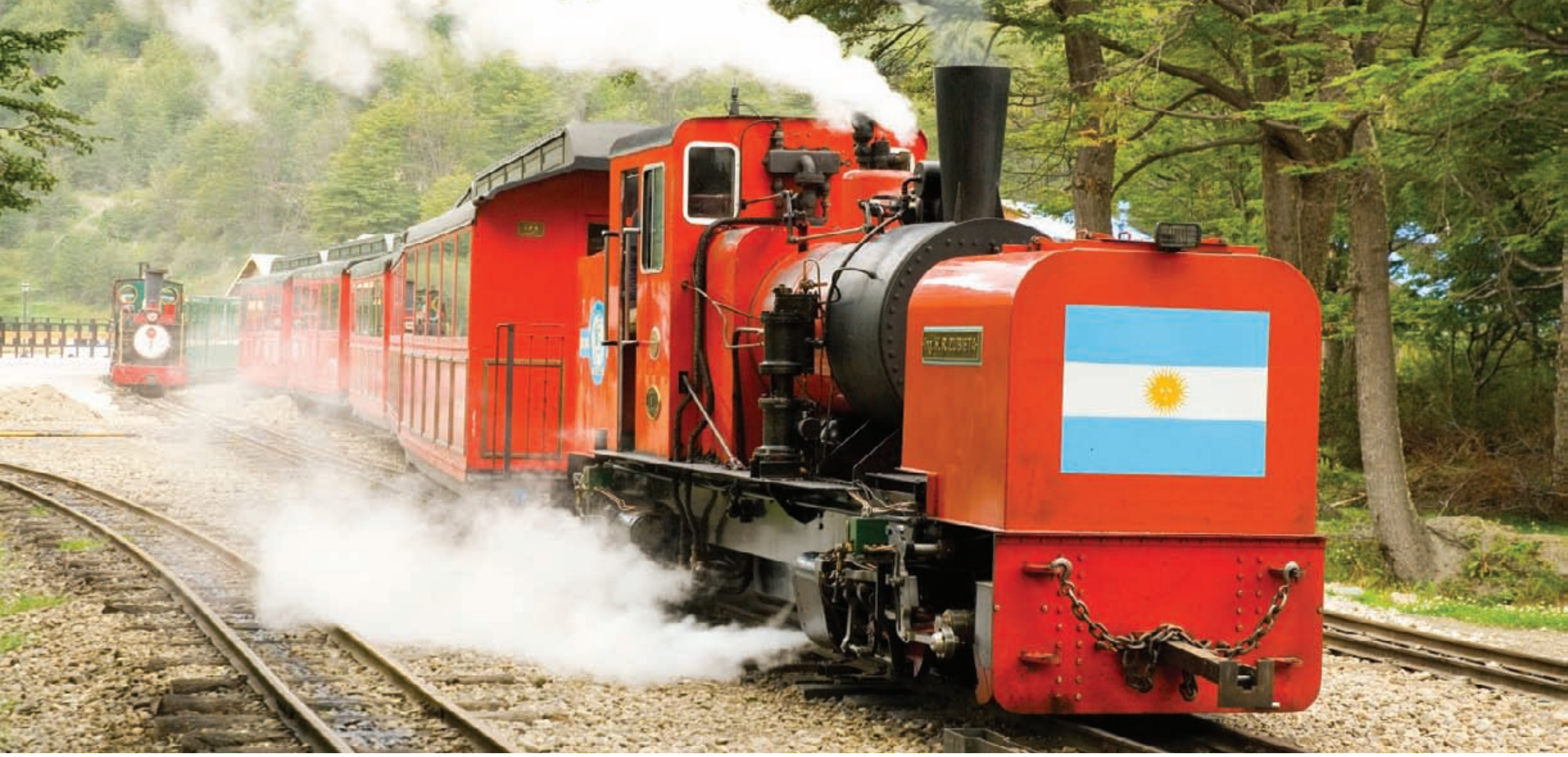
***A nearly unbelievable success,*** *the TIA water treatment was employed by the SNCF at its Nice locomotive depot in connection with a fleet of North American-built 141R locomotives, such as the one shown above. The treatment was so successful in reducing boiler maintenance costs that three locomotives, numbers 1156, 1158 and 1159, were able to operate a cumulative 5,500,000 miles with fewer than 900 man hours of maintenance attributable to the boiler, or an equivalent of approximately 0.2 man hours per 1000 miles of operation. In total, SNCF reduced boiler maintenance costs associated with the locomotives 90% while operating the locomotives with washout intervals twice that permitted in the U.S. The image above is of 141 R 568 built by the Baldwin Locomotive Works in 1946, photograph by Dider Duforest on November 11, 1981 - wikimedia commons.*

"nail in the coffin" of the steam locomotive at the time when diesel-electric locomotives were introduced. However the application of sound engineering principles has shown that problems associated with boiler water can be virtually eliminated from steam locomotive operation.

By the 1930's, railway suppliers had begun to develop chemical treatments which somewhat reduced these problems. By adding appropriate chemicals to the water prior to its introduction to the boiler, fouling could be significantly reduced. Some railways were more advanced than others in their methods of water treatment. In America, railways such as the AT&SF and N&W worked with suppliers such as Nalco to deploy water treatment and were able to reduce boiler repair costs by some 50 to 60 percent. This is significant as boiler repairs were the most expensive part of steam locomotive maintenance, often accounting for more than 90 percent of upkeep costs.

In France, an advanced treatment was developed known as *Traitement Integral Armand* (TIA), named after its developer. M. Armand had started working on this system in 1940, basing his investigations on the physio-chemical action of tannin on a soda environment and, at temperatures of locomotive boilers, on the calcium encrusting salts. This system employed a 'disencrustor,' consisting of carbonate of soda, phosphate of soda, caustic soda and tannin introduced into the feed water by a distributor. Following the Second World War, a number of older French locomotives as well as some of the newly arrived 141R class were used to prove the efficacy of the new program before fleet-wide deployment. It so significantly reduced problems relating to scale buildup in locomotive boilers, that many boiler repair shops on the SNCF system were closed.

The Argentinian engineer L.D. Porta went on to develop a simplified, heavy duty version of the TIA system and applied it to a number of locomotives in Argentina. Advances in the system allowed locomotives to operate without boiler washouts for six months or more, even in what were known as 'bad water' districts. In addition, hard fouling of internal boiler surfaces was completely eliminated. This state of affairs significantly extended boiler life. Some locomotives using Porta's treatment system operated for some 30 years without replacement of any tubes or firebox plates.



*FCAF PROMOTIONAL PHOTO*

## 2. PRECEDENT STUDY: APPLICATION OF A MODERN BOILER WATER TREATMENT AT *FERROCARRIL AUSTRAL FUEGUINO*

The concept of internal boiler water treatment has for a long time been as misunderstood a subject as locomotive exhaust systems, with many myths and old tales being allowed to take over from proper investigation and rigid implementation of corrective systems. Such systems are derived from proper scientific testing with railway engineers working in conjunction with high academics, running shed staff, and locomotive crews. It may be said that over the years, too few locomotive mechanical engineers placed their faith in the high academics and, by the same token, neither did they go out on the engines often enough to gain practical experience as firemen and engineers (the exception to this being Chapelon in France – see CSR White Paper on Chapelon). As a result, too much 'progress' was achieved in trial and error fashion, stabbing punches in the dark and without being aware of the practical implementations of instructions.

The *Ferrocarril Austral Fueguino* (FCAF), or the "Southern Fuegian Railway," was a classic case of a former working railway being re-opened as a commercial tourist line. FCAF was essentially rebuilt from scratch between 1993 and 1994 on part of the old state prison railway. It was re-opened as a commercial tourist passenger line on October 11, 1994.

The present length of FCAF is 5.25 km (3.2 miles) with extreme adverse gradients, the most severe of these being 4.5% (1 in 22) on the outward journey at the approach to the intermediate station of 'La Macarena'. The mainline passenger service is operated by three steam locomotives:

No.2 'Ing. L.D. Porta' (formerly named 'Nora'), 0-4-0 + 0-4-0 KM Garratt, built at Carupa workshops, Buenos Aires, Argentina in 1994 ;
No.3 'Camila', 2-6-2T, built by Winson Engineering of the UK in 1995; and
No. 5 'Ing. H.R. Zubieta', 0-4-0 + 0-4-0 KM Garratt, built by Girdlestone Rail Workshops in 2006.

Locomotives 2 and 3 have undergone Stage 1 modification and rebuild as part of the FCAF locomotive modernization program, the work for which was undertaken at FCAF's 'End of the World Workshops' at Estacion fin del Mundo, Ushuaia, while locomotive 5 was built new by Girdlestone as an advanced steam locomotive.

Following a traffic boom that took place during 1996 and 1997, the Author led a technical review of FCAF during 1998. As a result of this review, it was decided by senior management to go ahead with a locomotive modernization program. One very important aspect of any such program is that of corrective INTERNAL boiler water treatment. Indeed, it is unimaginable to visualize advancing steam without the correct internal boiler water conditions.

One could say that FCAF provides one of the hardest testing grounds for railway engineering systems - a line that operates all the year round with: an intensive high season service; minimal resources; a small shop staff with a low level of technical training; a geographically unfriendly location; winter service in temperatures as low as negative 25 degrees Celsius (negative 13 degrees Fahrenheit) in severe snow drift conditions; and within a country that saw the breakdown of most national systems during the financial crash of 2001. FCAF is the most southerly railway in the World, being some 360 km (601 km by road) nearer to the South Pole than the neighboring RFIRT (see CSR White Paper on the Rio Turbio Railway). Ushuaia is just over 2,300 km south of the capital Buenos Aires (very little in terms of populated areas separate the two locations). As a result of the geographical location of FCAF, the reader can imagine the difficulties experienced in conjunction with maintaining the infrastructure of such a line. However that is the reality of this narrow gauge railway, it is a 'no frills' operation allowing a minimal margin for error.

A corrective boiler water treatment regime was implemented on the railway during 1998 as a result of L.D. Porta's first critical review of the locomotive situation at the time. Unfortunately, the application of the system failed completely since supervision of such did not exist, thus each driver was allowed to opine over whether the treatment was a good thing or a bad thing or indeed whether it was too much effort to remember to dose the locomotives water tanks on a daily basis!

***Winter weather abounds*** *at the Southern-most railway in the world. This FCAF promotional photograph shows locomotive 5, "H.R. Zubita" and a short train beside the Pipo River. Locomotive 5 was built new in South Africa under the guidance of locomotive mechanical engineer Phil Girdlestone.*

**OF NOTE:**

*Some years prior to being employed by TRANEX, the Author had begun research into internal boiler water treatment systems in the UK. The British private chemical treatment company, M & S WATER SERVICES LTD. had looked closely at the work of Porta in this field and essentially followed the same train of thought as far as this was concerned. This state of affairs eventually led to the writer being offered a permanent position within that particular company in order to set up a section devoted to steam locomotive internal boiler water treatment in the UK and possibly further afield. This fairly lucrative offer was humbly declined as the Author's plans to move to the ALFRED COUNTY RAILWAY in South Africa were well advanced by the end of 1993. However relatively successful internal water treatment systems based on the adoption of Porta's thinking and practices by M & S (and others) were implemented at the FFESTINIOG, WELSHPOOL & LLANFAIR, SNOWDON and ISLE OF MAN RAILWAYS, and some years later the VALE OF RHEIDOL RAILWAY decided to adopt an internal treatment system.*

*Upon applying an internal chemical treatment system at the ALFRED COUNTY RAILWAY ("ACR"), the Author was soon accused of applying 'witchcraft' to the steam locomotive fleet when he was to be seen directly dosing the boiler barrel of NGG 16 Class Garratts on shed at Port Shepstone depot following boiler washouts. It was thereafter explained to Mandla Cele (the boilermakers assistant) that what he was putting into the locomotives water tanks and boilers was actually for the benefit of the engine and not to harm it -some time had to pass before Mandla was fully convinced of this fact. Though the operating department of ACR was issued with a strict instruction to the effect of not blowing down the locomotive boilers, this long established South African Railways practice (it could probably be more accurately described as a ritual on the SAR!) was very difficult to control. As a result of this (minor, continuous boiler leakage was also a contributory factor due to the, by then, slack boilermakers' attitudes), the high level of totally dissolved solids required to achieve the predicted results was never attained. Nevertheless clean boilers on this section of the SAR system were achieved.*

***This image**, taken by and courtesy of William E. Botkin, shows one of the modernized ACR Garratts in operation on a revenue freight train in 1990.*

The Author arrived at FCAF in the capacity of full time Technical Manager in March 1999, and the water treatment regime was re-introduced, though this time under rigid supervision. Whilst the Author is an advocate of 'free creative thinking,' the application of quantified improvements in the field of steam locomotive engineering must be carried out under controlled conditions. A common vice within railway administrations worldwide is to wrongly blame any failure on the 'idea' and not the 'application of the idea.'

The short and long term benefits of such a system were explained in detail to FCAF maintenance and operating staff along with senior management and, by the end of the year, all were beginning to see the benefits of the work. The treatment that was in stock at the time, 'Stoker 130,' dated back to 1998 and it was decided to continue using the same product rather than change over to a different chemical. The composition of the treatment in powder form had been specified to the supplier by Porta some years earlier.

The TIA system was simplified into a "heavy duty" treatment for countries such as Argentina where locomotive engineers rose from the ranks of cleaners and firemen. FCAF engineers (locomotives are single manned on this line) are, with the odd exception, 'men off the street' or recruited from other branches of industry, therefore the application of any new system must be as simple and straightforward as possible.

Water tank and tender dispensers are normally used to distribute chemical water treatment into the feedwater. In the case of the FCAF locomotive fleet, it proved practical to dose each locomotive by hand on a per trip basis. As well as being easy to dose the feedwater to accurately weigh out measurements, this system gave the operating staff (in this case the engineers) a good "hands on" feel to what was being done. FCAF managed to eliminate any imagined 'magic' that may have influenced a premature failure of the system.

The initial dosages were calculated as best as could be done in proportion to the amount of feedwater consumed per round trip. It should be remembered that prior to 1999, no record keeping as far as the engineering department was concerned had taken place and, therefore, the Author was beginning afresh with daily consumptions of any kind.

Initially a good estimate was taken as to how much water both 'Nora' and 'Camila' were using on a round trip and treatment dosages were applied on that basis. Looking back through the records relating to that period of time, the instruction issued to engine crews states a figure of "50 g Stoker 130 per water tank filling." During the winter of 1999, the Author oversaw the heavy overhaul and first stage modification of 'Camila' at the 'End of the World Workshops' and, at the same time, water and fuel tank gauges were fitted to the locomotive which made life a lot easier as far as accurate record keeping was concerned when this locomotive reentered service later that year.

By early 2000, the corrective water treatment system was well underway at the railway, with the Author generally supervising dosages and analyzing what was present in the boilers as best he could at that point in time. However, the results of not using any boiler water treatment for the previous four years came to light when the increased steaming rate of modified locomotive No.3 'Camila' revealed that the foundation ring and parts of the water space between the firebox inner and outer sheets were packed solid with hard scale. This state of affairs led to severe deformation (evident in the form of a white bulge) of the right hand side inner firebox sidesheet which resulted in the locomotive being withdrawn from service on February 12, 2000, certainly not a good state of affairs as FCAF was still in high Summer season and, therefore, left with 'Nora' and a diesel to deal with the rest of the season's traffic.

The original boiler designs did not lend themselves to easy inspection, maintenance, or cleaning, therefore apart from the lack of a corrective water treatment system, this factor had to be taken into account when

***A bulging side sheet** is an indication of overheating resulting from excessive scale buildup, as shown in this image of the inside firebox side sheet of 'Camila.'*

assessing the particular failure that we were faced with. They were also found to be lacking in certain safety features such as fusible plugs [SEE CAPTION ON PAGE 14] and a second water glass; all defects that were corrected during subsequent shoppings.

These shoppings also provided an opportunity to install fittings for foam height indicators. The foundation rings had also only been provided with 'diagonally' fitted washout plugs instead of plugs at all four corners. Whilst this allowed access to wash out nearly all of the foundation ring as long as one used a specially adapted head for the pressure washer along with flexible steel rodding, it made visual inspection of the water space in this crucial area very difficult. The washout plug accommodation bosses, as fitted to the foundation ring, were very long and therefore made life extremely difficult when it came to washouts. Neither of the boilers had been fitted with gauge glass frame extension tubes so as to give 'true' readings of boiler water levels rather than the optical illusion created by the circulation hump that appears at the backhead [SEE PAGE 12].

As 'Nora' continued in service, a thick brown "soup" was beginning to form inside the boiler and, as the treatment continued to do its work, the Author noticed that this was becoming increasingly mobile as the steaming cycle proceeded. Boiler washouts were initially set at 30 days in steam. As these were carried out, FCAF crews saw with their own eyes what had once been hardened scale beginning to break up into soft flakes some 50 mm by 20 mm [SEE PAGE 14]. A muddy deposit was also noticeable as FCAF crews drained the boiler water, flushed out the barrel followed by the foundation ring.

'Camila' was back in daily service by early October 2000 with the boiler as internally clean as possible following repair and hydraulic testing. Dosing with the requisite amount of "Stoker 130" continued. By now, the addition of the water tank gauge was showing its benefit and FCAF crews were at last able to calculate the amount of treatment required per trip, a good practical indicator being that the feedwater overflow from the injector should run with a tinge of red to it, something similar to a watered down red wine.

One may think at this point in time "this is all well and good, but what about carryover of the boiler water due to a high level of suspended and totally dissolved solids being in violent circulation?" The Author had

***Rain, sleet, or snow,*** *the trains must run. This image shows locomotive 3, 'Camila,' when in service on the railway post-rebuild and Stage 1 modification. Note the stack profile indicative of an advanced exhaust.*

***Holes drilled in the outer firebox*** *reveal a water space nearly completely encrusted with scale and mud. This is the inverse side to the photograph of the bulge shown on PAGE 9.*

***With a chunk of steel removed for making a patch,*** *this image shows the corrosion on the sheets resultant from poor water treatment.*

a fairly harsh experience of this phenomena whilst driving 'Camila' on a busy day not long after the engine had returned to traffic. The water treatment system is designed to work by maintaining a high level of alkalinity within the boiler. The mobile sludge had accumulated very quickly at this stage of development and the program was more advanced than the Author had thought it to be. The Author had been caught off guard because the level of alkalinity as a proportion of totally dissolved solids was too low -far too low in fact!

At that time, FCAF crews had recorded a pH number of 9.5, this was raised relatively quickly by adding caustic soda to the normal treatment dosages in order to give a pH number of 11, and the problem ceased. On the day in question, much blowing down of the boiler had to be carried out in order for 'Camila' to continue working its trains, and application was suspended for a couple of days whilst the problem was thoroughly investigated. In this particular case (which was relatively early on in the timescale of the project) blowing down was carried out in order to apply a temporary re-balance to the internal boiler water conditions. If re-application of the treatment causes a further imbalance of these conditions, then a full washout must be carried out before a new steaming cycle is started. This problem only reappeared twice in the future when FCAF was supplied with a poorly made batch of the treatment; in these isolated cases foaming occurred after only 14 days into the steaming cycle.

As concentration levels in the boiler rose, additional (and very powerful) polyamide antifoam was added to the treatment applications. Though this powdered antifoam is supplied with the Stoker 130 'as mixed', high concentrations of TDS require an extra amount to be added depending on the internal conditions of the boiler during the steaming cycle. These extra amounts are made as an addition to the normal dosages with the 'treatment dosing instructions' altered accordingly during the early stages of the program. If for any reason antifoam is unavailable for a certain period of time, cylinder oil can be added to the boiler water make up which acts as an antifoam. This application has the beneficial effect of 'lubricating' the steam which, in turn, extends the maintenance period of live steam control valves (especially if superheated auxiliary steam is used) and, allied with the use of stainless steel seated valves, represents a considerable saving in this area.

By the end of the 2000/2001 high Summer Season, the Author and the FCAF crews had achieved what


***This image** shows the angled washout plug mentioned in the text as well as the extent of the scale buildup on 'Camila,' so-indicated by the chalk arch along the outer side sheet of the firebox.*

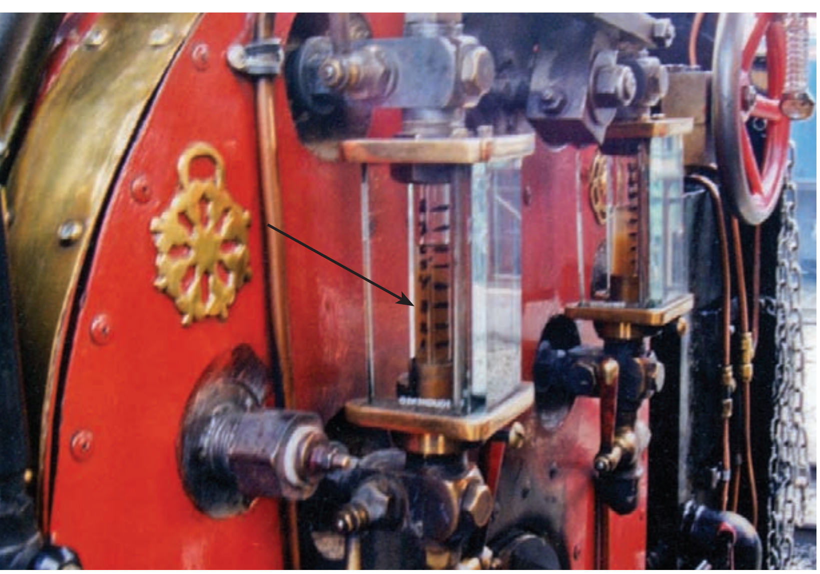
can only be described as a concentrated, fully mobile, brown sludge in the boiler of locomotive No.3 [SEE PAGE 12]. During that time, locomotive No.2 had seen limited service following No.3's return to traffic (even though this was the case it had worked as 'second engine' up until it suffered severe mechanical failure in late February 2001 which meant its withdrawal from service and commencement of rebuild and Stage 1 modification). Despite its limited use, it was possible to gather in-service data on locomotive No. 2 during this period of time, including detailed statistics relating to fuel and water consumption and internal boiler water conditions. Up until then, FCAF had used 'conventional' (for want of a better description) style washouts. It was decided to convert to the U.S. method of washing out boilers "hot." No other method of washing out is suitable to deal with such a sludge in mobile form. Prior to its winter maintenance period that year, the first of such involving this technique was very successfully carried out at Ushuaia.

Why is the U.S. method of washing out so essential to the success of such a treatment regime? If one is dealing with the removal of sludge that is mobile (and this is real sludge, imagine a very wet clay or even mud on a football pitch - not broken up pieces of scale), then the correct conditions must be created that will allow such to be cleared quickly and in its entirety. If the boiler was sufficiently cooled and drained, there would be a high risk of the sludge 'baking' itself to the internal water surfaces and, in its cold state, such would be very difficult, if not impossible, to remove using a cold washing method (even at reasonable washing pressures). The result would be that the internal water surfaces would be left coated with a layer of insulating material, thus heat transfer is theoretically reduced resulting in higher operating costs as is suffered with scale build up on these surfaces. Bear in mind that a scale buildup of only 1/16'' forms a SIGNIFICANT heat insulator.

Practically speaking, the residual sludge would very quickly go back into solution upon the startup of the new steaming cycle, but on the other hand if that were the case then why wash out at pre-determined interval in any case? In brief, the U.S. boiler washout method relies on such being carried out in a hot state rather than cold state. At the start of the washout, the boiler should be in 'just off the boil' condition (obviously NOT in steam!). If there is any risk of the internal surfaces temperatures being lower than optimum, then the light-oil-burning locomotive is lit up for a brief period of time immediately prior to the commencement of washout plug removal. Hot, pressurized water is used in order to remove sludge and any cases of broken down (softened) scale.

During these initial days of the U.S. hot washout method at FCAF, heavy duty braided wire (such as is used for stabilizing telephone poles) was used to scrape the fouled water space between the tubes. Water for washing out was provided by FCAF's mobile pressure washer, however this is not an ideal technique as such washers are designed to operate for relatively short periods of time, hence a purpose built steam washing plant is the correct installation so as to ensure continuous success (and not causing frequent failure of the workshop pressure washer).

Washing out is performed in the normal manner, positioning of the lance so as to end up with an accumulation of sludge that can be flushed out of the foundation ring. The internal water surface is left in a 'no scale' and 'no sludge' state. The boiler is refilled with hot water and immediately steamed as the boiler has altered its temperature dramatically with respect to the fireside and waterside. Other benefits of washing out hot are that the locomotive is out of service for a matter of a few hours rather than days and return to 'in steam' condition is very short. Availability of the steam locomotive fleet is thus higher. Nowadays at FCAF, crews tend to do wash outs in the evening after the engine has worked its final turn of the day, steam being dropped upon return to the works allowing washout to commence not long afterwards. The subject locomotive is normally back in full steam before midnight, ready and checked over for the next day's service. If one considers that the operation at FCAF requires maximum steam locomotive availability allied



***Brown water is the norm with PT,*** *indicating that there is a high level of total dissolved solids in the boiler water. This image of the backhead of 'Camila' makes apparent the coloration of the water in the sight glasses.*

***Even darker brown is acceptable,*** *as is evident with this image of just-off-of-steam hot boiler water draining from the boiler of 'Camila.' With PT, the levels of TDS required are not harmful to the boiler.*

with a small number of maintenance staff, then the importance of such modern practices become apparent.

By July 2001, the Author and the FCAF crews had adopted the term 'PT' (Porta Treatment) for the water treatment they were using, in recognition of the fact that this was an advancement on the TIA (the latter mentioned previously). 'Camila's' foam height indicator (the term monitor or meter is also used to describe this apparatus), accommodation bosses, and electrodes (common automotive spark plugs) were in place and it had been the intention to fit this system in its entirety during this six week shopping period.

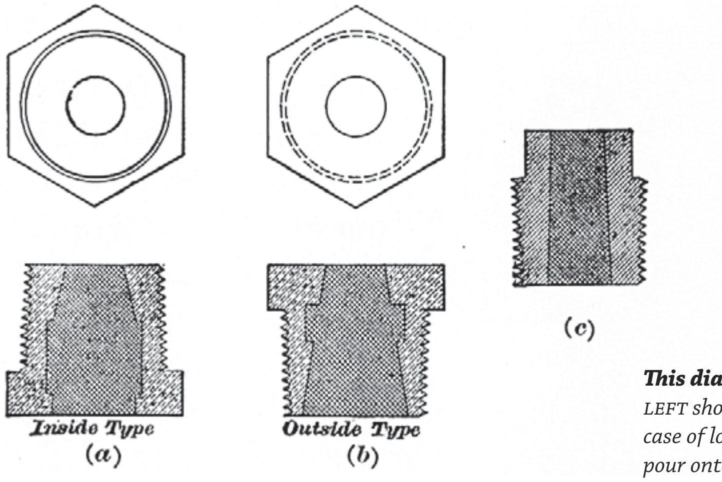
The boiler foam height monitor installed by the Author at FCAF is based on the Signal Foam Meter developed in the late 1930's by the Dearborn Chemical Company of the U.S. The design was modified slightly by Porta for application during water treatment trials in Argentina. In essence it allows the engineer to 'see' inside the boiler and is a great practical aid for monitoring internal conditions of the boiler water. It is an essential tool when working with antifoams and has been known to allow superheater elements last up to 30 years without repair or replacement.

The system consists of an open electrical circuit which is closed when the top of the foam layer touches the tip of the electrode sensor extensions mounted in the steam space. As this is the case, a series of indicating lamps are lit, such forming part of the locomotive's 'flight deck'. The electrode extensions are positioned at varying heights over the minimum water level, the longest one corresponding to 'half a glass' indication, the intermediate one to 'full glass' indication and the shortest one to 'over the top nut' indication. The circuit is fitted with test switches corresponding to the respective indicating lamps, thus the engineer is able to check functionality prior to departure. The system is permanently connected though an 'on/off' control switch is provided on the locomotives electrical control panel. In NO CASE is the system to be connected to other apparatus or its indications to be related to safety.

Regarding its first installation at FCAF, the Author had made a miscalculation as to the positioning of the electrodes! Theoretically, the foam height indicator should be positioned between the firebox outer wrapper and the steam collecting dome in order to take readings of foam height in an area where the water circulation is more violent. However, the throttle operating linkage for this particular locomotive passes through the water space to mate the throttle handle with the valve inside the dome itself. Therefore, whilst theoretically correct, it was not practical to fit the requisite sensors to the electrodes along the top center line of the boiler as the throttle linkage would foul them! The foam height indicator was not connected and trials continued without such. Meanwhile No.2's replacement boiler was being modified to fit to this locomotive during its rebuild (which was taking place at this point in time) and part of the modifications included the fitting of a foam height indicator, though this time positioned between the dome and the smokebox. The Author


***Step 1: Drain the Boiler*** *Washout plugs are opened on the top of the boiler to vent and on the bottom of the boiler to drain out the initial boiler water in the system.*


***Step 2: Hot Power Wash the Boiler*** *after the boiler water has been drained, a high-output steam cleaner is used to wash all interior surfaces of the boiler reachable from strategically-placed wash out plugs.*





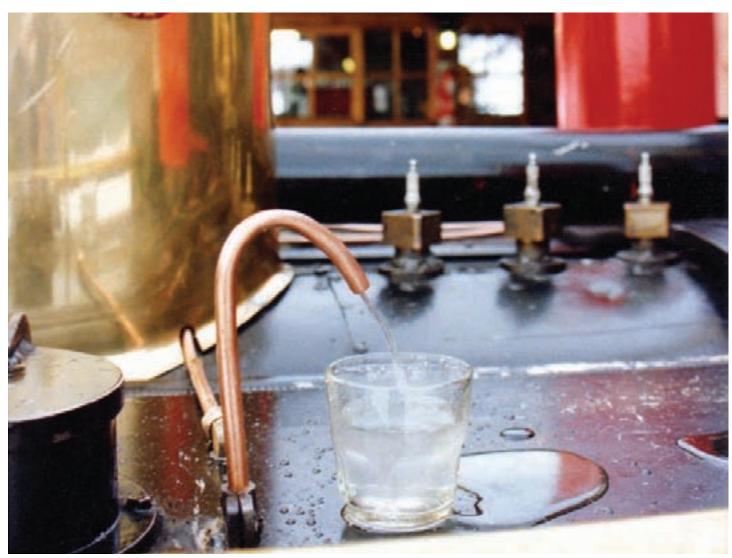
***This diagram and photo*** *show the fundamentals of the fusible plugs. The diagram at* LEFT *shows three types of plugs. In each case, a core of lead alloy is cast such that, in the case of low water, that core melts prior to the softening of the sheets, causing water to pour onto the fire and put it out. The image at right shows the plug from FCAF No. 3. Note the different metal in the core of the plug*

determined at a much later date the importance of being able to fit such an indicator on the firebox side of the dome.

High levels of alkalinity keep silica in solution. If this were not the case, such would lead to a hard egg shape type of scale. Scale in this form is a silicate (such as glass); therefore sight glasses can be dissolved. Such is not 'erosion' of the glasses as many have believed it to be in the past as such an action is mechanical; in this particular case it is chemical. Alkali-resistant glass should be used for sight glasses in conjunction with PT, otherwise the ends of the tubes become dangerously thin and cause a safety hazard for engine crews. It is interesting to note that fusible plugs have been developed which avoid alkalinity attack and therefore frequent changing. The fusible element composition in these plugs is: Pb 88%, Sn 12% allowing a melting point 258°C (496°F). Thin copper plating has also been developed as a means to countering this effect.

Antifoams were mentioned earlier in this text. It should be remembered that antifoams are substances that have a limited life in the boiler, exponentially diminishing with temperature. As this is the case, a long station stop or layover could result in depriving the boiler water of their presence. As a result of experiencing this first hand with the 15:00 departure from *Estacion fin del Mundo* while in the cab of 'Camila', a means of rapid injection of antifoam into the feed line was investigated and means of fitting such to this locomotive and No.2 are now complete. Whilst on the subject of rapid injection and mixing of feed elements, it is worth drawing attention to the fact that locomotive No.2

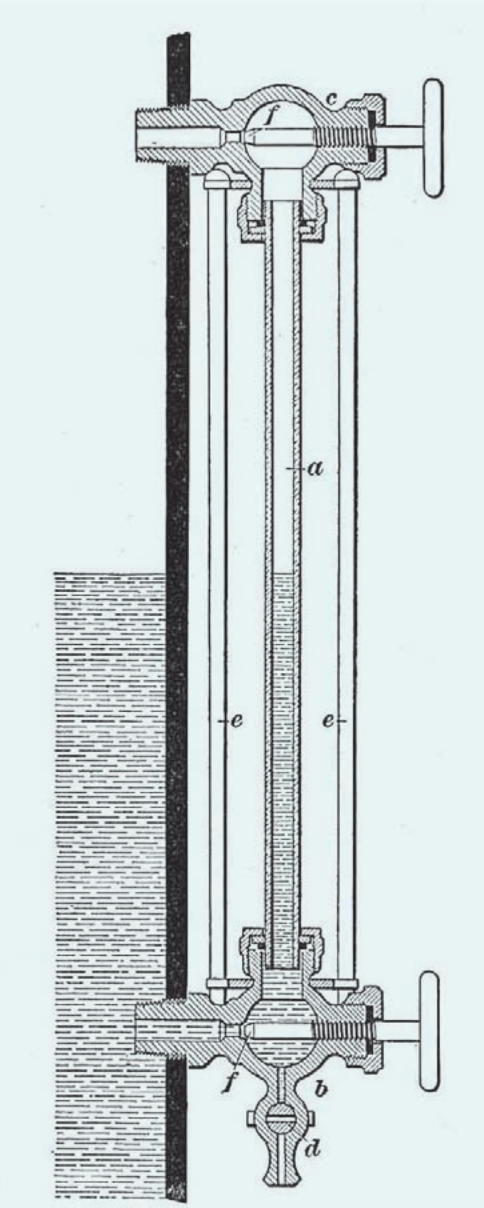
***Following the initial application of PT,*** *these large chunks of scale began to wash out of 'Camila's' boiler. The high pH level of the boiler water, combined with other chemicals, stripped this scale from the boiler.*

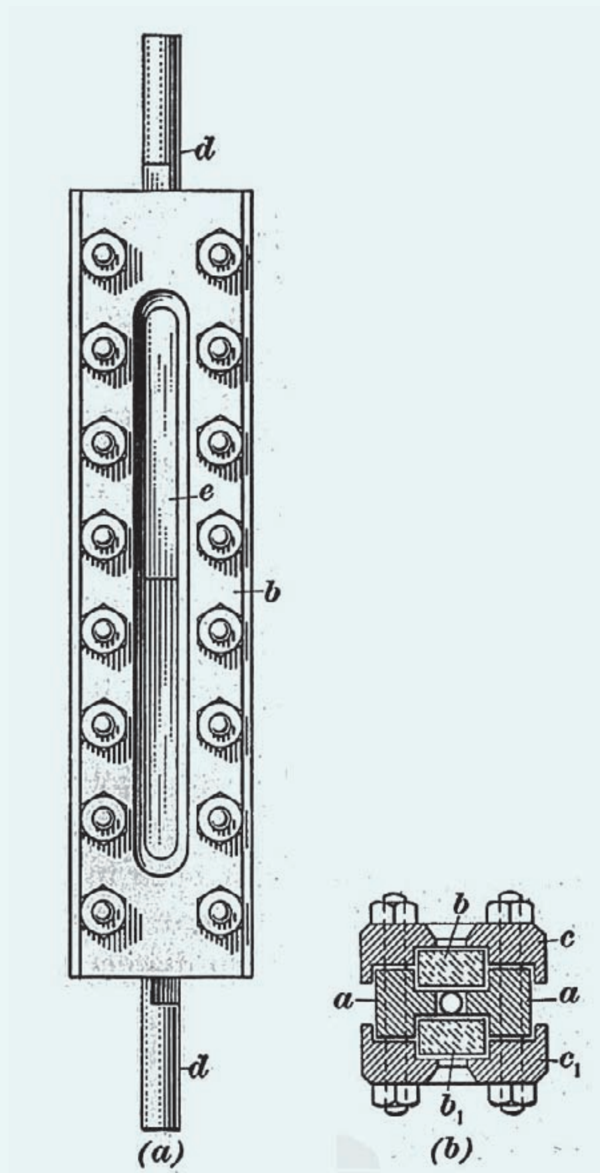


***Despite the brown water,*** *pure steam is generated in the boiler for propulsion. This take-off spout pulls steam from the dome and is used for purity trials. Compare the color of this water to that on* PAGES *12 and 13.*

**OF NOTE:**

*The following is a brief explanation of the two most commonly used types of water glasses found on steam locomotives around the world.*




***The Traditional Sight Glass** is shown above is a glass tube mounted to the boiler with two valves. Valves 'b' and 'c' are tapped into the boiler, and a glass tube 'a' extends between them. The water level in the glass reflects that in the boiler. The high alkalinity levels in the advanced water treatment are known to attack certain types of traditional sight glasses, so it is important to ensure that the glass used is Alkali-resistant.*

***The Transparent Gage Glass** is the alternative to the traditional sight glass tube. Tube 'd' connects to the boiler, and water fills the void between two pieces of flat, polished glass 'b' and '$b_1$.' In some cases, glass 'b' would be made with a ground prism on the water side in a derivation of the Transparent Gage Glass is known as a Reflex Glass. If fluid is present, the light continues through the glass and reflects off the back of the level gage, providing a black color for fluid level regardless of the actual color properties of the process fluid. If fluid is not present, the light is reflected off the glass back towards the user, providing a shiny silver or mirror-like appearance to indicate vapor space.*

is fitted with side boiler feeds whilst 'Camila' is fitted with a top feed arrangement. Tannin is incorporated as part of the treatment for various purposes one of these being to serve as an oxygen scavenger together with sodium sulphite. The physiochemistry of the process of precipitation dictates that feedwater be introduced below the boiler water level, therefore no opportunity exists to use the steam space in order to de-gasify the incoming water as is the case with a top feed system.

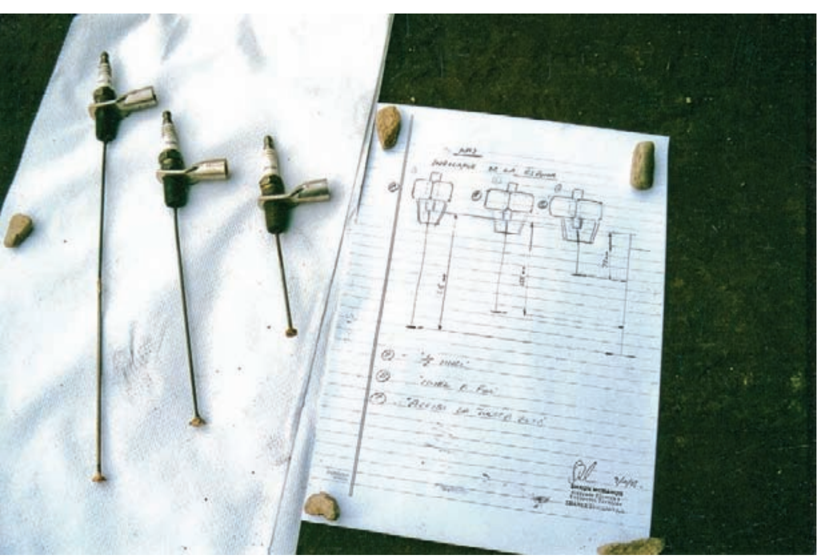
With all going according to plan as far as the application of PT to 'Camila,' it was decided to go for a longer steaming cycle and this was achieved during Spring 2001 when the locomotive achieved over 90 days in steam on normal passenger train duties, the locomotive only being 'shopped' for a couple of hours during evenings in order to replace its fusible plug at 25 day intervals along with a sight glass inspection. The best that FCAF had achieved before this cycle was 45 days in steam earlier on during the same year, severe attacks of foaming during the 43rd, 44th and 45th day signifying that a full washout was required.

Working on the principle that boilers should have water treated both when in and out of service, dosing of No.2's replacement boiler had begun once fitted to the main cradle frame of the engine in September 2001. A heavy quantity of Stoker 130 was applied along with caustic soda. This was subsequently mixed inside the boiler using a compressed air hose attachment. Once in traffic, the Author monitored the effect of treatment application to a new corrosion free boiler.

The modified Garratt locomotive No.2 'Ing. L.D. Porta' suffered a premature mechanical failure in traffic in April 2002 and PT trials recommenced during November of the same year upon completion of a second phase of component repair and renewal. The completion of the foam height indicator as fitted to 'Ing. L.D. Porta' has proved to be popular amongst drivers as their 'third eye' so as to keep a close check on internal boiler water events.

Long steaming cycles of locomotives are now normal practice at the railway, if at least 90 days in steam are not achieved, then something is suspected to be out of place. The aim is to double this time period so as to wash out locomotive boilers on a semi-annual basis.

Repair and maintenance work in this area has been significantly reduced, locomotive drivers are fully partaking in this interesting project, and they are now able to 'control' the behavior of the boiler water by the use of simple instrumentation and chemicals that are applied by hand to the feedwater in the locomotive tanks. More importantly, operating and maintenance staff, having witnessed the effectiveness of the treatment, understand its importance and trust in it - unfortunately in many cases (especially steam locomotive engineering) what is not understood is all too often thought of as 'wrong'!



***Implementation and planning,*** *this photograph shows the three foam height meter electrodes and the general schematic the Author worked up for their design, fabrication and installation.*


***Once installed in the boiler,*** *the electrodes feed a central processing unit that indicates whether water (or foam) is in contact with the end of the device. This informs crews as to whether the antifoam is adequate.*

## OF NOTE:

*There are many reasons for locomotive boiler water to be carried over into the steam circuit. The terms 'priming' and 'foaming' are commonly used to describe this action, though the reasons for both cases are different. A good summary of boiler carry over/steam contamination is given in Porta's introduction to the boiler foam height monitor and reads as follows (the Editor has made a few minor alterations to the wording in this text, though on the whole it is as Porta wrote it in 1984):*

*Technically, pure steam is a must in locomotive technology. Impurities result from boiler water solids being entrained by four mechanisms:*

> *1. Aquaglobejection, in which tiny water drops resulting from the bursting of bubbles in the water/steam interface are projected into the steam space, as in the case of a soda glass;*
> *2. Light foaming, in which the whole of the steam space is partially or completely filled up with large foam bubbles;*
> *3. Heavy foaming in which the liquid concentration of the foam filling the steam space greater up to the point of showing as wet steam on the exhaust; and*
> *4. Heavy contamination consisting of slugs of water entrained as a result of a violent increase in the steam demand leading to a rapid pressure drop, the latter causing a steam flash over the whole mass of boiler water. The resulting swelling is the cause of the slugs.*

*Provided that there is a foam layer on the water surface, mechanism 1 does not occur. This condition is met when the level of Total Dissolved Solids (TDS) is greater than 6000 ppm and a powerful antifoam is used (not all antifoams are powerful!). Reaching this concentration of TDS in the boiler as quickly as possible after washing out was found to be convenient in research work carried out in Germany. Mechanism 2 was the most frequent condition found when no antifoams were used, this leading to some 2% moisture in the steam. Mechanism 3 occurs as a result of an increased tendency of the water to foam, whilst Mechanism 4 occurs when said sudden steam demands are not instantaneously counteracted by the production of steam by an instantaneous increase of heat liberation in the furnace. This can occur, in coal burning locomotives, if the fire is too thin and in oil burning locomotives if the fireman does not react almost instantaneously with the oil valve.*

*ALL DESCRIBED PHENOMENA HAPPEN WITH GREATER INTENSITY WHEN THE STEAM SPACE IS SMALL, hence the sensitivity of the old men to work with "no more than three fingers in the glass!" When a powerful antifoam is added and boiler water conditions are appropriate for its action, (the presence of tannin and high alkalinity when diestearilethytendiamide is used), bubble bursting over a 2 to 3 inch foam layer occurs in such a way that Mechanism 1 does not happen, no foam fills the steam space (which then shows transparent) and technically pure steam results even if the volume of the steam chamber is perhaps as small as one third of the normal. This occurs no matter what the TDS (tests having been made up to a level of 50,000 ppm) or the suspended matter concentrations are. Thus it is possible to work with the boiler at maximum load even with the water "on the top of the glass." A powerful antifoam can only palliate the effects of Mechanism 4, the only cure to this being careful driving. Residual contamination (about 1 to 2 ppm) occurs mainly because the flow of steam in the steam chamber entrains liquid much like the wind entrains liquid droplets over the surface of the sea.*


***A Victim of Catastrophic Priming,*** *the locomotive in this image is British Railways A2 Peppercorn Class 4-6-2 number 60532, named "Blue Peter." While starting a train on the mainline in 1994, the locomotive began to slip. The engineer controlled the initial slip by closing the throttle, but by opening it quickly to regain acceleration, the engineer inadvertently sucked additional water into the dry pipe and superheaters. This caused the throttle valve to jam open and, when the engineer went to center the reverser, the non-powered screw wound device broke free from his hand (causing significant harm to the engineer) and put the locomotive into full forward gear. The engine spun its wheels uncontrollably, destroying the cylinder heads and the motion. The locomotive underwent an 18 month rebuild and returned to service in 1996. Photograph by Hugh Llewlyn, wikimedia commons.*

***Locomotive number 2 'L.D. Porta'** hauls a typical Autumn train in the national park portion of FCAF's right-of-way. This FCAF promotional image shows how efficiently the locomotive steams (note the lack of smoke) and the beauty of its surroundings.*

## 3. COMMENTS AND CONCLUSIONS

The Author 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 realized 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 this system and resulted in the boilers the railway's 'Santa Fe' Class locomotives working extended periods of time without having to be removed for heavy repair work.

During 1969 the Argentine State Railways called upon *Instistuto Tecnologica Industrial* (INTI) to solve the widespread epidemic of water carryover and severe corrosion problems that its locomotives were suffering in the north of the country. C 16 class 4-8-2 locomotive No. 1802 was set up as a test engine and worked between Salta and Socompa (a northern section of the *FC Belgrano* system). A regular crew was allocated to 1802 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 two years due to severe scaling of the internal surfaces. One should remember that the results of a corrective system are not gained overnight, however by 1974 locomotive 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 labor and infrastructure costs, not to mention ease of operation for the crews themselves.

At FCAF, feedwater quality is of low hardness as it is derived from melting ice and snow, however during what is locally known as the 'flood season' the river water contains a large amount of suspended solids (clay and various other impurities). Given the use of tannin in a highly alkaline medium, a lack of corrosion relating to boiler tubes, firebox sheets, general piping, and water tanks has been observed.

The most important point regarding the PT system is the following: IT IS NOT WHAT IS PUT INTO THE BOILER THAT COUNTS, BUT WHAT ONE ALREADY HAS IN THE BOILER. PT is an internal treatment system and therefore relies on what is built up inside the boiler, not what is fed into such. This was stressed to the Author in the past and having now gained experience of the system he also stresses this point to the rest of the railway world!

The TIA system was the result of the necessity to provide an answer to heavy boiler maintenance resulting from a number of treatments, which included, as in Britain, wayside feed water-treating plants. There is always some good luck involved with development programs, and the writer is of no exception to this rule (as has been proven at FCAF).

A whole new book could be written on the subject of PT, this paper merely touches the tip of the iceberg as far as the subject is concerned, concentrating on the recent experience gained during its application at FCAF in Argentina. The Author, as well as being a steam locomotive development engineer, is a practical engineman and therefore much of what is stated here relates to the overall view of making it work in adverse conditions, while at the same time ensuring that the system is as user friendly as possible.

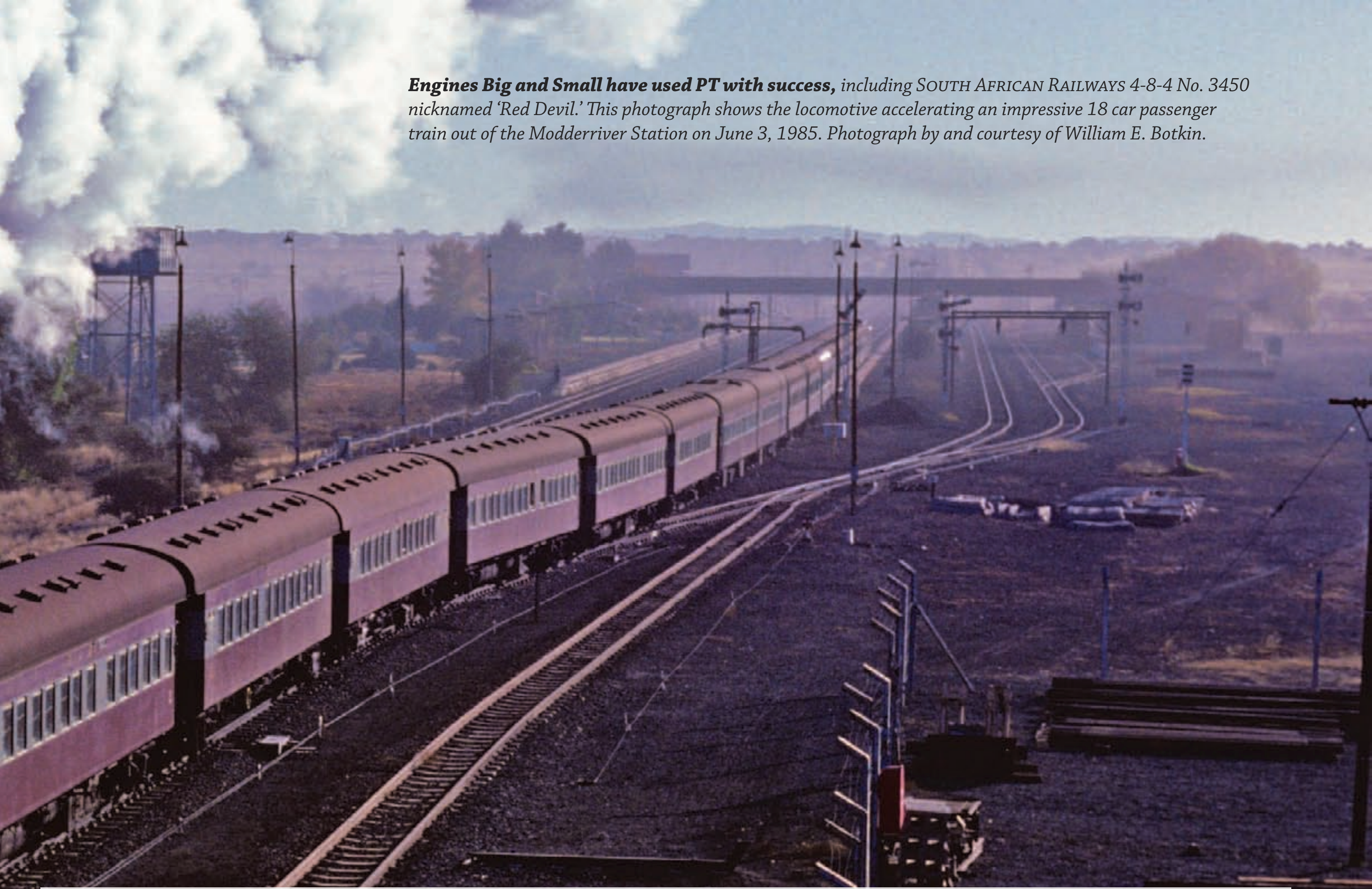
The Author would like to recap on some fundamental points relating to such an advanced internal boiler water treatment system:

1. The necessity of an advanced water treatment system for low tech countries led to research and development work that produced a system that was somewhat more advanced than the TIA and British Railways systems. In such an advanced system, the boiler is considered a crystaliser.
2. Highly advanced and very powerful antifoams allow the boiler water chemistry to be 'played' with at will.
3. High concentrations of TDS allied with high quantities of sludge formation are sought after.
4. This type of water treatment is an integral part of advanced steam locomotive technology, and it is unthinkable to be able to advance in this field without such.
5. Operation at engine house level has been simplified to the extent that chemists are not required on site.
6. Washouts are suppressed and blowing down is eliminated.
7. Boiler water specifications lie within very wide limits.
8. Very high alkalinity levels are aimed at in the boiler water.
9. The treatment chemicals are designed for rough handling by running shed and footplate staff. One member of staff can control the boiler water of up to 30 locomotives in one running shed.
10. The whole system is based on a revised physiochemistry relating to scale formation phenomena.
11. Chemists can carry out their work at central laboratory level, remote to the railway.
12. Foam height control apparatus permit a very high loading of the available steam space.
13. The use of tannens in the boiler water treatment inhibit caustic embrittlement associated with high pH levels.
13. Advanced concepts of points 1 to 13 allows one to envisage the application of corrective treatment or 3rd generation steam locomotives working at 60 bar and 550°C (870 PSI and 932°F).

Once major areas of improvement and modification work have been tackled, in this particular case the steam locomotive fleet of the FCAF, reliability in service is significantly dependent upon component performance. This is achieved by patient observation and detailed correction, each railway administration indeed builds up its own 'tradition' dependent on location, local culture, and general working environment. Such requires cost (yes, hard cash!), however the result is being able to offer a trouble free service to the traveling public.

The experience at FCAF proved the failure of the concept that narrow gauge, commercial tourist railways can be managed by the much loved 'good enough steam locomotive engineering' principles. Fortunately, nowadays this is not practiced at Ushuaia, but it unfortunately continues to be adopted elsewhere in the world by other railway administrations.

The failure to provide the most up-to-date, best developed internal boiler water treatment is an example of the 'good enough' principle!



***Engines Big and Small have used PT with success,*** *including South African Railways 4-8-4 No. 3450 nicknamed 'Red Devil.' This photograph shows the locomotive accelerating an impressive 18 car passenger train out of the Modderriver Station on June 3, 1985. Photograph by and courtesy of William E. Botkin.*

## 4. AFTERWORD

The development of an advanced internal boiler water treatment system has been tested in locomotives on four continents, but it has yet to be brought to the U.S. for trials or certification. The Coalition for Sustainable Rail (CSR) is working in connection with the Natural Resources Research Institute at the University of Minnesota - Duluth to perfect the chemicals necessary to use Porta Treatment in the U.S. The CSR Board of Directors recently refined its mission to reflect its dedication to the safe and efficient operation and preservation of historic rail equipment, and the need to use an effective boiler water treatment is tantamount to safe operations of all steam locomotives.

Since the time of writing this paper in 2003, it has been confirmed to the Author in more than one way that a better understanding of the application of PT is required by potential users. It is not 'rocket science,' yet a good understanding of its handling is necessary in order to achieve the levels of success that the Author has obtained in recent decades.

The results obtained up to 2003 greatly assisted in the development of the 1998-proposed 2 cylinder compound locomotive which by then had become the LVM 803 in joint Porta-McMahon form. This in itself later on led to the MVM 150 power generator design which these days forms one of the pillars of the CSR modern steam development area.

Though an economic decision had to be taken by FCAF during 2004 due to the shaky financial state of the country still reeling from the economic meltdown of 2001, the manufacture of a second KM class Garratt proved to be a success in the short term. After 10 years in service at the railway, No. 5 is a testimony to the proper application of the PT to the locomotive fleet. The boiler of FCAF No.5 is designed to the American Society of Mechanical Engineers (ASME) code which compensates for corrosion/erosion in terms of material thickness.

The use of boilers on FCAF No. 2 (referred to as boilers 'A' and 'B') more than 23 years after manufacture with minimal repair work during their working lives again pays testament to PT having extended their useful life, even though both boilers were designed and manufactured to a non-standard code of practice in the rough industrial conditions of Buenos Aires. During 2015, FCAF decided to manufacture a third boiler to this same design as a spare or to facilitate the possible manufacture a third KM Garratt at FCAF in Ushuaia.

Due to an error being committed during the repair of the boiler 'B,' the Author is now in possession of the full tube bank of that boiler, and he will lead a complete analysis to quantitatively define the performance of the PT in relation to such later this year.

The Author left full time employment at FCAF during April 2004 so as to take the position of Project Director at the Rio Turbio Railway. The continued success of the treatment during the Author's absence proves the claims made by him during 2003 that the system can be handled at running shed level by semi-skilled personnel using only the simplest of testing methods. The degree of success has been such that boiler washout frequency has been extended to greater than one year at the FCAF!

The treatment is being extended to other railway administrations outside Argentina under the supervision of the Author as well as extended industrial applications. In the U.S., CSR will be applying PT as a standard component of development work on a number of rail systems.

In Argentina itself, PT is being included as a standard part of the current modern steam program being carried out by the Author through his current R&D work at INTI. The *Ferroclub* has been using the treatment for a number of years, however a full revision of its application is being undertaken at this point in time so as to increase its effectiveness, and the opportunity is being taken to train more operating and maintenance staff in relation to such.

Due to a small number of unfortunate failures that the Author has witnessed in recent years in relation to the application of PT, he emphasizes the importance of not only using the correct chemicals, but also the proper handling of the application process, especially during the initial period of set up. Once the system is established within the boiler, it will run itself using very broad and crude application parameters. After all, it is designed for third world handling!
Setting up of proper, yet modest, on site monitoring

***The Author, at RIGHT,*** *is shown affixing a test apparatus to a locomotive during steam purity trials on the Welshpool & Llanfair Light Railway in 2012.*

facilities is important, even in the most remote corner of the world. It is also key to allocate a dedicated person within the administration so as to ensure proper application of chemicals at proper intervals. The latter is second to none, as this person must provide consistency and coherence in order to achieve success. In fact, dedication of a key person is the most vital ingredient to the success of the Author's application of the system since 1992, both in the 'first world' and the developing world.

Nearly 13 years after writing this paper, Stage 2 modifications of the FCAF locomotive fleet have yet to be carried out. This is due to a number of reasons and factors inclusive of Argentina having suffered one of its most complicated political periods under the same government from May 2003 through to December 2015. FCAF has fought successfully to keep its head above water during this time period, and it has done so where other small private companies have been wiped out as a result of the economic backlash suffered for more than a decade.

Stay tuned to CSR for a follow-on piece relating to Porta Treatment. Until then, be sure to review all of CSR's White Papers online (www.csrail.org/whitepapers), and if you like what you read, please consider making a tax-deductible donation to support the not-for-profit organization online, **www.csrail.org/support.**

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**The Center for Railroad Photography & Art**, www.railphoto-art.org, based in Madison, Wisconsin, preserves and presents significant images of railroading. Executive Director Scott Lothes graciously provided CSR the photograph published on page four.

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