AST Trust
Advancing Steam Traction

NEWSLETTER No. 18 - MAR 2022

BURE VALLEY RAILWAY No. 6 'BLICKLING HALL', COMING ON SHED AFTER THE FIRST DAY OF THE LATEST ROUND OF ECOAL TRIALS - SEE PAGE 8

CONTENTS

CHAIRMAN'S PIECE
John Hind

Although our interests are in the technical side of steam locomotives, we have to run several 'back office' activities and we have been lucky enough to have found members willing to do this and also find members to step in when someone stands down. An example of this is Owen Jordan taking over the role of Auditor from Richard Coleby. Unfortunately, our Treasurer has unexpectedly fallen ill and had to step down, so we are looking for a new Treasurer – an appreciation of Paul's work and more details of the Treasurer's role follow later in the Newsletter. If you would like to take on this role, please read my notes in 'We're Recruiting'.

An annual chore that falls on our membership secretary Chris Newman is chasing up annual subscriptions. The simplest way to pay is by a direct debit. To minimise admin, we have a policy of just sending out one reminder and one newsletter once a subscription has lapsed. So if you have not paid up - pay up or this will be your last newsletter!!!! Even better set up a direct debit.

MEMBERSHIP MATTERS
Chris Newman

We welcome six new members who have joined since our No 17 Newsletter was circulated:

- **Tony Cox** from Bedfordshire. Tony is a qualified Production Engineer and has spent 15 years in HM Inspectorate of Railways (ORR) and 40 years in HM Inspectorate of Factories (HSE). He is also a member of the Permanent Way Institute. He's been responsible for railway safety cases, railway safety audits and has been a responsible inspector for several TOCs, FOCs and NR's west coast route (south). He has had a lifetime interest in railways, is a member of the Ivatt Diesel Recreation Society and has spent 10 years filming steam around the world.

- **Alex Tring** from Ulverston, Lancashire. Alex has just completed an MSc in Renewable Energy Engineering at the University of Central Lancashire, and has begun the process for a doctorate study. He has therefore joined as a Student Member. He is a volunteer fireman on the Stainmore Railway.

- **Manikandan (Mani) Venkataramanan** from Chennai (India). Mani has a Bachelor of Commerce degree (2009), is registered with the Institute of Chartered Accountants of India, and is a Financial Risk Manager with the (US) Global Association of Risk Professionals. Latterly he has gained a Master of Science in Finance from the University of Pittsburgh. He is also a Director, The World Alliance of Tourist Trams and Trains (WATTRAIN).

- **Sandy Smeaton** from Glasgow. Sandy is a retired Mechanical Engineer whose career was with James Howden & Co Ltd (compressor manufacturers) in Glasgow and Renfrewshire. He is a volunteer fireman at Bo'Ness and has been a train timer since 1964.

- **Richard Pengelly** from Harrow Middlesex. He is a student of Electrical and Railway Engineering at University of Birmingham. He is currently writing a report on the future of heritage railways in an environmental context. He has enrolled as a Student Member.

- **John Scott** from Cambridge. John has an Engineering Science degree from Oxford and has worked for a number of engineering organisations. He is now a consulting engineer working on a variety of engineering projects. He has volunteered on the Talyllyn Railway since 1967, and is a qualified steam and diesel driver on the railway, where he currently acts as Head of Mechanical Engineering. He has undertaken locomotive testing on the Festiniog, the RHDR, and on the Bure Valley Railway, and has acted as ICP for Lyn on the L&B Railway, and for projects on the BVR.
- **Jack Walker** from Leighton Buzzard. Jack is our 9th Student Member and is studying for a BTech in Engineering at Silverstone UTC. He is 19 and now our youngest member. Jack has volunteered on the Ffestiniog for five years and is keen to be involved in our bio-fuel trials. He hopes he may learn something from us about Lempors and GPCS.
- **Peter Best** from South Gloucestershire. Peter is a retired owner of an engineering component manufacturing company. He owns four locomotives including Black Five No 44806, WHR Garratt No 130, S160 No 2253 and Barclay 0-4-0 No 1823, plus a traction engine. He is also an ex NYMR fireman.

Membership Numbers

I'm delighted to report that all of our 2021 members have renewed their subscriptions. This is the first year that we've retained 100% of our members. Membership numbers are now:

Full Members:	27	UK members:	70
Associate Members:	61	EU:	13
Student Members:	9	USA	6
		Australasia:	6
Total Membership:	97	Asia:	2

INFORMATION WANTED
Liang Cheyuan

I am very curious about the axle load of class 93 (InterCity 250) locomotives. A few years ago, China Railway Corporation and CRRC designed a similar push-pull train. But they found that although the axle load of 17T locomotive will reduce the impact on the rail, it will also reduce the acceleration ability. If aluminium alloy was used to make the passenger coach, the price will be close to EMUs, such as CR300AF / BF. They have had to reduce the design speed from 250 to 200, Hope to replace the expensive CRH6A with a lower price, but now the project is suspended. I know that InterCity 250 conducted a bidding from 1990-1991. I don't know whether the bidding documents have requirements for axle load. GEC-Alsthom, Bombardier, Prorail, and an ABB/British Rail Engineering Limited participated in the bidding. Some technical details were submitted before the end of the project in 1992. I am very curious about the axle load of the locomotive in their scheme.

SHAUN McMAHON 1964-2022
Chris Newman

We are deeply saddened to report the untimely death of Shaun McMahon. It is understood that he died in Buenos Aires from complications associated with Covid.

Shaun began his railway career on the Ffestiniog Railway, joining the permanent staff there as a trainee technician engineer in 1984 when Phil Girdlestone was Works Manager. Thus began a working relationship between the two of them that continued up until the time of Phil's death in 2016.

Shaun moved from the FR to the Vale of Rheidol Railway in 1989, becoming heavily involved in boiler water treatment schemes on various UK preserved lines. At this time he formed "Day McMahon Steam Technical Services" with Nigel Day. A number of successful locomotive redraughtings were carried out by the partnership.

Shaun McMahon standing beside Santa Fe No 107 at Rio Turbio in 2005.

© Chris Newman

In 1994 Shaun became Assistant Mechanical Engineer to Girdlestone on the Alfred County Railway in South Africa, continuing on there until 1999 when he moved to Argentina as Technical Manager for the Argentine railway development company Tranex Turismo S.A. He was subsequently employed by Tranex as Technical Projects Manager at the Ferrocarril Austral Fueguino on Tierra del Fuego (FCAF). This 500 mm gauge railway has become well known for its innovative program of steam loco development for hauling tourist trains over its 7km of steeply graded track.

Shaun must have had good language skills because he quickly picked up Spanish and was fluent in the language within a few years.

In his early years in Argentina, Shaun benefited from the guidance of Livio Dante Porta and was frequently charged with getting Porta's ideas translated into hardware, particularly on the FCAF railway.

From 2009, Shaun worked for INTI, the government scientific establishment in Buenos Aires where Porta had been head of the Thermodynamics Department from 1960 (when he left the Rio Turbio Railway) until his retirement in 1982.

In recent years, Shaun had been working on the restoration of an Argentinean North British-built Class 8A 2-6-2T No. 3351 dating from 1906. He had also been busy supervising the restoration of two of the Rio Turbio 2-10-2s which he planned to return to Rio Turbio to haul tourist trains and perhaps even coal trains over the railway. One (No 119) was being restored to Porta-modified condition while the other (No 120) was to be upgraded to incorporate later advances in steam technology. (No 107, featured in the photo above, has already been restored to its original ex-Mitsubishi as-built condition.)

Shaun was only 57 years old. His untimely death leaves a big hole in the "modern steam" community in South America that will be very difficult to fill.

He is survived by his wife Betti.

PUBLICATIONS PAGES
Chris Newman

Book Sales

35 books have been sold in the five months since Newsletter No 17 was circulated. These are listed as follows:

Publisher	Author	Title	Sales since N/L 16	Total Sales
ASTT	L.D. Porta	Porta's Papers Vol 1	5	122
	L.D. Porta	Porta's Papers Vol 2	6	117
	L.D. Porta	Porta's Papers Vol 3	8	70
	Ian Gaylor	Lyn Design Calculations	2	96
	David Wardale	5AT FDCs	4	204
	Alan Fozard	5AT Feasibility Study	0	38
Camden	David Wardale	Red Devil and Other Tales ..	0	260
	Phil Girdlestone	Here be Dragons	1	32
	Jos Koopmans	The Fire Burns Better …	1	6
	L.D. Porta	Advanced Steam Design	0	4
Crimson Lake	Adrian Tester	A Defence of the MR/LMS 4F 0-6-0	5	26
	Adrian Tester	Introduction to Large Lap Valves	3	15

Future Publications

- **Volume 4 of Porta's Papers** covering boiler water treatment, feedwater heating and boiler water circulation remains a work in progress. Martyn Bane is undertaking the editorial work but has been waylaid by the 6024 Society that has appointed him project manager for the reassembly and steaming of *6024 King Edward I*.

- **A Compendium of Articles and Papers to celebrate the Centenary of the birth of the eminent Argentinian Locomotive Engineer Livio Dante Porta 1922 - 2003 Volume 1**. Limitations of time and space have made it necessary to divide this book into two volumes. It is hoped that this first volume will be in print before Porta's centenary on 21st March. The volume contains 20 articles and papers covering Porta's early years and his work on the Rio Turbio Railway in Argentina. It has 230 pages and will sell for £27 (£21.60 to members). Unlike the Porta Papers volumes, some of its images are in colour. Its table of contents is copied overleaf.
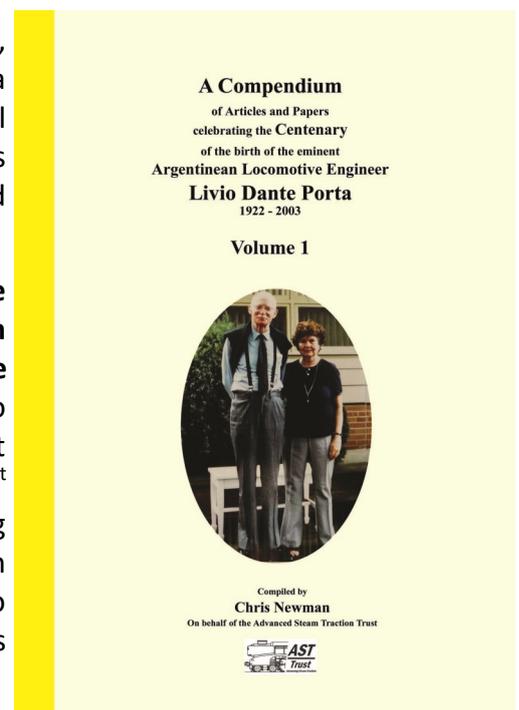
A Compendium
of Articles and Papers
celebrating the Centenary
of the birth of the eminent
Argentinean Locomotive Engineer
Livio Dante Porta
1922 - 2003

Volume 1

Compiled by
Chris Newman
On behalf of the Advanced Steam Traction Trust

A Compendium of Articles and Papers to celebrate the Centenary of the birth of the eminent Argentinean Locomotive Engineer Livio Dante Porta 1922 - 2003 Volume 1.

Table of Contents

Authors' Legend:

CN – Chris Newman (Editor)	MB – Martyn Bane	Click – John Click
LDP – Livio Dante Porta	RC – Richard Campbell	GH – Gary Hunter
SM – Shaun McMahon	DW – David Wardale	KM – Ken Mills
S&W - M. Swift & R. Wilkinson		

Porta's Centennial Anthology Volume 2
Appeal for Help
by Chris Newman

Shaun McMahon's untimely death has left has left me with two holes to be filled in the second volume of the Porta Centennial Anthology that I'm assembling. I split the book into two volumes in order to give Shaun time to complete a couple of contributions that he offered to provide, namely: a biography of Porta (of which he sent me three pages in 2018), and a report on the current situation with rolling stock restoration and future operating plans for the Rio Turbio railway in Argentina.

In recent years (c.2015), Shaun sent me several photos of work being done on the restoration of 2-10-2 No 119 and mentioned work that was planned for Nos. 105, 107, 113 and 120. He also gave me a few pointers on plans that were being made for returning some level of service to the railway. But I have little in the way of recent or detailed information.

Below is a listing of the articles that I have in hand to fill the pages of the second volume of the Anthology. Those highlighted in yellow are as yet unwritten. If necessary, I'll compose a few pages on the ACE project and wil write a few more on what I can discover about the current status of things at Rio Turbio. But I will have difficulty filling more than 200 pages to complete the book.

If any AST members can help me to fill a few extra pages, either with additional articles relating to Porta's life and work, or with information that might help me expand on the Rio Turbio status, or about the ACE Project, then I'll be very grateful to receive them.

	Prospective Table of Contents – Porta Anthology Volume 2			
1	Preface	CN		2
More biographies				
2	Part-written biography of L.D. Porta	SM	2018	3
3	The World's Most Active Advocate (Loco & Railway Preservation mag)	GH	1997	9
4	John Click's biographic material for David & Charles	Click	1984	24
Later Days				
5	1802 story	MB		6
6	Paraguay - 4-6-0 No.286	MB	c2003	2
7	ACE Project	CN?		5
8	Steam Engines Return (from Technology Tomorrow – Transport magazine)	??	1980s	7
9	Article on 1816 by José Olmo Pérez	Perez	2003	15
10	LVM 800	MB	2003	20
11	LVM 801 Series.	SM		3
12	"Doña Teresa Christina" coal railway Brazil	MB	2003	2
13	Steam Railway magazine article on A1	Elliott	1993	8
14	"My difficulties"	LDP	2000	11
Other Papers from Martyn Bane's website				
15	The Gas Producer Combustion System	RC	2003	2
16	Austerity 0-6-0ST as modified by L.D. Porta & Hunslet	MB		20

continued overleaf

	Papers by Martyn Bane published in Locomotives International Magazine				
17	Turkish Class 57601 2-10-0 Modernisation	MB	2014	3
18	Porta's Crosti	MB	2013	3
19	Porta's FC88 2-10-0 and Related Locos	MB	2014	4
20	Porta's Fireless Locomotive	MB	2014	3
21	Porta's Gas Producer in a SNCF 141R	MB	2014	3
22	Porta's "Nobel Boiler"	MB	2013	4
	Post Scripts			
23	FCAF – from SAT website	SM	2014	5
24	Rio Turbio Post Scripts 1 – the railway's situation in 2004	MB	2004	7
25	Rio Turbio Post Scripts 2 – the railway's situation in 2005	CN	2005	8
26	Rio Turbio Post Scripts 9 – the railway's situation in 2022	CN?	2022	5
	Obituaries			
27	Guardian Obituary by Jonathan Glancy	JC	2003	2
28	Hugh Odom's obituary to Porta	HO	2003	1
29	CN Obituary from SAT website	CN	2003	2
30	Don Livio Dante Porta "to the Master, with love"	RC	2003	9
	Total			198

Authors' Legend:

CN – Chris Newman (Editor)   MB – Martyn Bane   Click – John Click
HO – Hugh Odom   RC – Richard Campbell   GH – Gary Hunter
SM – Shaun McMahon   Pérez – José Olmo Pérez   DE – David Elliott
LDP – Livio Dante Porta

PAUL HIBBERD - AN APPRECIATION
John Hind

Paul Hibberd has stepped down as our treasurer because of health reasons, which came to us as bit of a shock. Back in our early days back in 2013 Paul was our constitution and legal guru, who guided us through the long and slow process of setting us the legal structure we have today and out of the 'black economy' that supports heritage steam. In our early days we were a group of engineers with no particular knowledge of Company Structures, so his help was invaluable.

Paul has been a great supporter of the steam locomotive fraternity and while not an engineer has asked searching technical questions, which has made many of us think.

WE'RE RECRUITING!
John Hind

To fill Paul's shoes, we need someone to take on the Treasurer's role.

We have well established and managed procedures for recording income and spends and the main duties of the Treasurer are turning these into balance sheets, reporting back to the Committee, liaison with our Auditor - Owen Jordan and for filing at Companies House.

Part of the funding plans for Revolution is to reclaim VAT on spends and Tax Relief on donations, so it will be an added bonus if the new treasurer has experience in these fields.

The role does not need a great deal of time, with the main effort being in the two months between the end of our financial year and the AGM.

BIOCOAL UPDATE
John Hind & Ian Gaylor

Ian Gaylor loading Blickling Hall with a measured quantity of Ecoal50

In the last newsletter, I wrote about the June trials at the Bure valley with Coal Products E-coal. I also did a presentation at our conference and was invited to give a presentation to the Heritage Railway Association's Autumn conference on them. We also fed back the results to Coal Products who produced a trial blend more suitable for locomotives than the 'off-the shelf' product. One of the differences is that it was a larger size closer to a man's fist.

The objective of the trials was to test the fuel under more arduous working conditions and also try it on a second engine, extending the knowledge base of how the fuels perform under different working conditions and on other locomotives.

The trials, took place over two days, Tuesday 23rd November and Wednesday 24th November. The morning departures to Wroxham burnt the Welsh coal from Ffos-y-fran as a base comparator and the afternoon's burnt a variant of Ecoal50 developed by CPL based on the feedback from the June trials.

The Tuesday trial used the previous test locomotive No. 6 Blickling Hall which is fitted with a Lempor exhaust and Wednesday used No. 1 Wroxham Broad, which is fitted with a conventional exhaust.

The trials with No. 6 increased the load to 180% of the normal BVR load to really test the locomotive under the most arduous combustion conditions that are found on the mainline or Welsh narrow-gauge railways. No. 1 was loaded to 113 % of what it would normally haul.

The trials with No. 1 gave an opportunity to test the fuel on a different locomotive, which is smaller than No. 6 and also due for its 10-year overhaul in 2022.

Scott Bunting was the driver for these trials and the June trials. On both days the railhead conditions were not ideal, with leaf contamination and on the Wednesday with No. 1 the additional complication of light drizzle. Both locomotives were working at the limit of their adhesion even with the use of sanding and were a test of driver skill.

The test protocol was the same as in June with the fuel in the tender weighed and the water consumption measured. The ash in the ash pan and the char in smoke box were also weighed. Transducers were rigged to a computer in the lead carriage to measure smoke box vacuum, which gives an indication of maximum combustion rate, exhaust performance.

ASTT produced the test protocol, provided the test equipment and supervised the trials and CPL attended the trials to see at first-hand how the fuels performed.

The June trials were only on one locomotive and at moderate firing rates and showed that No. 6 steamed as well with Ecoal50 as Ffos-y-fran but Ecoal50 fuel consumption was 28% greater than Ffos. To extend the knowledge base we were keen to trial the fuel at heavier loads with greater combustion rates and on another locomotive.

The 'gut feel' on the day from the footplate crew was that, with this variant of Ecoal50 the locomotives steamed adequately but not as well as with Ffos-y-fran. The initial thought is that this is because of unburnt fuel carryover especially at higher rates of working. We also saw clinker on one run.

No. 1 Wroxham Broad

Ffos y-fran in the firebox of No. 6

Ecoal50 in the firebox of No. 6

Having run 6 test trains, we are now able to build up a picture of performance with different fuels, different locomotives and different firing rates.

On a qualitative basis with Ffos-y-fran coal both locomotives steamed freely under all conditions, with Ecoal 50 No.6 steamed freely under 'Average Conditions' with Ecoal Special but under 'Demanding Conditions' both locomotives Nos.6 and 1 steamed adequately but less freely.
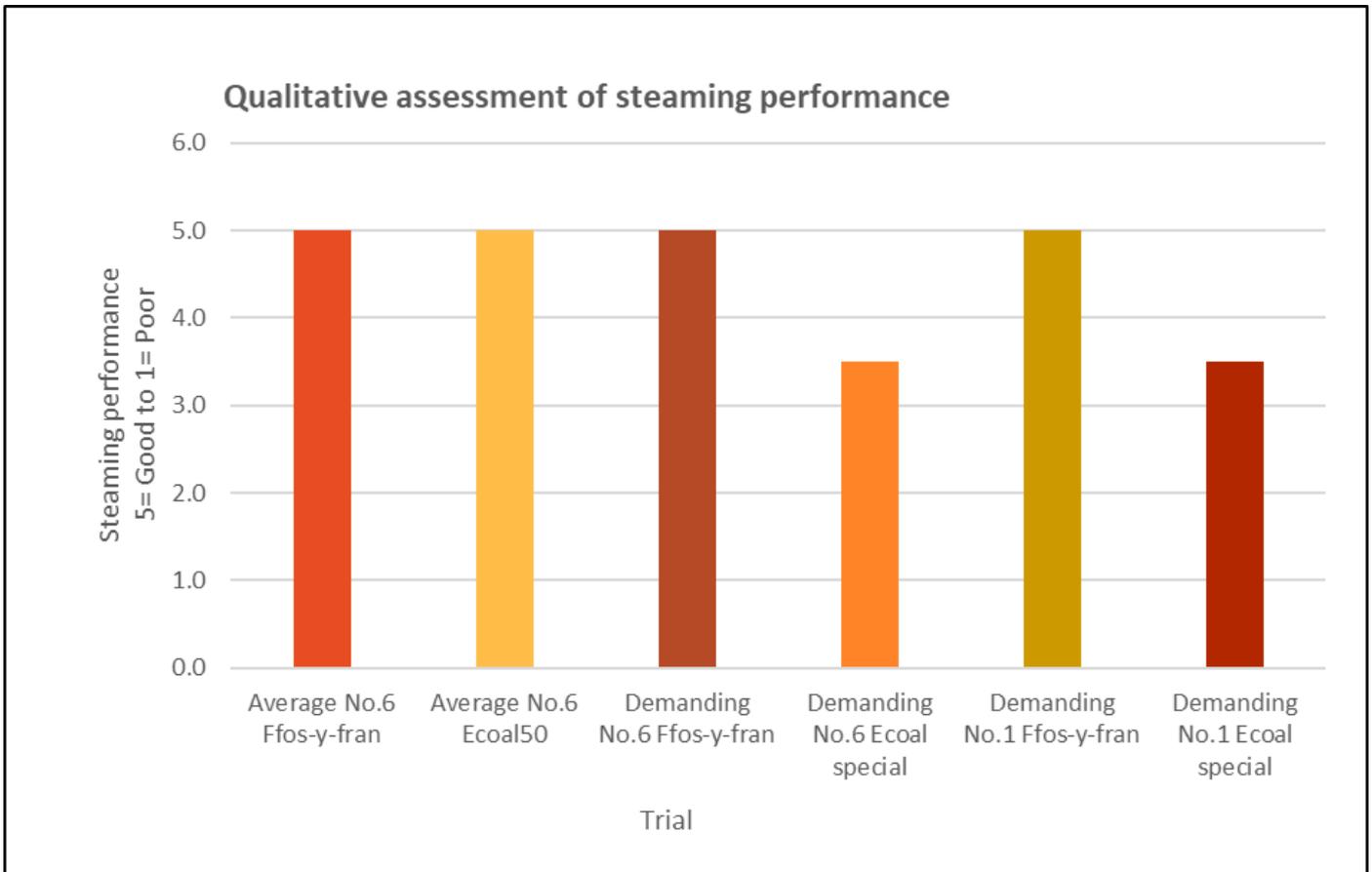
This is confirmed by the amount of fuel required to evaporate the water. The consumption of both *Ecoal* samples was greater than *Ffos-y-fran* with the increase becoming more pronounced under *'Demanding work conditions'*.
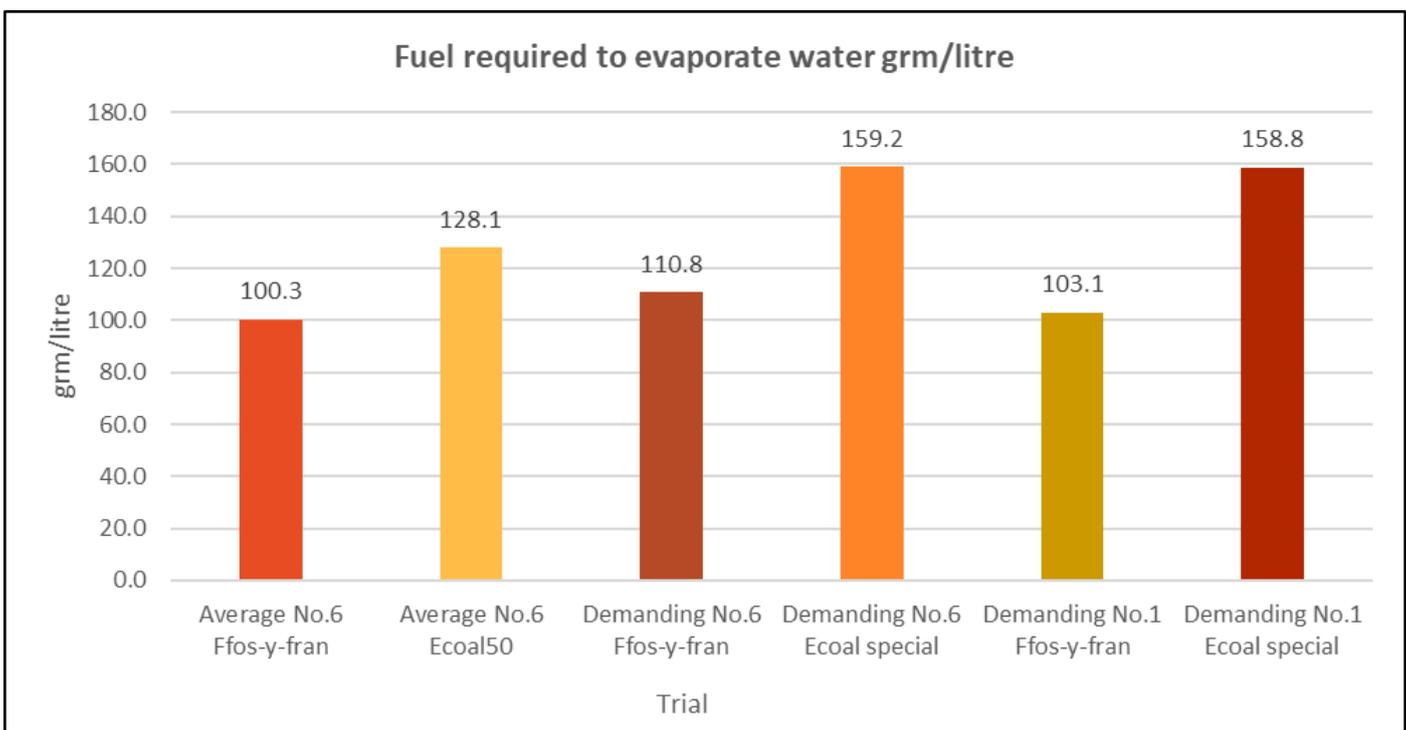
The calorific values of Ffos-y-fran and the Ecoal are very similar at 32824 kJ/kg and 31031 kJ/kg respectively and the increase in use of the Ecoal is explained by the increase in carryover as indicated by the amount of char found in the smokebox.

Smokebox char grm/litre of water evaporated
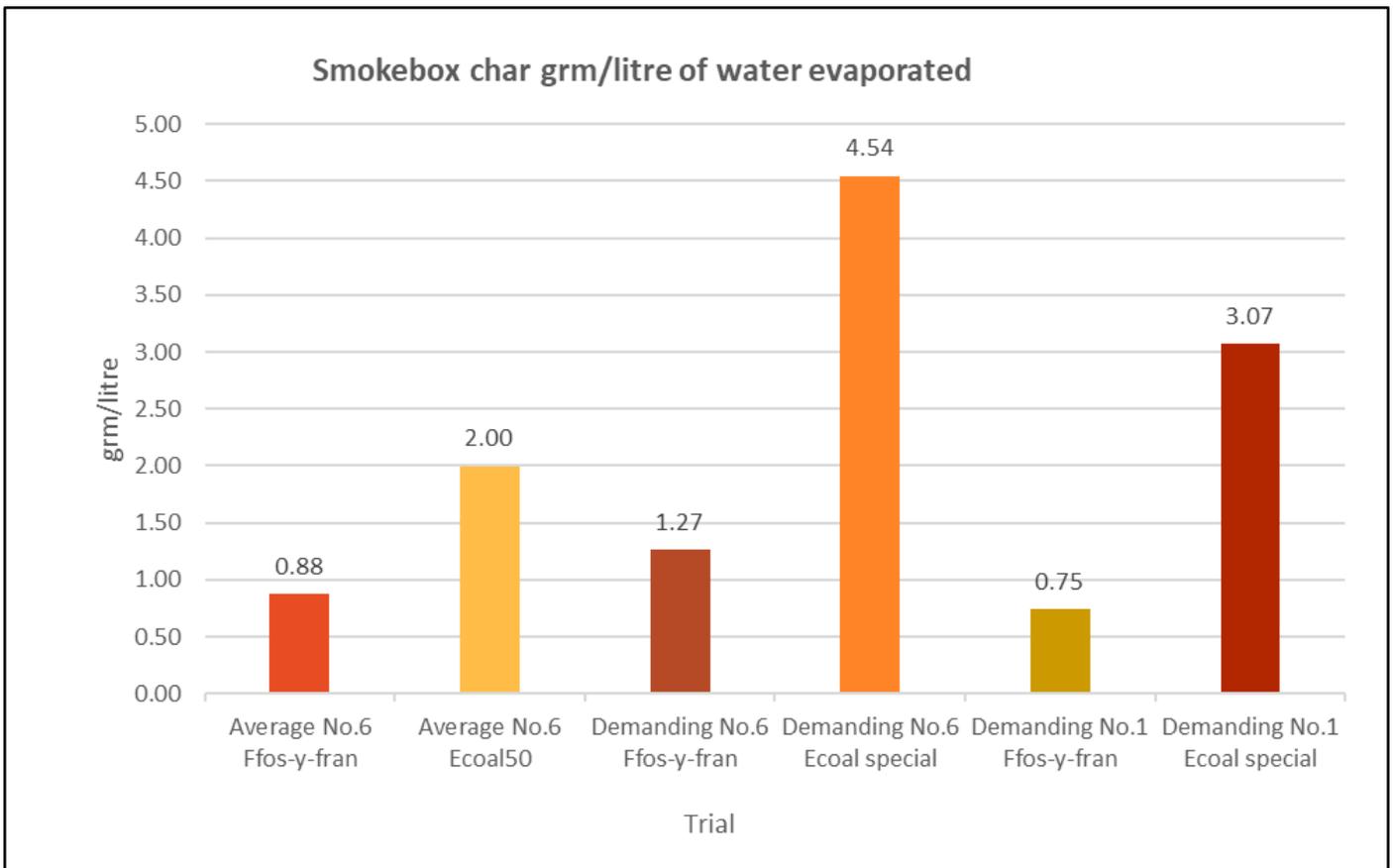
The results have been fed back to CPL and for the next set of trials, CPL are going to produce a different blend that is hoped to reduce carryover.

CPL have produced a batch of 40 tons because of the interest in Ecoal within the Heritage Railway industry and the plan is to run some trials on standard gauge locomotives, firstly at the Keighley and Worth Valley Railway and if these are successful then on the North Yorkshire Moors Railway. Assuming the trials at the KWVR are successful, then we plan to run trials at the Bure Valley on the same basis as the June and November trials so that we get quantative figures under the same set of test conditions.

SOME COMMENTS ON LOCOMOTIVE FRONT END DESIGN PART 4
Martin Johnson

1. COMMENT ON ARTICLE IN ASTT NEWSLETTER 17

I was fascinated by Steve Rapley's article about the internal aerodynamics of the Merchant Navy class. I noticed that Figure 6 shows a very "peaky" velocity profile, ranging from 3 m/s at the chimney wall up to 162 m/s over a very small area at the centre. With minor modifications to the blast nozzle angles, Figure 10 shows a much "flatter" velocity profile ranging from 0 m/s at the wall to 57 m/s at half radius and around 50 m/s at the centre. (I think the two figures are at different steaming rates, but the pattern is important.) The two figures provide a good illustration of the point I was making in Section 4 of Part 1 of this series of articles about the importance of exit velocity profile and kinetic energy correction factor on front end efficiency.

2. INTRODUCTION

This article introduces a novel method of examining the interaction of a locomotive front end design with its boiler. I have had reservations for some time about attempting to design a front end based on a single definition of draught to be produced at a given steam and flue gas flow. This article represents the fruits of my deductions. As far as I know, the approach is novel in this application (although similar to matching a variable speed water pump to a system), so I have explained the logic in developing the method in detail.

2.1. Gas Flows

Throughout this article, I use gas flows as calculated by the Lawford Fry method. I have come to the conclusion that this method gives erroneous estimates of gas flow, which may well be the subject of another article. Readers might also refer to Ref. 11.8 for Porta's assessment of the Lawford Fry method. Nevertheless, results from Fry's method serve to illustrate the trends, if not the precise quantities, that I wish to discuss.

3. THE DESIGN SPECIFICATION

Previous sections (and other authors) have started from the implicit assumption that we know what mass flow of exhaust products and what draught the front end is to achieve.

As usual Porta has some very relevant comments on the subject:

> "*It is clear that the design, or the prediction of performance, cannot have better accuracy than the boiler data on which are based L, D, draught, vb, etc. and also the steam conditions at the blast pipe tip. These can be forecasted with reasonable accuracy by means of laborious calculations, but undoubtedly actual test data are far more desirable. However, this is not enough: a locomotive ejector, the very heart of the machine, must incorporate due allowances for maintenance standards, fuel quality variations, service required from the locomotive, unavoidable*

steam and gas leaks, etc. .... To account for these phenomena, the ejector should be designed for 5% extra gas quantity and 10% more draught."

I agree with Porta's comments and approach, and defer to Porta's experience in choosing the safety margins. However, I think there is more to consider than a single design point.

4. DRAUGHT REQUIREMENT

Starting with the obvious, each design of locomotive exhibits a curve of draught requirement against gas flow through the locomotive.

As an example, Figure 1 shows the Rugby test data for a Standard Class 5, No. 73031. I have searched the Rugby data for other engine classes, but none give such full data as this series. The losses are presented as loss across each component as noted. The effect of varying damper position in the tests has been eliminated by relating losses to the ashpan measured draught except for the smokebox vacuum data.

I have plotted data against gas flow, as this is the variable that creates the losses. I am also of the opinion that gas flow (as opposed to firing rate) should be the principal independent variable for most locomotive analysis. For a rough calibration, a firing rate of 100 lbs/sqft/hr on this locomotive gives a gas flow rate of around 17200 kg/hour.
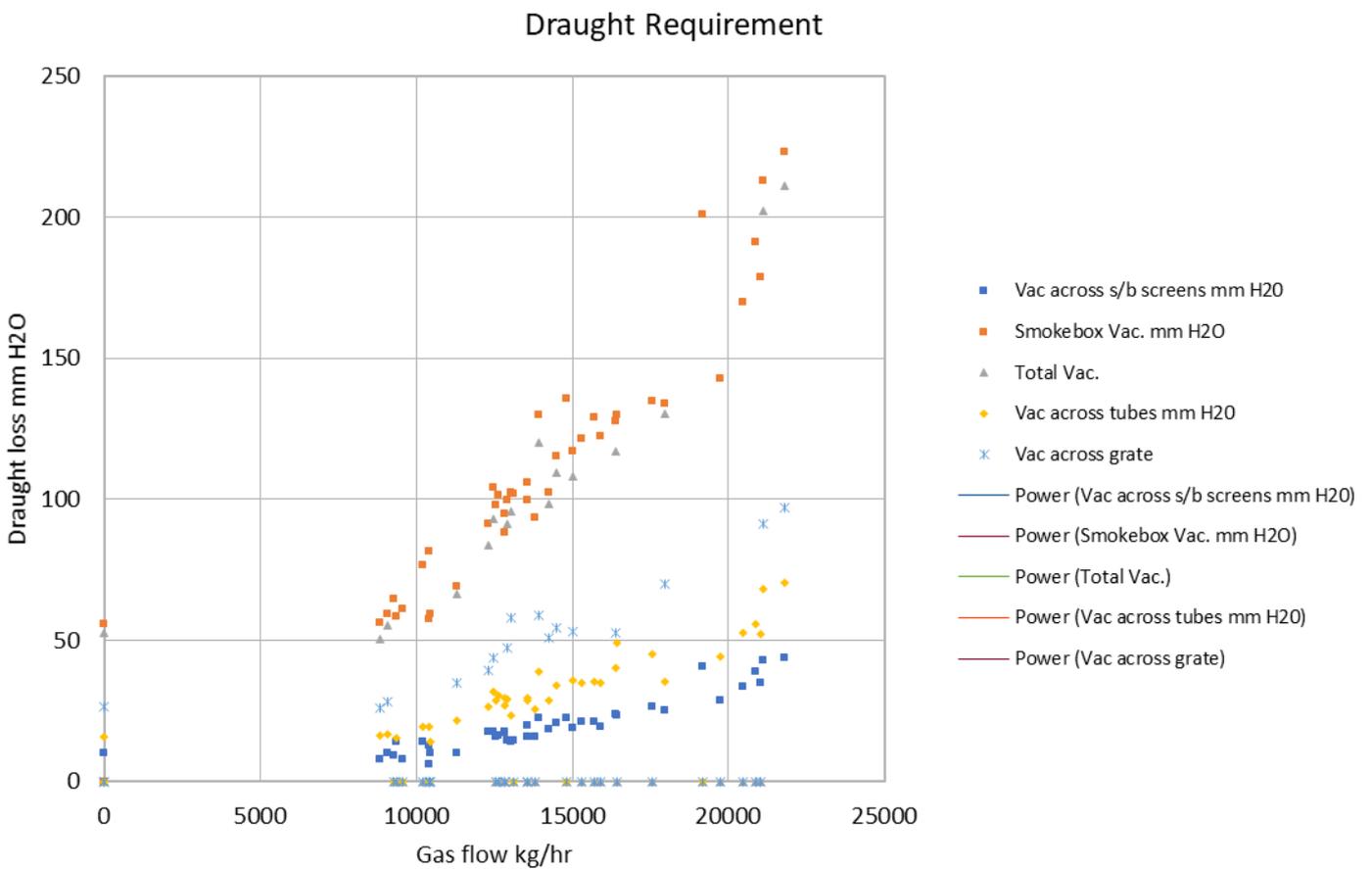
Figure 1: Total draught, smokebox vacuum and breakdown of draught losses.

All the data shown in Figure 1, fits a power law model quite well. However, the index is well below 2 (a square law) that would normally describe turbulent flow under steady conditions. Considering each draught loss component:

- Smokebox Vacuum - The smokebox vacuum varies in proportion to gas flow to the power 1.4, but this includes the effect of any adjustments to dampers during the test. Dampers would be most likely to be used at lower steaming rates and gas flows, hence the effect would be to increase draught at lower gas flows, which reduces the power index compared to the total draught.

- Total Draught - The total draught varies in proportion to gas flow to the power 1.5.
- Grate and Firebed Draught - The loss across the grate and firebed is the largest (and hence most important) loss of draught. The loss varies in proportion to gas flow to the power 1.38. Possible reasons are that the gas temperature (and hence properties) varies with gas flow. Another factor might be that the mean particle size of the firebed gets larger at higher gas flows due to loss of small fuel particles to the chimney. Mean particle size is a determinant of losses through any permeable bed. Draught loss across the fire is influenced by coal type and particle size with factors such as coal breakage, coal agglomerating (caking) with heat and clinkering all playing a part. It is a matter of common observation that the particle size distribution of a locomotive fire is not the same as that of the coal which is fed into the fire. There is very little other data in the Rugby tests to make any more detailed determination of loss across the fire and grate, which seems odd given the importance of draught loss through the fire. It seems to me that attempting to calculate draught loss across a firebed would be extremely difficult, so we must depend on correlations of experimental data.
- Tube Bank Draught Loss - Draught across the tube bank varies in proportion to gas flow to the power 1.53. This is probably due to the gas temperature variation. There is sufficient Rugby data to determine that for other locomotive classes and tests, the power index varies from 1.3 to 1.87, the average being 1.57. The magnitude of loss is also a function of how clean the tube bank is; corrosion, accumulation of soot and bird nesting all have significant influence. Calculation of tube bank losses is reasonably straightforward with computer assistance.
- Smokebox Screen Loss - Draught across the smokebox screens varies in proportion to gas flow to power 1.71. The magnitude of this loss varies with the degree of blockage of the screens and the effectiveness of the screens. There is a design trade off in particle capture efficiency against draught loss through the screens. Screen losses are relatively easy to calculate.

4.1 Size

The above observations apply to a reasonably large locomotive (for British practice). From other work I have done, I know that draught requirement in models will be significantly different due to:

- Tube bank flow will usually be laminar below 7.25" gauge models.
- Fire depths are significantly shallower and particle size is much smaller in models. There is also significantly more edge effect which reduces the resistance through a porous bed.
- Screens are seldom fitted in models, but are sometimes used above 7.25" gauge.

It seems reasonable to surmise that the picture may also be different for smaller locomotives and narrow gauge work.

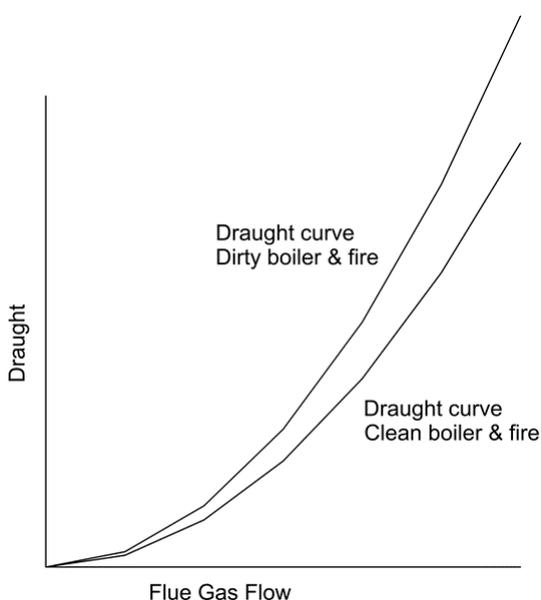## 4.2 Draught Loss Curve in Real Life

Figure 2: Illustration of expected variation in draught curve due to condition of boiler.

Figure 2 shows how a typical draught curve, plotted against flue gas flow, will vary over a range depending on the condition of the boiler. For simplicity, I have called the conditions "clean" and "dirty" but they could include other factors such as small particle size coal, blocked screens, firebars clogged, ashpan full etc. Factors such as leaking tubes or leaking smokebox door would increase the gas flow required at the chimney, compared to gas flow at the fire which is the important area.

> **Key point - the draught required by a boiler depends on many factors such apart from basic design, such as gas flow, maintenance, size or scale, fire condition, spark arresting screen condtion, ashpan design and damper opening.**

5. EXHAUST STEAM TO COMBUSTION GAS RATIO

A typical ratio of 1:2 is frequently quoted which is approximately true at certain conditions. However, Figure 3 showing the Rugby test data for Standard Class 5 73031 suggests a more complex relationship. The data gives a reasonable fit to a power law line with an index of 0.81 and the reducing gradient of such a line reflects the greater losses of heat to exhaust gas at high rates of steaming - i.e. a reducing boiler efficiency. Figure 3 shows the ratio is above the 2:1 ratio at low steaming rates, but above 2:1 at high rates.

If test data is not available, the steam to gas ratio would need to be derived from a knowledge of the coal analysis, the boiler geometry and the required rate of working. Consider the following:

- Boiler condition - Fouling either on the gas or water side of a boiler will hinder heat transfer and cause a drop in efficiency. That will increase the combustion gas exit temperature and reduce the evaporation rate per unit volume combustion gas.

- Superheat - on a saturated engine, all the boiler heat is used to generate steam, whereas on a superheated engine a proportion of the heat is used for superheating. Therefore, a saturated engine will tend to a ratio above 1:2.

- Size of engine - Boiler efficiency for model and miniature boilers will typically be around 50%, whereas a large boiler will have an efficiency of around 80%. Smaller engines will thus have a ratio greater than 1:2.

- Coals with low calorific value will not produce as much steam per unit of combustion gas, thus tending to a ratio greater than 1:2. (Ref. 11.7)

- Train heating demand and other sundries will take steam away from the quantity passed to exhaust, the effect will be to drop the entire curve.

- General leakage from glands, clack valves etc. will reduce the volume of steam reaching the front end.

- The effect of a an exhaust steam injector will be more subtle as steam is taken away from the front end, but by feeding hotter water to the boiler evaporation is improved for a given flue gas quantity.

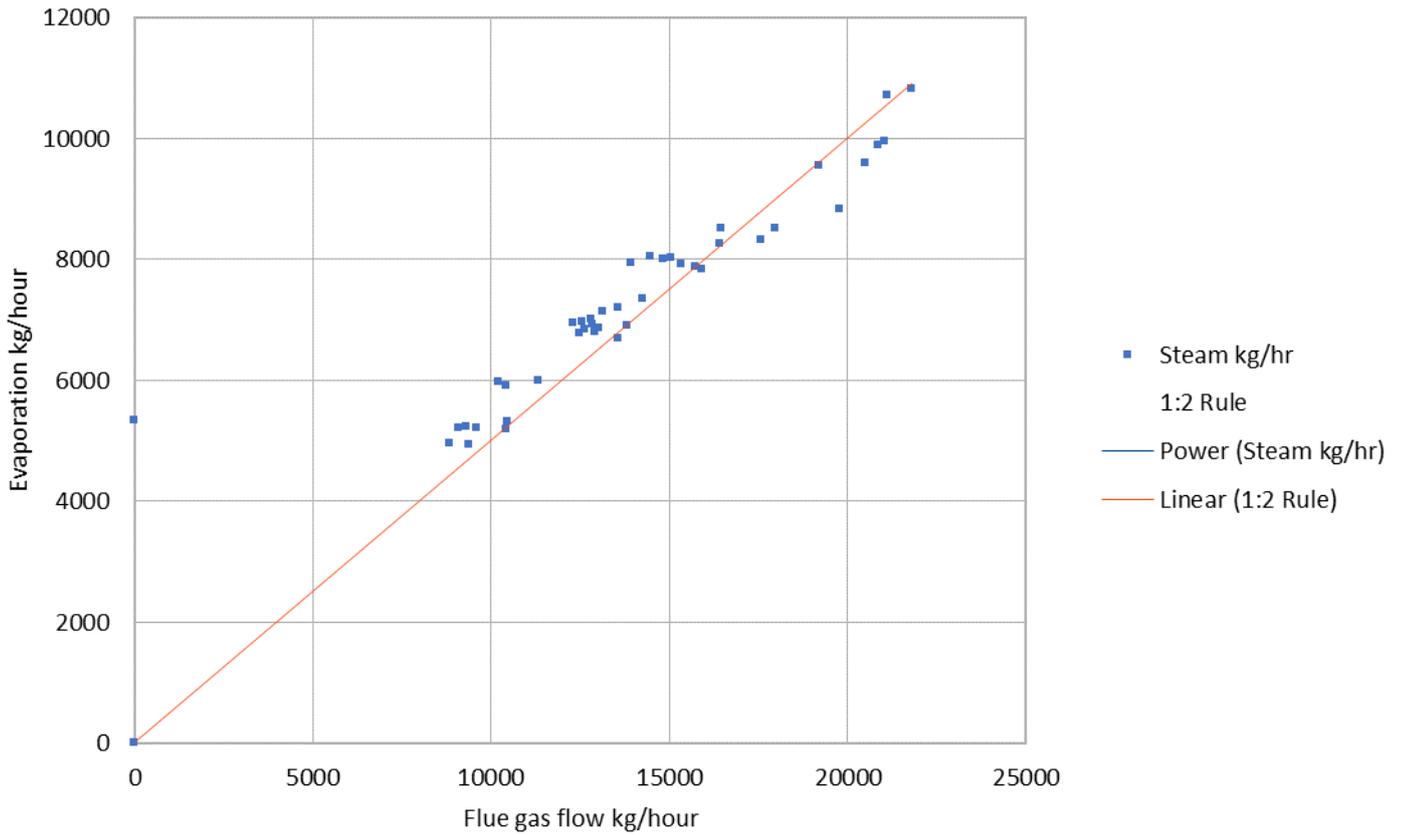## Evaporation rate as function of flue gas flow

Figure 3: Evaporation rate as a function of flue gas flow.

In summary, while Figure 3 shows a well defined relationship between steam generation and flue gas flow for a given locomotive design under test conditions on a given fuel, factors such as boiler condition, fuel calorific value or steam use for other auxiliary demands will change that relationship. So in real life, a range of evaporation Vs. flue gas flows will be seen as illustrated in Figure 4.
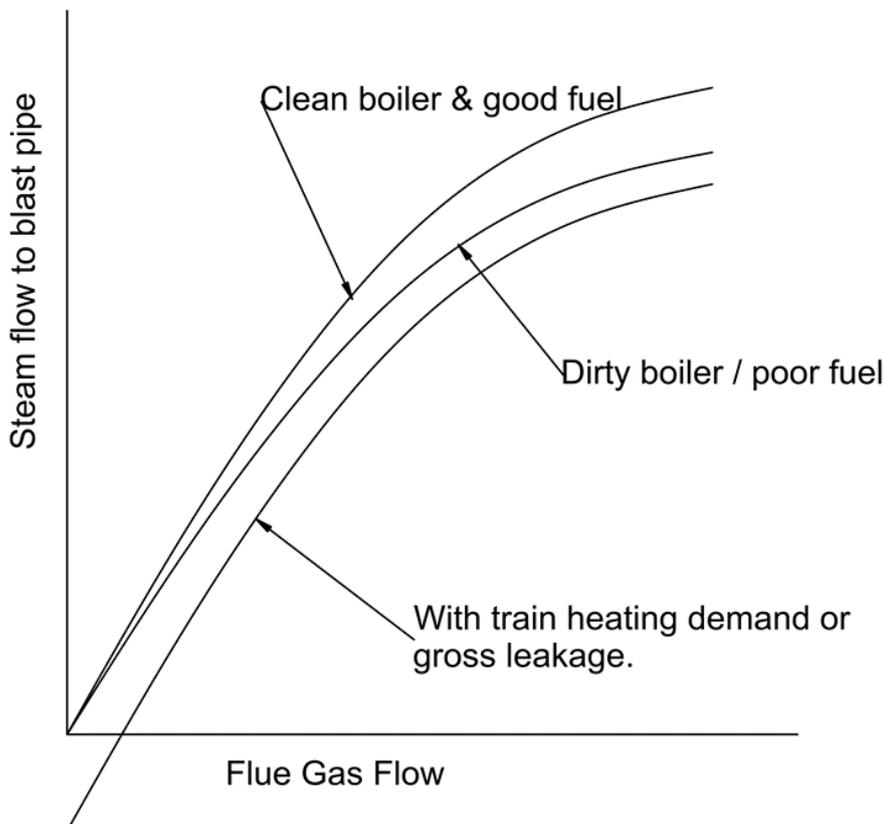

Figure 4: How external influences change the steam flow / gas flow relationship

The curve as shown in Figure 4 will also drop due to front end leakage (leaking smokebox door, for example) where the front end is required to pump extra flow that does not pass through the fire. Prolonged periods with the firehole door open have a similar effect.

> **Key point - there is a well defined relationship between evaporation and flue gas flow. However, the relationship can change with boiler condition, fuel type, steam demand from auxiliaries, degree of superheat, steam leakage.**

6. FRONT END PERFORMANCE

We now need to consider how the front end performance varies with changing gas and steam flow. Reference 11.6 shows that a jet pump operating in the non compressible regime (i.e. at blast pressures below 11 p.s.i approx.) has a near straight line performance that extends from zero entrained flow (at high smokebox vacuum) to zero smokebox vacuum (at high entrained flow). Other front end theories (E.g. Porta or Koopmans) can show the same result if the equations are solved for a range of entrained gas flows.

The performance of a jet pump can be conveniently described in non dimensional terms of:

- A flow ratio, M defined as Secondary (flue gas) flow volume flow / primary (steam) flow volume flow.

- A pressure ratio, N defined as secondary (flue gas) flow pressure rise / primary (steam) flow pressure drop.

- Hence a graph of N against M completely describes the performance of a jet pump.

- The values of the x and y axis intercepts M_0 and N_0 respectively are dependant primarily on the area ratio, R defined as Blast nozzle area / Throat area. Factors such as diffuser efficiency have some effect on the performance curve, better efficiency tending to increase the maximum M value.

So the typical front end performance as given in Ref. 11.6 is generally like Figure 5.
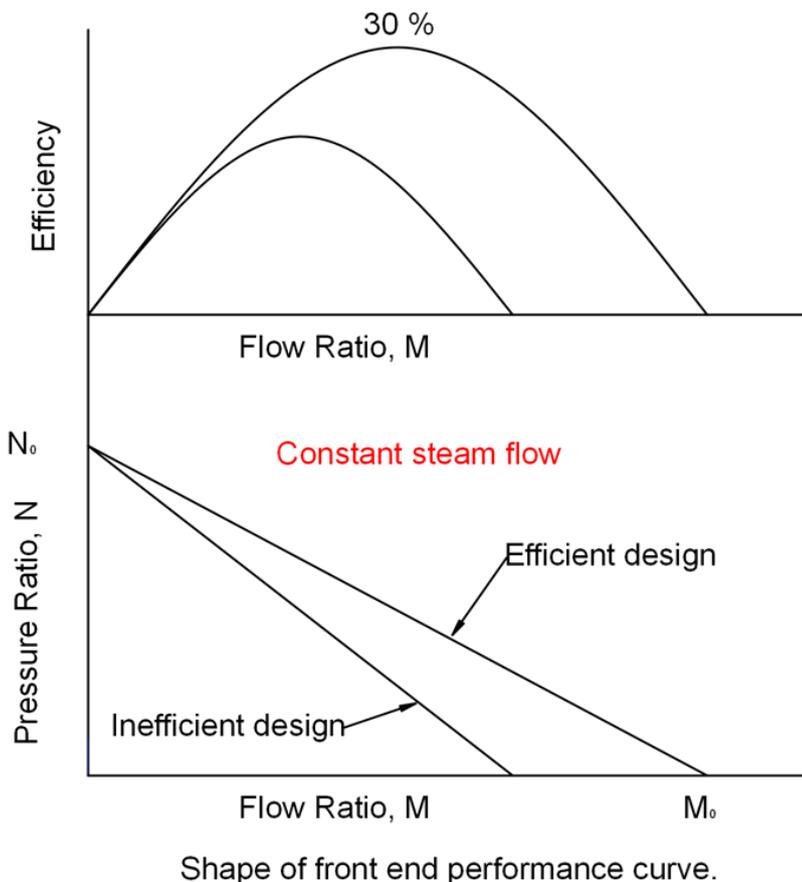

Figure 5: Shape of front end performance curve drawn for a 0.1 area ratio front end.

Figure 5 is effectively showing what happens as the entrained flue gas flow is changed. The more the flue gas flow is restricted, the higher the pressure ratio becomes. That is one reason why comparisons of front end performance as graphs of draught against blast back pressure are meaningless; on that basis, closing the dampers and clinkering the fire would be good methods of improving engine performance.

The peak efficiency - that is conversion of exhaust steam energy to pumping of flue gas - occurs at the mid point of the characteristic. I have shown a typical peak efficiency value for a well designed jet pump taken from Ref. 11.6 , but the extra losses associated with the short diffusers imposed by loading gauge restrictions take the peak efficiency of a loco front end to a much lower value.

The N_0 and M_0 values which define the characteristic shape as shown on Figure 5 can be determined as follows:

$$N_0 = \frac{(2R - R^2(1 + K_m + K_d))}{(1 + K_p - 2R + R^2(1 + K_m + K_d))}$$

$$M_0 = -b - \frac{\sqrt{(b^2 - 4ac)}}{2} a$$

where:

$$a = \frac{2CR^2}{1 - R} - CR^2(1 + K_m + K_d) - C(\frac{R}{1 - R})^2(1 + K_s)$$

$$b = -R^2(1 + C)(1 + K_m + K_d)$$

$$c = 2R - R^2(1 + K_m + K_d)$$

R = Area ratio blast nozzle / over chimney throat [dimensionless]
C = Ratio flue gas density / steam density [dimensionless]
K_m = Loss coefficient for parallel mixing section of chimney [dimensionless]
K_d = Loss coefficient for diffuser section of chimney [dimensionless]
K_p = Loss coefficient for blast pipe nozzle [dimensionless]
K_s = Loss coefficient for inlet section of chimney [dimensionless]

The effect of varying the area ratio (Blast pipe / chimney throat) is as follows:

	Decreasing area ratio	Increasing area ratio
	Larger blast pipe or smaller	Smaller blast pipe or larger
Pressure ratio at zero flow	Decreases	Increases
Flow ratio at zero pressure	Increases	Decreases
Value of peak efficiency	Falls	Rises up to R = 0.3 approx.

> **Key point - the characteristic curve of draught Vs. steam flow for a front end can be defined by a set of equations.**

6.1 Blast Pipe Pressure Drop
In the last instalment I showed that steam velocity depends on the square root of enthalpy drop from cylinder exhaust pressure to atmospheric pressure. Putting this another way, the enthalpy drop is proportional to the square of flow through a given blast nozzle. However, calculating the performance of a blast pipe is not all plain sailing as the comparisons in Figure 6 will show.
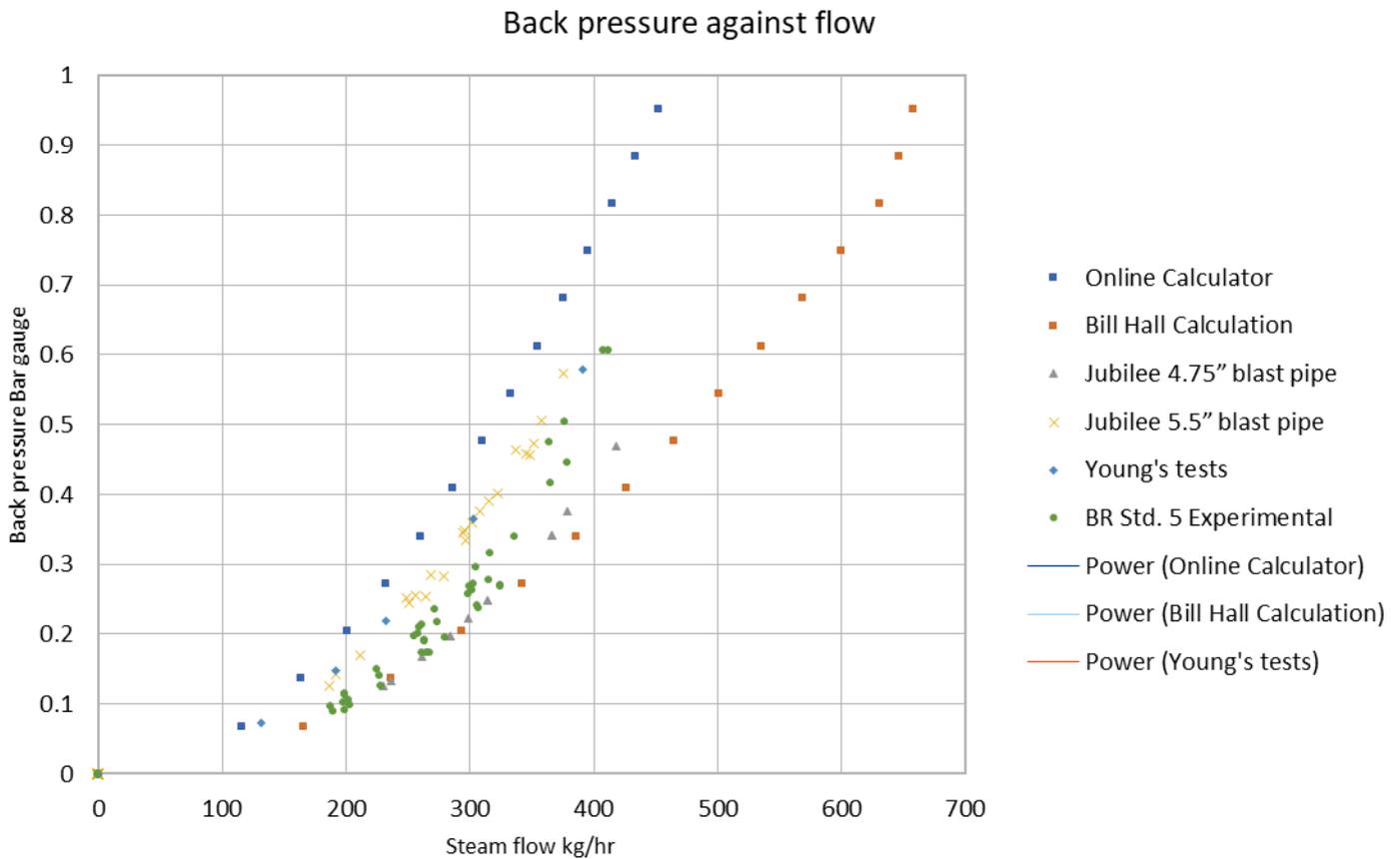
Figure 6: Comparison of back pressure across orifices and blast pipes from various sources. All data normalised for a 1" diameter orifice.

The lowest line on Figure 6 has been obtained using the method outlined by Bill Hall in Ref. 11.9 for mildly superheated steam in an orifice of Cd = 1.0 i.e. a 100% efficient nozzle, so if you see test results that fall below this line, be very suspicious. The top line is the same calculation found online at https://www.tlv.com/global/UK/calculator/steam-flow-rate-through-orifice.html, but which assumes (but does not state) that the Cd = 0.66, which is equivalent to a square edged orifice in a very large pipe. I also include some of Young's test results, which have been corrected for velocity pressure (about 0.5 psi at 8 psi) It will be seen that the small selection of Rugby tests and all fall between the two extremes. It is interesting to see that when normalised, the Jubilee 5.5" blast pipe (orifice style), gives significantly higher pressure loss than the Jubilee 4.75" nozzle (tapered nozzle) as was explained in Section 2.2 of Part 2 in ASTT Newsletter 16.

Key point - There is a judgement in choosing an appropriate Cd value to the situation in hand, but the equations defining pressure loss through a nozzle are reasonably simple.

6.2 Front End Performance Plot

From Figure 5 we can see how the front end performance is related to a given steam flow and pressure by simple ratios. Section 6.1 above shows that as we vary the steam flow, blast pipe pressure varies as the square of flow rate, so combining the two we can generate a family of curves describing front end performance at various steam flows and pressures, as shown in Figure 7. The steam back pressure and draught are plotted to the same scale. The steam flow and gas flow are also plotted to the same scale, so steam flow is roughly half that of the gas at the best efficiency point on each performance curve.

Figure 7 shows how the front end performance changes with regular increments of steam flow, the figure is based on 1, 1.5 and 2 units of steam flow. It is also important to remember that the figure is for a single orifice design of front end with an area ratio of 0.1; changes to the area ratio or diffuser efficiency will

change the position of the curves, but the general pattern would remain.

Figure 7 also assumes that the maximum steam back pressure has not risen above the sonic limit (11 p.s.i. approx.). As discussed in the previous issue, once that happens we can expect a decrease in front end efficiency, which would give as a lower performance curve than would otherwise be expected.

Changing the blast pipe size steepens the blast pipe back pressure curve which in turn increases the front end performance curves in direct proportion until the sonic limit is reached.
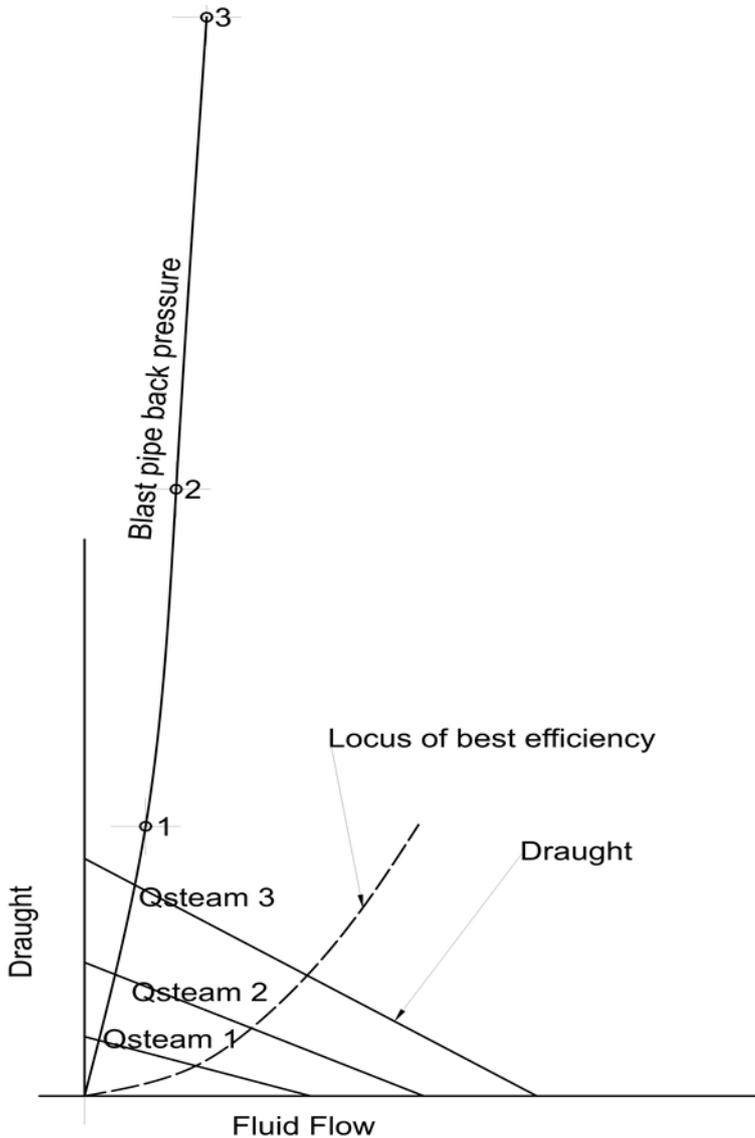
Figure 7: Family of draught curves along with blast pipe back pressure plotted to same scale.

Key point - There is a judgement in choosing an appropriate Cd value to the situation in hand, but the the performance plot for a front end comprises a family of draught Vs. flue gas flow curves each representing a different blast pipe flow condition.

7. COMBINED PERFORMANCE OF FRONT END WITH A GIVEN BOILER

So far, I have considered the boiler and the front end in isolation. However, it is the performance of the combination that counts. Both Figure 2 and Figure 7 are plotted on the same axes, so we can construct a combined plot showing the draught needed by the boiler (Figure 2) and the draught the front end is capable of (Figure 7) on the same diagram.

I have constructed such a diagram in Figure 8, using the data previously discussed from BR standard class 5 No. 73031. The figure shows:

- The rising blue curve shows the boiler total draught required, which is as the light green line in Figure 1.

- The descending straight lines show the front end performance. As an example, the yellow line is drawn for a steam flow of 9,750 kg/hr, which corresponds to a flue gas flow of 20,000 kg/hr as shown in Figure 3. Under steady state conditions, the yellow line could not extend beyond the 20,000 kg/hr point on the abscissa.

- For a gas flow of 20,000kg/hr, the steady state draught produced by the front end is shown by the "⬦⬦" symbol at 206 mm water gauge. However, the boiler only requires 174 mm draught. In normal operation, the dampers would be set to dissipate (206 - 174) mm of draught, thus bringing the system into balance. Alternatively, if trying to regain steam pressure then opening the dampers would allow a heat transfer rate equivalent to about 21,000 kg/hr gas flow, while only taking steam equivalent to 20,000 kg/hr.

- At all gas flows below about 20,000 there is a surplus of draught available from the front end above what is required by the boiler.

- However, if the locomotive were required to produce 11,700 kg/hr of steam, corresponding to an extrapolated gas flow of 25,000 kg/hr on Figure 3, then Figure 8 shows that the front end could not maintain sufficient draught. This effect seems to be an accident of the data set chosen for illustration. I have found that other methods of calculating gas flow would suggest a continuous increase in margin between draught available and required; presumably until sonic choking starts to affect the front end performance as I discussed in Newsletter 17. However, it is an aspect that would merit further investigation.
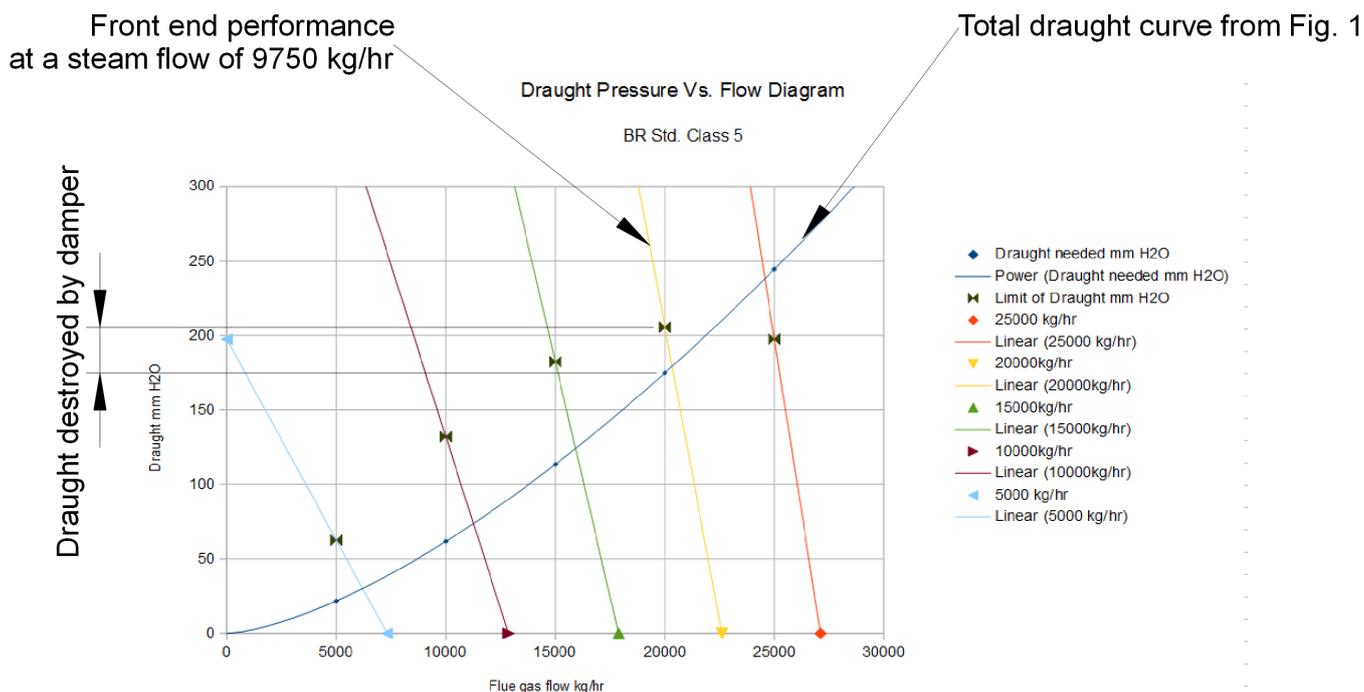

Figure 8: Composite draught curve drawn for BR Standard class 5

I do not claim Figure 8 is an accurate reflection of the Class 5 performance, because I chose the diffuser loss factor to ensure that the limit of performance was around 20,000 to 22,000 kg/hr to reflect the extreme limit of test shown in Figure 1. The diffuser loss factor I used was 0.9 compared to 0.65 corresponding to the diffuser geometry as discussed in Section 3 of Part 1 of this series, although I have previously indicated that published losses are likely to be unduly low when applied to front ends. Regardless of any accuracy issues, I am more interested in patterns here.

> **Key point - Plotting the draught demand and draught available curves Vs. flue gas flow on one diagram defines an acceptable operating envelope where draught available exceeds draught demand.**

7.1 Effect of Engine Condition on Performance

The aim of this article was to consider how a performance specification might be drafted for a locomotive front end, and I have now introduced the tool that I hope will make that task more rational.

Locomotive 73031 as tested at Rugby and reflected in my figures was probably in good condition, and managed by an expert crew using good quality coal - otherwise there would be little point in testing it. I include Figure 8 again, without the annotation to improve legibility as the reference result.
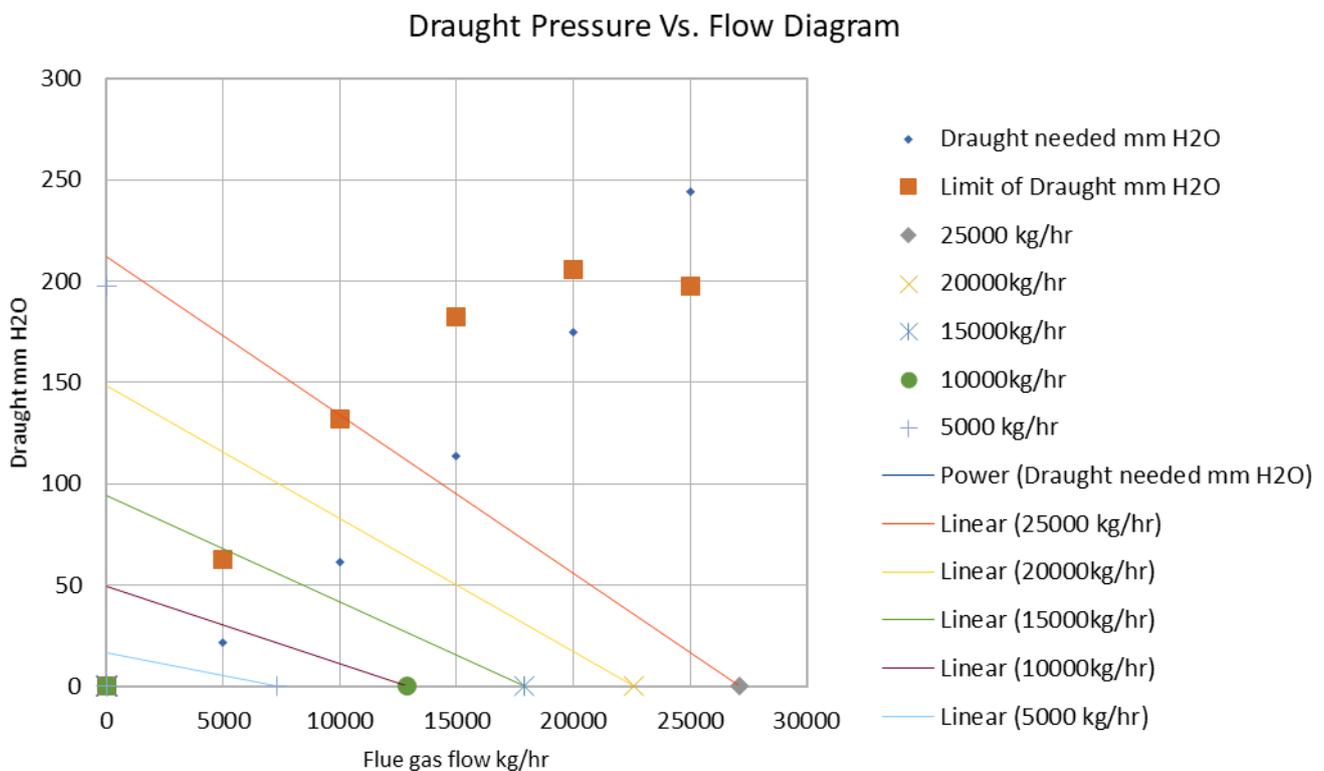

Figure 9: Draught Vs. Flow diagram for engine in good condition.

Figure 10 is a modified version of Figure 9 in which the draught requirement (dark blue curve) has been increased by 10%, which would be a reasonable reflection of tubes badly in need of cleaning, clogged smokebox screens or a part clinkered fire. At 20,000 kg/hr the spare draught has been reduced to virtually zero, but the maximum gas flow has only been reduced from around 22,000 to 20,000 kg/hr. The margin between draught available and draught required at lower gas flows has also been reduced, which would make the engine somewhat less responsive to changes in steam demand or recovery from low boiler conditions, but still able to perform quite well.

> **Key point -**
> **The performance envelope is only slightly reduced by increases in draught required by the boiler.**
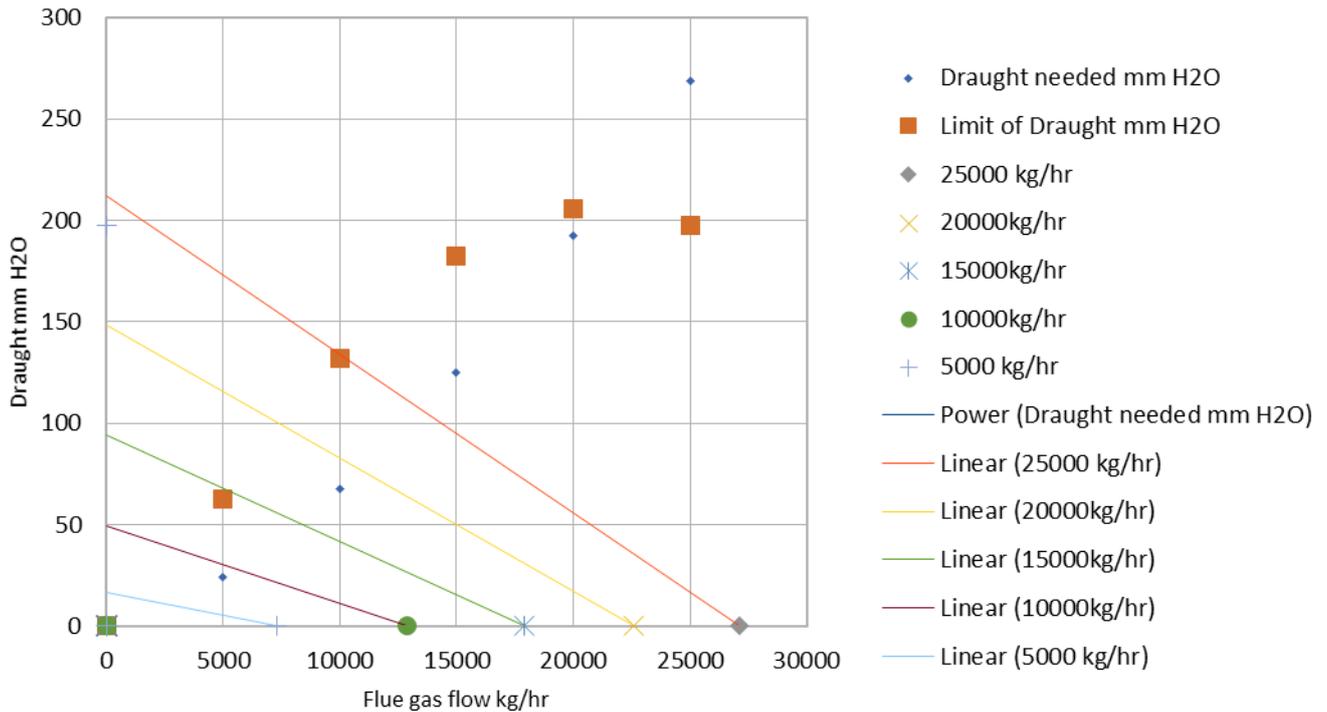
Figure 10: Performance with increased draught resistance (E.g. dirty / blocked tubes)

Figure 11 shows the effect of reducing the evaporation rate curve by 5%. This might reflect a locomotive in need of a washout (water side fouling) or tube sweeping (soot accumulation reducing heat transfer), excessive steam leakage, heavy steam demand for train heating or poor fuel of low calorific value. The effect is to reduce the maximum gas flow by 25% to 15,000 kg/hr, with a corresponding reduction in evaporation by 25%. In addition, the margin between draught required and draught available at lower steaming rates has been significantly reduced; it would be a nightmare to try and keep time on such an engine.

The poor performance could be rectified by reducing the blast nozzle size or improving draughting efficiency. However, that is scant comfort to a crew struggling to maintain time and needing yet another "blow up".
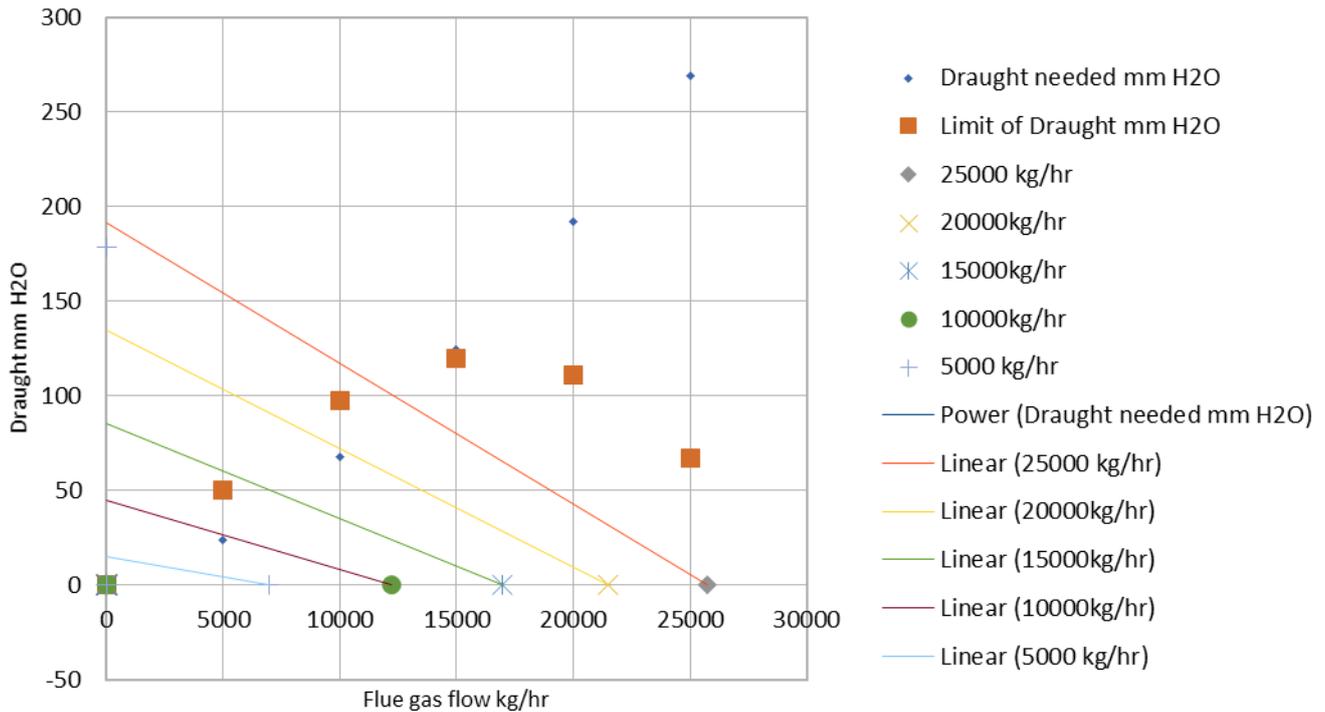
Draught Pressure Vs. Flow Diagram

Figure 11: Performance with reduced evaporation (E.g. in need of washout, poor coal, train heating steam demand etc.) and increased draught resistance.

> **Key point - Any reduction in the evaporation Vs. gas flow relationship significantly reduces the operating envelope and "manageability" of the boiler.**

8. HOW NOT TO IMPROVE FRONT END EFFICIENCY

While writing up these notes, I noticed that the draught required curve intersects the front end performance curves near the extreme right hand end. Since the optimum front end efficiency is at 50% of the zero draught gas flow (See section 6.2), this means that the front end is operating well away from the optimum point. The best efficiency point can be moved to the right by reducing the blast pipe / chimney throat area ratio, which makes for a flatter front end performance line, extending to greater gas flows.

I tried this approach using the spreadsheet I put together to draw the above figures and the results are shown in Figure 12, which is drawn for the same engine condition as Figure 9, but with the following front end geometry:

	Revised design	BR Std. 5 design
Blast pipe / chimney throat area ratio	0.08	0.13
Blast pipe diameter (inches)	6.38	5.13
Chimney throat diameter (inches)	22	14.25
Chimney top diameter (inches)	25	16.28
Chimney height (throat to top)	28.38	28.38
Assumed diffusion loss factor for chimney	0.9	0.9

The revised blast pipe diameter was chosen to give the same maximum gas flow as my analysis of the original Standard 5 design, so on a simple assessment the two versions give the same performance, but with a reduction of around 5 psi in back pressure.

However, Figure 12 shows that the margin between draught required and draught produced across the entire performance range has been dramatically reduced. Trying to fire such an engine would be like walking a tightrope with no margin for error at all.
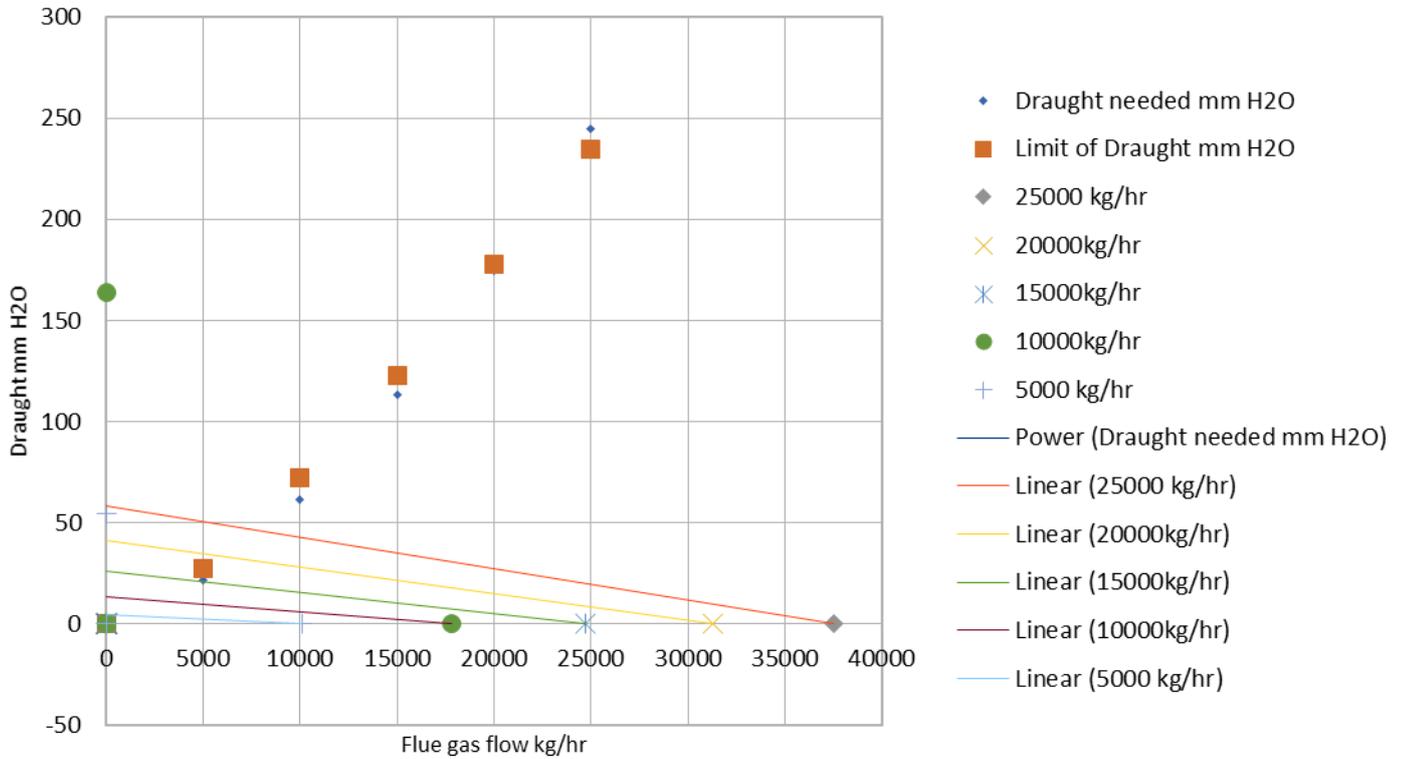

Figure 12: Effect of decreased area ratio on overall performance.

Key point - Front end design is about a lot more than just achieving a single design point with minimum blast pipe pressure.

9. CONCLUSIONS

- I have introduced a novel method which shows the interaction between draught demanded by the boiler and draught produced by the front end across a range of flue gas and steam flows.

- The operating envelope of an engine is defined by the draught required and draught available curves.

- The ease with which a locomotive can be fired and managed depends on the margin between the two curves.

- Minimising blast back pressure at the expense of reducing the operating envelope is unlikely to improve engine performance.

- I have still to explore how an examination of existing designs would indicate "good" and "bad" design practice in terms of specifying an operating envelope. Further work required.

10. NEXT TIME

I had hoped to start discussing time dependent aspects of the front end, but have already filled quite enough newsletter. So in preparation for the next article, consider this thought experiment:

> If we could put a very large steam tank in the exhaust line between cylinders and blast pipe, would the engine still go "chuff"?

11. REFERENCES

11.1 Porta, L.D. - "Theory of the Lempor Ejector as Applied to Produce Draught in Steam Locomotives" http://www.trainweb.org/tusp/lempor/lempor_theory.pdf (1974)

11.2 Koopmans J.J.G. - "On the Calculation of Steam Locomotive Front-End Performance" Publ. Jnl of Stephenson Locomotive Society September/October 2017- No. 907, Volume 93 p. 201 also available at: https://www.researchgate.net/publication/320756980_On_the_calculation_of_steam_locomotive_front-end_performance

11.3 Young. E.G. - "A Study Of The Locomotive Frontend, Including Tests Of A Front-End Model" Bulletin 256 University of Illinois May 30th 1933 also available at: *https://www.ideals.illinois.edu/handle/2142/4435 and https://www.ideals.illinois.edu/handle/2142/4484*

11.4 Collins, W.F. "Standing Locomotive Tests" Railway Mechanical Engineer Feb 1941 pp 57-59 & March 1941 pp 96-100 (1941)

11.5 Massey B.S. "Mechanics of Fluids" 3rd Edition Publ.Van Nostrand Rheinhold 1968

11.6 Anon - "Ejectors and Jet Pumps - Design and performance for incompressible liquid flow", Publ. ESDU Intl. Item No. 85032, (Dec. 1985)

11.7 Porta L.D. - Application of the Gas Producer Combustion System to the 141R - an Exercise. Updated Nov. 1998. Included in "Selection of Papers by L.D. Porta Vol. 3" Transcribed & Edited by C. Newman Publ. 2021 by ASTT

11.8 Porta L.D. - A Criticism of the Lawford Fry Method. Revised July 1976 Included in "Selection of Papers by L.D. Porta Vol. 3" Transcribed & Edited by C. Newman Publ. 2021 by ASTT

11.9 Hall W.B. - "Predicting Locomotive Performance" available at https://www.advanced-steam.org/wp-content/uploads/2017/08/Predicting-Locomotive-Performance.pdf

MAINLINE & MARITIME

LOCOMOTIVES INTERNATIONAL

February - March 2022
Issue 135

UK Price £5.95

9 771353 709018

35

Featuring: AUSTRALIAN NRM - INDIAN NG - SBB "MICHELINES" DURBAN - POLAND - CHINA - CFTV - **AND MORE!**