

Pulverised coal as steam loco fuel

A largely forgotten chapter in steam locomotive development and
history

Eelco de Bode

Pulverised coal as steam loco fuel

- The usual disclaimers..
- Lopulco
- STUG
- AEG
- Deutsche Reichsbahn (G.D.R. post 1945)
- Victorian Ry.
- A future?

The problem with conventional coal burning

- Human labour capacity
 - The grate limit
 - The cost of coal
-
- First two factors limit the power output of a steam locomotive by limiting the firebox energy input.

Techniques doing away with manual firing

- Mechanical Stokers gradually coming into use as of 1900 in the US first, as engines became too big to fire manually. Later other countries followed.
- With the exception of –maybe- France, Czechoslovakia, Poland, mechanical stokers were never widely employed in Europe, inc. the UK.
- Oil firing. Technology of end of 19th century. Outside the UK, post 1950 fairly widely employed in a number of European countries. France, Spain, Germany. A number of US roads. Oil still too expensive around 1910-20.
- Pulverised coal. 1915-ish technology. Both sides of the Atlantic

Why pulverised coal?

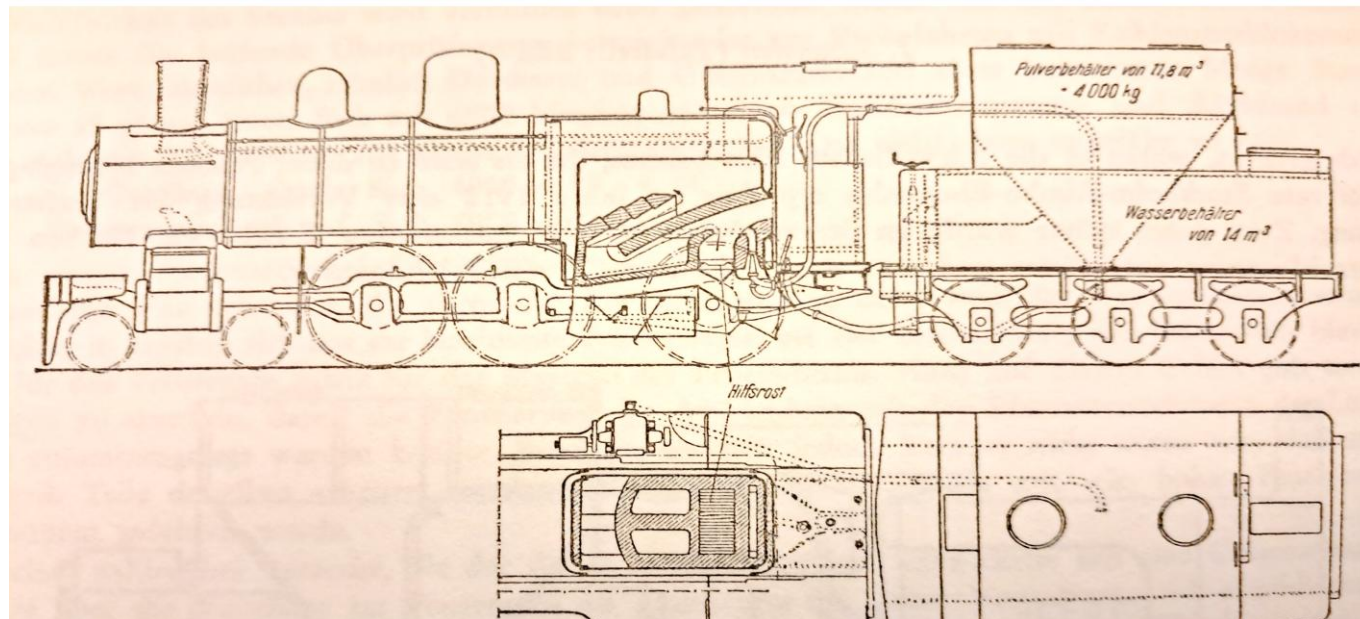
- Coal prices skyrocketed after 1916
- Additional bonus: low fuel costs
- In the USA, the use of pulverised coal promised an easy way to increase steam loco output, without extra physical labour for the fireman

Waste in coal production

- e.g. UK in 1920, some 230 million tons of coal were mined in the UK.
- In that year all railways in the UK combined consumed some 12 million to 13.5 million tons.
- Total losses 30% in the entire production and transport chain. Some 75 million tons of waste material.
- These immense losses were a strong driving force behind development of pulverised coal as loco fuel: use of waste material.

The first experiments with pulverised fuel

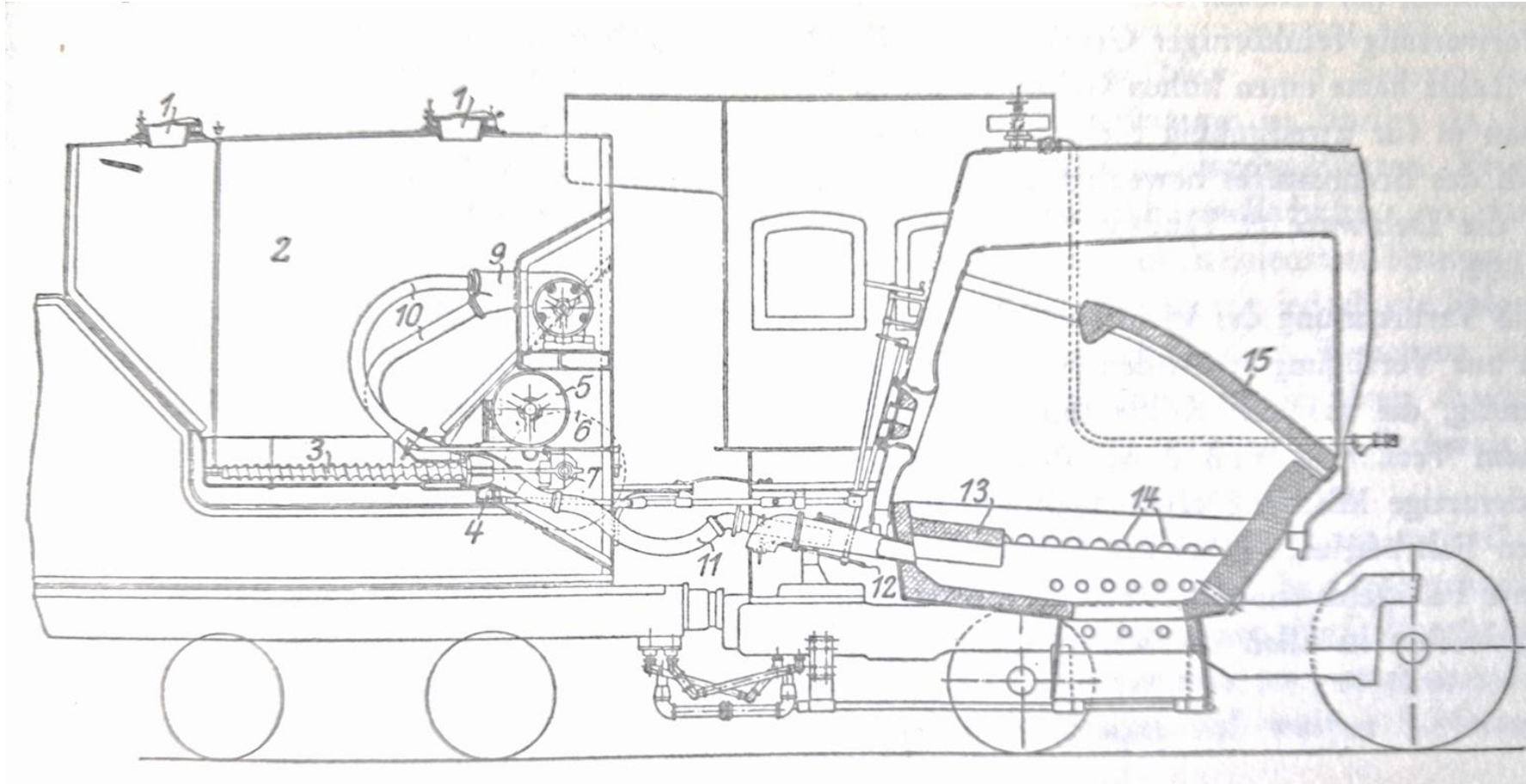
- To my best of knowledge, the first application of a dust type locomotive fuel took place in Sweden in 1912, using peat dust. Source of inspiration most likely oil burning.
- Some 27 locomotives were successfully converted used between 1914 and 1932. Not many details are known. Converted back to coal after 1932.



The first experiments with pulverised coal

- In 1914 the New York Central started experimenting with pulverised coal. Loco 2147, a 2-8-0, was used for stationnary experiments.
- Technology came from the Locomotive Pulverised Coal company : Lopulco
- Pulverised coal and air were electrically (!) mixed and fed.
- Later, the mixer and blower were steam driven.

USA: The Lopulco system on NYC 3131



The 1917 promise

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THE NEW YORK TIMES, SUNDAY, FEBRUARY 4, 1917.

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PULVERIZED COAL MAY REVOLUTIONIZE RAILROADING

Will Save From 20 to 40 Per Cent. in Fuel, Says Expert, Increase Boiler Efficiency From 10 to 15 Per Cent., and Utilize Low Grade Coals and Refuse Now Practically Valueless

COAL is going to be a pretty hard thing to get before long, so it is gratifying to learn that a year's experiments just completed show that the use of pulverized coal in locomotives not only saves fuel, but does away with a very large part of the smoke nuisance. The expenditure for locomotive fuel for the steam railways in the United States now approximates \$200,000,000 a year, which from \$75,000,000 in 1900, 000 represents the proportion that is expended to handle, prepare, clean, and maintain fires on grates when locomotives are standing, or otherwise not actually using steam to move themselves, either alone or with trains.

John E. Mulholland of the American Society of Mechanical Engineers, this city, says that the performance of locomotives in regular road passenger and freight service during the past year has demonstrated that the burning of pulverized coal saves from 20 to 40 per cent. in fuel of equivalent heat value fired, and increases the efficiency of boilers from 10 to 15 per cent.

This accomplishment not only means a decrease in the cost per ton for locomotive fuel, says Mr. Mulholland, but also the release of a large tonnage of commercial anthracite, which is becoming more scarce and in greater demand each year. The possibilities of making use, in pulverized form, of the low-grade coals in the West, which now have to be passed over as unsatisfactory for locomotive use, will also be readily recognized.

It has also been shown in the tests just completed that the burning of fuel in pulverized form on locomotives eliminates the necessity for electrification to provide smokeless, cinderless, sparkless, and noiseless operation. But, although the technical advantages are numerous, the thing that will be best understood and appreciated by the general public is that it will be feasible to utilize existing refuse and such grades of fuels as cannot be readily disposed of by mine operators in the commercial trade, and which now make up from 25 to 50 per cent. of the mine output necessary to produce the domestic readily salable store.

between the pieces of coal and the products of combustion pass off in the flues. Coal dust does not burn under such conditions, as the particles are so fine that sufficient air for combustion does not reach the coal through the cracks between the particles.

To burn powdered coal successfully it must be burned while in suspension in the air. In such a position each particle is surrounded by the air, which supports the combustion. The Portland cement industry uses a form of furnace that is favorable, since it is very long and affords plenty of room for combustion in suspension. Boiler furnaces, because of form and proportion, make more difficult the problem of burning coal in that manner.

The chief item of expense in the use of pulverized fuel is the installation of the necessary plant for grinding the coal and distributing the dust to the points where it is to be burned. The effect there items of cost, the labor required is said to be less with dust firing than with the usual method.

From tests made with pulverized lignite having an analysis of about 1.8 per cent. moisture, 47 per cent. volatile, 41 per cent. fixed carbon, 9.6 per cent. ash, and 0.75 per cent. sulphur, and a heating value of 10,000 British thermal units per pound, in regular passenger locomotive service, the same satisfactory results were obtained as with bituminous coals, the combustion and operating being entirely smokeless, sparkless, and cinderless, and the steam pressure being fully maintained, says Mr. Mulholland.

With pulverized fuel the control of steam is nearly perfect. A locomotive can be fired up and the fuel consumption then stopped until a few minutes before starting time. At the end of the run the fire can be extinguished at will and quickly rekindled without any special equipment or materials. A locomotive with boiler full of water and 185 pounds of steam pressure, after standing eleven hours without fire, still had 80 pounds of steam pressure.

Comparative tests made between similar locomotives in the same service resulted in the use of 2,775 pounds of lump coal, hand-fired to get up steam, and for terminal handling and dead time, as compared with 1,569 pounds of pulverized screenings to produce the same result, or an increase of over 75 per cent. The greatest

saving is in the firing up alone, this requiring 1,700 pounds of lump coal as compared with 750 pounds of pulverized screenings, or an increase of over 225 per cent.

"In the engine house terminal handling there is the least possible delay and expense. No more time or facilities are required than for fuel used in locomotive operation; and oil-burning locomotives. A locomotive fired up at 6 o'clock can leave with its train at 7.

"From results established during the past six months, the quantity of live steam required for the operation of pulverized fuel-burning equipment when the locomotive is being worked to its maximum boiler horse power capacity is about 15 per cent. of the saturated steam generated, which is considerably less than what is required for the steam-jet operation of mechanical stokers when firing coal on grates, and very much less as compared with what is used in the generally existing steam-jet practice of burning fuel oil; this latter amount, according to reports made by the United States Naval Board, is approximately about 60 per cent. of the total steam generated, exclusive of the reduction of efficiency in combustion due to the evaporation of steam into hydrogen and oxygen and back into H₂O in the firebox.

"Comparing the use of pulverized fuel and fuel oil for steam locomotive purposes, it may be stated that with pulverized coal at \$2.75 British thermal units, costing \$2.35 a ton, and fuel oil at 19,000 British thermal units, costing \$2.75 a ton, an amount of at least \$2.50 must be expended for the fuel oil necessary to perform the same useful work as will obtain from \$1 expended for pulverized fuel.

"During the last decade the cost for moor, labor, and material entering into the financing, new general construction and equipment, and the maintenance and operation of railroads, including taxes, has increased enormously; while the gross operating revenues for each passenger and for the ton-mile have decreased," says Mr. Mulholland. "For this reason the credit of many properties, which is dependent upon the net profits and the probability of earning capacity, has seriously depreciated.

"To continue to establish satisfactory credit in order to provide adequate capital at reasonable cost, a steam railway must preserve the proper ratio between operating revenues and expenses; and this ratio is largely contingent upon the effectiveness of its developed means for moving traffic.

"As next to labor the largest single item of cost for transportation is the fuel used in locomotive operation; and in the final analysis the cost of such revenue passenger or the ton-mile is largely conditional upon the capacity, effectiveness, and economy of the unit of motive power per hour it is easy to realize to what extent the result of a steam railway is controlled by its locomotive performance and expense.

"Necessity for conserving the limited supply of oil in the rapidly exhausting fields, for other than railway fuel purposes, will soon eliminate this fuel from locomotive service; while the higher prices and shortage in supply of the larger sizes and better grades of solid fuels that are in demand for the commercial trade will bring about the use of the less salable general by-product of the mines in pulverized form by the railways and industries adjacent to the mines.

"The extraordinary expenditure required for first cost and fixed charges, as well as for combined maintenance and operation, together with the necessity for reliability and flexibility in motive power, precludes the general use of electricity either from an engineering or an operating standpoint for the movement of heavy traffic over long distances.

"However, there are now certain established rules and regulations governing the manufacture, storage, handling, and use of pulverized fuel which make it comparatively easy to avoid trouble where ordinary care is exercised, as confirmed by the records of industrial plant operations.

"Where pulverized fuel has been stored in dry, airtight, and fireproof bins and kept below a temperature of 150 degrees Fahrenheit no cases of spontaneous combustion are known to have occurred.

"From investigations to date, any solid fuel that, in a dry, pulverized form, has two-thirds of its content combustible is suitable for steam-generating purposes.

"Domestic and steam ships and qualities of anthracite, bituminous, and semi-bituminous coals, and lignite and peat, as well as the inferior grades, such as anthracite culm, dust, and slush, and bituminous and lignite slack, screenings and dust, are all suitable for burning in pulverized form.

"To produce the best results these fuels should be mechanically dried and milled so that they will be of about the same dryness and fineness as Portland cement; or so that the moisture will not exceed 1 per cent., and so that 5 per cent. of the total will pass through a 100-mesh screen, and 50 per cent. of the total will pass through a 200-mesh screen. This applies to anthracite as well as to bituminous coals.

"As over 8,000,000 tons of pulverized fuel are now being used annually in the United States for industrial kilns and furnaces, it is not thought that the equipment or process for preparing pulverized fuel requires any comment.

"The total cost to prepare pulverized fuel properly in a suitably equipped drying and pulverizing plant will range from 15 to 45 cents a ton, depending upon the capacity of the plant. For a railway coaling station of average capacity this total cost will be less than 25 cents a ton, an item which will be more than offset by the difference in the cost on the tender of the grade of coal purchased for pulverizing and those that would be required for burning satisfactorily on grates.

"A solid cubic inch of coal exposed only six square inches for the liberation of heat, while in pulverized form a cubic inch of coal exposes from 50 to 25 square feet, insuring possibly a much more uniform production of gas.

"The steam railways in the anthracite coal mining district generally use for their locomotive fuel mixtures which will run from 25 to 50 per cent. of bituminous and the balance of anthracite pea and buck sizes which will pass through a seven-eighths-inch and over a five-sixteenths-inch round opening. As anthracite coal is very low in volatile, ignites slowly, and is a poor conductor of heat, the bituminous mixture is used to overcome the trouble this causes when the smaller sizes must be burned on grates, and even then it necessitates the use of unusually small exhaust nozzles to create sufficient draft.

"In the experiments with pulverized anthracite fuel for locomotives the idea has been to utilize the grade of coal of lowest commercial value, such as slush, which is of a size that will pass through a five-sixteenths-inch and over a one-sixteenths-inch round opening, as well as the refuse called culm or slush, which passes through the one-sixteenths-inch round opening and is usually wasted in the washery water or used for back-filling the mines. To reclaim this slush, a couple of wooden bins were installed, through which the washery water could be finally passed for the collection of the solid matter.

"At the beginning of the development work the locomotive was equipped to burn the following mixtures, the last of which," Mr. Mulholland says, "is now being used with satisfactory results as the 60 per cent. bituminous and 40 per cent. anthracite.

First—25 per cent. run-of-mine bituminous and 75 per cent. anthracite slush.

Second—45 per cent. run-of-mine bituminous and 55 per cent. anthracite slush.

Third—60 per cent. run-of-mine bituminous and 40 per cent. anthracite slush.

Fourth—50 per cent. run-of-mine bituminous and 50 per cent. anthracite slush.

Fifth—30 per cent. run-of-mine bituminous and 70 per cent. anthracite slush.

Sixth—10 per cent. run-of-mine bituminous and 90 per cent. anthracite slush.

"Further work along this same line," Mr. Mulholland says, "will determine just how great a percentage of anthracite slush can be used to the best advantage, but the comparative results so far obtained—that is, about seven pounds of water from feed-water temperature a pound of coal—indicates that considerably more than a 60 per cent. anthracite slush mixture may be utilized. This accomplishment not only means a decrease of 25 per cent. in the cost a ton for locomotive fuel, but also the release of a large tonnage of commercial anthracite, which is becoming more scarce and in greater demand each year.

"The principal trouble to be overcome has been on the lubrication runs, as it is more difficult, with the less than with the higher volatile coals, to maintain proper combustion with a clear fire and to regulate the fuel after the feed has been stopped for a time.

For more than thirty years various schemes for burning powdered coal in boiler furnaces have been suggested, and numerous patents have been taken out on various processes and burners, but until recently without any marked degree of success. In the Portland cement industry commercial success was attained more than fifty years ago.

The early experiments were naturally crude, and failed largely because of the lack of proper machinery for reducing the coal to the required size and for distributing it so that it would be exposed to the heat of the fire in the form of dust.

During the early years of the Portland cement industry in this country coal was employed as a fuel. This was conveyed into the burner end of the furnace with a jet of compressed air at pressure.

The oil was employed successfully, but due to the increasing cost after 1850 its use was very unattractive. From 1850 to 1900, the increase in price was such as to make the use of oil nearly prohibitive from a commercial point of view, and was the principal incentive for developing the use of pulverized coal.

In 1874 a series of experiments relating to the use of pulverized coal was started by the Atlas Cement Company, and these experiments and its many discoveries, the increase of various parts, and finally the commercial development of the process, thirty and a half years, and the re-invention of the Atlas Company, are entitled, according to Professor C. C. Carpenter, the Cornell authority, to the credit of the first successful use of pulverized coal in the cement industry. The success of the process of burning pulverized coal, having been established, the process in other mills until about 1900, when the process was put in successful operation in various plants by independent investigators.

That the subject has not been neglected by inventors is shown by the fact that during the last twenty years there have been more than twenty patents issued for pulverized coal burners. Claude Hottelinger of Johns Hopkins, South Africa, where the price of coal is high, attacked the problem by designing a boiler especially for use with pulverized fuel. He took out his first patent in the United States, but his boiler was first commercially exhibited in England. He met his death in an accident about four years ago.

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The promise

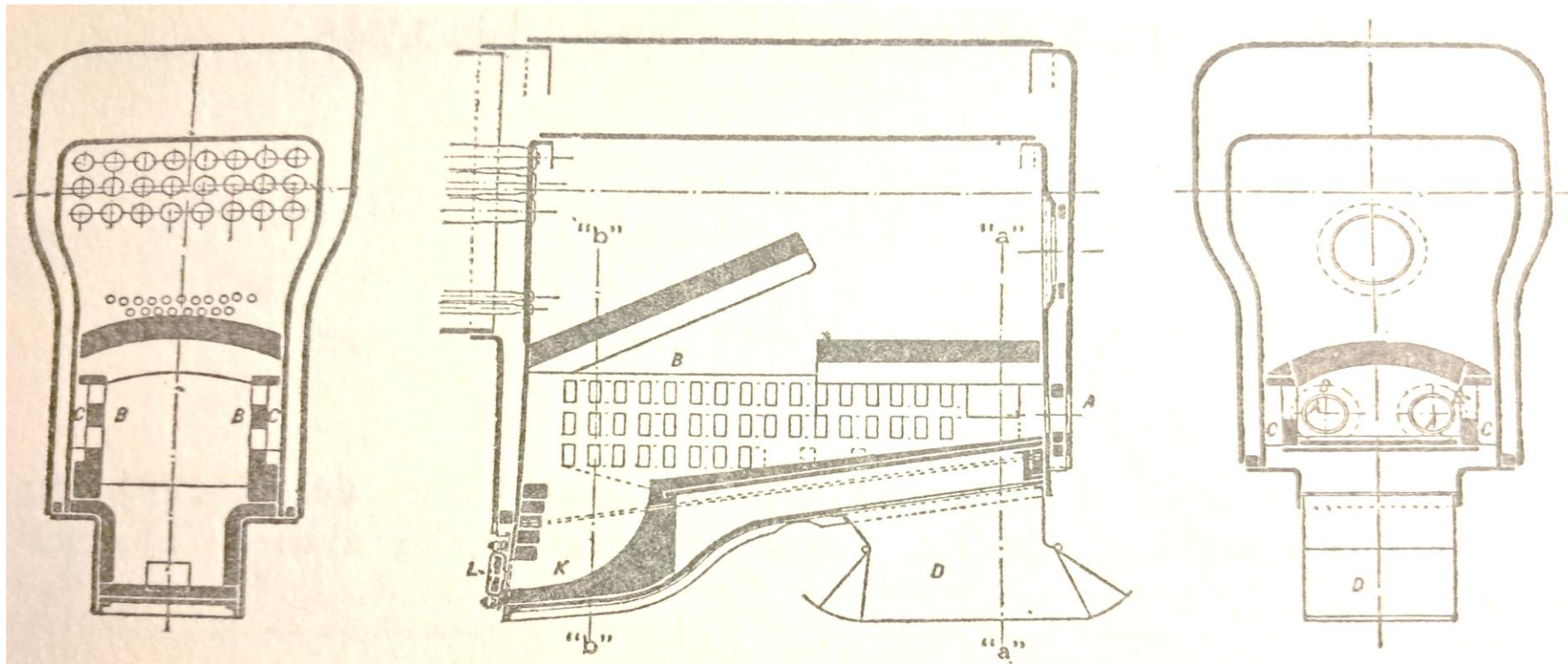
- Improved cab cleanliness
- No more heavy manual labour
- Uniformity of fuel
- Cheap fuel
- Better control
- Improved steaming/higher efficiency + increased output
- Elimination of smoke

In the US several companies experimented

- Results were a mixed bag, very coal dependant
- Lots of wear and tear
- Fuller Lehigh Engineering became Lopulco's (later renamed in the Combustion Engineering Company) main competitor
- By 1930 all experiments had come to an end

The UK

- The Great Central Railway nr. 353, converted by J.G. Robinson around 1917 based on Robinson's patent.



Great Central Railway

- Bunker on tender
- Two screws for two mixture inlets in the firebox
- De Laval blower for blowing the air-coal dust mixture into the firebox
- Secondary air inlets at sides of the firebox



Southern Railway

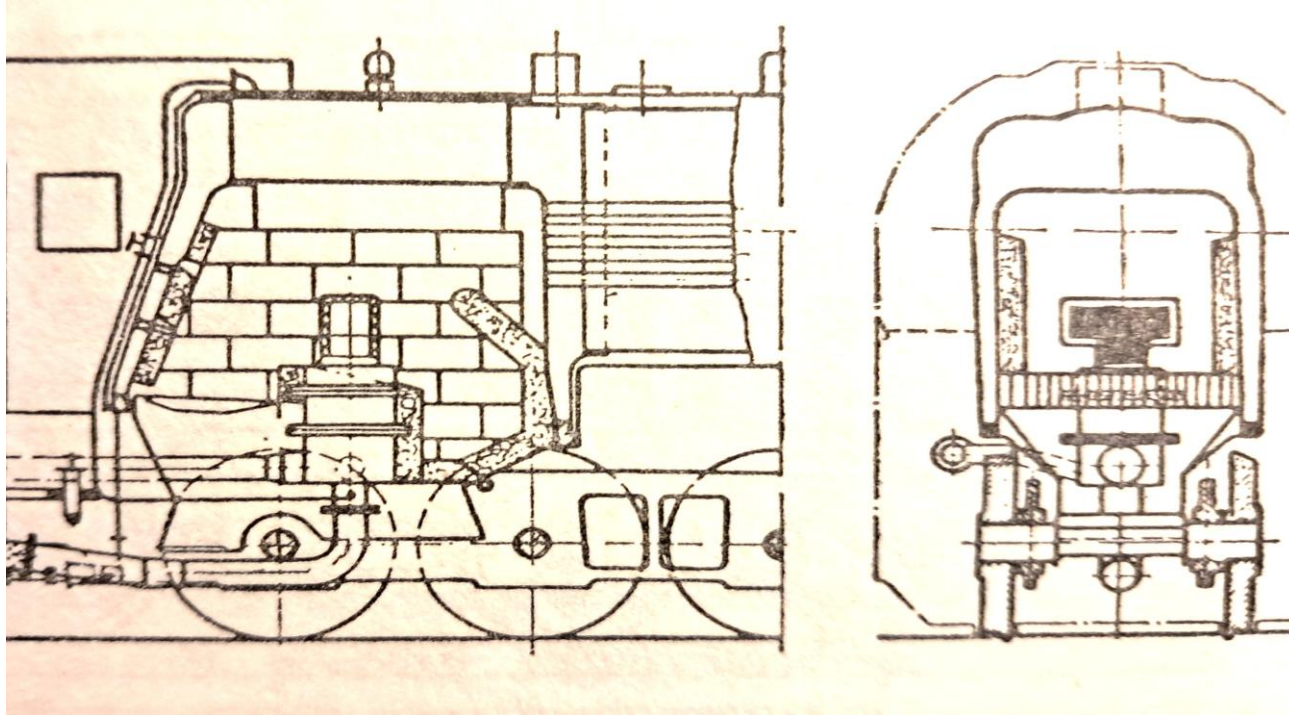
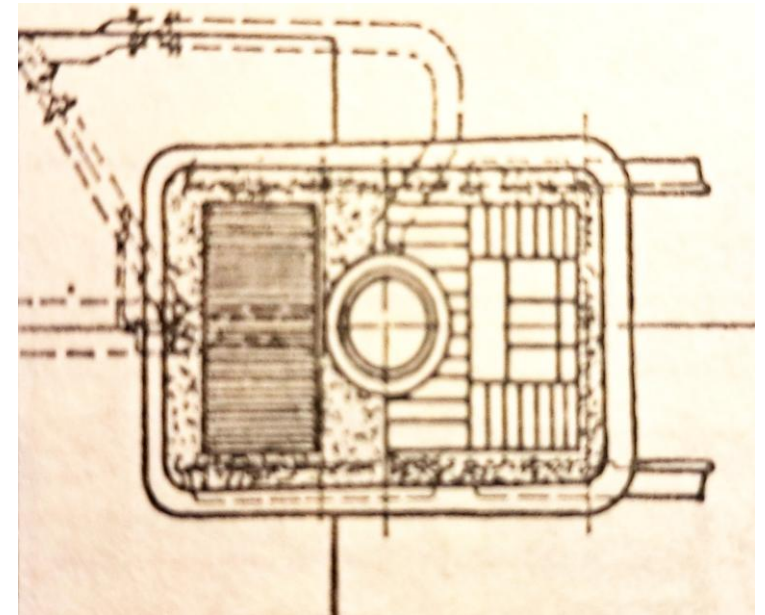
- Short lived 1927-1929 experiment on U class locomotive 628.
- Ended after a minor coal dust explosion



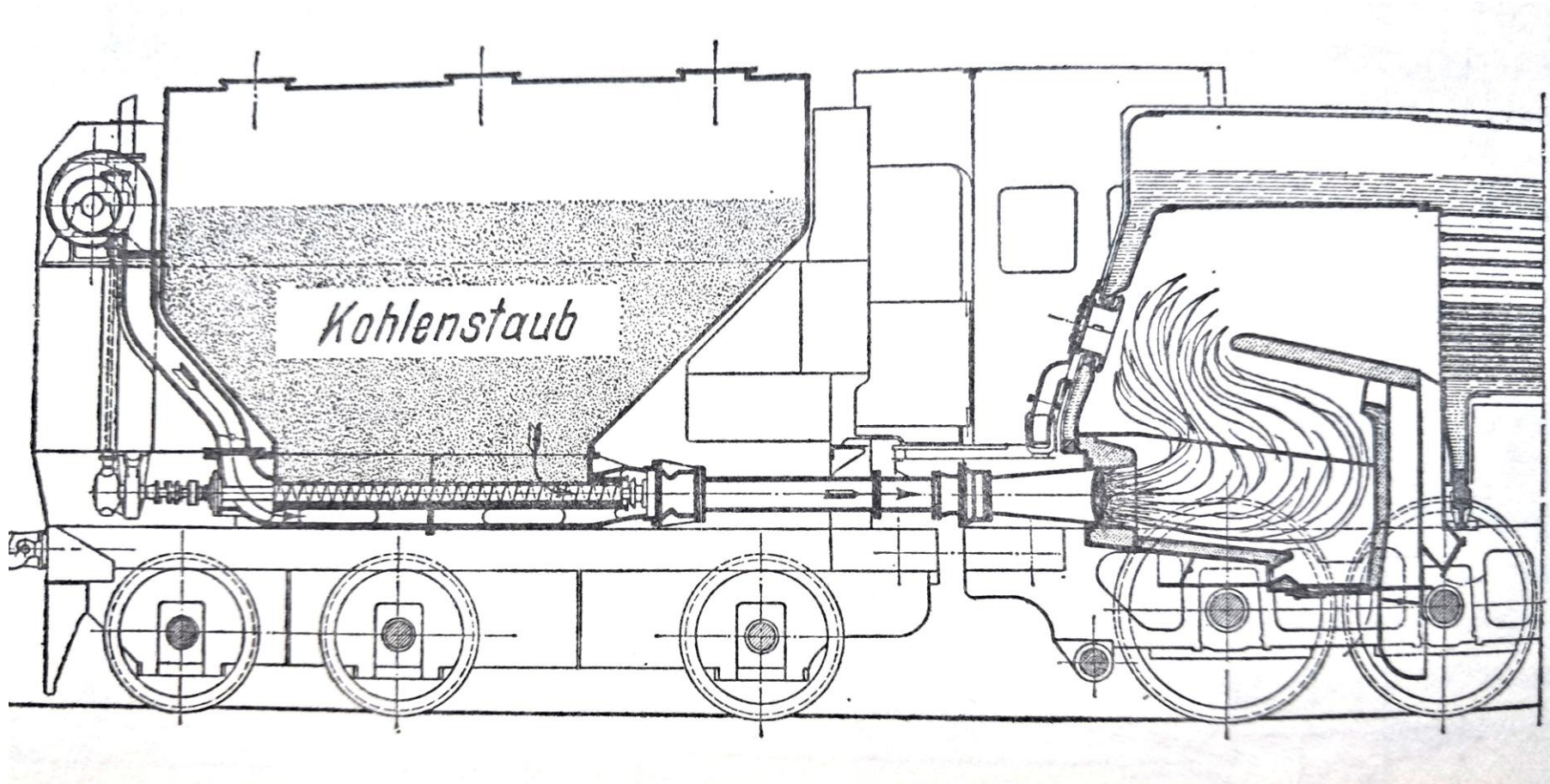
Germany: AEG and STUG

- As of 1923 STUG (Study Council for pulverised coal) started its work.
- STUG consisted of representatives of all major loco builders and all major coal producers in Germany. This type of cooperation was very common in Germany. R&D resources were thus easily coughed up.
- AEG followed suit in 1924

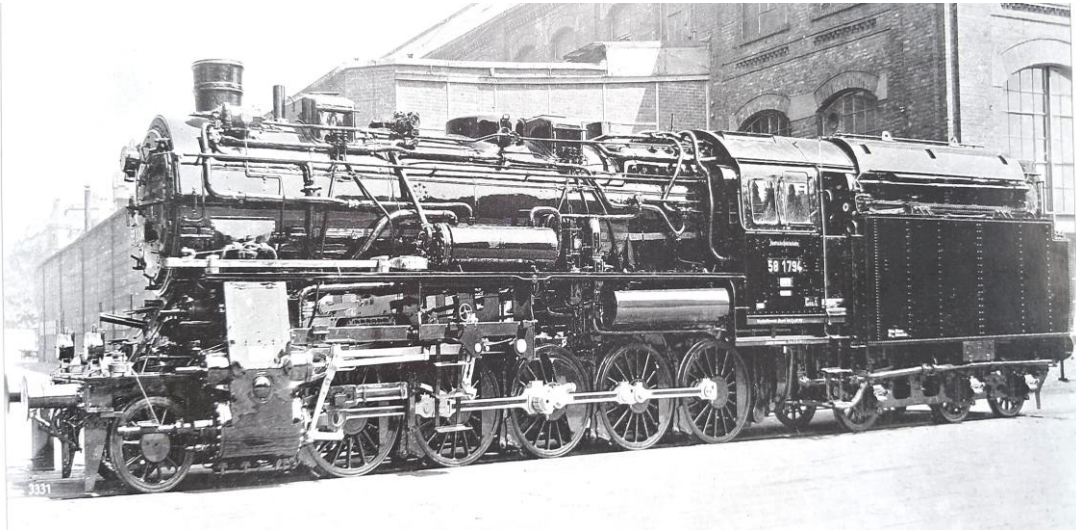
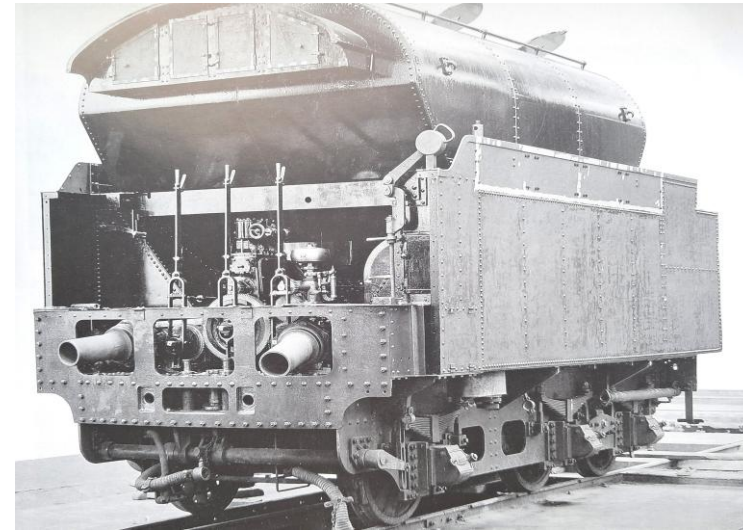
STUG' first designs: a vertical burner 1924



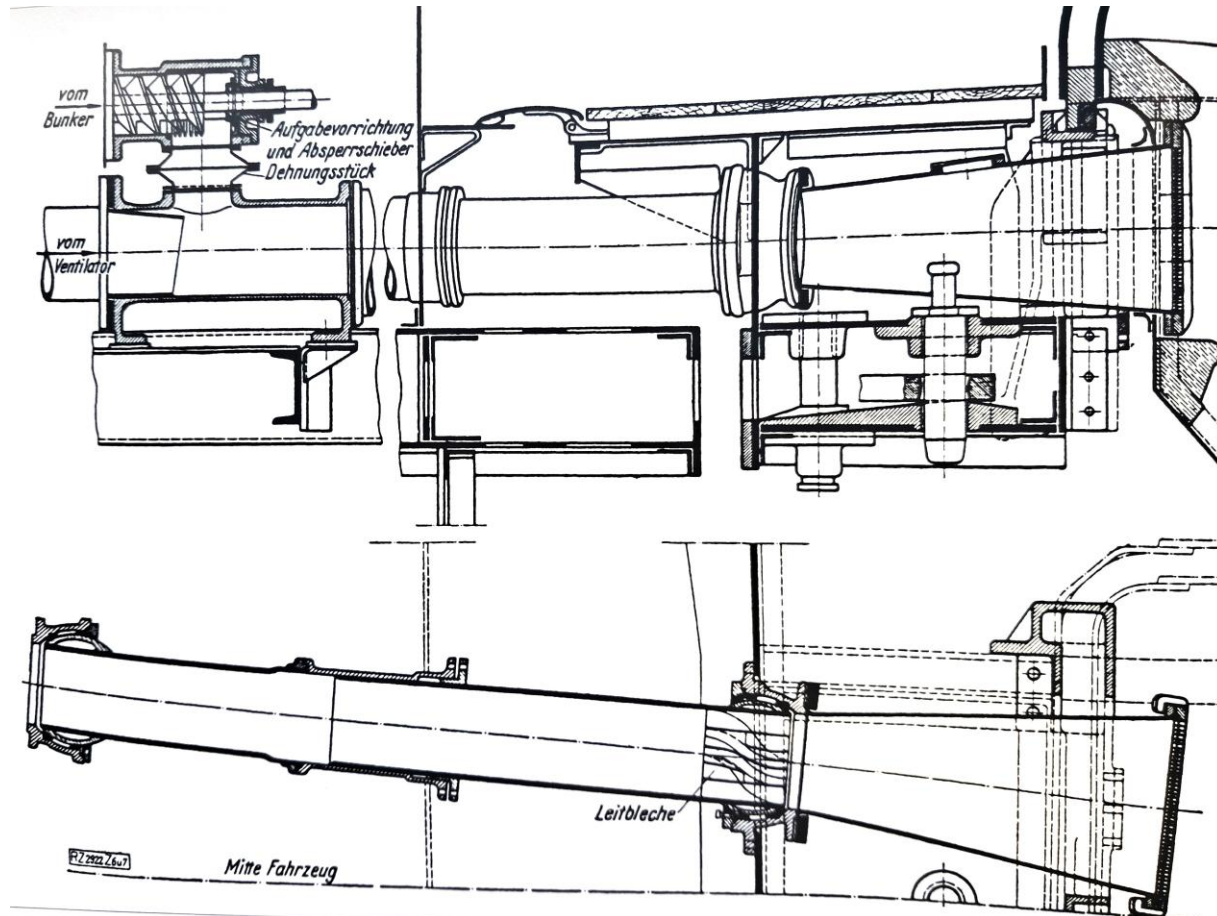
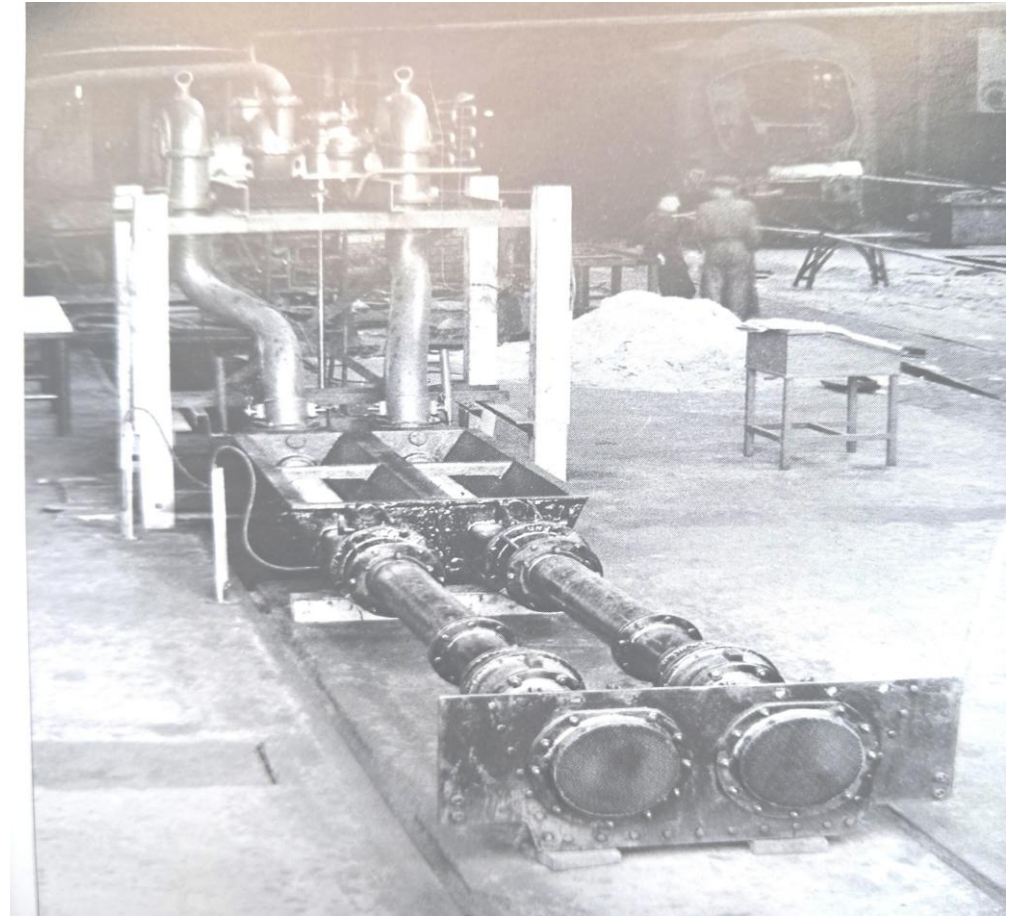
STUG 1930 on DR class 58



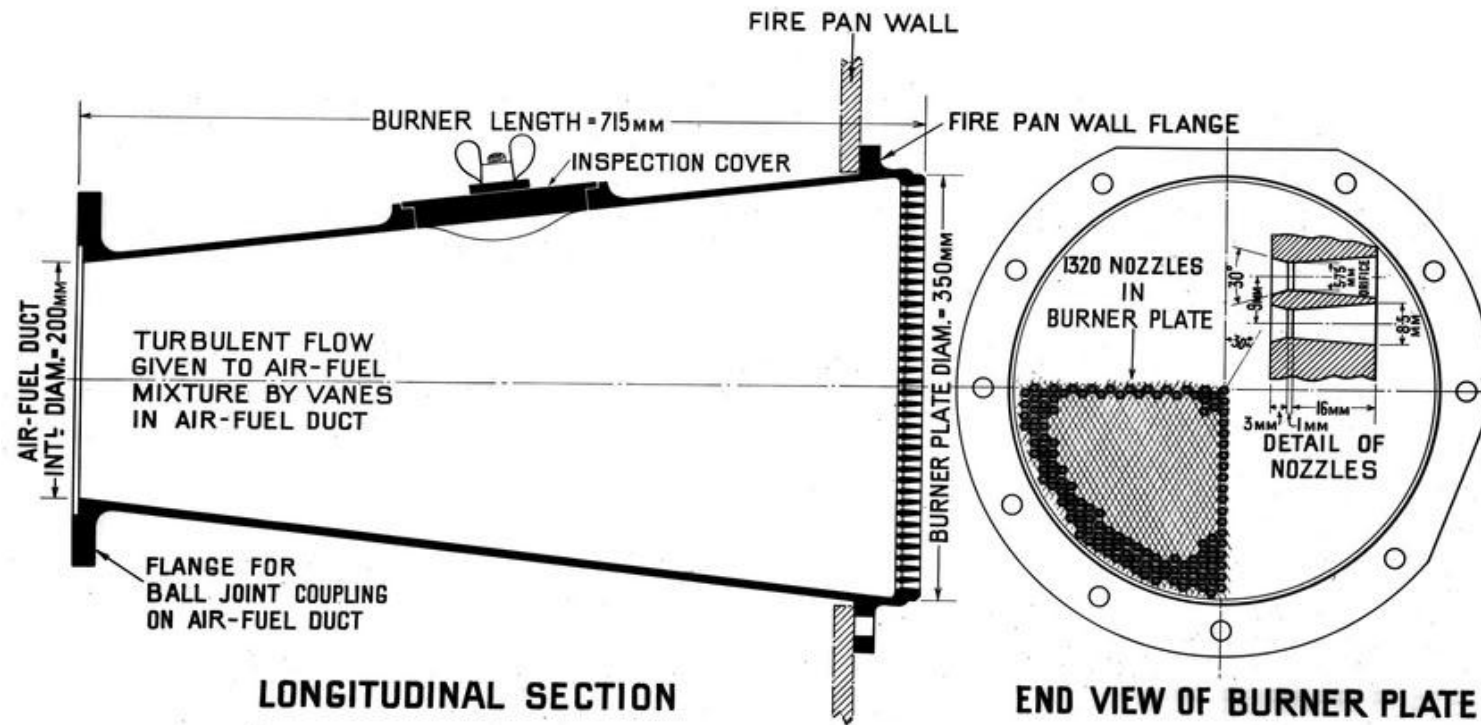
DR Class 58/G12 PC Tender



STUG 1930



Burner detail



"STUG" PULVERISED BROWN COAL LOCO. BURNER
(CAPACITY 3000 LB. PER HOUR)

Allgemeine Elektrizitäts Gesellschaft/ AEG

- In 1924 AEG started experiments with pulverised coal firing
- Applied on newly built DR class 56, not a modification of existing locomotives
- Biggest difference with STUG in its final version was the use of side burners

Allgemeine Elektrizitäts Gesellschaft/ AEG

Source of inspiration rather obvious...

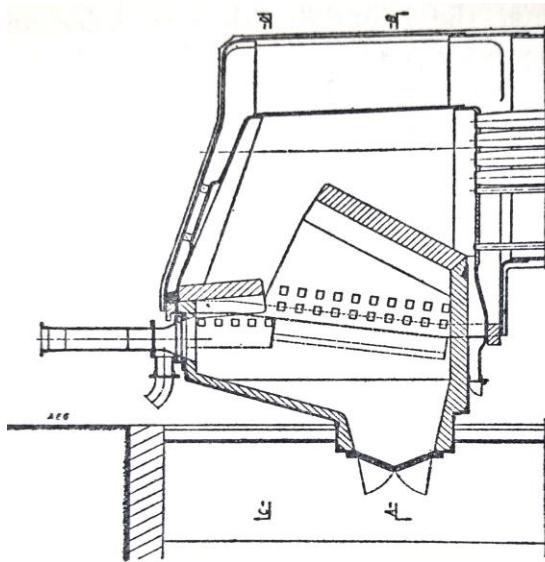
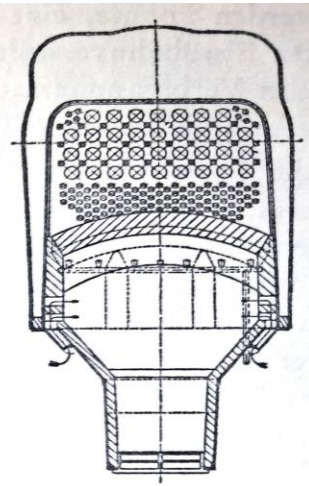
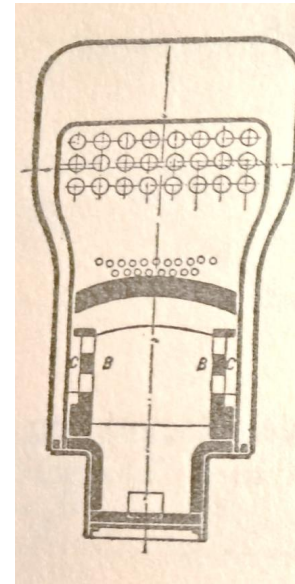
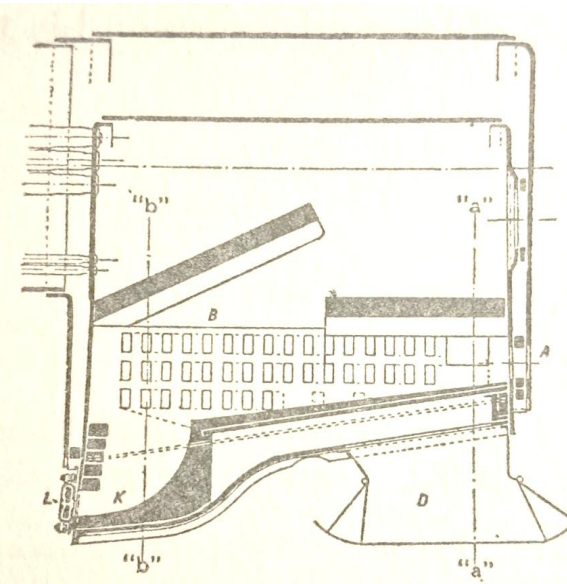
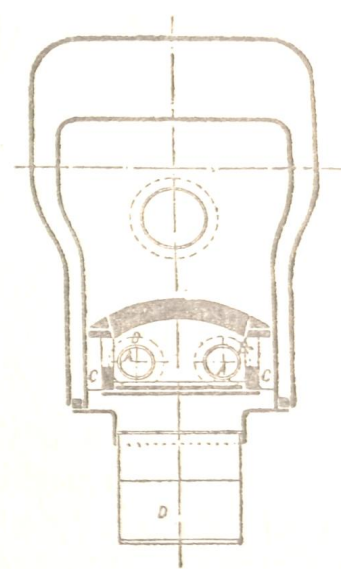
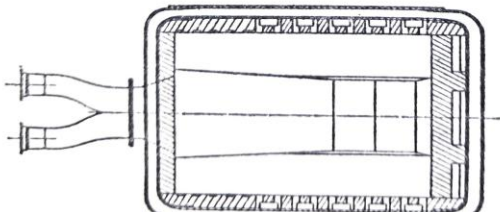
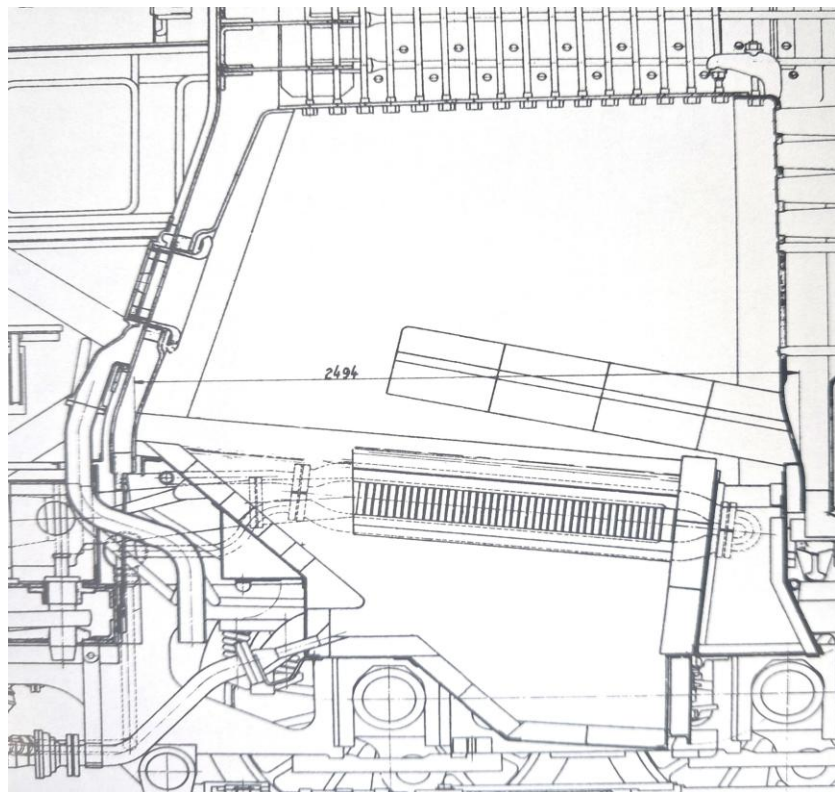
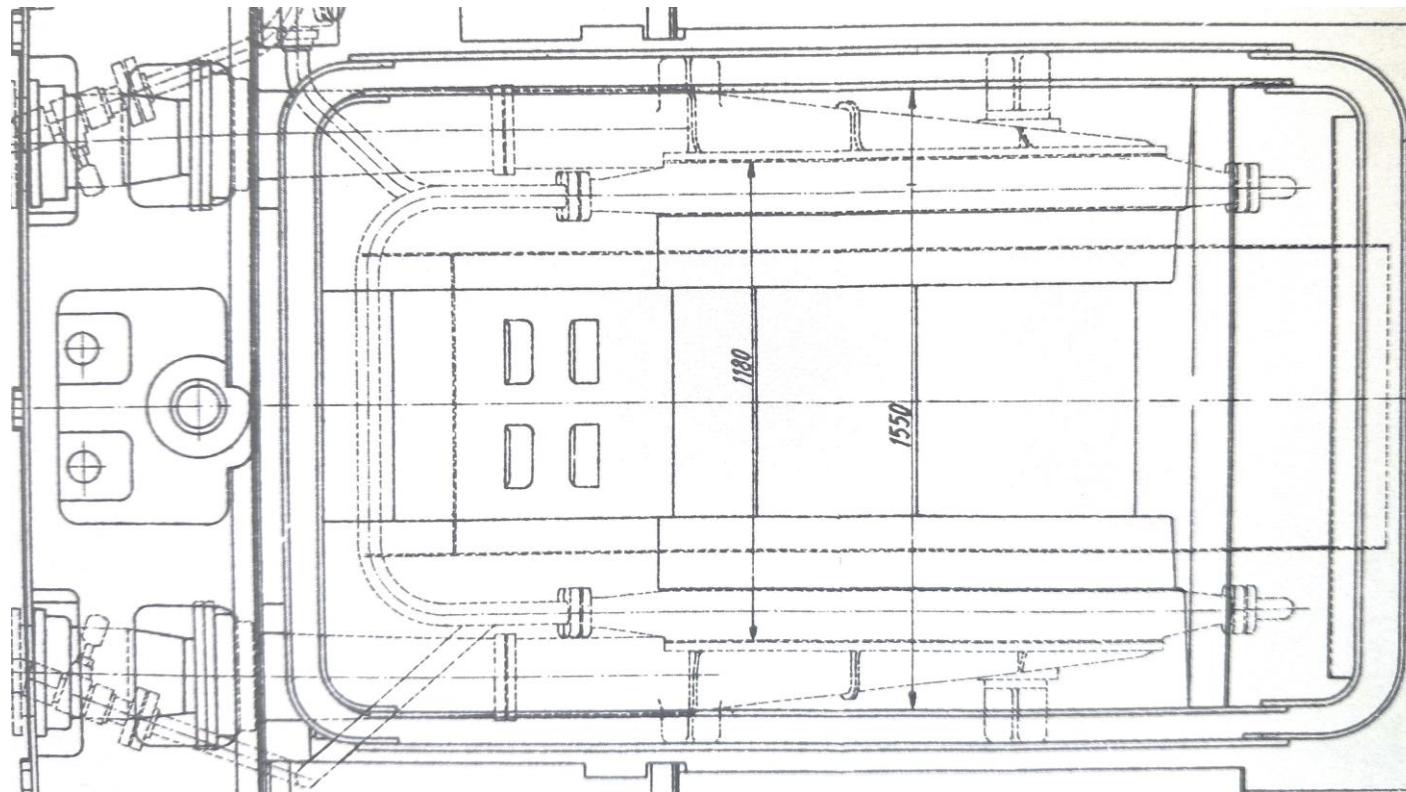


Abb. 13: AEG-Versuch

AEG Final version



AEG system Grunewald tests

- In May 1930 very extensive measurement trials were carried out with DR 58-1416 between Potsdam and Burg. Some 80 kilometers.
- Highest output results rather spectacular: more than 30% higher than regular class 58/G12.

The Potsdam-Burg tests: 40km/h

Schieberkastendruck atü	kg/cm ²	13,0	3,2	13,0	13,0
Zylinderfüllung	%	34,1	20	37,5	27,5
Mittlerer indizierter Druck	kg/cm ²	—	—	6,726	4,49
Druck im Blasrohr atü	kg/cm ²	0,22	0,03	0,18	0,24
Zugkraft am Haken der Lokomotive	kg	11 740	0	13 650	8 500
Indizierte Leistung	PS _i	—	—	1 736	1 930
Zughakenleistung	PS _e	1 744	0	1 519	1 577
Temperatur im Schieberkasten	°C	410	275	398	404
Temperatur im Ausströmröhr	°C	183	—	169	167

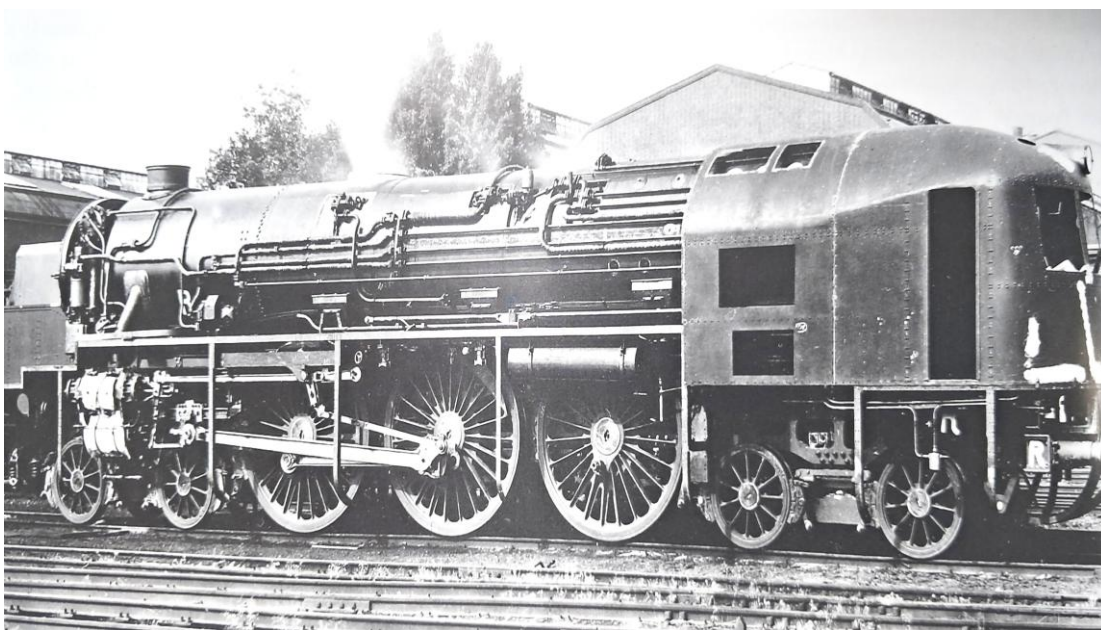
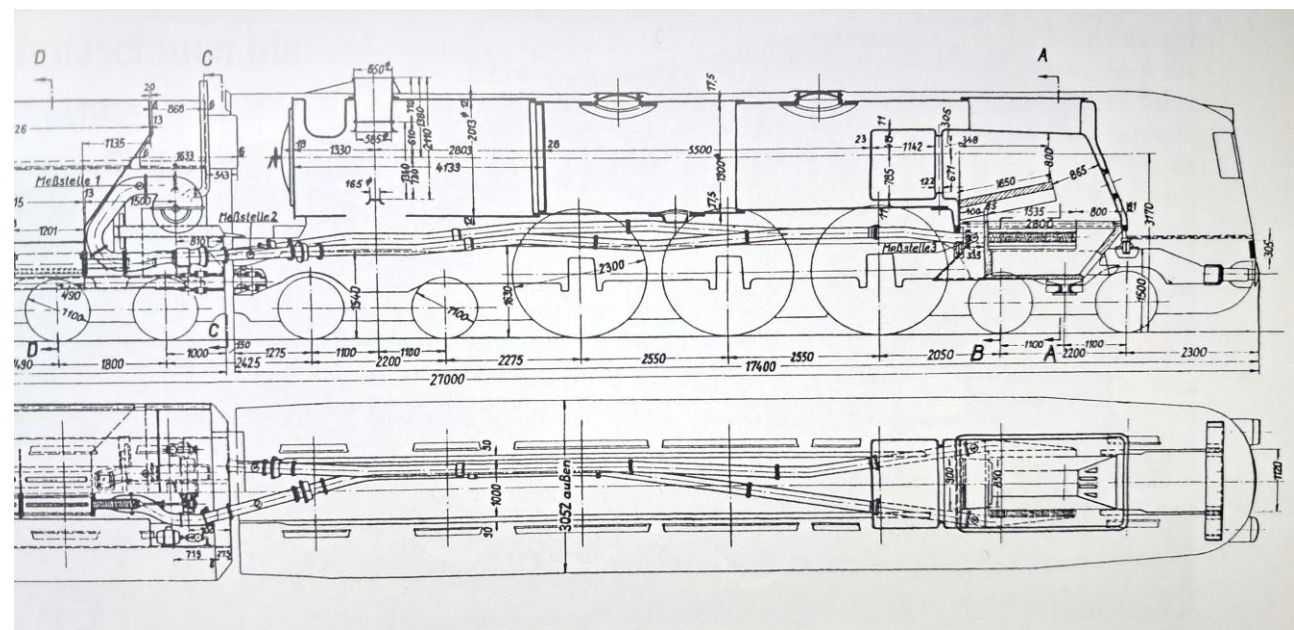
The Potsdam-Burg tests: 60km/h

Schieberkastendruck atü	kg/cm ²	13,0	13,0	5,0	11,0	13,0
Zylinderfüllung	%	37,5	27,5	20	20	25
Mittlerer indizierter Druck	kg/cm ²	6,726	4,49	0,441	2,568	3,911
Druck im Blasrohr atü	kg/cm ²	0,18	0,24	0,01	0,12	0,18
Zugkraft am Haken der Lokomotive	kg	13 650	8 500	0	4 660	7 210
Indizierte Leistung	PS _i	1 736	1 930	228	1 324	2 018
Zughakenleistung	PS _e	1 519	1 577	0	1 038	1 600
Temperatur im Schieberkasten	°C	398	404	319	370	401
Temperatur im Ausströmröhr	°C	169	167	—	139	167

DR: Halle I Depot (BW Halle I)

- 1931 : concentration of all p.c. loco's in one depot.
- 4 loco's class 56; 6 loco's class 58
- Daily exploitation was relatively problem free after initial fine tuning and trouble shooting
- Wear of the copper fireboxes was excessive: max 9mm after 65.000 km (40.000 mile)
- No more conversions due to lack of economic gains

The infamous DR 05-003: a total failure



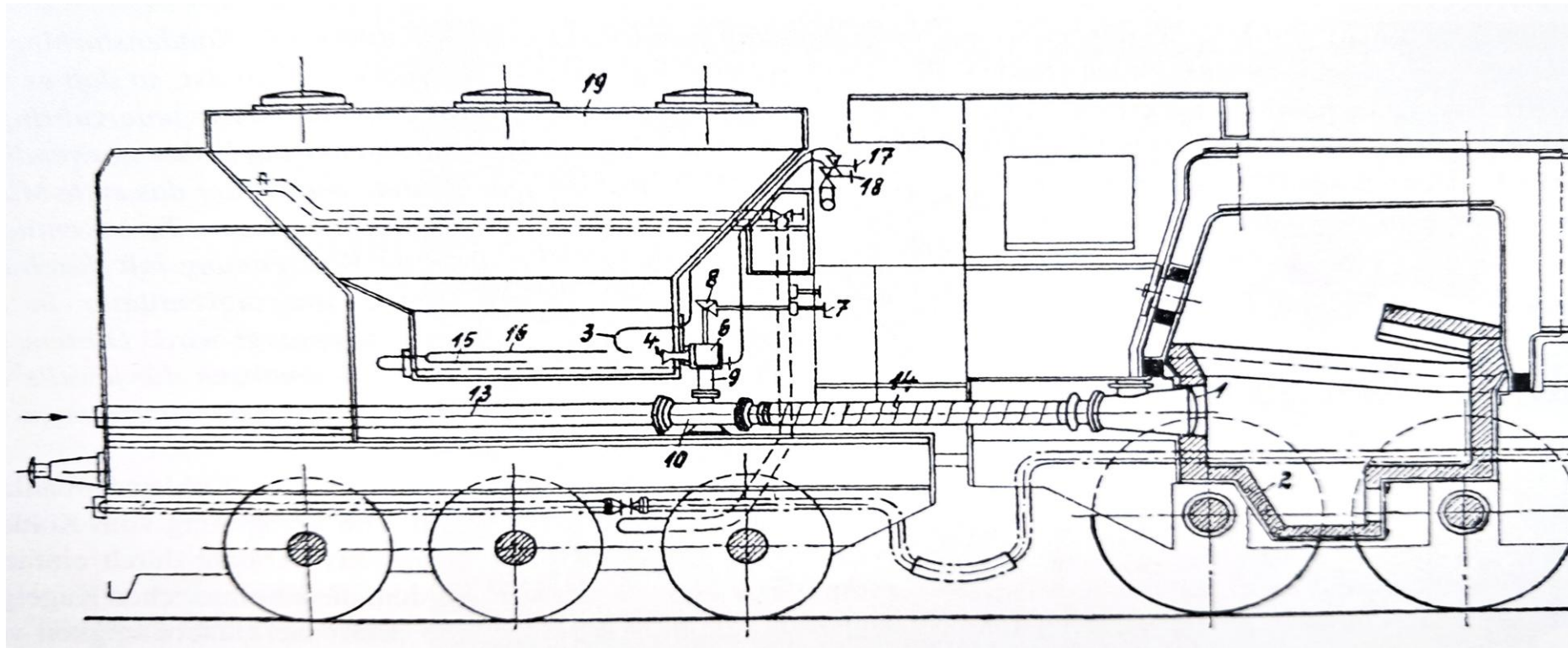
Wendler and postwar D.R. experiments

- East Germany had no coal mines of any real substance.
- Brown coal widely available
- The original 10 DR pulverised coal loco's were all in East Germany
- All sorts of fantastic plans...
- Enter: Hans Wendler

Wendler

- The quest for simplicity brought back some of the STUG technology
- AEG was too complex for post war conditions
- Wendler designed a system a la STUG, but simplified.
- No blowers: all action by smokebox vacuum and air pressure in bunker
- Brown coal briquette production leftovers

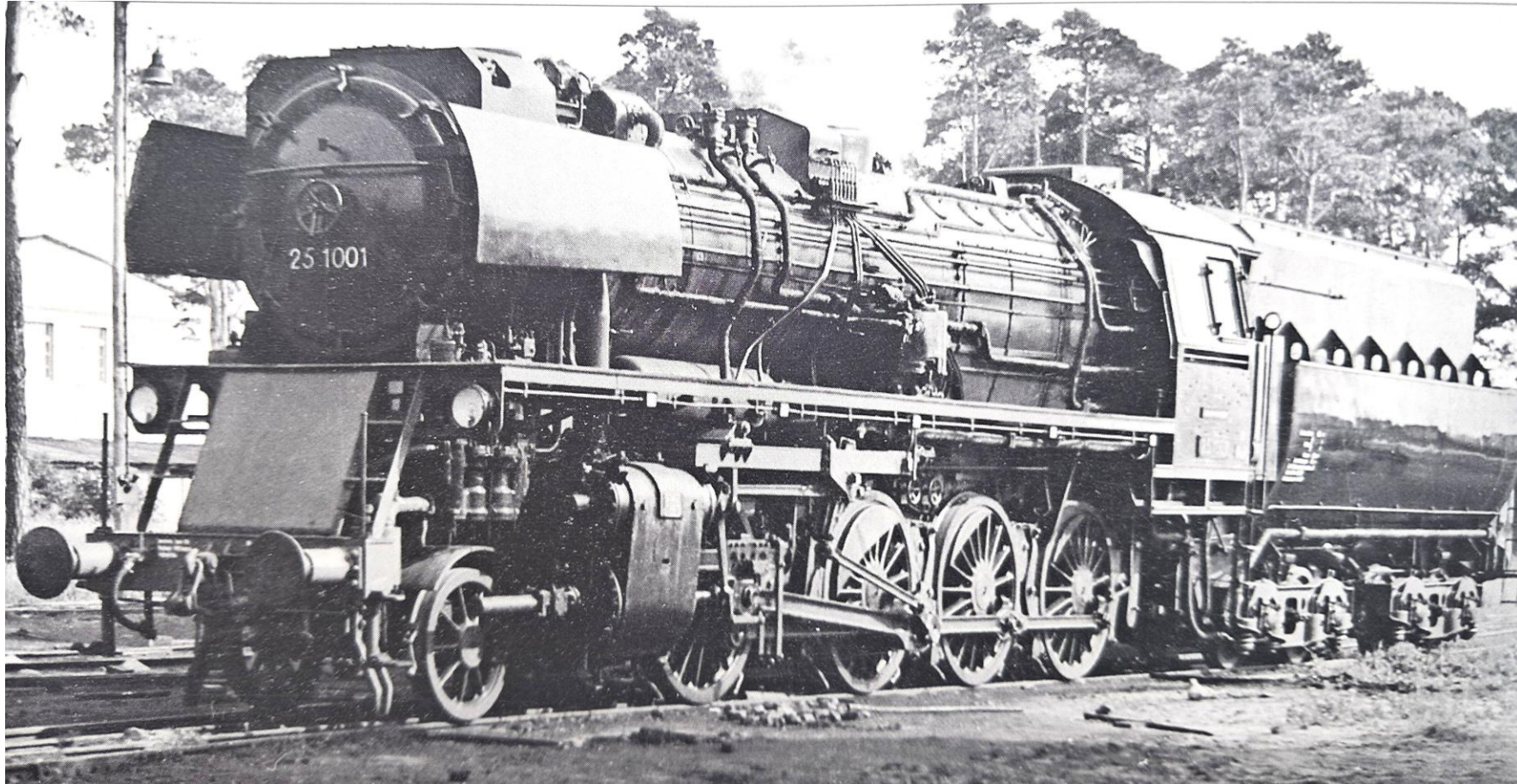
Wendler



17-1119: reaching for the stars..



DR: Another experiment 25-1001



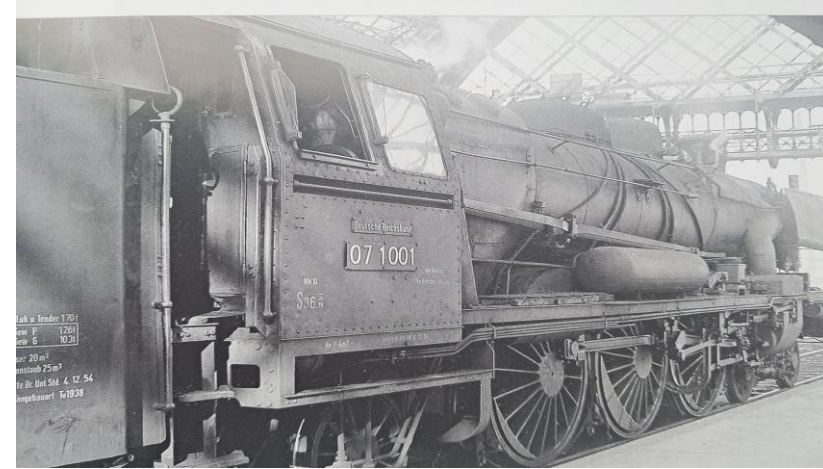
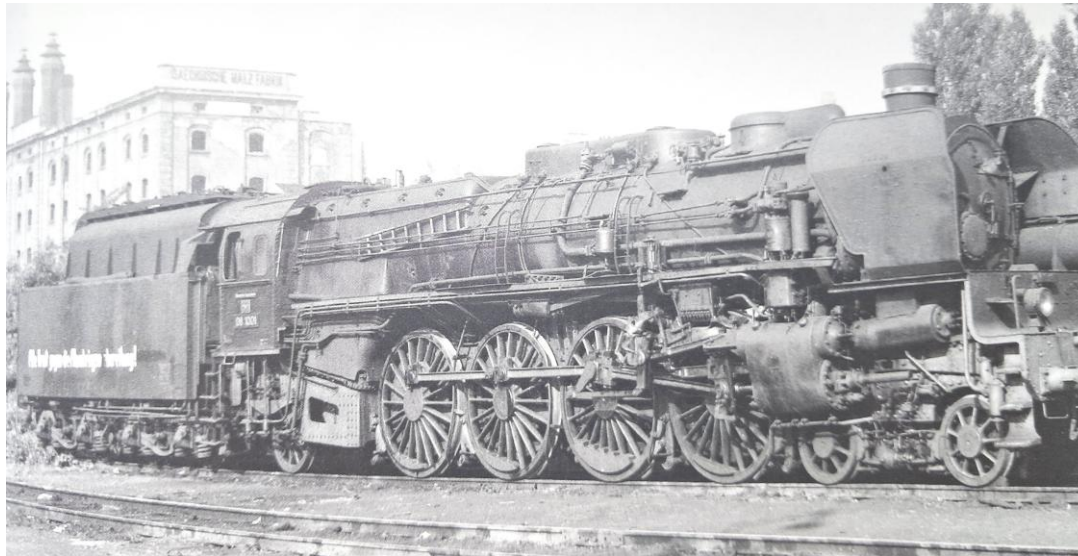
Wendler pushed forward

- The programm of 1949:
- 15 Goods loco's class 58
(25 years old on average)
- 14 Passenger loco's class 17-10
(former S10-1: 30+ years old on average)
- Many more planned in later years

DR 1951-1954

- 42 loco's class 58
 - 12 loco's class 44
 - 14 loco's class 17-1
 - 12 loco's class 52
-
- Overall performance once again a mixed bag:
 - Maintenance and repair costs higher than conventional coal firing
 - Marginally more economic
 - Frequent failures
 - Complex infrastructure

DR Dust Express Locomotives: a funny lot



The end: Arnstadt and Senftenberg late 70ties

- Around 1960 the class 17 locos were withdrawn
- Around 1968 the class 58 idem
- Class 44 and 52 survived, fairly succesful, until 1976 in Arnstadt and Sebftenberg depots. Arnstadt nowadays is a museum depot.
- Senftenberg held out even until 1978
- DR 52-9900 only survivor

And then in 1983... BKW Geiseltal

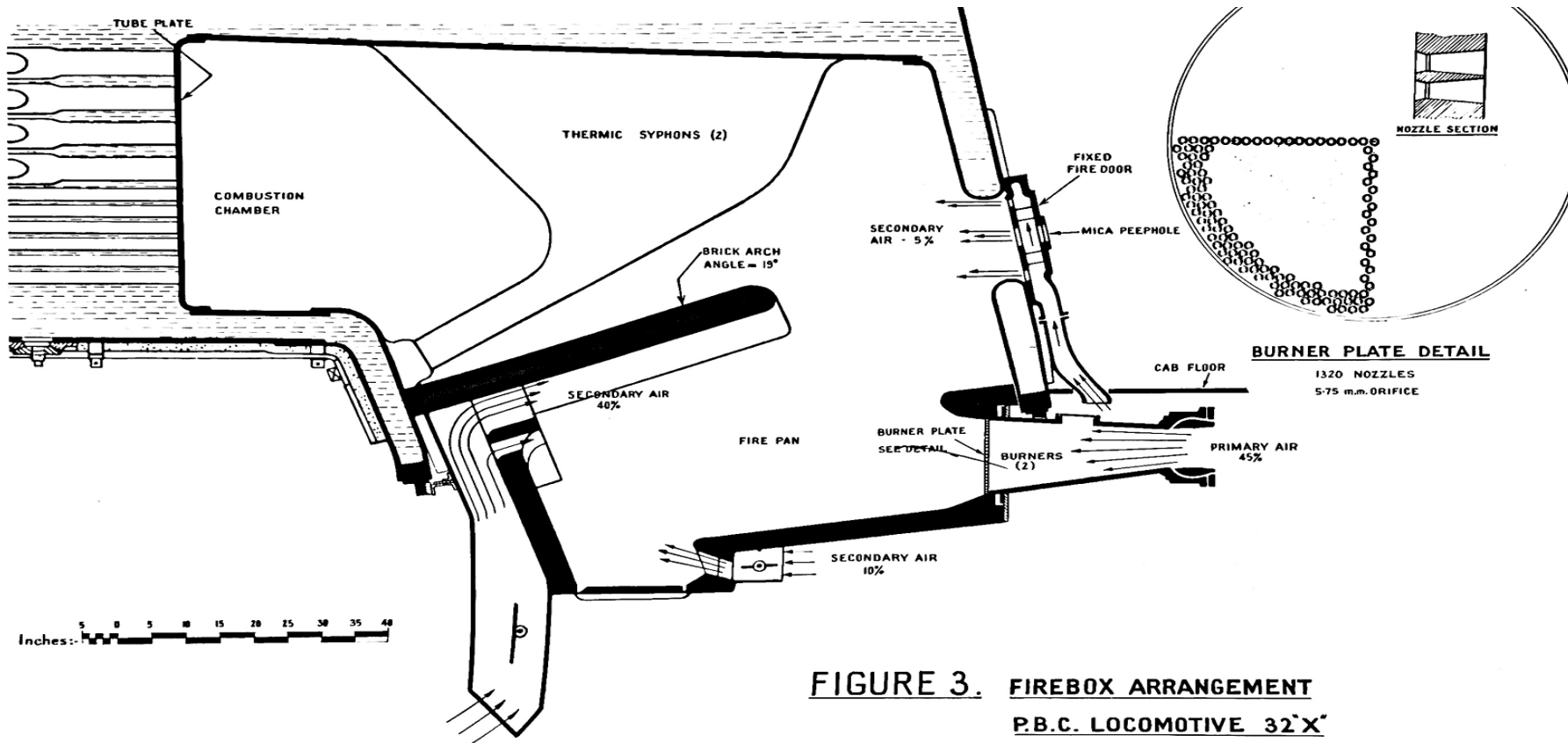


AUS: Victorian Railways

- In 1950 Victorian railways successfully tried pulverised coal on locomotive. STUG technology based. Equipment bought in Germany.



Victorian Railways



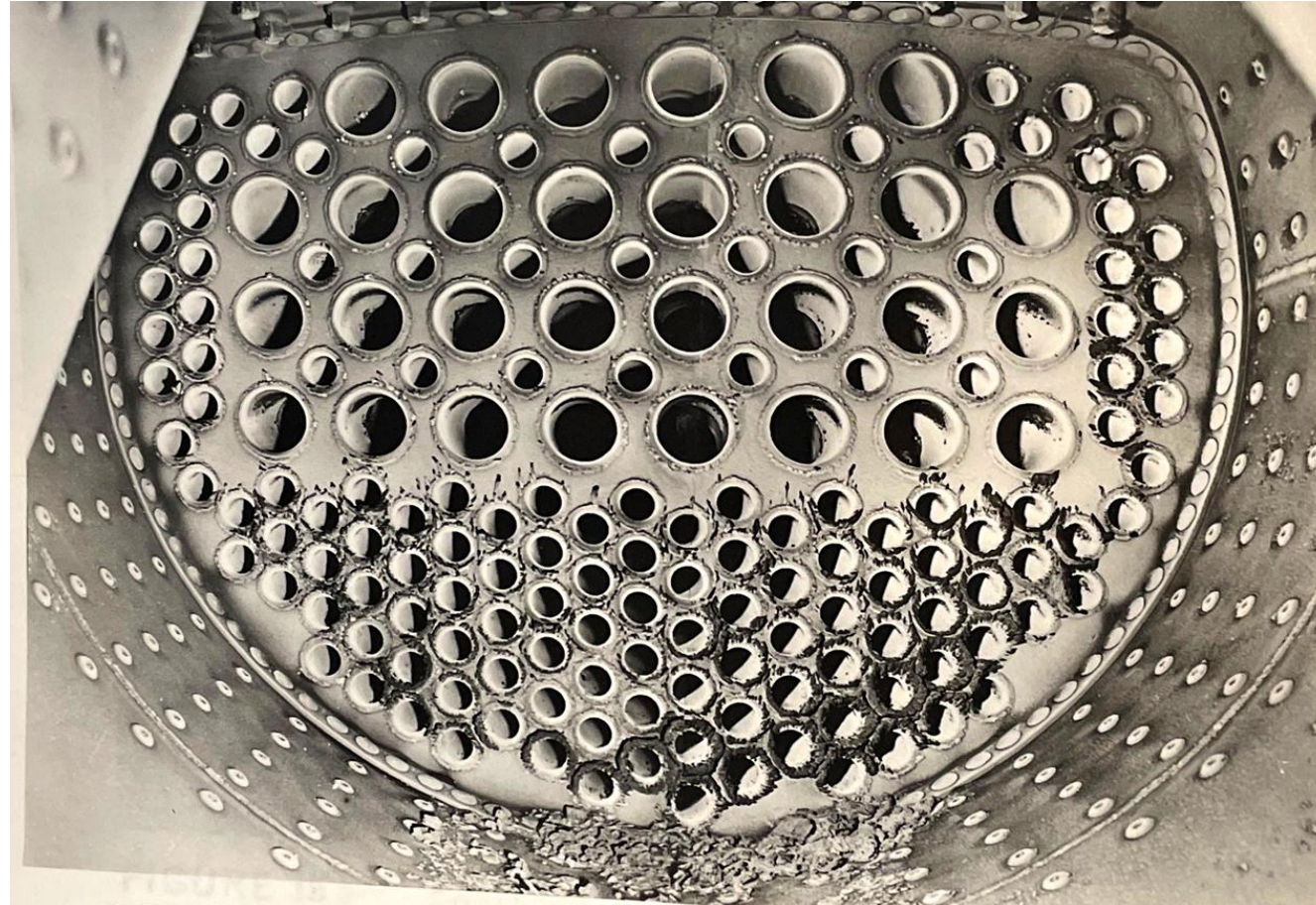
Victorian Railways

<u>Comparison of principal Standing Test results</u>			
	32 'X' P.B.C. Firing	30 'X' Grate Firing	
		Maitland Coal	Lithgow Coal
Maximum evaporation (lbs./hr.)	30,240	31,100	26,463
Coal consumption at max. evap. (lbs./hr.)	5,250	4,620	5,240
Superheated steam temp- erature at max. evap. (°F.)	656	589	597
Boiler horse-power at max. evap.	1,455	1,494	1,272
Equiv. evap. at 26-28,000 lbs. evap. (lbs./lb.)	7.98	9.75	6.78

Victorian Railways

	32 'X' Pulverised Brown Coal	30 'X' - Grate Fired		
		Maitland	Lithgow	Wonthaggi
Load & No. of vehicles (tons)	652 = 40	651 = 38	652 = 39	649 = 33
Running time (mins.)	472	462	501	503
Avg. Boiler pressure (lbs./sq.in.)	204	207	202	202
Avg. superheated steam temperature (°F.)	635	611	612	605
Equivalent evaporation (lbs./lb.coal)	8.12	9.18	7.74	7.53
Work units per lb.coal (2×10^6 ft.lbs.)	0.186	0.220	0.180	0.172
Calorific value of fuel (B.T.U./lb.)	10,425	13,553	11,489	11,032
Boiler efficiency (%)	75.5	65.8	65.4	66.2

Typical issue with p.c.: Deposit in flues and tubes



idem

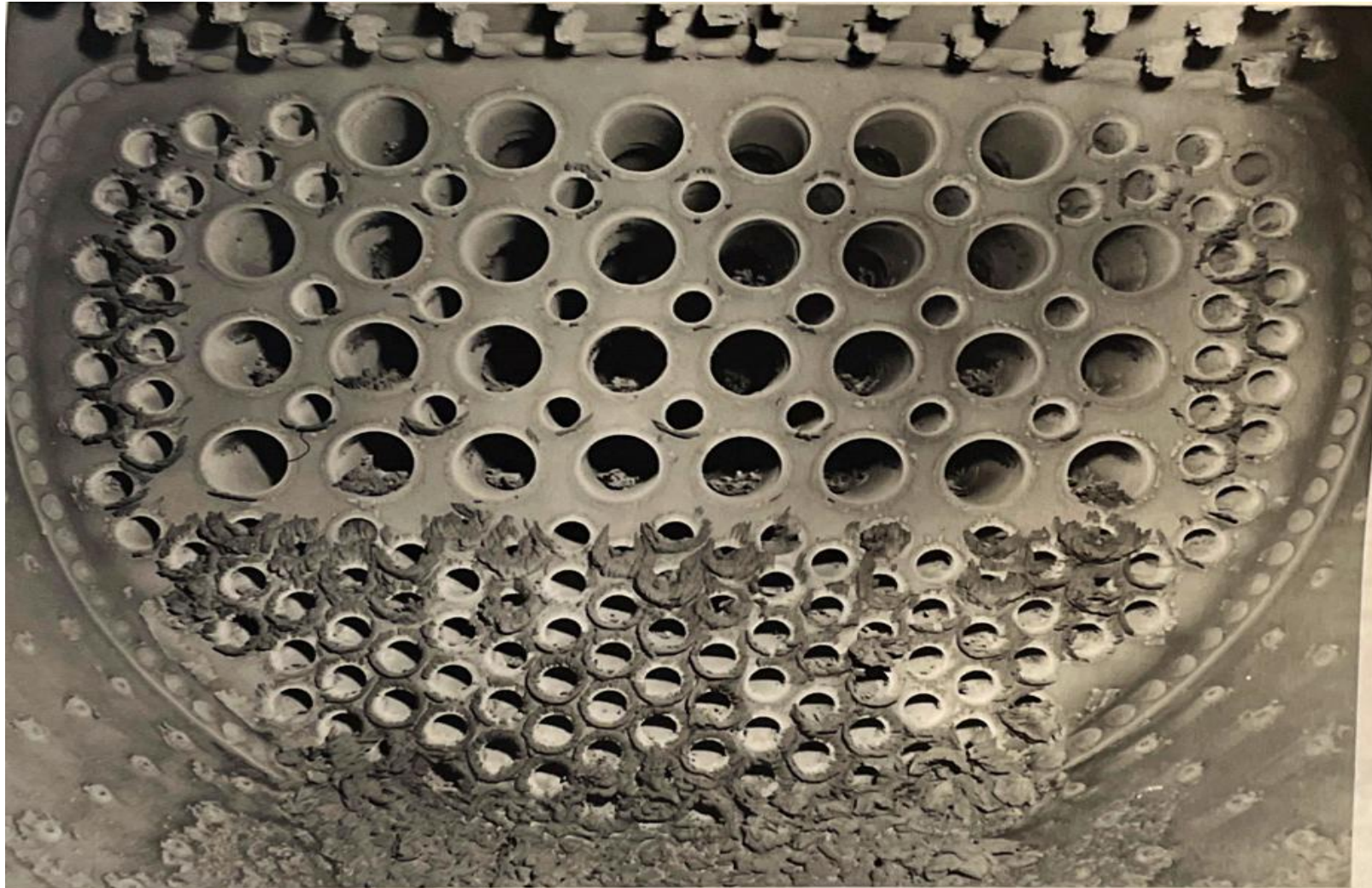


FIGURE 15 :- "SWALLOWS NESTS" DEPOSITS ON THE TUBE PLATE OF "32 X"
[1550 MILES AFTER CLEANING]

Victorian Railways

- Tests considered to be a success. Loco's appeared to have been successful in daily operation until diesels ended their career.
- 1 type X Goods, two type R Express converted
- Mandatory to clean the flues every 1500 miles for successful combat of the infamous "swallows nests", a typical plague for p.c. fueled loco's
- Limiting factor capacity of the firing equipment, not the loco
- Limiting factor with Maitland coal: spark arrester blocking

Filling X32



Making up the balance:

- If functioning properly, good to superior performance
- Complex equipment on locomotive
- Increased maintenance costs: firebox, brickwork, tubes..
- Complex fuel transport and infrastructure
- Fuel not as cheap as originally thought

Pulverised coal on Heritage Railways?

- The Wardale and Franklin Cy. lessons: it is not the technology, it is the steam environment that is the real problem
- The astonishing simplicity of a conventional coal fired steam locomotive is quite suitable for steam in the 21 century. If that simplicity is not kept...
- My view: not realistic. Neither are other powder type fuels or pellets
- Mike Stockbridge kindly suggested rapeseeds or crushed charcoal powder