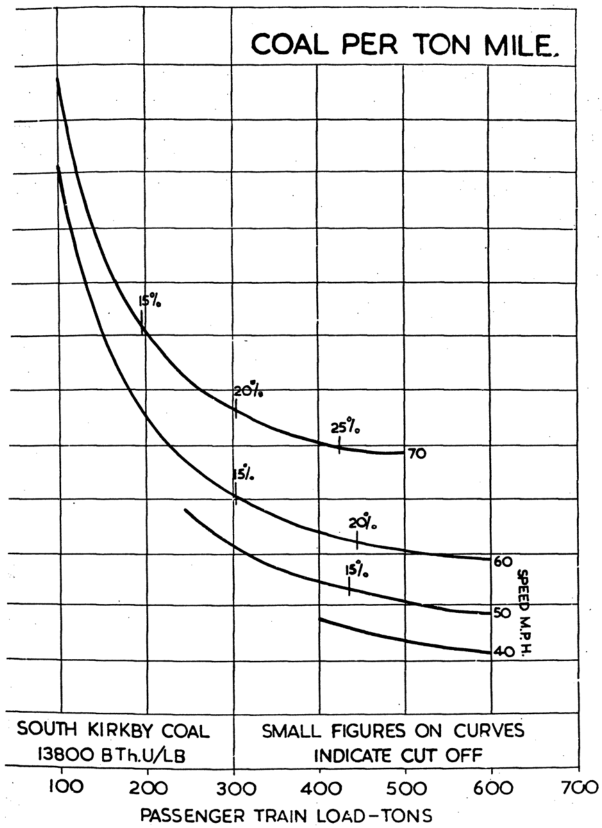
Appendix C The boiler of the HSM 814

In the English text "The preliminary design of ..", Appendix B, the method of Eckhardt is used to determine the performance of the boiler. This is based on the requirement that the locomotive can run at 120 km/h with a train of 400 tons. This provides some preliminary data. The required thermodynamic performance is then determined by using the data from the test of the British Railways LNER B1 and BR class 4. From these reports it can be calculated that the BR4 delivered, at 75 miles per hour with a train of 400 tons, a thermodynamical effort of approximately 3831 MJ/h. The exhaust injector used limited the LNER B1 to 20,000 pounds of steam. The locomotive ran at 70 miles per hour, however, with a train of 400 tons. The data from tests with the LMR Class 2, 2-6-0 No 46413, showed that the reported specific wagon resistance increases directly with speed and not to its square. Since the train weight constitutes most of the load of the locomotive, the performance of the B1 can be conveniently extrapolated from 70 mph to 75 mph by taking the actual performance of 3580 MJ / hour, and multiply by 75/70, the result will be 3836 MJ / hr, which is virtually equal to the value of the test with the BR4.

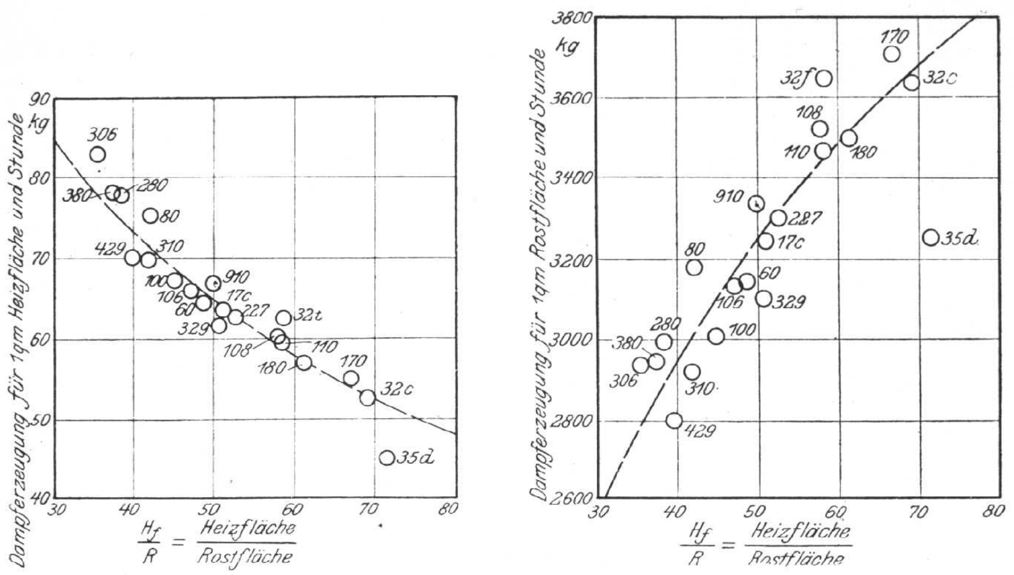
The conclusion of the additional calculation for a 4-6-0 locomotive is that between 6600 and 7723 kg/h steam is required, this depends mainly on the temperature of the exhausted steam. Apart from this the margins must be determined within which it can be made certain that the locomotive is indeed delivering the required performance.



For the calculation of the effort of a small boiler for a 4-4-4 locomotive the amount of MJ/h should be determined , and from there the amount of steam delivering this content. It should be taken into consideration that the LNER B1 locomotive had a separate tender which weighed around 53 tons. Because the HSM 814 will be a tank locomotive the weight differences should be accounted for. In reality the B1 with a 300 ton train had a further 53 additional tonnes in tow. As such a train weight of about 250 tons can be used. Both reports cited show that for a 250 tonne train the cut-off % can be diminished from about 25% to 15%. The graph shown on the left is taken from the report of the B1. The scale of the vertical axis is 0.01 lbs / tonmile (and starts at the bottom at 0.02). It can be seen that for the B1, with 400 (450) train tons, a cut-off of 24% is necessary. In a 250-ton train, in fact 300 tons, the cut-off diminished to 17.5%. In fact this means that 17.5 /24 or 73% of the calculated maximum steamrate should be sufficient for the requested performance of the HSM 814. This is then rounded off to 75% of this 7723 kg, or 5792 kilos of steam per hour.

The boiler design
When designing steam locomotive boilers a number of important ratios exist:

1. Firstly is the ratio of the size of the Heated Surface (H) relative to the area of the grate (R). There is a rule of thumb that this ratio for passenger locomotives should be about 50. The value is around 40 for the HSM locomotives based on a grate of 2.04 m^2 and a heated surface of about 81 m^2. According to data from Sanzin-Kochy (ZVDI 1921) from the graph below, this has the consequence that for each m^2 evaporating surface at a H/R of about 40 about 74 kg steam / hour is produced. Given their data in the graph it is even an art to sink far below the 70 kilo. The old boiler produces approx. 6000 kilos of steam/hour, apparently enough for the type of service of these engines. Formally, the data is valid only for coal with a calorific value of 6250 Kcal / 26.2 MJ / kg. Giesl-Gieslingen (Lokomotiv-Athleten page 24) gives a correction for abnormal combustion values: 2/3 of the difference should be reckoned with. Because the BR used test coal of 32 MJ / kg there must be an inclusion of 2/3 of 32/26, 14.8% more, so that the 74 kilos of steam increase to about 85 kg per m^2 per hour.



Nenndampfleistung von Lokomotivkesseln nach Sanzin-Köchy für Stückkohle von 6250 kcal/kg ohne Speisewasservorwärmung, in Abhängigkeit vom Verhältnis der Verdampfungsheizfläche zur Rostfläche; im linken Bild bezogen auf die Heizflächeneinheit, im rechten auf die Rostflächeneinheit.

2. The second major ratio is the free passage of the flues relative to the total of flues and tubes. Easily it can be seen that, the larger the flow of gases along the elements of the superheater, the higher will be the temperature of the superheated steam. According to the data of Eckhardt in his "Die Konstruction of Dampflokomotive und Ihre Berechnung" Technik Verlag, Berlin 1952, a correlation exists between the area ratio, the boiler load and the temperature arrived at.

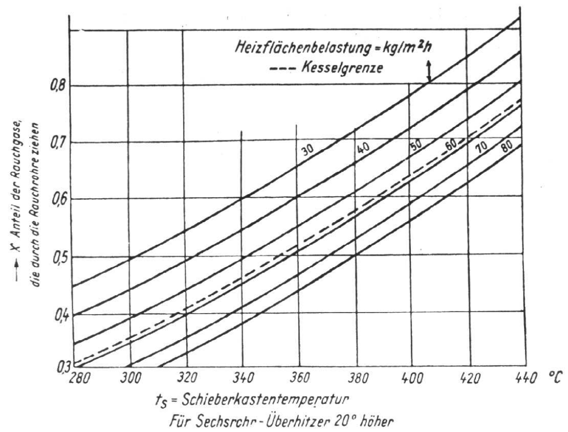


Bild 82. Schieberkastentemperatur f (x) und der Heizflächenbelastung

From the graph to the left can be seen that, if the ratio of 50% of the available cross-section of the total of the former boiler is used, the steam temperature is only about 350 °C. From a Dutch point of view this is not that bad, it was usually lower. A higher temperature can therefore be achieved by increasing the area with superheater elements.

3. The third ratio is related to the ratio of the resistance of a firetube compared to that of the flue with elements. In a firetube, the length - diameter ratio is used of which the ratio of 100 is considered to be optimal. A flue and its contents is more difficult to determine, which is why Wagner (ZVDI 1929, p.1217) has resorted to the ratio of the internal pipe area *S* with respect to its free cross-section *A*. It is easy to see that for a pipe that internal surface is $l * \pi * d$ and the sectional area $\pi / 4 * d^2$ so that the ratio is $l * \pi * d / (\pi / 4 * d)$ or $* 4 l / d$. With such an optimal fire tube, the value is 400. The same could be calculated for a flue. The total wall area will be that of the flue itself plus that of the superheater elements and the cross-section becomes that of the flue minus that of the elements.
The original locomotive shows a ratio of 362 for the flues and 346 for the firetubes. It is easy to see that a pipe shorter than 100 times its diameter, will yield a lower ratio, in the case of, for example 90 times the diameter it is 360. Because this ratio has to do with the flow resistance, the shorter tube has less resistance, it now appears from this that the flow resistance of the flue with superheater was larger than that of a fire tube in the original locomotive.

The unpleasant consequence of this conclusion is, that in a speeding locomotive, with a increasing boiler load, the flue gases more and more prefer to pass through the fire tubes, and not trough the flues. The superheating will therefore not increase but decrease! This is one of the major causes of the lowered temperatures of the superheated steam in Dutch Steam Locomotives. In English literature this phenomenon is called "preferential draughting" and is one of the causes of indifferent behavior of steam locomotives. It should therefore certainly be prevented at all costs.

4. A fourth ratio is a practical one. The passage within the elements of the superheater in total must be larger than that of the steam supply pipe into the boiler. Superheating expands the steam and a larger passage volume is needed. According to the drawing of the boiler by Werkspoor the feed tube has about 120 mm internal diameter. The tube has 0.01131 m^2 in sectional area.

The new requirements to be imposed on the boiler.

Since with any new boiler increased demands should be made, the locomotive must run 120 instead of 90 km/h the following changes are proposed:

- Change of the steam pressure of 10.2 bar to 15 bar. It should be noted that all the calculations are based on this pressure. As can be seen from figure 3 of the text of Appendix B, the specific steam consumption decreases from above 6 kg to less than 5.5 kg at the specified 420 ° C. The pressure acts in this more or less as an independent variable. There is only 11 kJ/kg difference in enthalpy of saturated steam of 10.2 bar and 15 bar, and any overheating to 420 °C decreases this to 5 kJ/kg.

- a higher superheat, to be realized by a change of the passage ratio between the flues and the firetubes. For the desired temperature of approximately 420 degrees with a steam production which can be up to about 80 kg /m^2 a ratio of ca 6 2, 5% is desirable.

- The difference of the flow resistance between the flues and firetubes to be changed to the disadvantage of the fire tubes

Practically, this can be realized by:

1. Placing a fourth row of flues with superheater elements

In this case the superheating area is enlarged. In addition, the area for passage of the flue gases along the elements increases. The space is at the expense of firetubes, but it has already been established that the tubes of the old boiler had an unfavorable L / D ratio.

Changing the flow resistance by the following:

2. The use of a smaller size superheater elements, 35 mm (1 3/8 in.), instead of 38 mm. These pipes were also applied in the NS 6300 at that time and increased the flow through the flues. The superheater surface is increased already by 24/18 so that the reduction is compensated by the larger amount of flue gas. It also brings the change of the *A / S* of the tube below that of the fire tubes.

An alternative could consist of:

3. The increase of the diameter of the flue, using 133/125 mm instead of 127/119 mm. These tubes appear to be well supplied, so this is a viable solution. The mutual effect is identical to a reduction of the fire tubes. These flues, however, do not appear to fit in the already small pipe plate and are thus unusable.

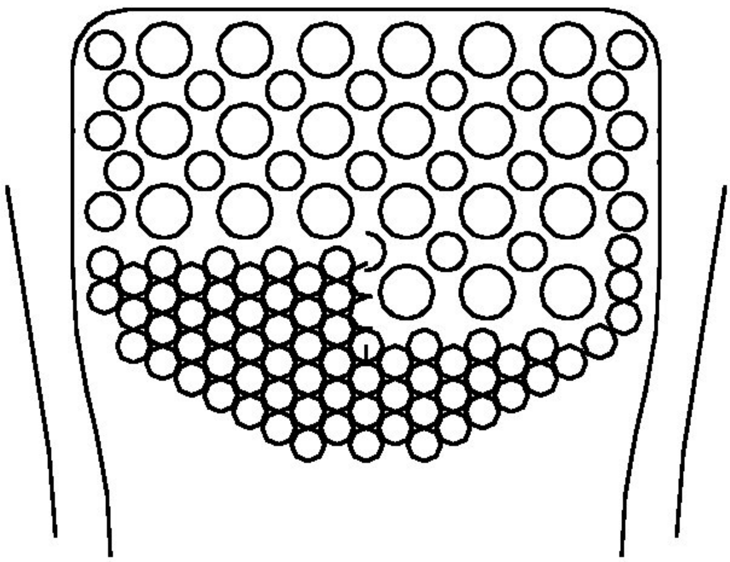
4. The slightly higher placement of the boiler. The firebox can therefore get a larger area while the volume also increases. The first is something at the expense of overheating and the latter is beneficial for smokeless combustion. The starting point under consideration is to have a boiler positioned 200 mm higher and consequently about 1.2 m^2 more evaporation surface.

This combination of changes creates a boiler that has the following properties:

1. Application of standard 127/119 mm flues, 40/45 mm tubes and 35/28 mm superheater elements. All these sizes are available from the normal boiler pipe trading stock. In connection with the intermittent use of the engine a 1 mm greater wall thickness of the tubes and pipes would be better for the service life. In addition, the values reported above would change.
2. The Heating surface will have 24 flues and at least 73 fire tubes giving in total 74,21 m^2
3. The superheater surface is approximately 28 m^2 in place of 22.83 m^2
4. The superheater passage is about 0.0146 $m^{2,}$ the feeding tube can be adapted accordingly.
5. The nett flue passage surface, with respect to the total area, is increased to 65.5%, the value requested.
6. The flue length / hydraulic diameter becomes 82, below 100, the fire tube length / diameter ratio is 86.5. The *S/A* ratio is 328, respectively, and 346.

For a grate of 2.04 m^2 and 47,21 m^2 heated surface the steam production per m^2 according Sanzin-Kochy would the be 5525 / (35 +74.21 / 2.04) = 77.4 kilos of steam, the correction for the calorific value according to Giesl gives 88 kilos combined, a total of between 5744 and 6600 kg/h. The passage of 65.5% of the amount of flue gases insures that a steam temperature of around 420 ^oC. is arrived at.
Due to the changed conditions, this temperature could increase at higher loads, because under these conditions the flue gas has a preference for the flues because of the increased resistance of the tubes.

The practical execution.



Sketch design of the backpipeplate in the firebox of the HSM 814, old (left) and modified (right) implementation

According to the accompanying drawing, 73 fire tubes can still be accommodated, a modified pattern can probably still show an enlarged number.

According to the statements in the book "Our Dutch steam locomotives" by Waldorp the HSM locomotive boilers had the following data. The details of the new boiler design are positioned right

		HSM800-812	814	
Main dimensions:	Heated surface firebox	10, 3	11, 5	m^2
	Area tubes and flues	71	62,7	m^2
	Superheater area	23	28	m^2
	Grate area	2.04	2,04	m^2
	Maximum steam pressure	10.2	15	bar

The amount of flues and tubes are in Karskens book "The locomotives of the HIJSM" and can also be read from the drawings.
The diameters of the flues - tubes of all Dutch railway locomotives can be found in Table XXIV in the "Manual for Railway Engineering" Part III, page 135.

Conclusion: by choosing slightly different flue and fire tube numbers, fire tube and superheater diameters it is quite possible to change the boiler design in such a way that the steam production and the desired steam temperature is increased. Requested was 5792 kg/hr and the minimum delivered is 5744 kg /hour with a temperature of 420 ^oC. The condition is the combustion of coal with a calorific value of at least 30 MJ / kg.

JJGKoopmans
July 2012
Rev.02