For further details concerning Figure 4, reference should be made to the paper by Bardwell and Laudeman.†

Conclusion

If the work on the Chesapeake and Ohio Railway shows that boiler cracking has decreased in the past 2½ or 3 years, it will prove: (1) that feedwater treatment can be used to prevent embrittlement in locomotive boilers, and (2) that if non-embrittling conditions are established according to the detector tests, then there is sound reason to believe that the locomotives will not crack.

Table 1 shows the number of boilers cracked during each six months and each year since 1934. From this time through 1938 there were never less than 22 in any year and a peak of 40 was reached. The average was 15.6 for the six months interval and 31.2 for the year.

During the latter part of 1938 and early 1939, treatment was started with waste sulfite liquor. No appreciable decrease in cracking was noted during 1939, nor was it expected since old cracks in the boilers must be found and repaired—a process which will probably require a few years for completion.

In 1940 the last six months showed a decrease in the number of cracked boilers and the total for the year is well below the average for the previous five years. In 1941 cracking rose in the first six months but results for the last five months are extremely gratifying, for only two boilers were found cracked. This is particularly significant since the engine mileage during this period has been much greater than that for any similar period in the previous years which are shown. The results furnish strong evidence that this railroad is on its way to elimination of its embrittlement troubles.

The fact that intercrystalline or embrittlement cracking can be controlled through water treatment is not a justification for poor boiler construction. Improperly laid-up seams, with excessive distortion of the metal can create leaks and high stresses which add to the difficulty of securing satisfactory water conditions. It is also possible that a steel could be developed with increased resistance to intercrystalline cracking and this would aid the railroads materially. Investigation to develop such steels is desirable. Welded boiler drums, when their general use is permitted, will offer another escape from this trouble. In the meantime, however, for boilers which are now operating and for those being built with riveted seams, treatment of the boiler feedwater can be used to eliminate embrittlement cracking.

TABLE 1

Effect of Waste Sulfite Liquor and Sodium Nitrate on Cracking in Locomotive Boilers

	Number of Cracked Boilers			*Special Feedwater Treatment to Prevent*
Year	*First 6 Months*	*Last 6 Months*	*Year*	*Embrittlement*
1934	19	21	40	None
1935	15	9	24	None
1936	20	19	39	None
1937	9	13	22	None
1938	20	11	31	None
Average	15.6		31.2	
1939	18	13	31	Use of waste sulfite liquor started early in year.
1940	14	5	19	Waste sulfite liquor
1941	11	2*	13	Use of sodium nitrate started early in year.

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* Value for last five months.

Mr. Harper: Thank you, Dr. Schroeder.

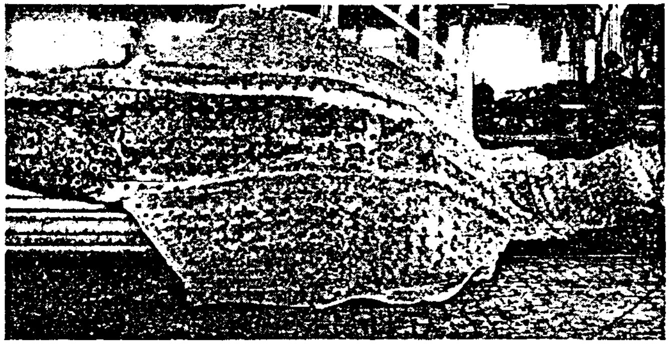
I now take pleasure in introducing Mr. Ray McBrian, Engineer of Standards and Research, Denver, Rio Grand & Western Railroad, who will give us a progress report on the servicing of firebox and boiler steel. He will also present some natural color photographs on slides of sections of the firebox on one of the D. & R. G. locomotives which recently exploded, and will show what the effect of using steel with higher physical properties at elevated temperatures might have been. Mr. McBrian.

Mr. Ray McBrian (Engineer of Standards and Research, Denver & Rio Grande Western Railroad): Gentlemen: Mr. Harper asked that I give you a short paper covering current information which we have acquired in connection with our research studies of steel for firebox boilers.

We have continued our studies on the effect of aging properties and effect at elevated temperatures and surface decarburization. In addition to the damping capacity tests for aging we have now under construction an X-ray diffraction unit for the study of internal stresses and the identification of complex compounds occurring in microscopic cracks. By use of this equipment we hope to secure some knowledge as to the mechanism of the various types of cracking associated with firebox and boiler problems.

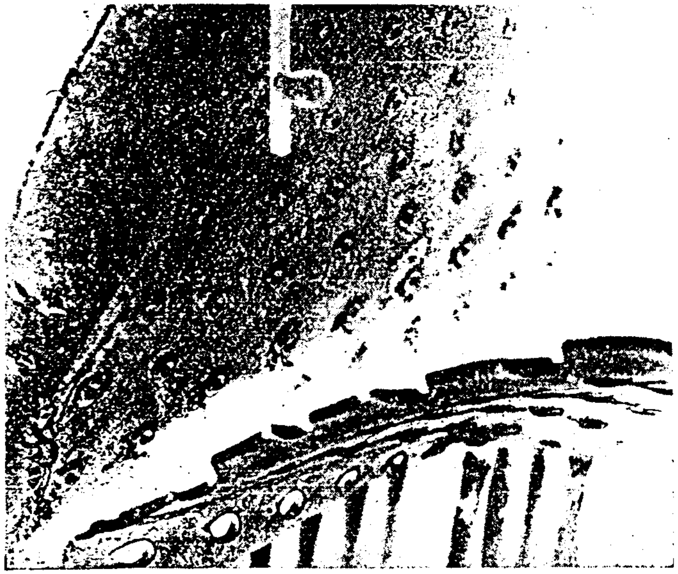
In spite of the interest that has been manifested failures continue to occur and on our own road we are trying to correlate the study of service failures with research. For example our unfortunate explosion of passenger locomotive 1804 brought out very forcibly the added factor of safety which would be available by the use of materials with higher strength at elevated temperatures.

A novel feature of this investigation was the use of color photography. I have had prepared some color photographs from the original which I would like to show. *Slide (1)* is portions of the crown sheet, door, and sides of firebox syphons. It will be noted that the syphons sides display a normal steely color; the crown sheet and portion of the door show the discoloration from overheating. The origin of the failure was at a point adjacent to combustion chamber syphon and the highest point of the crown sheet.



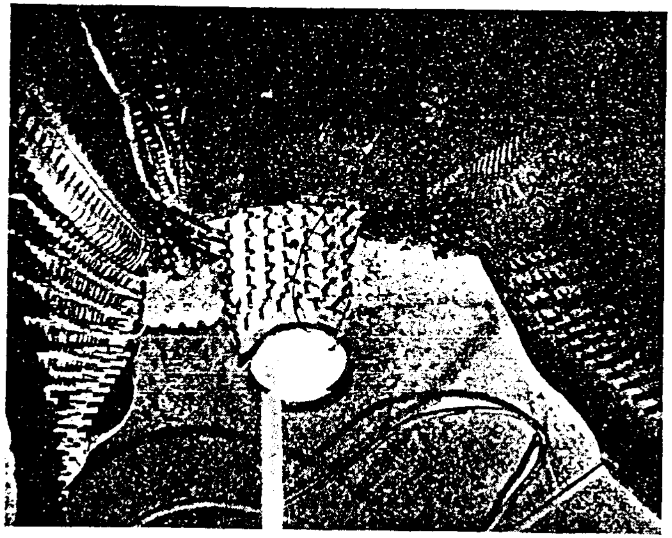
Slide 1

Slide (2)—Is a photograph of the combustion syphon and portion of crown sheet at point of rupture. Note the reduction of area around staybolt holes and also the horizont color line coincident with the fourth row of syphon stays.



Slide 2

Slide (4)—Slide 4 shows the discoloration down to the first row of staybolts above the fire door.



Slide 4

Slide (5)—Is a picture of the section of the door sheet missing from the portion shown in slide (4).

Color pictures demonstrate the conditions found in this firebox after the explosion which is impossible to show by the use of normal black and white photography.

These color photographs show obviously that the primary cause of this explosion was due to overheating from low water. Metallurgical examination and study indicates that by the use of a material with greater strength at elevated temperatures this failure might have been prevented.

The microstructures found at various locations around the firebox showed that maximum temperature was reached at a point coincident with the origin of the explosion and established the maximum temperature as between 1350° and 1400° F.

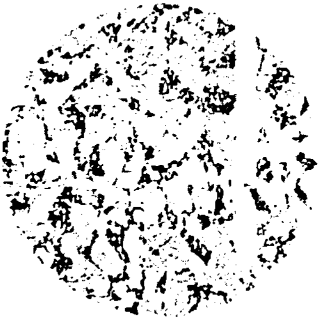
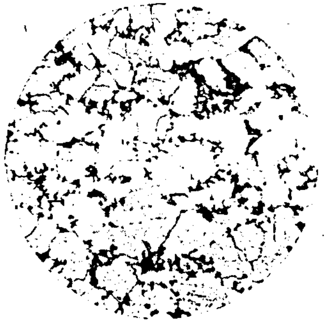
Slide 5

Slide (6)—Shows the microstructure of a portion of the crown sheet which had been heated to this temperature.

For comparison pieces of the crown sheet were heated 1350° F. This is shown in the next *Slide (7)*, to 1650° F. this is shown in the next *Slide (8)*, and to 1800° F. and this is shown in the next *Slide (9)*.

The effect of microstructure on heating to the different temperatures, is shown by comparison of these three slides and shows the method by which the temperature to which the crown sheet had been heated was determined. It will be noted that the structure obtained by heating to 1350° F. was almost identical to that shown in the crown sheet sample. All of the micrographs were made at 200 diameters.

To determine the strength of the crown sheet at the temperature at which it failed, tensile tests were made at 1385° F. Tensile tests were also made of carbon molybdenum firebox steel at this same temperature, for comparison. The molybdenum content of the firebox steel was ½ of 1%.

Slide 6 Slide 7

Slide 8 Slide 9

The results of these tests are shown in the next *Slide (10)*. It will be noted that the tensile strength of the crown sheet when it failed was approximately 5,600 pounds per square inch, or only 1/9 the value at room temperature. The carbon-molybdenum firebox steel at this temperature had a tensile strength of 13,400 pounds per square inch or more than double the strength of plain carbon steel. To demonstrate that the reduction in strength due to overheating alone could cause the failure of this firebox, the following calculations were made:

Using the formula

$$S = \frac{Pa^2}{4\ T^2}$$

Where S = Maximum working fibre stress (P. S. I.)
P = Boiler pressure (P. S. I.)
A = Staybolt pitch (inches)
T = Thickness of plate (inches)

A ⅜" plate and a staybolt pitch of 4" give a working stress of about 8,000 pounds per square inch for 280 lb. boiler pressure.

From the elevated temperature tests it was shown that for the plain carbon steel the strength at 1385° F. was only 5,600 pounds per square inch or 2,400 pounds per square inch lower than the working stress at that temperature. It was found then, that the boiler pressure alone was sufficient to cause a failure when the temperature of the crown sheet approaches 1350° F.

Also, it was found that the molybdenum steel, due to its higher strength at elevated temperatures, would not have failed at the working stresses at 1385° F.

Comparison of Carbon and Carbon-Molybdenum
Firebox Steels at 1385 deg. F.

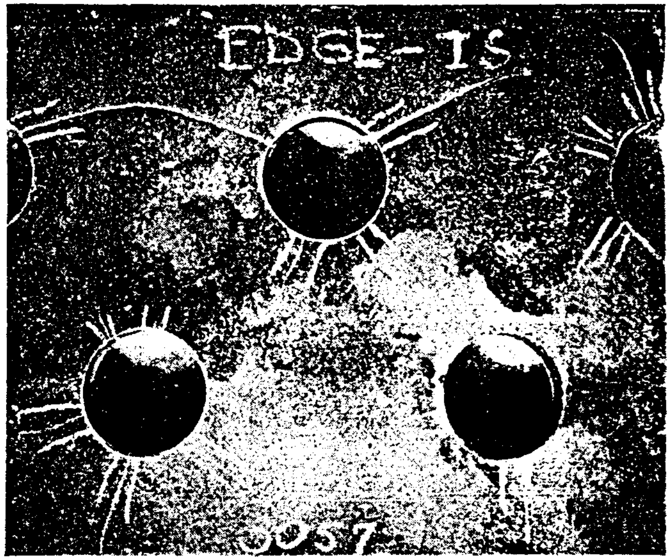
	Ultimate Tensile Strength (Psi.)	Elongation (% in 1 in.)
A.A.R. Carbon Firebox Steel..........	5,600	98.5
A.S.T.M. A-204 C-Mo Firebox Steel...	13,400	128.0

Slide 10

The results of this investigation certainly emphasizes the necessity for recognizing the importance of the elevated temperature strength properties of boiler and firebox materials.

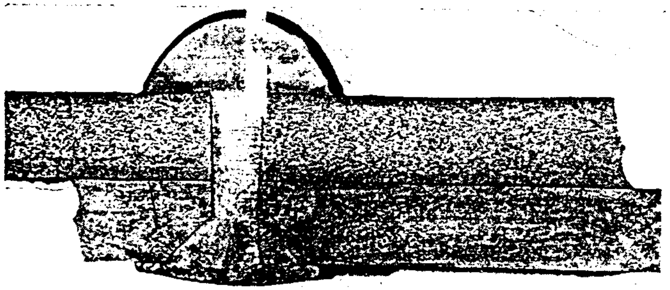
The importance of fabrication practices is further demonstrated as shown by the failure illustrated in the next *Slide (11)* which shows cracks in a section of a boiler shell seam. These cracks are outlined with magnaflux powder and indicated by white lines. The micrographs showed these cracks to be transcrystalline, and this brings out the important point of properly identifying failures.

It was found that these cracks originated at the sharp edges of the holes. Some had referred to them as embrittlement cracks; the micrographs show they were transcrystalline. This brings out the need for recognizing the necessity for removing all sharp edges from riveted seams, as sharp knife edges only result in localized stress concentration and possible failure.



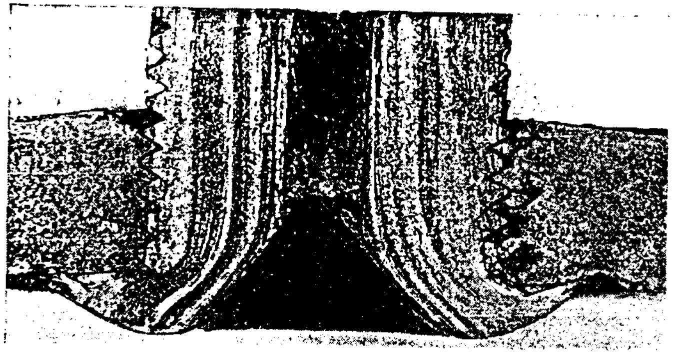
Slide 11

The next *Slide (12)* is a etched cross section of a riveted seam showing the sharp corners in the r t hole and the deformation of the plate from high caulking pressure. This actice helps to provide the conditions necessary to get failures from stre concentrations which can develop intergranularly or transcrystalline.



Slide 12

The next *Slide (13)* is of a section of firebox side sheet and staybolt, showing a crack originating in the interior of the sheet at the root of a thread where the stress is concentrated at a sharp corner. This etched section again demonstrates the need for understanding the elevated temperature properties of both the side sheet and staybolt materials. The side sheet was corrugated, indicating lack of the necessary strength under load under operating pressure and temperature.



Slide 13

The effect of corrugation is to cause the threads to engage mostly on the fire side of the sheet. In consequence of such action the staybolt bears all its load at the last few threads. Since the end of the bolt is at a relatively higher temperature, the net effect especially with the ordinary iron or steel bolts, is that the bolt is much weaker than calculated and its sustaining unit load is much greater, due to its loss of strength from temperature effects.

We have found that by t use of such an alloying element as molybdenum we can secure an iron r steel alloy with the increased strength at elevated temperatures.

I appreciate this opportun to again come before you and outline some of the problems which we a studying in our research investigation; by which we hope to find some of he answers to the problem of service failures and to secure increased life r materials used.

Thank you.

Remarks by B. C. King on Topic No. 4

In a paper presented before the Master Boiler Makers' Association at the 1940 Annual Meeting I told you about the changes we had made in water treatment on the Northern Pacific, with the idea in mind of increasing the length of engine runs and the reduction in the number of Boiler washes and water changes. Mr. Grime, our Water Service Engineer, will tell you more in detail how the water treatment was modified. But what we have accomplished as a result of the changes will, I think, be interesting to all railroad men, especially those working in territories having water similar to those encountered in the Northwest.

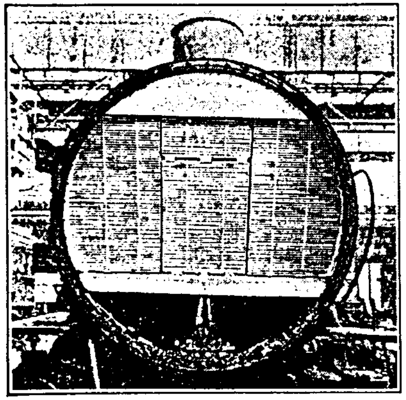
If there is any type of water, good or bad, that we do not have between St. Paul and Seattle, it would be interesting to learn about it. The first ten stations west of St. Paul, contain calcium carbonates and practically nothing else. Wayside treatment has proved to be the best for these waters. The next six supplies to and including Mandan, N. D., shows a gradual increase of calcium sulphate. Lime, soda and sodium aluminate treatment is used with Nalco No. 8 as after treatment. The trouble really begins west of Mandan, because the next eleven supplies have everything in them, and in large amounts. A supply containing up to 40 grains of sodium carbonates may be followed by one containing 140 grains of sodium sulphates. Treatment is mostly the same as that east of Mandan, lime, soda, sodium aluminate, with Nalco No. 8 as after treatment.

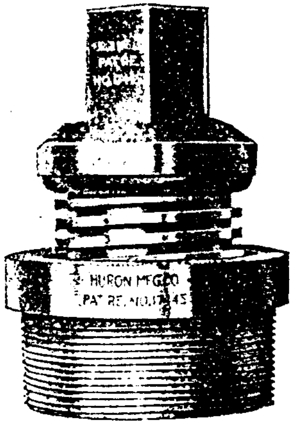
Obviously, to modify and correlate treatment so as to make the mixture of good and bad water behave in a boiler had to be the work of more than one man. Formerly, with short runs and frequent washes, there were few operating problems, and water treatment was quite satisfactory if it kept the boilers reasonably clean and free from corrosion and pitting. When in 1939, we decided to increase engine mileage by longer runs and by extending the washing period as far as possible, we set our goal at maximum locomotive mileage, consistent with good operation.

We wanted to be able to work any locomotive to the limit without dangers of damage to boilers and pitting and corrosion, leakage or foaming. Previous experience had taught us that if we kept a locomotive in a certain water district, we had no staybolt or flue leakage, but if we ran the same locomotive over two or more districts, we would have leakage, it used to be said that the water would not mix, and nothing was done about it. The obvious fact that the treatment did not mix was overlooked. When the treatment angle was investigated we found that something could be done about it, and that is what I had in mind when I mentioned correlation of treatment.

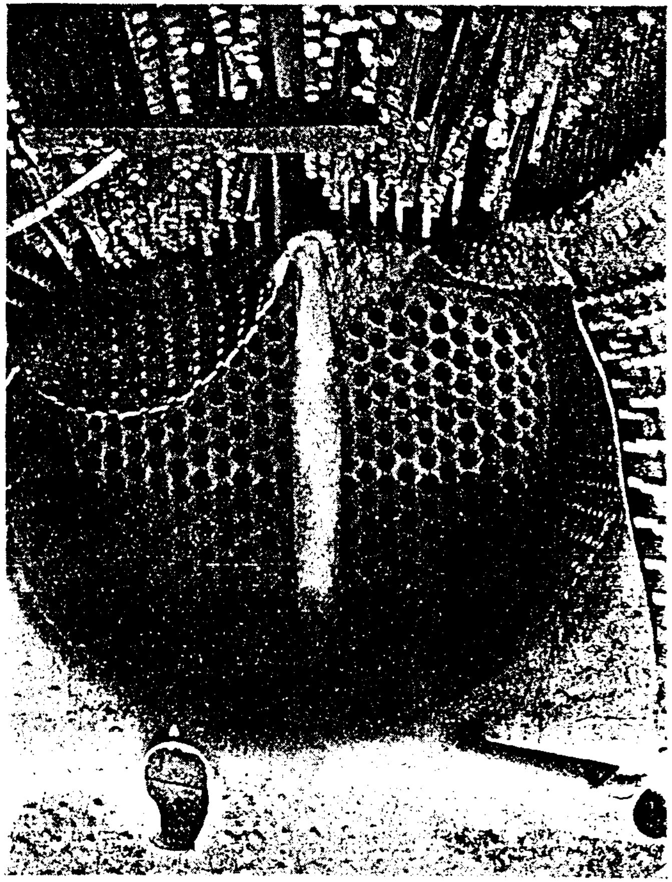
The only reason a railroad has for existing is to get traffic over the road as rapidly as possible consistent with efficient operation. Clean boilers free from scale are very desirable to help produce best results, but if the operation of producing clean boilers cause delays due to foaming with subsequent cut bushings and packing, we fail to justify our cause.

For this reason we decided to review our system of water treatment with the thought of improving operations. Before any changes were made its purpose was explained to the Boiler Foremen and Road Foremen of Engines. They were taught how to analyze the water, they know what the alkalinity, alkalinity ratios, and dissolved solids should be in a boiler, and these are checked when an engine returns to a terminal. If any of the treatments are out of line, a careful check of the water treating plants are made and corrected without delay.





Slide (3)—Is a photograph taken inside the firebox of the combustion chamber syphon, the back flue sheet, and the same portion of crown sheet shown in slide (2). The discoloration is shown down to the 8th row of flues showing the extreme low water condition at the time of the explosion. From the color line in the firebox and from the boiler dimension it has been calculated that at the time of the explosion the water level was at least 2,750 gallons below the bottom of the gauge glass. Of passing interest it will be noted that the combustion chamber syphon adds considerable structural stiffness to the crown sheet as shown in the manner in which the crown sheet sagged on both sides of the syphon.



Slide 3