REPORT OF TESTS LOCOMOTIVE 815
WITH LABYRINTH FRONT END,
MULTIPLE JET EXHAUST NOZZLE,
AND SELLERS EXHAUST STEAM INJECTOR
MAY - JUNE 1940

UNION PACIFIC RAILROAD COMPANY
RESEARCH & MECHANICAL STANDARDS

Report of Tests of Locomotive 815 With the Labyrinth Front End, Multiple Jet Exhaust Nozzle, and Sellers Exhaust Steam Injector.

May - June 1940

Introduction

Extensive tests were run on Locomotive 815 April - December 1938 on the Locomotive Economizer Corporation's and the Master Mechanic's front ends; annular ported, round hole, and multiple jet exhaust nozzles; 15 and 20 percent air opening grates; three stacks of 21, 26.7, and 30 inches top diameter; 9 and 11 row brick arches; the ash pan as it came from the builders and lowered to obtain more air opening; and with and without secondary air over the fire.

April - December 1938 tests showed the best performance was obtained with the Locomotive Economizer Corporation's front end, the multiple jet exhaust nozzle, the 30 inch top diameter stack, a 11 row brick arch, 20 percent air opening grates, the ash pan lowered, and secondary air admitted over the fire.

Compared with Locomotive 815 an improved stack and multiple jet exhaust nozzle was designed and tested on Locomotive 7006 April - June 1939. This design was also applied to 820-34 class locomotives which were being built while tests were in progress on Locomotive 7006.

During September - October 1939 the Labyrinth front end was developed and tested on Locomotive 7006. The Labyrinth front end, improved stack, and improved multiple jet nozzle proved successful on Locomotive 7006. In December 1939 substantially the same design was applied to Locomotive 2295 which also proved successful.

As a result of the good performance of Locomotive 7006 and Locomotive 2295, the Labyrinth front end with improved stack and exhaust nozzle was applied to Locomotive 815 in March 1940. At this time the Elesco Exhaust Steam Injector was removed and the Sellers Exhaust Steam Injector reapplied. The original Sellers Exhaust Steam Injector changed from exhaust to live steam operation and vice versa by steam pipe pressure, while the injector applied to Locomotive 815 made this change by exhaust pipe pressure.

At this time the ash pan was also modified from a two to a three hopper design. This design gave more air opening and also increased the volume for ash.

Object of Tests

Tests were made to determine the Sellers Exhaust Steam Injector performance, and the performance of the Labyrinth front end. Tests were run February - March 1938 on Locomotive 814 with the Sellers Exhaust Steam Injector having the change over controlled by steam pipe pressure and this data is used as a comparison for injector performance.

Summary of Results

Fuel savings due to operation of the exhaust steam injector are lower with the exhaust steam control than with the live steam control for the change over. This is the opposite of what would be expected and can only be accounted for by the differences in injector tube design. Locomotive 814 had 8000 gallon tubes, while 815 due to increased power and boiler demand with the Labyrinth front end had 9000 gallon tubes. A comparison of fuel savings is shown by Figure No. 7, and the following tabulations.

Fuel Saved By Operation of Sellers Exhaust Steam Injector.

	Fuel Saved Lbs. Per Hr.		Percent Fuel Saving.	
Firing Rate Lbs. Coal Per Hour.	Live Steam Change Over	Exhaust Steam Change Over	Live Steam Change Over	Exhaust Steam Change Over.
7000	0	90	0	1.27
8000	395	220	4.71	2.68
9000	740	350	7.60	3.74
10000	905	480	8.30	4.58
11000	1050	630	8.71	5.42
12000	1190	808	9.02	6.31
13000	1330	1070	9.28	7.60
14000	1470	-	9.50	-

The Sellers Exhaust Steam Injector has a rather limited range. With 60 degree Fahr. tank water a maximum delivery of 74600 lbs. of water per hour could only be attained with a full tank of water. The minimum delivery is 55900 lbs. of water per hour.

While the 8000 gallon tubes with the live steam change over show a better fuel saving than the 9000 gallon tubes with the exhaust steam change over, from on operating standpoint the exhaust steam change over

is preferable since the injector is much more stable. With the live steam change over the injector usually breaks at slow speeds with a wide throttle since the control sets the injector for exhaust steam operation but the exhaust pressure is not high enough to operate the injector.

The performance of the Labyrinth front end was very satisfactory. Spark arresting was good and the front end cleaned itself well. As shown by the table of Average Pressures, Temperatures, and Drafts in this report, the draft at the top and bottom of the front flue sheet and at top and bottom of the combustion chamber show no or very little differences. Also the temperatures at the top and bottom of the combustion chamber are quite uniform. This indicates a uniform gas flow through all the tubes and flues.

Compared with the Economizer front end, the Labyrinth front end shows higher drafts for the same back pressures although some of this gain must be credited to the better stack and nozzle. Figure No. 4 shows the drafts obtained with the Labyrinth front end while Figure 5 shows the drafts obtained with both front ends.

Tests with the Economizer front end were run with 34 - 2-1/4" tubes for secondary air and a 11 row brick arch. It is the opinion of roundhouse forces that on 800-19 Class Locomotives a 11 row arch aggravates cinder cutting and it is the opinion of some firemen that 34 tubes for secondary air supplied too much air over the fire and made the locomotive hard to fire. Accordingly at the time of the application of the Labyrinth front end all 800-19 Class Locomotives had 24 tubes for secondary air and a 9 row brick arch. Figure No. 6 shows the effects of these changes. Regardless of the Labyrinth front end the boiler efficiency was better with the Economizer front end particularly at the higher firing rates as shown by the following tabulation.

Firing Rate LBS. Coal Per Hour.	Million B.T.U's Absorbed By Evaporative Heating Surface Per Hour.	
	Economizer Front End 34 Secondary Air Tubes 11 Row Brick Arch.	Labyrinth Front End 24 Secondary Air Tubes 9 Row Brick Arch.
7000	42.8	43.1
8000	47.2	47.2
9000	51.6	51.3
10000	56.1	55.4
11000	60.5	59.5
12000	64.8	63.5
13000	68.8	67.0
14000	72.5	69.9

Territory And Trains

Tests were run in both directions between Cheyenne and Omaha. All east bound runs were made on Train No. 28 consisting of from 13 to 16 cars. West bound runs were made on Train No. 717 consisting of from 15 to 19 cars and Train No. 27 consisting of from 15 to 17 cars.

Locomotive

The front end dimensions are shown by the following tabulation:

Type Front End	Labyrinth
Type Nozzle	Multiple Jet
Nozzle Area - Square Inches	47.17
Nozzle Tip to Bottom of Front End--Inches	23-3/4
Nozzle Tip to Bottom of Stack Flare - Inches	17-1/4
Total Length of Stack Including Flare - Inches	67-1/2
Inside Diameter of Stack at Choke--Inches	26-1/4
Inside Diameter of Stack at Top - Inches	32-1/2

The important locomotive dimensions are shown by the following tabulation:

General Classification	4-8-4
Union Pacific Classification	FEF-1
Service	Passenger
Starting Tractive Effort - Pounds	63,500
Weight Locomotive - Pounds	465,000
Weight Locomotive and Tender Loaded - Pounds	817,200
Tender Water Capacity - Gallons	20,000
Tender Coal Capacity - Tons	25
Expansion of Steam	Single
Number of Cylinders	2
Cylinder Diameter - Inches	24-1/2
Cylinder Stroke - Inches	32
Valve Gear	Walschaert

Valves:

Diameter - Inches	12
Full Gear Travel - Inches	7
Lap - Inches	1-3/8
Lead - Inches	5/16
Exhaust Clearance - Inches	1/4

Boiler:

Working Pressure - Lbs. per Sq. In.	300
Length between flue sheets - Feet - Inches	20 - 6
Number of 2-1/4 inch diameter tubes	201
Number of 5-1/2 inch diameter flues	58

Firebox:

Length - Inches	150-1/16
Width - Inches	96-3/16
Grate Area - Sq. Ft.	100
Arch Tubes	5

Heating Surface - Square Feet

Firebox and Combustion Chamber	380
Arch Tubes	54
Boiler Tubes	2416
Boiler Flues	1705
Total Evaperative Heating Surface	4555
Superheater	1535
Total Heating Surfaces	6090

Diameter of Drivers - Inches	77

Description of Sellers Exhaust Steam Injector.

The Sellers Exhaust Steam Injector is a two stage injector designated as Type "RF". It is fitted with 9000 gallon tubes. When operating upon exhaust steam, the first or heating stage receives exhaust steam for its operation. When operating on live steam the first stage is furnished with live steam throttled down through a choke to a low pressure.

On either live or exhaust steam operation, the second or forcing stage is always furnished live steam.

The change over from live to exhaust or exhaust to live steam operation is controlled by the pressure in the exhaust steam pipe to the injector. When the exhaust pressure is high enough for the injector to operate on exhaust steam, the exhaust control valve shuts off the live steam which operates the live steam admission valve and the latter valve automatically closes thereby opening the exhaust regulating valve which then admits exhaust steam and closes off the throttled live steam to the heating set of tubes.

When the exhaust pressure drops too low to operate the heating set of tubes, the exhaust control valve admits live steam to the live steam admission valve which opens, thereby admitting live steam which closes the exhaust regulating valve and also furnishes throttled live steam to the heating set of tubes.

No trouble was experienced with any of the control apparatus and it is an improvement over the control which operated by steam pipe pressure.

Three levers are required in the cab to operate the injector. They are the steam starting valve lever, the water valve lever, and the exhaust steam valve lever. To start the injector requires opening the water valve, opening the steam starting valve to its first notch position, opening the exhaust valve until a vacuum is established in the heating set of tubes (this may require moving the exhaust lever back and forth), and finally opening the steam starting valve wide open upon which the injector delivers water to the boiler. To shut off the injector requires closing of the steam starting valve, exhaust valve, and water valve.

Data

All data necessary for the determination of front end, boiler, and exhaust steam injector performance were taken.

Coal consumption was determined by measurements of the coal space at the start of a run, before and after taking coal, and at the end of a run. Tank water consumption was determined by measurements of the water in the tank at the start of a run, before and after taking water, and at the end of a run. All blow downs were timed with a stop watch to determine the weight of water blown down. A continuous record was kept of the time the injector was operating on exhaust steam, on live steam, or shut off. A venturi meter was applied to the suction line of the Sellers Exhaust Steam Injector. Thus, the rate at which tank water was being fed to the boiler was always known and furthermore, combining the rate with the time gave the weight of tank water delivered to the boiler on live steam operation.

A record was kept of the train movement.

The following pressures were taken:

(1) Boiler, (2) Valve Chamber, (3) Exhaust Passage, (4) Exhaust in the Injector, and (5) Injector Live Steam Nozzle.

The following temperatures were taken with distant reading and mercury thermometers:

(1) Tank Water (2) Exhaust Steam at the Injector (3) Water leaving the Heating Set of Injector tubes, and (4) Delivery Water to the Boiler.

The following temperatures were taken with a potentiometer:

(1) Steam to Left Cylinder (2) Flue gas leaving a 2-1/4 inch Tube (3) Flue gas leaving a 5-1/2 inch Flue, and (4) Flue gas entering Stack.

Another potentiometer was used to obtain temperatures with aspirating thermocouples at both the top and bottom of the combustion chamber. Aspirating thermocouples eliminate the effect of radiation on the thermocouple and therefore the temperatures obtained in the combustion chamber are accurate.

Drafts were taken at (1) Top of Front Flue Sheet, (2) Bottom of Front Flue Sheet (3) Near the Smoke Stack (4) Top of the Combustion Chamber, and (5) Bottom of the Combustion Chamber.

Compiled Data And Graphical Presentation:

The data taken during the tests and all calculated results are shown in condensed form on sheets in this report under the following headings:

1. General Performance.
2. Average Pressures, Temperatures, and Drafts.
3. Injector Performance.
4. Boiler Performance.
5. Fuel Saved by Operation of Sellers Exhaust Steam Injector.

The following curves are presented:

Figure No. 1. - Relation Between Heat Absorbed by Evaporative Heating Surface and Firing Rate.

Figure No. 2. - Relation Between Fuel Fired and Fuel Saved by Sellers Exhaust Steam Injector.

Figure No. 3. - Relation Between Heat Absorbed by Evaporative Heating Surface and Firing Rate. Shows method of Calculating Fuel Saved by Exhaust Steam Injector.

Figure No. 4. - Relation Between Exhaust Passage Pressure and Draft.

Figure No. 5. - Relation Between Exhaust Passage Pressure and Draft. Comparison of Labyrinth and Economizer Front Ends.

Figure No. 6. - Relation Between Firing Rate and Boiler Heat Absorption Rate. Comparison with Master Mechanic's, Economizer, and Labyrinth Front Ends with Changes in Arch Lengths and Secondary Air.

Figure No. 7. - Relation Between Fuel Fired and Fuel Saved by Sellers Exhaust Steam Injectors. Shows Results with Injector on Locomotive 814 with 8000 gallon Tubes and Steam Pipe Change Over and Locomotive 815 with 9000 gallon Tubes and Exhaust Pipe Change Over.

Criterion of Performance for Evaluating Heat and Fuel Savings by Operation of the Exhaust Steam Injector.

If it were possible to exactly duplicate runs, always pulling the same train, running at the same speed under the same weather conditions, the fuel saved by an exhaust steam injector could be determined directly by making a number of runs with the live steam injector and then comparing them with a number of runs using the exhaust steam injector. However, road conditions are variable and the variations are even too great in passenger service for direct comparisons.

On this test, runs were made using the live steam injector to determine evaporations, evaporation ratios, and the heat absorbed by the boiler. As shown by Data Sheet No. 4 on Boiler Performance, the results are better with the Exhaust Steam Injector. However, this data was not used directly for the determination of fuel savings.

Fuel savings were determined by making use of the known fact that regardless of what device is used to feed the boiler, a definite relation exists between the firing rate and the boiler heat absorption rate. It follows that the fuel saved by feed water heating is due to the fact that the boiler is required to supply less heat for the same evaporation. That is, the boiler is relieved of furnishing the heat supplied by the feed water heater which is recovered in the exhaust steam condensed.

Referring to Figure No. 3 an example is given of the determination of fuel saved by operation of the exhaust steam injector. Figure No. 3 shows the relation between the firing rate and the boiler heat absorption rate. This relation holds true regardless of what device is used to feed the boiler. On any run the heat absorbed by the boiler is calculated and from Figure No. 3 the corresponding firing rate is determined. If the live steam injector had been used for the same run, the required heat absorption is determined from the temperature rise due to exhaust steam and the corresponding firing rate determined from Figure No. 3. The fuel saved for the run is the difference in firing rates multiplied by the running time.

In this report all exhaust steam injector performances are based upon data for the entire trip. As an example, if when working the locomotive, the temperature rise due to exhaust steam were 100 degrees Fahr. but due to some of the territory being down grade one half of the tank water were fed to the boiler with the injector on live steam operation, the net temperature rise due to exhaust steam for the trip would be only slightly more than 50 degrees Fahr.

Discussion of Sellers Exhaust Steam Injector Performance

The fuel savings obtained with the Sellers Exhaust Steam Injector with 9000 gallon tubes ran from 1.27 per cent to 7.60 per cent at firing rates from 7000 to 13000 pounds of coal per hour. With 8000 gallon tubes, the Sellers Exhaust Steam Injector on tests of Locomotive 814 February - March 1938 showed fuel savings of from 0 to 9.50 per cent at firing rates of from 7000 to 14000 pounds of coal per hour.

The injector with 8000 gallon tubes had the change over operated by steam pipe pressure while the injector with 9000 gallon tubes had the change over operated by exhaust pipe pressure. The lower fuel saving with the exhaust steam change over can not be charged against the change over. In fact with the exhaust steam change over the injector will operate on exhaust steam whenever exhaust steam of sufficient pressure is available, while with the steam pipe change over the steam pipe pressure may not be high enough to change the injector over to exhaust operation even though the exhaust pressure is high enough for exhaust operation.

The idea of the exhaust pipe change over is correct, but the Sellers design is open to criticism in that it is not sensitive enough and requires to much pressure to operate. It took about 4-5 pounds exhaust pressure to change the injector from live to exhaust operation and as a result the injector operated on exhaust steam an average of only 19.5 per cent of the time on Cheyenne to Omaha runs. With the steam pipe change over on similar runs on Locomotive 814, the injector operated on exhaust steam 14.8 per cent of the time.

The range of the injector is too limited. With 9000 gallon tubes and a full tank of 60 degree Fahr. water the maximum delivery is 74600 pounds, while the minimum is 55900 pounds of tank water per hour.

As shown by westbound runs where the locomotive is worked almost the entire distance, the condensate return and heat recovery from the exhaust steam condensed are

low. Condensate returns ran from 4.10 to 5.24 per cent of the total water fed to the boiler while the net temperature rise due to exhaust steam ran from 46.4 to 60.3 degrees Fahr.

The injector is rather awkward to get on and sometimes the vacuum is slow to establish in the heating set of tubes. However, the ease with which the injector is put on and adjusted depends mostly upon the fireman's ability and familiarity with the device.

The exhaust control change over apparatus proved to be reliable. Also the injector itself proved reliable and stable.

The exhaust steam injector has two important advantages over any other type of feed water heating equipment from an operating standpoint in that (1) regardless of locomotive operation the boiler feed is always relatively hot, and (2) it is always positively known whether the injector is putting water into the boiler or not.

Discussion of Labyrinth Front End Performance.

As shown by Figure No. 5, compared with the Economizer front end the Labyrinth front end shows an increase in draft, but some of this gain must be credited to the better stack and nozzle design.

The Labyrinth front end is of a more simple construction and the entire front end is more accessible for inspection and repairs than either the Master Mechanic's or the Economizer front ends.

As for spark arresting and self cleaning properties the Labyrinth front end is superior to either the Master Mechanic's or the Economizer front ends.

The Labyrinth front end ran with a multiple jet nozzle of 47.17 square inches. While tests were run on Locomotive 815 with the Economizer front end using the same size nozzle, for every day service this size nozzle proved too large and before the conclusion of the tests the nozzle was reduced to 44.18 square inches.

One unusually good feature of the Labyrinth front end is the remarkable uniformity of drafts between the top and bottom of the front flue sheet and between the top and bottom of the combustion chamber. (See Average Pressures Temperatures, and Drafts Data Sheet No. 2). This results in a uniform draft over the fire and a uniform gas flow through the tubes and flues.

Discussion of Boiler Performance

As shown by Figure No. 8 the boiler efficiency with the Labyrinth front end ran from 0.7 per cent higher to 3.6 per cent lower than the efficiency with the Economizer front end. This is due to 34 air tubes for secondary air and a 11 row brick arch being used with the Economizer front end while 24 air tubes and a 9 row brick arch were used with the Labyrinth front end. The higher the firing rate the greater the gain in boiler efficiency due to additional secondary air and a longer arch.

Conclusions:

1. The performance of the Sellers Exhaust Steam injector with the exhaust pipe pressure change over control is satisfactory as to reliability and stability.

2. The exhaust pipe pressure change over control is not sensitive enough and on Locomotive 815 too high a back pressure is required for the change over. This resulted in considerable live steam operation which should have been on exhaust steam operation.

3. Fuel savings due to operation of the Sellers Exhaust Steam Injector ran 1.27 to 7.60 per cent at firing rates from 7000 to 13000 pounds of coal per hour. These savings are too low, but no doubt could be improved upon by a better tube design.

4. The range of the Sellers Exhaust Steam Injector is too limited. With 9000 gallon tubes and 60 degrees Fahr. tank water the maximum delivery is 74600 pounds of tank water per hour. The minimum delivery is 55900 pounds of tank water per hour.

5. On westbound runs where the locomotive is worked almost the entire distance, condensate returns ran from 4.10 to 5.24 per cent of the total water fed to the boiler, and the net temperature rise due to exhaust steam ran from 46.4 to 60.3 degrees Fahr. These figures show a low heat recovery from exhaust steam.

6. The Labyrinth front end showed good drafts with a Multiple Jet Nozzle having an area of 47.17 square inches.

7. The Labyrinth front end proved to be a very efficient spark arrester and the front end was self cleaning.

8. The Labyrinth front end gave a very uniform draft over the fire and through the tubes and flues.

9. The boiler efficiency is better with 34 air tubes for secondary air and a 11 row brick arch than with 24 air tubes and a 9 row arch. The gain in efficiency increases as the firing rate increases.

Office of
Vice President -R&MS
Omaha - May 16, 1941

GENERAL PERFORMANCE LOCOMOTIVE 815

DATE 1940	TRAIN No.	NO. OF STOPS	NO. OF CARS	CAR MILES	DURATION OF TEST TOTAL HOURS	TOTAL MINUTES	DEAD HOURS	DEAD MINUTES	RUNNING HOURS	RUNNING MINUTES	TOTAL POUNDS OF WATER ACTUALLY EVAPORATED BY BOILER	TOTAL POUNDS OF COAL FIRED	PER CAR MILE POUNDS WATER	PER CAR MILE POUNDS COAL	AVERAGE SPEED MILES PER HOUR
CHEYENNE TO OMAHA - 506.7 MILES EASTBOUND - SELLERS EXHAUST STEAM INJECTOR															
MAY 8	28	8	15	7601	10	18	0	48	9	30	335634	67949	44.2	8.94	53.3
MAY 12	28	13	13	6587	10	41	0	55	9	46	354757	68299	53.9	10.36	51.9
MAY 18	28	11	16	8107	10	21	0	45	9	36	371640	71870	45.8	8.86	52.8
MAY 20	28	11	13	6587	10	38	0	54	9	44	354073	71725	53.8	10.89	52.1
MAY 24	28	11	13	6587	10	37	0	54	9	43	363752	73811	55.2	11.21	52.1
CHEYENNE TO OMAHA - 506.7 MILES EASTBOUND - NATHAN LIVE STEAM INJECTOR															
MAY 31	28	12	16	8107	9	55	1	7	8	49	366083	81442	45.2	10.04	57.5
JUNE 2	28	11	15	7601	9	51	0	57	8	55	372158	80092	49.0	10.54	56.9
JUNE 10	28	10	16	8107	9	16	0	37	8	39	391395	83921	48.3	10.35	58.6
OMAHA TO CHEYENNE - 506.7 MILES WESTBOUND - SELLERS EXHAUST STEAM INJECTOR															
MAY 9	717	14	18	9121	10	25	0	59	9	26	527961	111807	57.9	12.26	53.7
MAY 11	717	13	17	8614	10	20	0	56	9	24	539262	115029	62.6	13.35	53.9
MAY 13	27	13	17	8614	10	40	0	55	9	45	591059	135867	68.6	15.77	51.9
MAY 19	717	14	18	9121	10	20	0	58	9	22	553058	122910	60.6	13.48	54.1
MAY 21	717	15	15	7601	10	25	0	56	9	29	485910	105561	63.9	13.89	53.4
MAY 23	717	15	19	9627	10	27	1	2	9	25	565251	126349	58.7	13.12	53.8
OMAHA TO CHEYENNE - 506.7 MILES WESTBOUND - NATHAN LIVE STEAM INJECTOR															
MAY 27	717	16	16	8107	10	25	1	34	8	51	509958	125037	62.9	15.42	57.3
JUNE 1	27	12	16	8107	10	17	0	59	9	18	550298	124851	67.9	15.40	54.5
JUNE 9	27	12	15	7601	10	12	0	53	9	19	506190	115806	66.6	15.24	54.4
JUNE 11	27	13	17	8614	10	23	1	0	9	23	549248	129511	63.8	15.21	53.9

DATE 1940	PRESSURE - POUNDS PER SQUARE INCH GAUGE: BOILER	VALVE CHAMBER	EXHAUST PASSAGE PRESSURE	EXHAUST IN INJECTOR	INJECTOR LIVE STEAM NOZZLE	TEMPERATURE - DEGREES FAHRENHEIT: TANK WATER	EXHAUST STEAM	WATER IN INJECTOR 1ST STAGE	DELIVERY TO BOILER	STEAM TO CYLINDER LEFTSIDE	FLUE GAS ENTERING STACK	FLUE GAS LEAVING 5-1/2" FLUES	FLUE GAS LEAVING 2-1/4" TUBES	DRAFT - INCHES OF WATER: COMBUSTION CHAMBER TOP	COMBUSTION CHAMBER BOTTOM	ENTERING STACK	AT FRONT FLUE SHEET TOP	AT FRONT FLUE SHEET BOTTOM	COMBUSTION CHAMBER TOP	COMBUSTION CHAMBER BOTTOM
CHEYENNE TO OMAHA - SELLERS EXHAUST STEAM INJECTOR																				
MAY 8	290.0	123.9	4.7	2.9	263.0	57	232	106	279											
MAY 12	286.8	128.7	4.9	2.8	258.8	62	244	113	277											
MAY 18	282.4	132.5	2.4	3.6	251.8	56	241	125	277	659	585	604	601	1852	1932	4.81	3.46	3.46	1.41	-
MAY 20	277.4	130.5	5.0	3.2	235.1	60	236	108	268											
MAY 24	289.0	151.5	3.3	1.8	258.5	58	232	109	268											
CHEYENNE TO OMAHA - NATHAN LIVE STEAM INJECTOR																				
MAY 31	289.0	184.2	4.0	THESE ITEMS		65	THIS	THIS	THIS	696	613	625	640	1981	2035	8.10	5.37	5.37	2.60	2.60
JUNE 2	293.2	136.4	3.5	DO NOT		66	DATA NOT	DOES NOT	DATA NOT	681	609	616	630	1975	2032	5.23	4.76	4.76	2.12	2.12
JUNE 10	291.3	147.8	4.2	APPLY		60	TAKEN	APPLY	TAKEN	672	597	637	603	1916	1927	7.26	4.58	4.57	1.96	1.92
OMAHA TO CHEYENNE - SELLERS EXHAUST STEAM INJECTOR																				
MAY 9	292.2	266.3	4.0	4.0	271.3	62	246	118	279											
MAY 11	285.4	272.2	9.0	4.3	265.8	64	247	122	277											
MAY 13	288.9	280.3	8.9	4.6	268.2	64	260	121	271											
MAY 19	296.3	281.9	8.5	5.3	274.8	62	262	131	290	680	652	672	659	2061	2154	11.45	7.68	7.68	3.22	-
MAY 21	291.4	244.7	6.1	4.1	269.7	62	238	121	288	672	630	670	648	1989	2094	9.68	6.59	6.82	2.45	-
MAY 23	294.7	285.8	9.2	5.5	274.3	64	255	126	279	666	648	681	652	2068	2125	12.35	8.54	8.54	4.25	-
OMAHA TO CHEYENNE - NATHAN LIVE STEAM INJECTOR																				
MAY 27	291.0	283.5	8.4			65				669	645	667	654	1970	-	11.75	8.28	8.28	4.25	-
JUNE 1	295.5	277.5	7.8	THESE ITEMS		70	THIS	THIS	THIS	713	653	677	669	2092	2134	11.74	7.92	7.92	3.72	3.72
JUNE 9	294.7	263.0	7.3	DO NOT		69	DATA NOT	DOES NOT	DATA NOT	688	634	676	655	2051	2115	10.97	7.01	6.70	3.43	3.43
JUNE 11	290.0	281.5	9.2	APPLY		67	TAKEN	APPLY	TAKEN	667	642	685	641	2090	2177	11.51	7.63	7.63	3.46	3.35

I N J E C T O R P E R F O R M A N C E - LOCOMOTIVE 815

DATE 1940	SELLERS EXHAUST STEAM INJECTOR: TIME ON EXHAUST STEAM MINUTES	SECONDS	TIME ON LIVE STEAM MINUTES	SECONDS	NATHAN LIVE STEAM INJ: TIME ON MINUTES	SECONDS	TANK WATER DELIVERED TO BOILER-LBS: BY SELLERS EXHAUST STEAM INJECTOR ON EXH ST OPERATION	ON LIVE ST OPERATION	BY NATHAN LIVE STEAM INJECTOR	TANK WATER TEMP. °F	TEMPERATURE WATER IN INJECTOR 1ST STAGE °F	TEMPERATURE WATER DELIVERED TO BOILER °F	CONDENSATE RETURN LBS X	CONDENSATE RETURN % OF TOTAL WATER FED TO BLR.	NET TEMP. RISE DUE TO EXHAUST STEAM °F - RE	TOTAL BTU'S RECOVERED IN EXHAUST STEAM
CHEYENNE TO OMAHA - SELLERS EXHAUST STEAM INJECTOR																
MAY 8	51	20	324	0	16	45	54875	319182	14118	57	106	279	2477	0.63	7.2	2,810,404.2
MAY 12	109	30	372	50	16	15	115303	261687	12558	62	113	277	5423	1.37	15.6	6,157,274.2
MAY 18	87	30	312	35	11	30	91912	294847	9204	56	125	277	5923	1.47	16.P	6,750,443.1
MAY 20	84	30	295	30	15	0	91160	292681	14040	60	108	268	4032	1.00	11.4	4,569,465.6
MAY 24	69	45	338	55	10	55	68040	334509	10481	58	109	268	3205	0.77	8.7	3,633,508.5
CHEYENNE TO OMAHA - NATHAN LIVE STEAM INJECTOR																
MAY 31									395903	65	THIS	THIS				
JUNE 2	THIS DATA DOES NOT APPLY								404513	66	DOES NOT	DATA NOT	THIS DATA DOES NOT APPLY			
JUNE 10									420725	60	APPLY	TAKEN				
OMAHA TO CHEYENNE - SELLERS EXHAUST STEAM INJECTOR																
MAY 9	435	45	52	40	21	30	468416	55014	20436	62	118	279	24288	4.27	48.6	27,591,168.0
MAY 11	434	15	64	40	5	35	473452	73728	5226	64	122	277	25516	4.42	50.1	28,940,247.2
MAY 13	481	35	43	50	45	5	511727	47356	38198	64	121	271	26921	4.31	49.2	30,703,400.5
MAY 19	448	25	66	55	3	30	487016	71837	3276	62	131	290	31101	5.24	60.3	35,750,599.5
MAY 21	398	0	96	50	8	40	409421	98845	8112	62	121	288	22058	4.10	46.4	24,974,067.6
MAY 23	448	40	68	45	24	10	483542	68396	22620	64	126	279	27862	4.63	52.6	31,706,956.0
OMAHA TO CHEYENNE - NATHAN LIVE STEAM INJECTOR																
MAY 27									563528	65						
JUNE 1									585400	70	THIS	THIS				
JUNE 9	THIS DATA DOES NOT APPLY								574989	69	DOES NOT	DATA NOT	THIS DATA DOES NOT APPLY			
JUNE 11									596598	67	APPLY	TAKEN				

BOILER PERFORMANCE - LOCOMOTIVE 815

DATE 1940	TOTAL TANK WATER-LBS.	CONDENSATE FROM EXHAUST STEAM INJECTOR-POUNDS	BLOW DOWN POUNDS	TOTAL POUNDS OF WATER EVAPORATED BY BOILER ACTUAL	TOTAL POUNDS OF WATER EVAPORATED BY BOILER ADJUSTED FOR BLOWDOWN	TOTAL LBS. COAL FIRED	POUNDS OF WATER EVAP. PER POUND COAL FIRED ACTUAL	POUNDS OF WATER EVAP. PER POUND COAL FIRED ADJUSTED FOR BLOWDOWN	BOILER PRESSURE PSI GAGE	TANK WATER TEMP. °F	TEMPERATURE RISE DUE TO EX. STEAM °F	RUNNING TIME HOURS	POUNDS OF COAL FIRED PER HOUR OF RUNNING TIME	MILLIONS OF BTU'S ACT. ABSORBED PER HOUR RUNNING TIME
CHEYENNE TO OMAHA - SELLERS EXHAUST STEAM INJECTOR														
MAY 8	388175	2477	55018	335634	352805	67949	4.94	5.19	290.0	57	7.2	9.5000	7153	43.16
MAY 12	389548	5423	40214	354757	366946	68299	5.19	5.37	286.8	62	15.6	9.7708	6990	43.14
MAY 18	395963	5923	30246	371640	380862	71870	5.17	5.30	282.4	56	16.8	9.6000	7486	45.75
MAY 20	397881	4032	47840	354073	368640	71725	4.94	5.14	277.4	60	11.4	9.7333	7369	43.73
MAY 24	413030	3205	52483	363752	380037	73811	4.93	5.15	289.0	58	8.7	9.7167	7596	45.36
CHEYENNE TO OMAHA - NATHAN LIVE STEAM INJECTOR														
MAY 31	395903	0	29820	366083	375366	81442	4.50	4.61	289.0	65	.0	8.8083	9246	49.49
JUNE 2	404513	0	32355	372158	382250	80092	4.65	4.77	293.2	66	.0	8.9083	8991	49.80
JUNE 10	420725	0	29330	391395	400631	83921	4.66	4.77	291.3	60	.0	8.6500	9702	54.02
OMAHA TO CHEYENNE - SELLERS EXHAUST STEAM INJECTOR														
MAY 9	543866	24288	40193	527961	539380	111807	4.72	4.82	292.2	62	48.6	9.4333	11852	63.81
MAY 11	552406	25516	38660	539262	549886	115029	4.69	4.78	285.4	64	50.1	9.4083	12226	65.02
MAY 13	597281	26921	33143	591059	600389	135867	4.35	4.42	288.9	64	49.2	9.7583	13923	68.48
MAY 19	562129	31101	40172	553058	564214	122910	4.50	4.59	296.3	62	60.3	9.3583	13134	66.58
MAY 21	516378	22058	52526	485910	500507	105561	4.60	4.74	291.4	62	46.4	9.4833	11131	59.06
MAY 23	574558	27862	37169	565251	575695	126349	4.47	4.56	294.7	64	52.6	9.4167	13418	67.85
OMAHA TO CHEYENNE - NATHAN LIVE STEAM INJECTOR														
MAY 27	563528	0	53570	509958	526666	125037	4.08	4.21	291.0	65	.0	8.8500	14128	69.12
JUNE 1	585400	0	35102	550298	561183	124851	4.41	4.49	295.5	70	.0	9.3000	13425	69.79
JUNE 9	574989	0	68799	506190	527559	115806	4.37	4.56	294.7	69	.0	9.3167	12430	65.54
JUNE 11	596598	0	47350	549248	563945	129511	4.24	4.35	290.0	67	.0	9.4000	13778	69.56

FUEL SAVED BY OPERATION OF SELLERS EXHAUST STEAM INJECTOR - LOCOMOTIVE 815

DATE 1940	Boiler Pressure, Lbs per Sq.In. Gauge	Tank Water Temperature °F	Temperature Rise Due to Exhaust Steam °F	Blow Down Lbs Total	Water Actually Evaporated by Boiler-Lbs Total	Running Time. Hours	Millions of BTU's Absorbed by Evap Heating Surface per Hour Actual	Millions of BTU's Absorbed by Evap Heating Surface per Hour If Boiler Were Fed By Live Steam Inj.	Pounds of Coal per Hour from Curve Exhaust Steam Injector Oper	Pounds of Coal per Hour from Curve Live Steam Injector Oper	Coal Rate Difference Lbs per Hour	Coal Saved for Trip Lbs
CHEYENNE TO OMAHA - Sellers Exhaust Steam Injector												
May 8	290.0	57	7.2	55018	335634	9.5000	43.16	43.46	7040	7115	75	713
May 12	286.8	62	15.6	40214	354757	9.7708	43.14	43.77	7035	7193	158	1544
May 18	282.4	56	16.8	30246	371640	9.6000	45.75	46.46	7679	7850	171	1642
May 20	277.4	60	11.4	47840	354073	9.7333	43.73	44.20	7183	7299	116	1129
May 24	289.0	58	8.7	52483	363752	9.7167	45.36	45.73	7583	7674	91	884
CHEYENNE TO OMAHA												
May 31	289.0	65	.0	29820	366083	8.8083	49.49	49.49				
June 2	293.2	66	.0	32355	372158	8.9083	49.80	49.80		LIVE STEAM INJECTOR		
June 10	291.3	60	.0	29330	391395	8.6500	54.02	54.02				
OMAHA TO CHEYENNE												
May 9	292.2	62	48.6	40193	527961	9.4333	63.81	66.73	12152	12947	795	7499
May 11	285.4	64	50.1	38660	539262	9.4083	65.02	68.10	12475	13330	855	8044
May 13	288.9	64	49.2	33143	591059	9.7583	68.48	71.63	13449	14584	1135	11076
May 19	296.3	62	60.3	40172	553058	9.3583	66.58	70.40	12902	14082	1180	11043
May 21	291.4	62	46.4	52526	485910	9.4833	59.06	61.69	10915	11592	677	6420
May 23	294.7	64	52.6	37169	565251	9.4167	67.85	71.22	13261	14414	1153	10857
OMAHA TO CHEYENNE												
May 27	291.0	65	.0	53570	509958	8.8500	69.12	69.12				
June 1	295.5	70	.0	35102	550298	9.3000	69.79	69.79		LIVE STEAM INJECTOR		
June 9	294.7	69	.0	68799	506190	9.3167	65.54	65.54				
June 11	290.0	67	.0	47350	549248	9.4000	69.56	69.56				

Relation Between Heat Absorbed By Evaporative Heating Surface And Firing Rate Locomotive 815

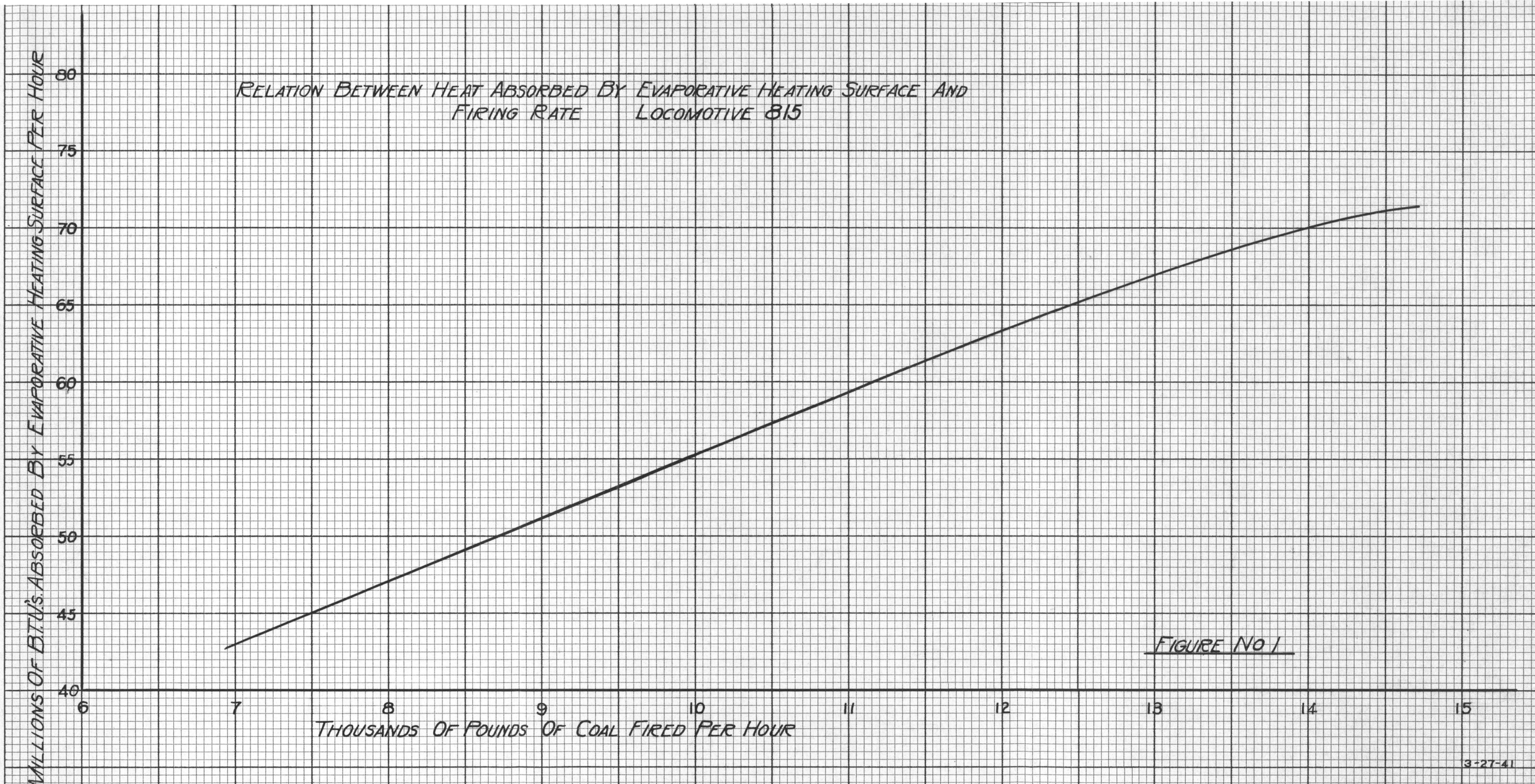


Figure No 1

3-27-41

RELATION BETWEEN FUEL FIRED AND FUEL SAVED BY SELLERS EXHAUST STEAM INJECTOR
LOCOMOTIVE 815

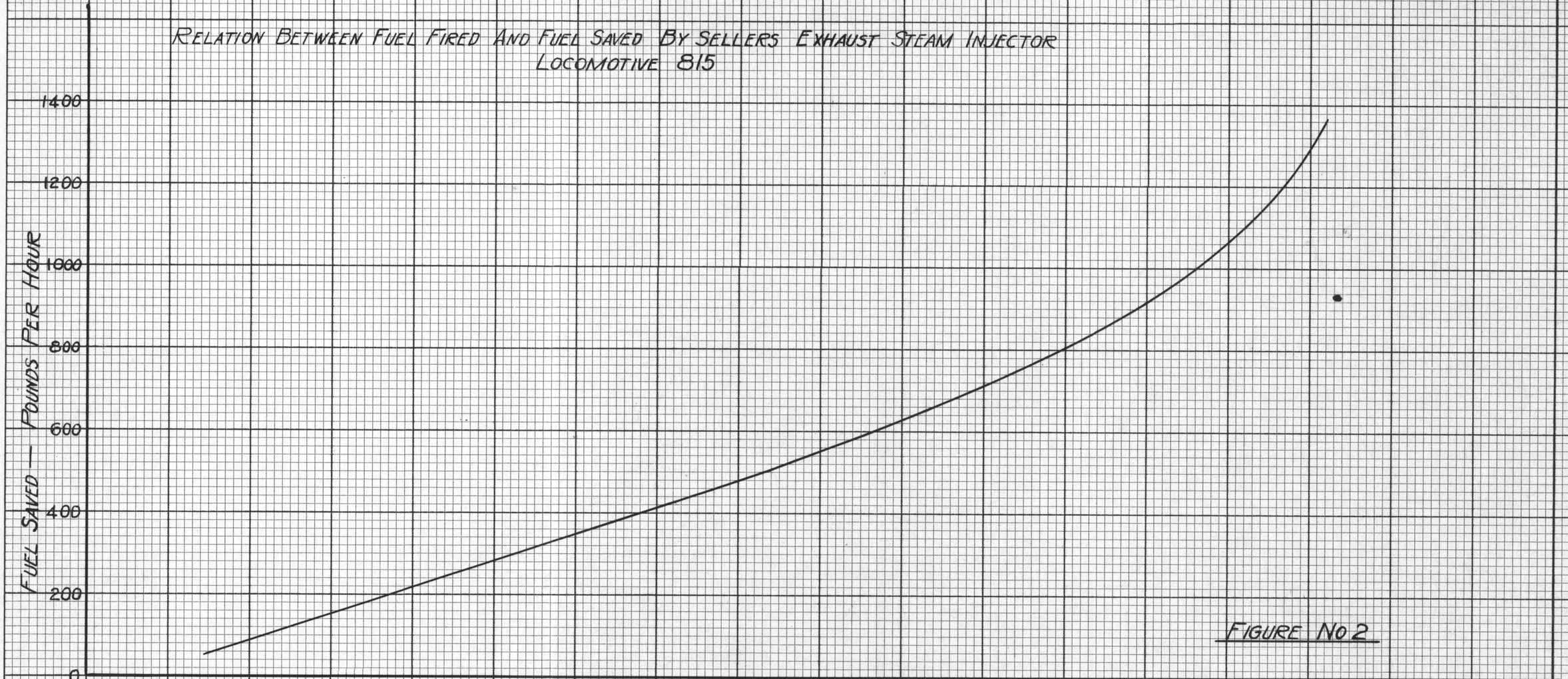
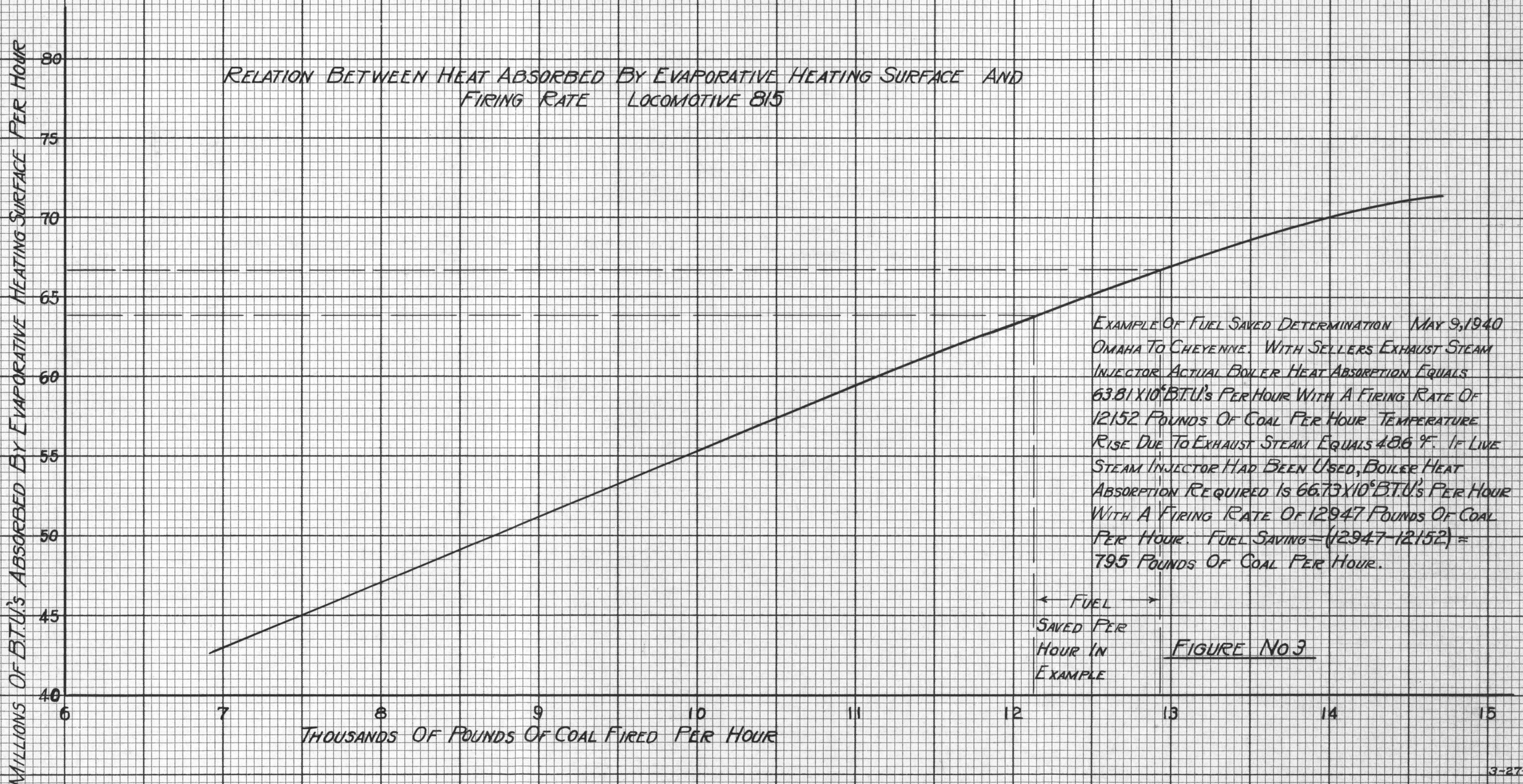


FIGURE NO 2

3-27-41

Relation Between Heat Absorbed By Evaporative Heating Surface And Firing Rate Locomotive 815



Example Of Fuel Saved Determination May 9, 1940 Omaha To Cheyenne. With Sellers Exhaust Steam Injector Actual Boiler Heat Absorption Equals 63.81 X 10⁶ B.T.U.'s Per Hour With A Firing Rate Of 12152 Pounds Of Coal Per Hour Temperature Rise Due To Exhaust Steam Equals 48.6 °F. If Live Steam Injector Had Been Used, Boiler Heat Absorption Required Is 66.73 X 10⁶ B.T.U.'s Per Hour With A Firing Rate Of 12947 Pounds Of Coal Per Hour. Fuel Saving = (12947 - 12152) = 795 Pounds Of Coal Per Hour.

← Fuel Saved Per Hour In Example →

Figure No 3

3-27-41

RELATION BETWEEN EXHAUST PASSAGE PRESSURE AND DRAFT
LOCOMOTIVE 815
NOZZLE AREA – 47.17 SQ. INCHES
NOZZLE TIP TO BOTTOM OF STACK FLARE – 17¼ INCHES
TOTAL LENGTH OF STACK INCLUDING FLARE – 67½ INCHES
STACK CHOKE DIAMETER – 26¼ INCHES
STACK TOP DIAMETER – 32½ INCHES
LABYRINTH FRONT END
NOTE :– BLOWER OPEN FOR
DRAFTS BELOW 4 POUNDS
EXHAUST PASSAGE PRESSURE

DRAFT IN INCHES OF WATER

0 2 4 6 8 10 12 14

DRAFT ENTERING STACK

DRAFT AT FRONT FLUE SHEET

DRAFT IN COMBUSTION CHAMBER

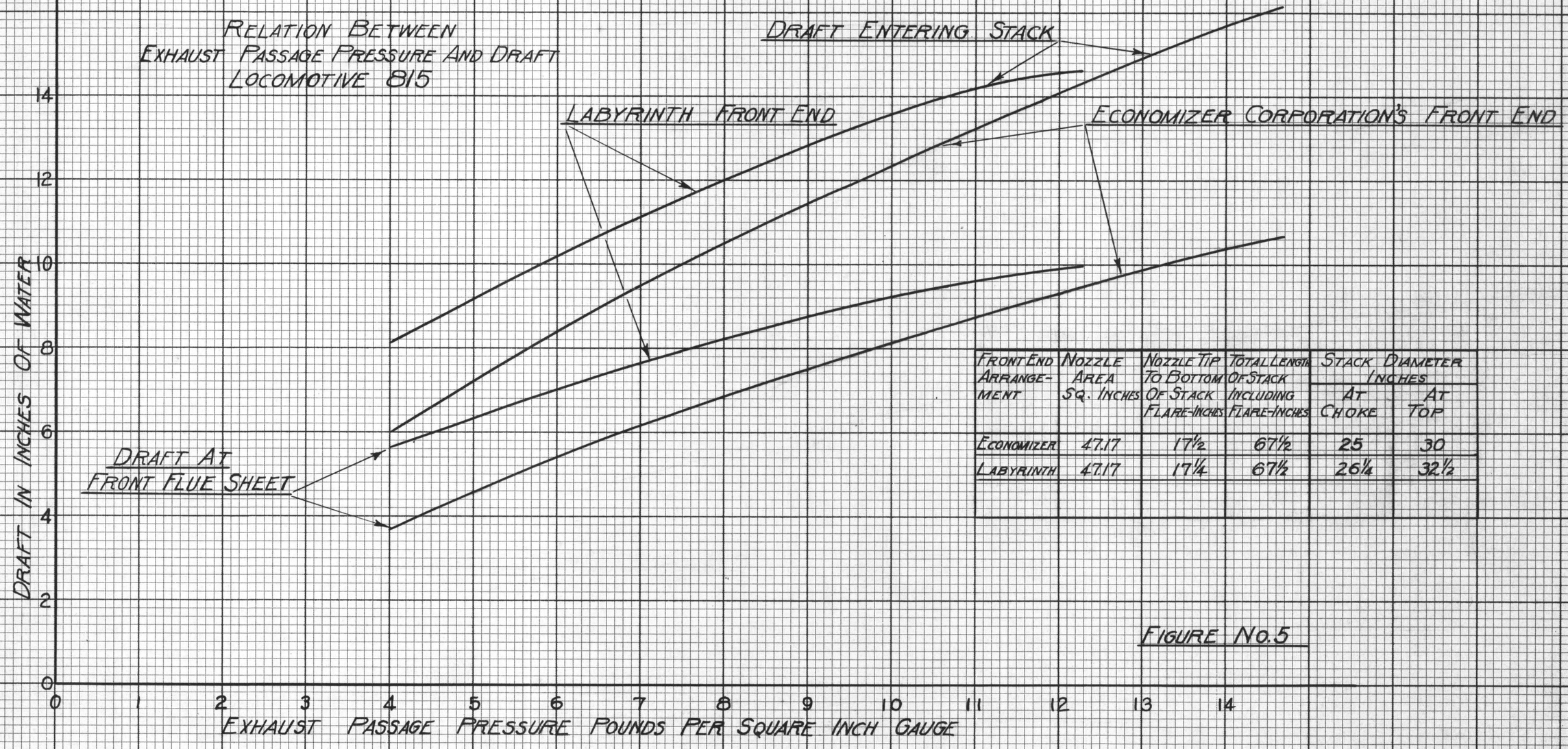
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

EXHAUST PASSAGE PRESSURE POUNDS PER SQUARE INCH GAUGE

FIGURE NO 4

3-27-41

Relation Between Exhaust Passage Pressure And Draft Locomotive 815

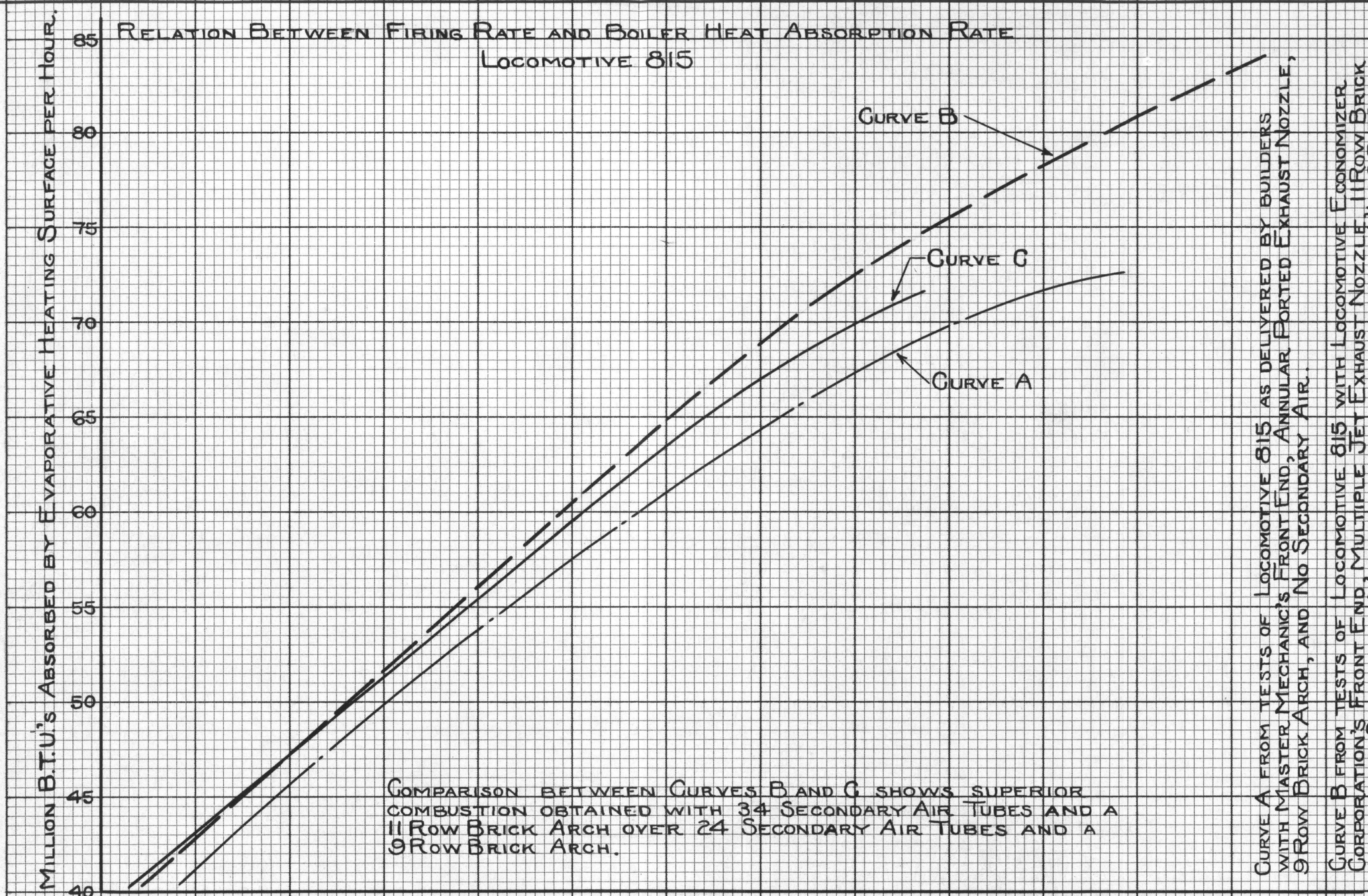


Front End Arrangement	Nozzle Area Sq. Inches	Nozzle Tip To Bottom Of Stack Flare-Inches	Total Length Of Stack Including Flare-Inches	Stack Diameter Inches	
				At Choke	At Top
Economizer	47.17	17½	67½	25	30
Labyrinth	47.17	17¼	67½	26¼	32½

Figure No. 5

4-16-41

Relation Between Firing Rate and Boiler Heat Absorption Rate
Locomotive 815



Curve A from tests of Locomotive 815 as delivered by Builders with Master Mechanic's Front End, Annular Ported Exhaust Nozzle, 9 Row Brick Arch, and No Secondary Air.

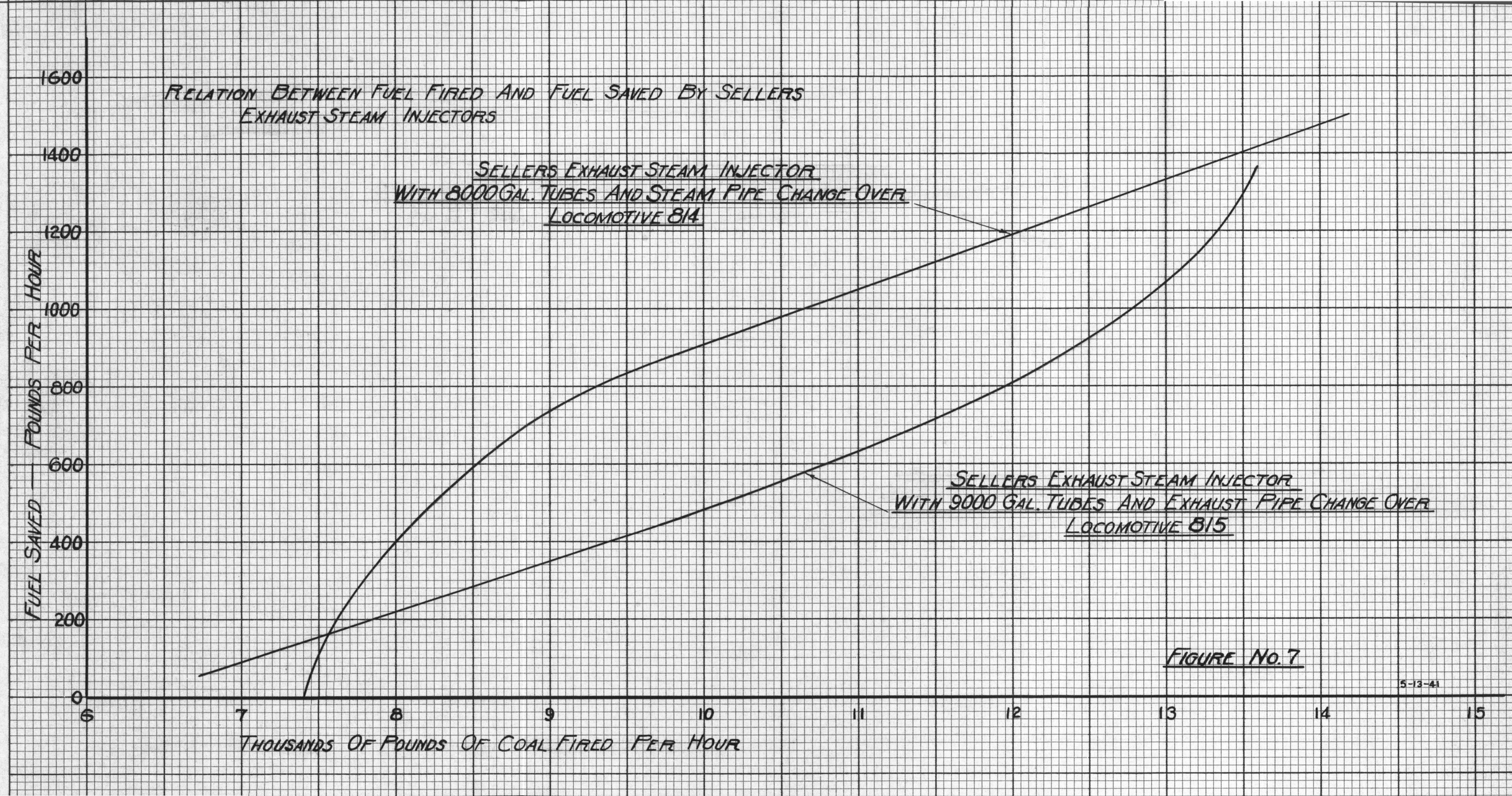
Curve B from tests of Locomotive 815 with Locomotive Economizer Corporation's Front End, Multiple Jet Exhaust Nozzle, 11 Row Brick Arch, and Secondary Air over the fire with 34 - 2¼ In. O.D. Tubes.

Curve C from tests of Locomotive 815 with Labyrinth Front End, Multiple Jet Exhaust Nozzle, 9 Row Brick Arch, and Secondary Air over the fire with 24 - 2¼ In. O.D. Tubes.

FIGURE NO. 6.

4-15-41

L. K. Botteron


RELATION BETWEEN FUEL FIRED AND FUEL SAVED BY SELLERS EXHAUST STEAM INJECTORS
SELLERS EXHAUST STEAM INJECTOR WITH 8000 GAL. TUBES AND STEAM PIPE CHANGE OVER LOCOMOTIVE 814
SELLERS EXHAUST STEAM INJECTOR WITH 9000 GAL. TUBES AND EXHAUST PIPE CHANGE OVER LOCOMOTIVE 815
FUEL SAVED — POUNDS PER HOUR
0
200
400
600
800
1000
1200
1400
1600
6
7
8
9
10
11
12
13
14
15
THOUSANDS OF POUNDS OF COAL FIRED PER HOUR
FIGURE NO. 7
5-13-41