SOUTHERN PACIFIC COMPANY
(PACIFIC LINES)

DYNAMOMETER TEST NO. 8
OF
GOLDEN STATE TYPE
(4-8-4)

LOCOMOTIVES NOS. 4418 AND 4419

CLASS GS-3

Dated: February 12, 1941

SOUTHERN PACIFIC COMPANY
Pacific System

DYNAMOMETER TEST NO. 8

Southern Pacific locomotives Nos. 4418 and 4419, Class GS-3, were put in test service during August, September and October 1940, for the purpose of obtaining the operating characteristics of this class of locomotive and to determine if any improvements could be effected. In addition, the operating characteristics of the feedwater pump system, and the effect of lubricating the driving journals with oil instead of grease were obtained.

PHYSICAL DATA

The locomotives tested were the 4-8-4 type, Class GS-3. They were built by the Lima Locomotive Works and delivered during November, 1937.

The engines have two simple cylinders using steam at 280 lbs. per square inch. Walschaerts valve motion is used, the cut-off being controlled by an ALCO power reverse gear.

The boiler is of conical, radial stayed, construction, with sloping back head, inside dry pipe equipped with a tangential steam dryer, type "E" superheater and a multiple front end throttle.

The boiler is supplied by an open type feedwater heater, capacity 9,000 gallons per hour and a non-lifting injector, capacity 8,200 gallons per hour.

The feedwater pump, air compressor, booster, oil burner and blower are operated by superheated steam. The injector, turbo-generator, hydrostatic lubricator, and steam heat use saturated steam.

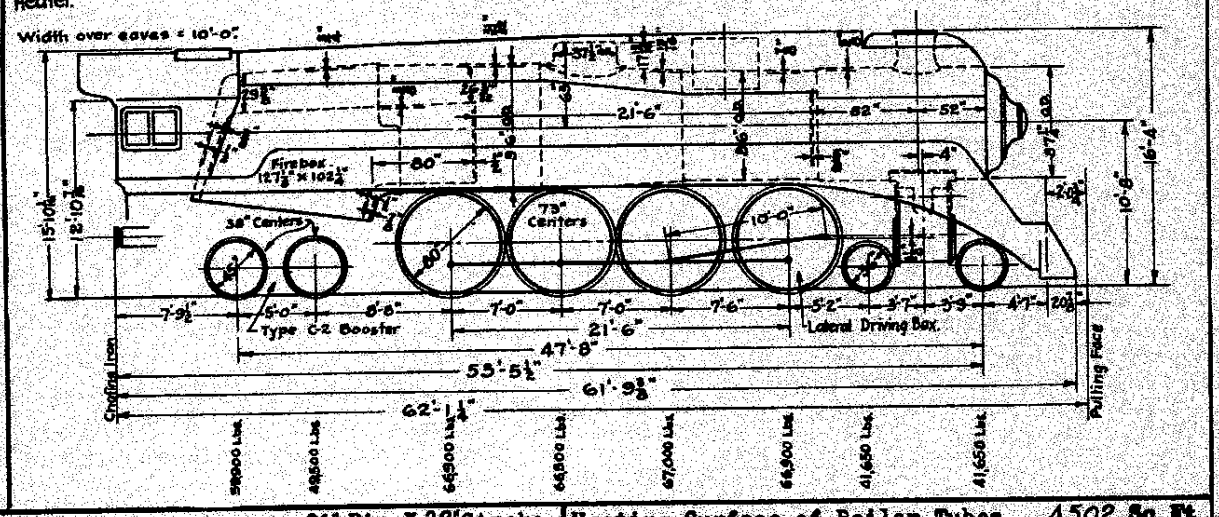
Engine 4418 is equipped with oil lubricated bearings on all axles on engine and tender and all are equipped with spring pad lubricators. Mechanical lubricators feed oil to all driving journals and to engine truck journals and shoe and wedge cavities in driving boxes, but the trailing and tender axles are lubricated solely by the spring pad lubricators.

Engine 4419 is equipped for grease lubrication on all driving axles and oil lubrication on engine truck, trailing truck and all tender axles. All journal boxes other than those on the drivers are equipped with spring pad lubricators which are the only source of lubrication.

The general arrangement and dimensions of the locomotive are as shown on the following two pages:

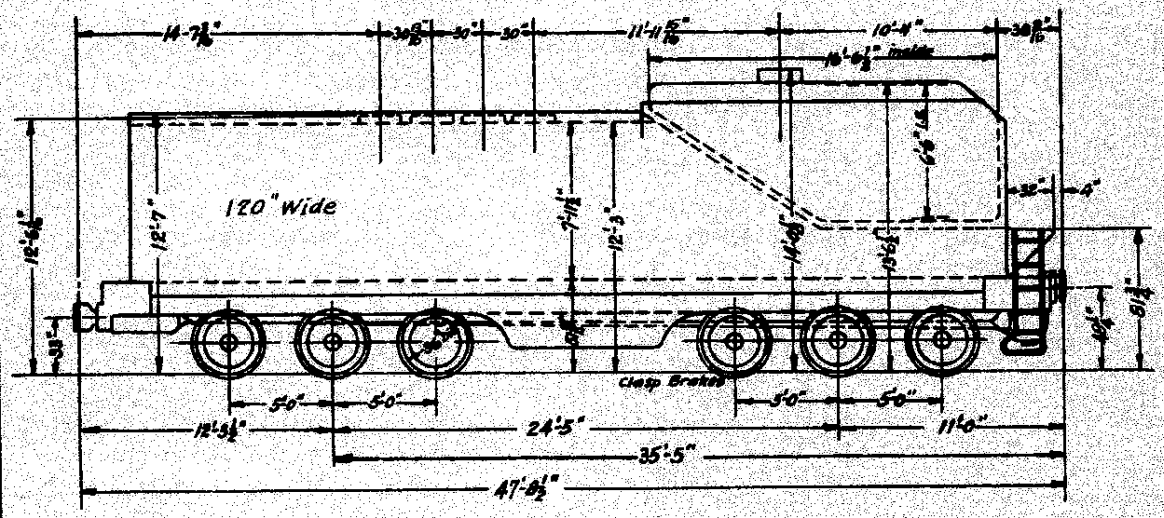
Equipped with № 5 SA Worthington Feedwater Heater.

Class G5-3, G5-80 $\frac{26}{32}$ $\frac{267}{8-109}$ -SF
Boiler Pressure 280 Lbs.



Cylinders	26" Dia. X 32" Stroke	Heating Surface of Boiler Tubes	4502 Sq. Ft
Weight on Drivers	267,300 Lbs	Heating Surface of Firebox	388 Sq. Ft
Weight on Front Truck	83,300 Lbs	Heating Surface-Evaporating	4890 Sq. Ft
Weight on Trailing Truck	109,400 Lbs	Heating Surface of Superheater	2565 Sq. Ft
Weight on Engine-Loaded	460,000 Lbs	Heating Surface-Combined	7455 Sq. Ft
Driving Axle Journals-Main	13" x 14"	Boiler Capacity	102.3 %
Driving Axle Journals-Front	12" x 14"	Tractive Effort to Adhesive Wt.	.235
Driving Axle Journals-Others	12" x 14"	Tractive Effort-(M.E.P. 83 %)	62,800 Lbs
Engine Truck Journals	7½" x 14"	Tractive Effort of Booster	13,850 Lbs
Trailing Truck Journals	Front 7" x 14", Back 9" x 14"	Total Tractive Effort	76,650 Lbs
Boiler Tubes-Length of	21'-6"		
Boiler Tubes-No. of	49-2¼" & 198-3½"		

TENDER CLASS 220-R-1



DIMENSIONS AND WEIGHTS FOR LOADED TENDER.

CAPACITY OF OIL TANK	6,275 GALS.	SIZE OF TRUCK JOURNAL	7" x 14"
GALLONS OF OIL TO MARKER BAR	6,000 GALS.	WEIGHT OF TRUCK	22500 LBS.
CAPACITY OF WATER TANK	21,600 GALS.	WIDTH OVER FRONT STEPS	10'-1⅛"
WEIGHT OF TENDER, EMPTY	145,000 LBS.	WIDTH OVER BACK STEPS	10'-0"
WEIGHT OF 21,600 GALLONS OF WATER	180,000 LBS.	EXTREME WIDTH (over front steps)	10'-1⅛"
WEIGHT OF 6,000 GALLONS OF FUEL OIL	48,000 LBS.	Width over end sills	9'-10"
WEIGHT OF TENDER, LOADED	373,000 LBS.		

PRINCIPAL DIMENSIONS AND WEIGHTS OF SOUTHERN PACIFIC 4-8-4 TYPE LOCOMOTIVES, CLASS GS-3.

Railroad	Southern Pacific
Builder	Lima Locomotive Works, Inc
Type of Locomotive	4-8-4
Road Class	GS-3
Road Numbers	4416 - 4429 (incl.)
Date Built	1937
Rated Tractive Force, Engine, lb.	62,800
Rated Tractive Force with Booster, lb.	76,650
Weights in working order, lb:	
On Drivers	267,300
On Front Truck	83,300
On Trailing Truck, front	49,500
On Trailing Truck, rear	59,900
Total Engine	460,000
Tender	373,000
Total Locomotive	833,000
Wheel Bases, ft. and in.:	
Driving	21- 6
Engine total	47- 8
Engine and tender total	95-10½
Overall dimensions, ft. and in.:	
Length (engine and tender)	110- 3-3/4
Height (top of stack from top of rail)	16- 4
Width (over running board)	10- 10
Driving Wheels, diameter outside tires, in.	80
Cylinders, number, diameter and stroke, in.	2 - 26x32
Valve gear, type	Walschaert
Valves, piston type, size, in.	12
Steam lap, in.	1-3/4
Lead, in.	1/4
Exhaust clearance, in.	3/16
Maximum travel, in.	7-1/4
Boiler:	
Steam pressure, lb.	280
Diameter, first ring, outside, in.	86
Diameter, largest, outside, in.	96
Firebox length, in.	127-1/8
Firebox width, in.	102-1/4
Combustion chamber length, in.	80
Tubes, number and diameter, in.	49-2-1/4
Flues, number and diameter, in.	198- 3½
Length over tube sheets, ft.-in.	21- 6
Fuel	Oil
Grate area, sq. ft.	90.4
Heating surfaces, sq. ft.:	
Firebox and comb.chamber	388
Tubes and flues	4,502
Evaporative, total	4,890
Superheating (Type E & Tangential Dryer)	2,565
Combined evap. and superheat.	7,455
Feedwater heater, type	Worthington No. 5SA

CONDITION OF THE LOCOMOTIVES

Locomotive No. 4418 was selected as the locomotive for the general test and the representative oil lubricated driving journal engine as it was in shop for Class 3 repairs and was being fitted for the oil lubrication. Locomotive 4419 was selected as a representative engine with grease lubricated driving journals.

While locomotive 4418 was in shop some of the test runs were made with locomotive 4419, the remainder being made at the conclusion of the test of 4418.

Locomotive 4418

This locomotive was originally placed in service during November 1937. It was shopped for Class 3 repairs during July and August 1940. During this period the engine was changed over from grease to oil lubrication on the driving journals.

After run #3, it was noticed that all boxes were running above normal. On inspection at the roundhouse, it was found that the left main driving box had been hot with white metal on the spring pad lubricator. The main driving wheels were dropped and a new bearing applied and the journal turned. Also, during the progress of the test it was necessary to adjust the oil burner, due to formation of carbon in the firebox.

Locomotive 4419

Locomotive 4419 was also originally placed in service during November 1937. At the time it was removed from regular service for test purposes, it had made approximately 22,190 miles, since the last general repairs and was in good mechanical condition.

TEST DATA

The Dynamometer chart made a continuous record of drawbar pull and buff, speed, steam chest pressure, back pressure, each 5-gallons of oil, feedwater pump strokes, brake pipe and brake cylinder pressures, throttle and reverse lever positions, time and distance, and location.

On locomotive 4418, readings were taken at 10 minute intervals, while the train was in motion, of the following:

Cab - boiler pressure, back pressure, and cylinder pressure, draft in the smoke box, feedwater temperature, fuel oil temperature at the burner, speed and cutoff indication of the Valve Pilot, and the throttle and reverse lever positions.

Front end - temperature and pressure of the steam to the cylinders, the pressure and temperature of the exhaust steam from the cylinders and to the feedwater heater, and the temperature of the smoke box gases. Readings were also taken of the carbon dioxide content of the smoke box gases. Because of the night operation and the high speeds it was not advisable to have an observer on the front end during the whole run and this data from the front end was obtained only during certain portions of the test.

All of the data referred to in the foregoing is not included in this report, as certain of it was primarily desired for reference purposes and was not obtained over the extended period of time necessary for inclusion herein.

Prior to beginning the test, meters were applied to the oil burner line and to the injector suction line. These were read at

the beginning and end of each run and at each stop of more than five minutes duration. The total water used from tender was measured by gage stick readings taken at the time the meters were read. Check readings were taken of the oil by means of a gage stick based on a calibration of the oil section of the tender.

Locomotive 4419 was not fitted up for test as completely as was locomotive 4418 because the two are identical for all practical purposes with the exception of the type of journal lubrication. The data taken on this engine at 10 minute intervals was as follows:

Cab - speed and cutoff as shown on the valve pilot, boiler pressure, steam chest pressure, exhaust pressure and temperature of the oil at burner.

Front end - no test equipment was installed on the front end and no data was taken there.

The oil and water used were determined from gage stick readings after calibrating the tender.

In the Dynamometer Car the continuous record was the same as that obtained for locomotive 4418, with the exception that the steam chest and back pressures and oil used, were not recorded on the chart.

Due to the fixed schedules and train consists of passenger service, and to the characteristics of the line, it was impossible to test the locomotive at full capacity for protracted periods. Engine crews were requested to arrange their running time so as to have full power operation at certain points, but this of course, could only be done to a limited extent to avoid all possibility of delaying the train. On certain runs where the train left San Luis Obispo late, as much as thirty minutes were made up between there

and Santa Barbara and tests were obtained at outputs more nearly approaching full capacity, although at times it was still necessary to shorten the cut off to avoid exceeding speed limits.

APPARATUS

The apparatus used on this test, excluding the Dynamometer Car, and the calibrated tenders, consisted of bourdon tube pressure gauges and calibrated dial and mercury tube thermometers. Draft in the smokebox was obtained at the front tube sheet and at the smoke box front in inches of glycerine and later converted to inches of water. The carbon dioxide content of the smokebox gases was obtained by means of an absorption device calibrated to read directly in per cent.

In the cab, regular cab devices were used for boiler pressure, cylinder and back pressures, and Valve Pilot speed and cutoff indications. A gage and a dial thermometer were applied in the cab to indicate the pressure of the steam to the feedwater heater and the temperature of the feedwater. The cutoff was obtained in the cab by means of the Valve Pilot indicator, which was checked frequently with markings applied to the crosshead of the power reverse gear at the time the valves were trailed. The cutoffs were recorded on the Dynamometer chart by the cab observer by means of a push button signal. The throttle position was indicated in quarters and recorded on the Dynamometer chart by push button signal.

On the front end the pressure and temperature of the steam to cylinders was obtained directly over one of the steam chests. The temperature and pressure of the exhaust steam to the feedwater heater were obtained by tapping into the exhaust steam pipe in the smokebox

about 15 inches away from the heater.

Smokebox temperature was obtained by use of a four foot mercury tube pyrometer extending through the front of the smokebox. Smokebox vacuum was obtained from pipes extending through the side of the smokebox, on the horizontal center line of the boiler and extending in to the vertical center plane of the boiler, both in back and in front of the spark arrester. The smokebox gas samples were obtained by means of a vacuum pump connected to a perforated sampler pipe in the smokebox near the tube sheet and approximately 20" from the floor of the smokebox.

The action of the feedwater pump was recorded on the continuous chart in the Dynamometer Car by means of a combination pressure and electrical arrangement.

Temperature of the water in the tender was obtained by means of a mercury thermometer immersed in the water.

TERRITORY

The major portion of the test runs were made between Los Angeles and San Luis Obispo, California. The total length of run being 223.5 miles. In order to separate a heavy grade district from one in which the territory is more rolling the test runs were separated at Santa Barbara, California, a station approximately midway between the terminal points of the total run.

The line is single track except for about 11 miles between Los Angeles and Burbank Junction Tower; 3.4 miles at Santa Barbara and 7 miles between Hadley Tower and San Luis Obispo.

Some few test runs were made over an additional district

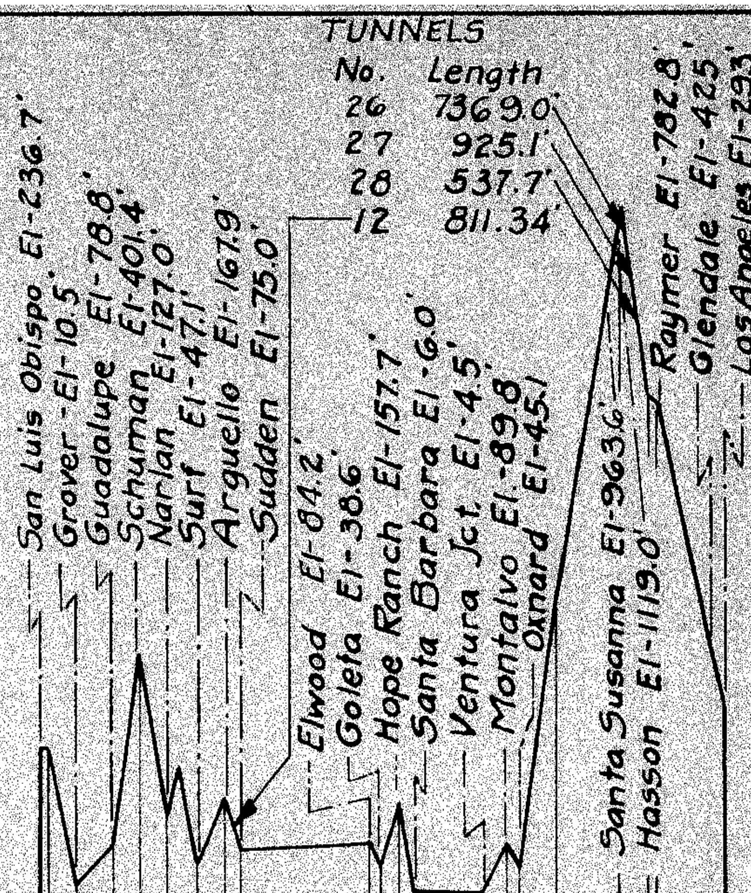
between San Francisco and Santa Margarita, California, in order to determine some of the operating characteristics at higher and more sustained speeds than were possible over the usual test district.

The following page shows a condensed profile of the test district:

PROFILE OF COAST LINE
San Luis Obispo to Los Angeles

Office of Gen'l Sup't. Motive Power
San Francisco, Calif. Aug. 1, 1940.

Scale
Horizontal ___ 1" = 60 Miles
Vertical _____ 1" = 300 ft.



Ruling Grade %	1.04	1.00	1.00	1.00	.68	1.00	
Milepost (from S.F.)	260	300	350	400	450		
Curved Line-Miles: From 0° to 6° inc.	7.754	4.707	6.142	20.441	11.024	6.018	4.335
" 6°01' " 8° "	0.077						
" 8°01' " 10°	0.147						
" 10° and over							

		San Luis Obispo	Santa Barbara	Los Angeles
Eastbound Schedule of Train No. 76	Ar.		5:58	AM 9:00
	Lv.	3:00 AM	6:10	8:42
Westbound Schedule of Train No. 75	Ar.	2:30 AM	11:37	
	Lv.		11:44	PM 9:27 9:00

TRAINS

In order to obtain as consistent and as continuous operation as possible during the test, all runs were made on the "Lark", trains Nos. 75 and 76. The normal consist of the test train was, test car, one baggage car, one mail car, one diner, one lounge and ten standard Pullman cars. From time to time traffic conditions required a total of sixteen revenue cars and as the operating department limits the total consist to this number it was not possible to make test runs at such times.

Over the test district the only regularly scheduled stops were at Glendale and Santa Barbara. The stop at Glendale was ordinarily of short duration. The stop at Santa Barbara was scheduled for twelve minutes eastbound and for seven minutes westbound. This amount of time was more than sufficient for making all oil and water quantity and temperature measurements.

FUEL

The fuel burned, was the present standard cracked oil of the Dubbs type, the weight per gallon at 70° being practically that of water and having a heat value of roughly 18,200 B.T.U.'s per pound. The moisture content of samples from the tender during the test was consistently less than 1%.

Because of its heavy body at normal temperatures this fuel must be heated to at least 150°F in order to reduce the viscosity sufficiently for the oil to atomize properly at the burner. This is accomplished by a closed type heater in the tender for maintaining a temperature there which will provide a free flow of oil from the

tender and up to a steam heated section of pipe called the "oil heater" which is located near the burner. A temperature gage placed in the cab, indicates to the fireman the temperature of the oil at the burner so that it may be maintained at the desired temperature by use of the oil heater.

Changes Made During The Test

No changes were made to locomotive 4419 either before or during the course of the test.

On locomotive 4418, the first three runs in each direction were made with the locomotive standard in all respects, as was locomotive 4419, in order that the comparison might be made on an equal basis.

All other runs on locomotive 4418 were made with the exhaust nozzle opened up to 8¼" as it was found that the engine still steamed freely and well and no difficulties in maintaining the boiler pressure were experienced.

The only other change from standard was in the length of the cold water spray valve sleeve in the heater chamber of the Worthington open type feedwater heater.

The length of this spray valve sleeve affects the temperature of the feedwater in that it acts as a shield for the cold water as it is sprayed into the exhaust steam in the heater chamber. A change in sleeve length, changes the distance the cold water travels through the relatively high temperature exhaust steam and hence changes the final temperature of the feedwater and the per cent of condensation.

The maximum temperature the water could attain would be that of saturated steam at the pressure existing in the heater chamber. To heat the feedwater to this maximum temperature would of course be the

ideal condition as it would be the condition of maximum possible condensation of exhaust steam with its attendant saving of waste heat, virtual increase in tender capacity, improvement in quality of feedwater and reduction of the stresses and strains produced in the boiler by the induction of the feedwater.

The necessity of pumping the water from the heater chamber to the boiler, places a limit on the temperature to which the water may be heated in that a certain lowering of pressure occurs during the suction stroke of the reciprocating pump and for temperatures too close to that of the saturated steam, the heat content of the water is sufficient to cause a portion of the water to vaporize at this lower pressure. Consequently on the suction stroke the pump chamber can only partly fill with water, the remaining portion being occupied by steam. Then the pump piston begins its discharge stroke, pressure in the pump rises and the steam is recondensed causing the pump piston to abruptly encounter solid water which it then forces into the boiler. For extreme temperatures, the result is that the pump "races", that is, makes a large number of strokes during a short period of time and yet does not put any considerable amount of water into the boiler.

In order to determine at what maximum temperature, that is with what minimum length of spray valve sleeve, the pump would make regular and steady strokes during steady locomotive operation, it was necessary to arrange a device so that the strokes of the hot water pump would be registered on the chart in the Dynamometer Car. It was then necessary to change the length of the spray valve sleeve and observe the operation of the pump and the temperature of the feedwater

corresponding to various exhaust pressures.

DATA AND RESULTS

The pages immediately following are devoted to the tabulation and graphs of the data and results.

AVERAGED DATA AND RESULTS

LOCOMOTIVE 4418 CLASS GS-3 DYNAMOMETER TEST NO. 8

LOCATION OF TEST	SAN LUIS OBISPO TO SANTA BARBARA				
TEST RUN NOS.	4 & 6	8 & 10	12 & 14	16 & 18	20 & 22
NOZZLE DIAMETER-INCHES	8	8.25	8.25	8.25	8.25
FWH SPRAY VALVE SLEEVE LENGTH-INS.	4	3	2	1.25	No Sleeve
DISTANCE-TIME-SPEED					
TOTAL TIME HRS., MIN	2:53.5	2:52	2:40	2:47.5	2:30
STANDING TIME-HRS., MIN. DURING RUN	0:10	0:06	0:00.5	0:00	0:00
RUNNING TIME-HRS., MIN.	2:43.5	2:46	2:39.5	2:47.5	2:30
NUMBER OF STOPS DURING RUN	1	0.5	0.5	0	0
DISTANCE RUN-MILES	119.4	119.4	119.4	119.4	119.4
AVERAGE SPEED-M.P.H.	43.8	43.1	44.9	42.7	47.8
TRAIN DATA					
TOTAL NO. CARS, INC. TEST CAR	15.5	15.0	15.5	15.0	15.5
WT. OF TRAIN, EXC. OF LOCO., M'S	2702	2626	2723	2626	2723
WT. OF TRAIN,EXC. OF LOCO., TONS	1351	1313	1361.5	1313	1361.5
TON MILES, EXC. OF LOCO.	161,310	156,770	162,560	156,770	162,560
AVERAGE PRESSURES-LBS.PER SQ.IN.					
BOILER PRESSURE	279	276	277	275	276
STEAM CHEST PRESSURE	202	160	193	115	168
EXHAUST STEAM PRESSURE	2.6	1.5	3.0	1.5	3.0
AVERAGE TEMPERATURES ^{o}F					
TEMPERATURE WATER IN TENDER	69	71	70.5	68.5	69.5
TEMPERATURE WATER TO BOILER	187.5	175.0	203.0	200.5	205.5
TEMPERATURE OIL IN TENDER	189.5	186.0	173.0	192.0	187.5
TEMPERATURE OIL AT BURNER	162.0	159.5	153.0	166.0	163.5
MISCELLANEOUS DATA					
DRAFT AT FRONT TUBE SHEET-IN. H_2O	11.5	-	11.3	7.6	12.2
DRAFT AT SMOKE BOX FRONT-IN. H_2O	10.7	7.2	10.2	6.9	11.0
OIL AND WATER USED					
OIL FIRED-GALLONS	1047	1002.5	1077	981.5	1175.5
WATER USED FROM TENDER-GALLONS	12,692	11,510	12,428	11,837	14,520
RESULTS (AVERAGE)					
GALLONS WATER PER 1000 TON MILES	79.0	73.4	76.7	75.5	89.2
GALLONS OIL PER 1000 TON MILES	6.49	6.39	6.63	6.26	7.23
DRAWBAR H. P. HOURS, ADJ.	4,158	3,176	3,764	3,653	4,924
LBS. OIL PER DRAWBAR H. P. HR., ADJ.	2.10	2.63	2.38	2.24	1.99

AVERAGED DATA AND RESULTS

LOCOMOTIVE 4418 CLASS GS-3 DYNAMOMETER TEST NO. 8

LOCATION OF TEST	SANTA BARBARA TO LOS ANGELES				
TEST RUN NOS.	4 & 6	8 & 10	12 & 14	16 & 18	20 & 22
NOZZLE DIAMETER INCHES	8	8.25	8.25	8.25	8.25
FWH SPRAY VALVE SLEEVE LENGTH IN.	4	3	2	1.25	No Sleeve
DISTANCE-TIME SPEED					
TOTAL TIME-HRS. MIN.	2:49.5	2:51.5	2:56.0	2:50.0	2:42.0
STANDING TIME-HRS. MIN. DURING RUN	0:04	0:04	0:04.5	0:04.5	0:03.5
RUNNING TIME-HRS. MIN.	2:45.5	2:47.5	2:51.5	2:45.5	2:38.5
NUMBER OF STOPS DURING RUN	1	2.5	1	1	1
DISTANCE RUN-MILES	104.1	104.1	104.1	104.1	104.1
AVERAGE SPEED-M.P.H.	37.7	37.3	36.4	37.7	39.1
TRAIN DATA					
TOTAL NO. CARS, INC. TEST CAR	15.5	15.0	15.0	15.0	15.5
WT. OF TRAIN, EXC. OF LOCO., M'S	2702	2626	2625	2626	2723
WT. OF TRAIN, EXC. OF LOCO., TONS	1351	1313	1312.5	1313	1361.5
TON MILES, EXC. OF LOCO.	140,640	136,680	136,680	136,680	141,730
AVERAGE PRESSURES-LBS.PER SQ.IN.					
BOILER PRESSURE	276	274	274	276	271
STEAM CHEST PRESSURE	147	173	157	175	160
EXHAUST STEAM PRESSURE	4.1	3.5	4.0	3.0	3.0
AVERAGE TEMPERATURES ^{o}F					
TEMP. WATER IN TENDER	73.5	73	71.5	71.5	72.5
TEMP. WATER TO BOILER	198.5	204.5	195.0	200.0	198.5
TEMP. OIL IN TENDER	192.5	204.5	179.0	190.0	193.5
TEMP. OIL AT BURNER	176.5	178.5	162.0	169.5	168.5
MISCELLANEOUS DATA					
DRAFT AT FRONT TUBE SHEET-IN. H_2O	13.4	-	12.3	11.0	11.6
DRAFT AT SMOKE BOX FRONT-IN. H_2O	11.7	10.5	11.0	9.8	10.9
PERCENT CO_2 IN FLUE GAS	11.1	11.7	11.4	10.7	10.7
OIL AND WATER USED					
OIL FIRED - GALLONS	1068	1040.5	1072	998	1047
WATER USED FROM TENDER-GALLONS	13,497	12,489	12,661	12,466	13,213
RESULTS (AVERAGE)					
GALLONS WATER PER 1000 TON MILES	95.9	91.3	92.6	91.2	93.1
GALLONS OIL PER 1000 TON MILES	7.59	7.61	7.84	7.30	7.39
DRAWBAR H. P. HOURS, ADJ.	3,974	3,745	3,981	3,831	4,097
LBS. OIL PER D. B. H. P. HR., ADJ.	2.24	2.31	2.24	2.17	2.13

AVERAGED DATA AND RESULTS

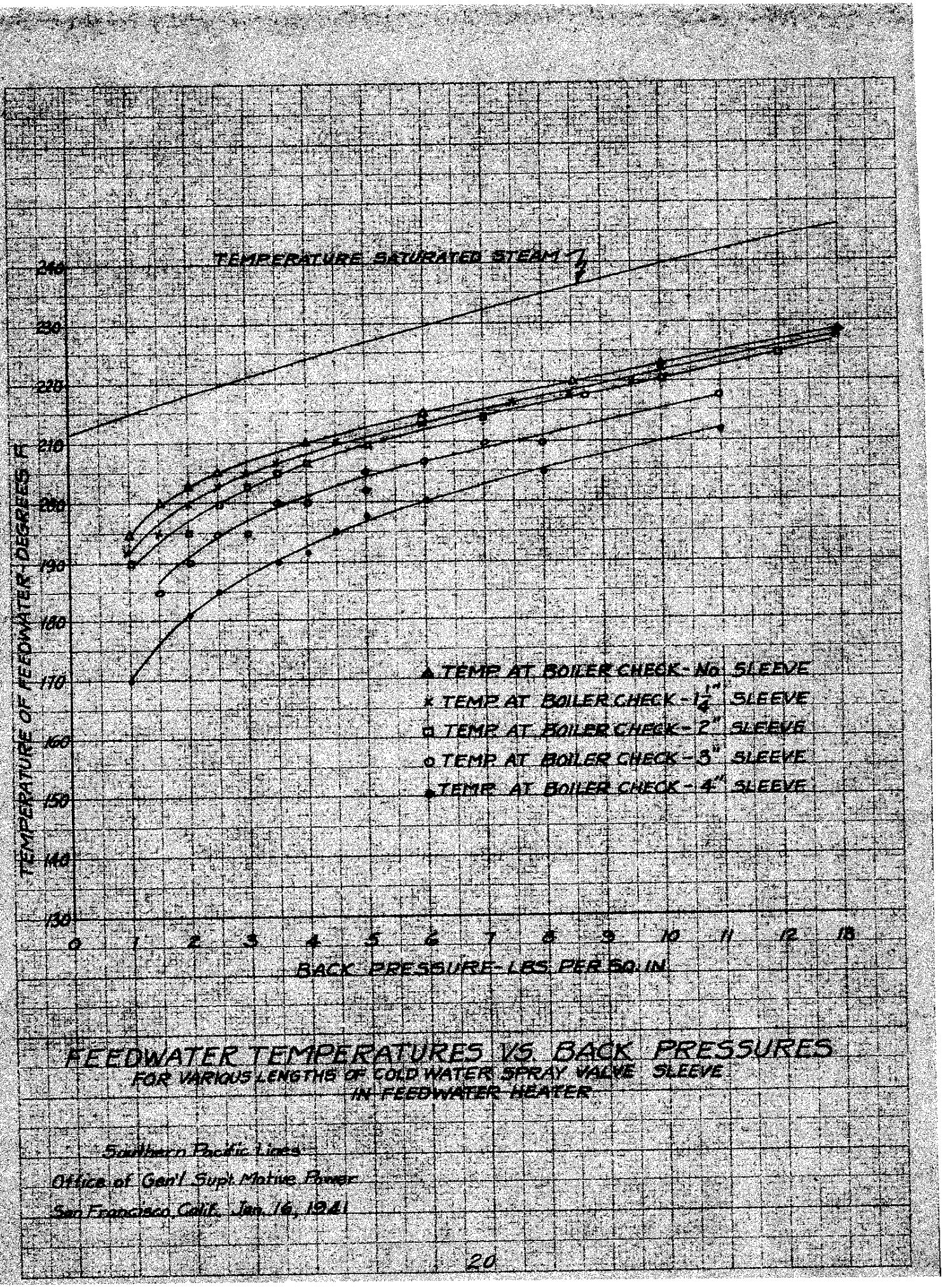
LOCOMOTIVE 4418 CLASS GS-3 DYNAMOMETER TEST NO. 8

LOCATION OF TEST	LOS ANGELES TO SANTA BARBARA				
TEST RUN NOS.	1, 3 & 5	7 & 9	11 & 13	15 & 17	19 & 21
NOZZLE DIAMETER INCHES	8	8.25	8.25	8.25	8.25
FWH SPRAY VALVE SLEEVE LENGTH INCHES	4	3	2	1.25	No Sleeve
DISTANCE-TIME-SPEED					
TOTAL TIME-HRS., MIN.	2:33.6	2:47	2:36.5	2:35.5	2:36.5
STANDING TIME-HRS., MIN. DURING RUN	0:03.6	0:12	0:05.5	0:06.5	0:08
RUNNING TIME-HRS., MIN.	2:30	2:35	2:31	2:29	2:28.5
NUMBER OF STOPS DURING RUN	1.3	3	1	1	3
DISTANCE RUN-MILES	104.1	104.1	104.1	104.1	104.1
AVERAGE SPEED-MPH	41.6	40.3	41.4	41.9	42.1
TRAIN DATA					
TOTAL NO. CARS, INC. TEST CAR	14.3	15	14.5	14.5	14.5
WT. OF TRAIN, EXC. OF LOCO., M'S	2486	2495	2517	2525	2535
WT. OF TRAIN, EXC. OF LOCO., TONS	1243	1247	1259	1263	1268
TON MILES, EXC. OF LOCO.	129,396	129,800	131,060	131,480	132,000
AVERAGE PRESSURES-LBS.PER SQ.IN.					
BOILER PRESSURE	278	275	277	279	277
STEAM CHEST PRESSURE	153	160	147	154	132
EXHAUST STEAM PRESSURE	2.6	4.4	3.5	4.0	3.5
AVERAGE TEMPERATURES ^{o}F					
TEMPERATURE WATER IN TENDER	74.6	74.5	72.5	72.5	73.0
TEMPERATURE WATER TO BOILER	208	202	203	207	211
TEMPERATURE OIL IN TENDER	155	174	167	178	168
TEMPERATURE OIL AT BURNER	140	153	145	156	144
MISCELLANEOUS DATA					
DRAFT AT FRONT TUBE SHEET-IN. H_2O	9.5	-	11.5	11.8	10.6
DRAFT AT SMOKE BOX FRONT-IN. H_2O	8.6	11.5	10.4	10.8	9.9
OIL AND WATER USED					
OIL FIRED - GALLONS	988	1077	978	1000	1013
WATER USED FROM TENDER-GALLONS	11,414	12,430	11,130	11,270	11,160
RESULTS (AVERAGED)					
GALLONS WATER PER 1000 TON MILES	88.2	96.0	84.8	85.6	84.4
GALLONS OIL PER 1000 TON MILES	7.63	8.30	7.46	7.60	7.67
DRAWBAR H. P. HOURS, ADJ.	3,453	3,624	3,236	3,603	3,751
LBS. OIL PER D. B. H. P. HRS., ADJ.	2.38	2.47	2.51	2.31	2.25

AVERAGED DATA AND RESULTS

LOCOMOTIVE 4418 CLASS GS-3 DYNAMOMETER TEST NO. 8

LOCATION OF TEST	SANTA BARBARA TO SAN LUIS OBISPO				
TEST RUN NOS.	1, 3 & 5	7 & 9	11 & 13	15 & 17	19 & 21
NOZZLE DIAMETER-INCHES	8	8.25	8.25	8.25	8.25
FWH SPRAY VALVE SLEEVE LENGTH-INCHES	4	3	2	1.25	No Sleeve
DISTANCE TIME SPEED					
TOTAL TIME-HRS., MIN.	2:43	2:47	2:44	2:42.5	2:44.5
STANDING TIME-HRS., MIN. DURING RUN	0:0	0:08.5	0:01.5	0:0	0:02
RUNNING TIME-HRS., MIN.	2:43	2:38.5	2:42.5	2:42.5	2:42.5
NUMBER OF STOPS-DURING RUN	0	1.5	1	0	0.5
DISTANCE RUN-MILES	119.4	119.4	119.4	119.4	119.4
AVERAGE SPEED-M.P.H.	43.9	45.3	44.1	44.1	44.1
TRAIN DATA					
TOTAL NO. CARS, INC. TEST CAR	14.3	15	14.5	14.5	14.5
WT. OF TRAIN, EXC. OF LOCO., M'S	2486	2495	2517	2525	2535
WT. OF TRAIN, EXC. OF LOCO., TONS	1243	1247	1259	1263	1268
TON MILES, EXC. OF LOCO.	148,414	148,900	150,300	150,800	151,400
AVERAGE PRESSURES-LBS.PER SQ.IN.					
BOILER PRESSURE	275	274	277	276	277
STEAM CHEST PRESSURE	155	165	202	158	164
EXHAUST STEAM PRESSURE	2.1	2.3	3.0	3.0	1.5
AVERAGE TEMPERATURES °F					
TEMPERATURE WATER IN TENDER	74.6	74.5	73.0	73.0	72.5
TEMPERATURE WATER TO BOILER	196	191	200	200	197
TEMPERATURE OIL IN TENDER	168	171	169	179	174
TEMPERATURE OIL AT BURNER	149	151	148	155	156
MISCELLANEOUS DATA					
DRAFT AT FRONT TUBE SHEET-IN. H_2O	9.0	-	11.5	10.9	8.0
DRAFT AT SMOKE BOX FRONT-IN. H_2O	8.7	8.6	10.2	9.6	7.5
PER CENT CO_2 IN FLUE GAS	-	-	10.3	9.8	9.8
OIL AND WATER USED					
OIL FIRED--GALLONS	1069	1153	1140	1128	1057
WATER USED FROM TENDER-GALLONS	12,327	13,373	12,711	13,119	12,036
RESULTS (AVERAGED)					
GALLONS WATER PER 1000 TON MILES	83.1	90.1	84.6	87.1	79.5
GALLONS OIL PER 1000 TON MILES	7.20	7.78	7.59	7.50	6.98
DRAWBAR H.P. HOURS, ADJ.	4225	4485	4216	4453	4269
LBS. OIL PER D. B. H. P. HRS., ADJ.	2.11	2.14	2.25	2.11	2.06



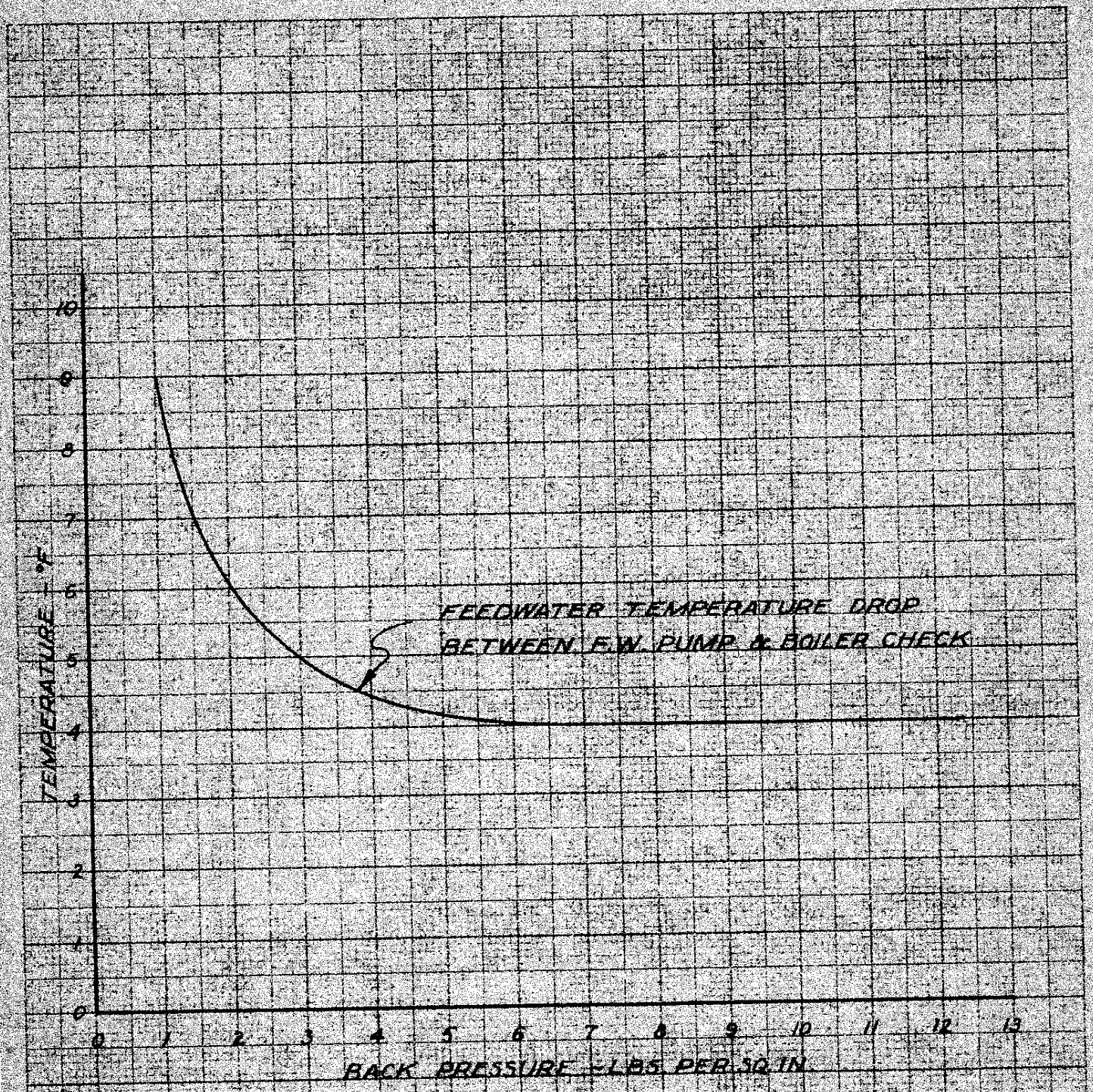
FEEDWATER TEMPERATURES VS. BACK PRESSURES

FOR VARIOUS LENGTHS OF COLD WATER SPRAY VALVE SLEEVE IN FEEDWATER HEATER

Southern Pacific Lines

Office of Gen'l Supt. Motive Power

San Francisco, Calif. Jan. 16, 1941



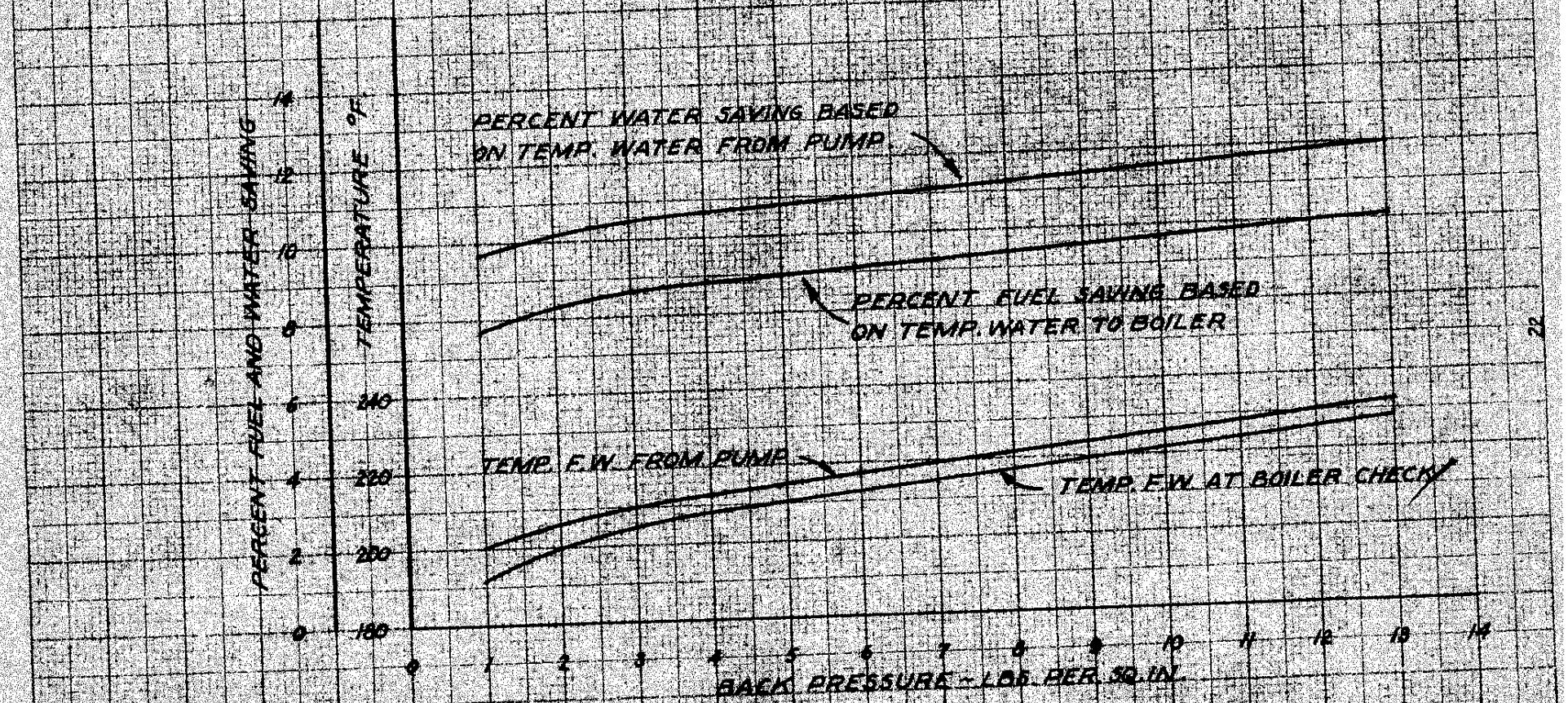
TEMPERATURE LOSS IN DELIVERY PIPE OF FEEDWATER HEATER - WITH 1¼" SPRAY VALVE SLEEVE AND 8 1/4" NOZZLE

LOCO. NO. 4418 - CLASS GS-3

Southern Pacific Lines
Office of Gen'l Supt. Motive Power
San Francisco, Calif. Jan. 16, 1941

FUEL AND WATER SAVING WITH FEEDWATER HEATER

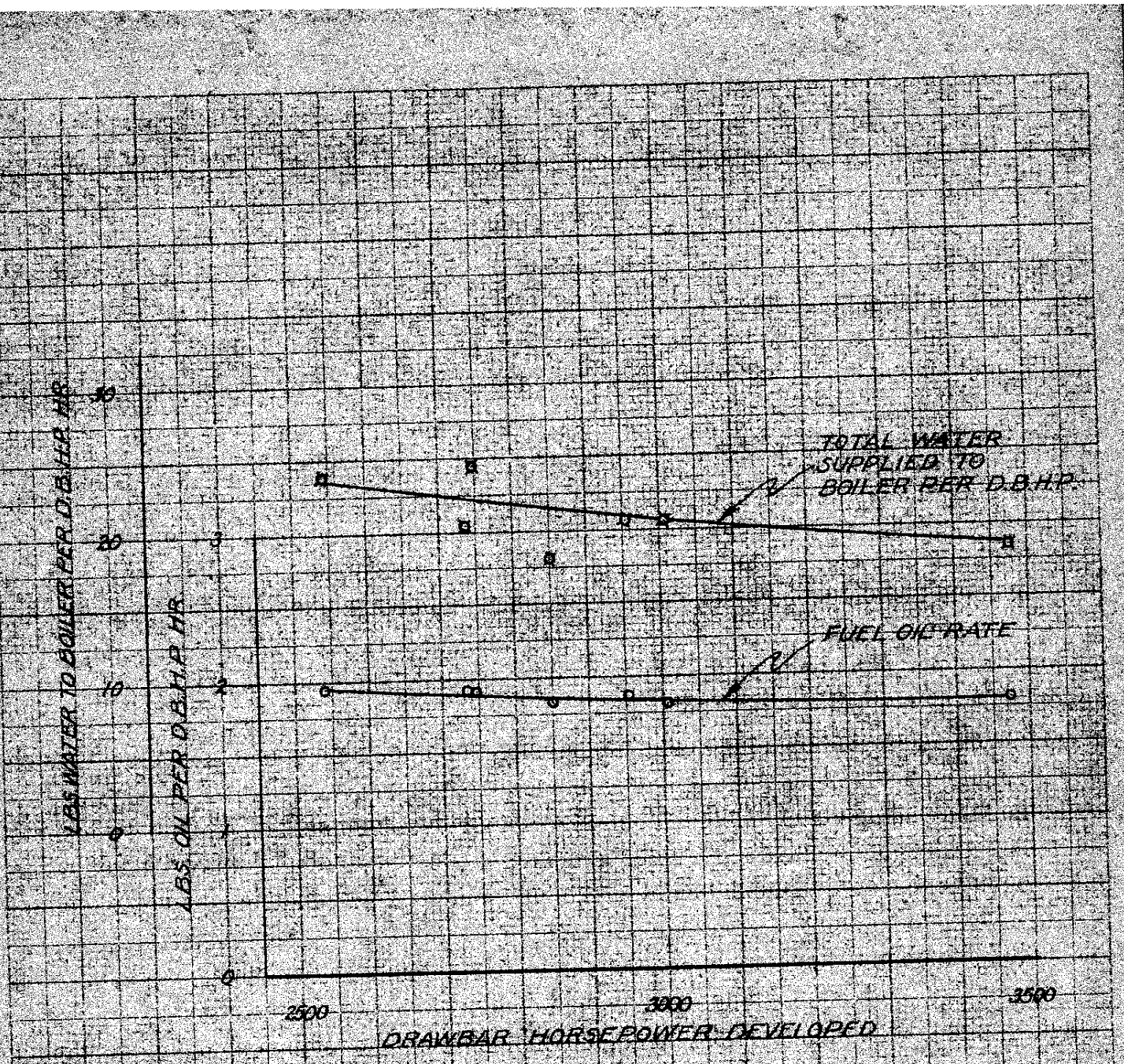
(BASED ON ASSUMED LIVE STEAM INJECTOR OPERATION)



NOTE:
Fuel saving shown is based on heat recovery only and does not include fuel saving that would accrue due to improvement in boiler efficiency and reduction in back pressure, especially at high power outputs.

Southern Pacific Lines
Office of Gen'l. Supt. Motive Power
San Francisco, Calif. Feb. 10, 1941.

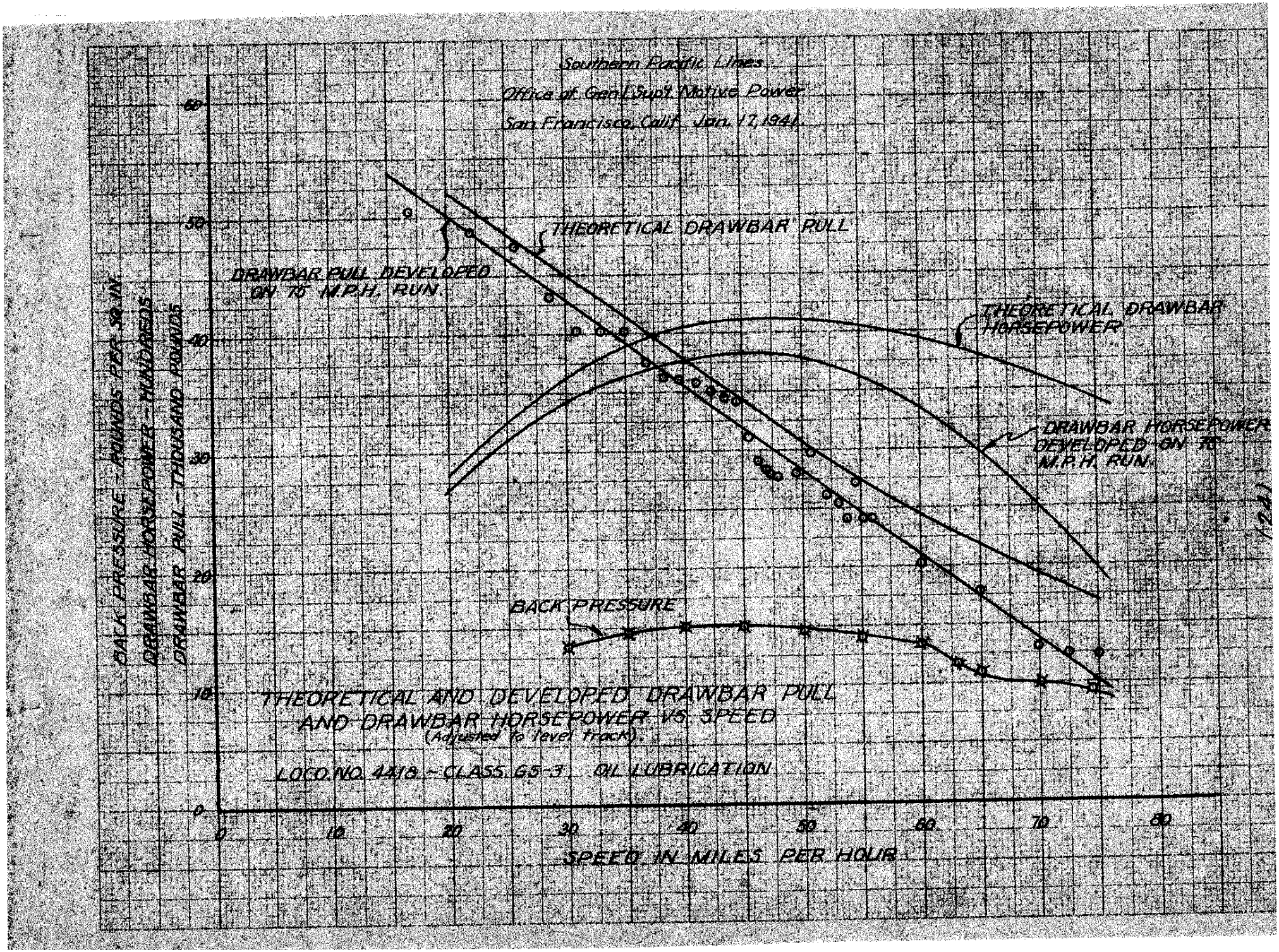
22

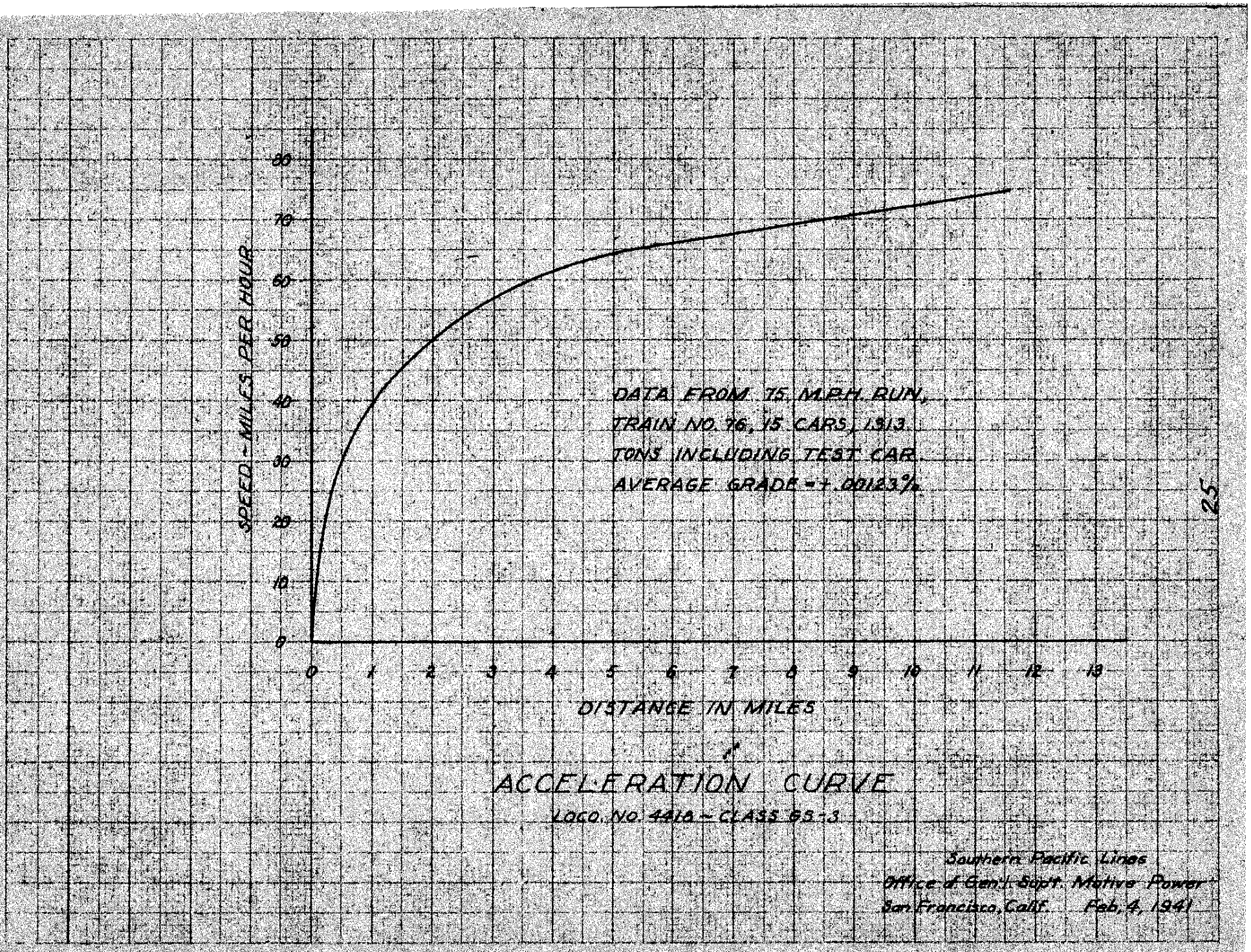


OIL AND WATER RATE VS. HORSEPOWER

LOCO. NO. 4418 – CLASS 6S-3 – TRAINS NO. 75 & 76
FULL THROTTLE OPERATION

Southern Pacific Lines
Office of Gen'l Supt. Motive Power
San Francisco, Calif. Jan. 16, 1941


Southern Pacific Lines
Office of Genl Supt Motive Power
San Francisco, Calif. Jan. 17, 1944.
THEORETICAL DRAWBAR PULL
DRAWBAR PULL DEVELOPED ON 75 M.P.H. RUN.
THEORETICAL DRAWBAR HORSEPOWER
DRAWBAR HORSEPOWER DEVELOPED ON 75 M.P.H. RUN.
BACK PRESSURE
BACK PRESSURE - POUNDS PER SQ. IN.
DRAWBAR HORSEPOWER - HUNDREDS
DRAWBAR PULL - THOUSAND POUNDS
THEORETICAL AND DEVELOPED DRAWBAR PULL AND DRAWBAR HORSEPOWER VS. SPEED
(Adjusted to level track).
LOCO. NO. 4418 - CLASS. GS-3 - OIL LUBRICATION
SPEED IN MILES PER HOUR
0
10
20
30
40
50
60
70
80

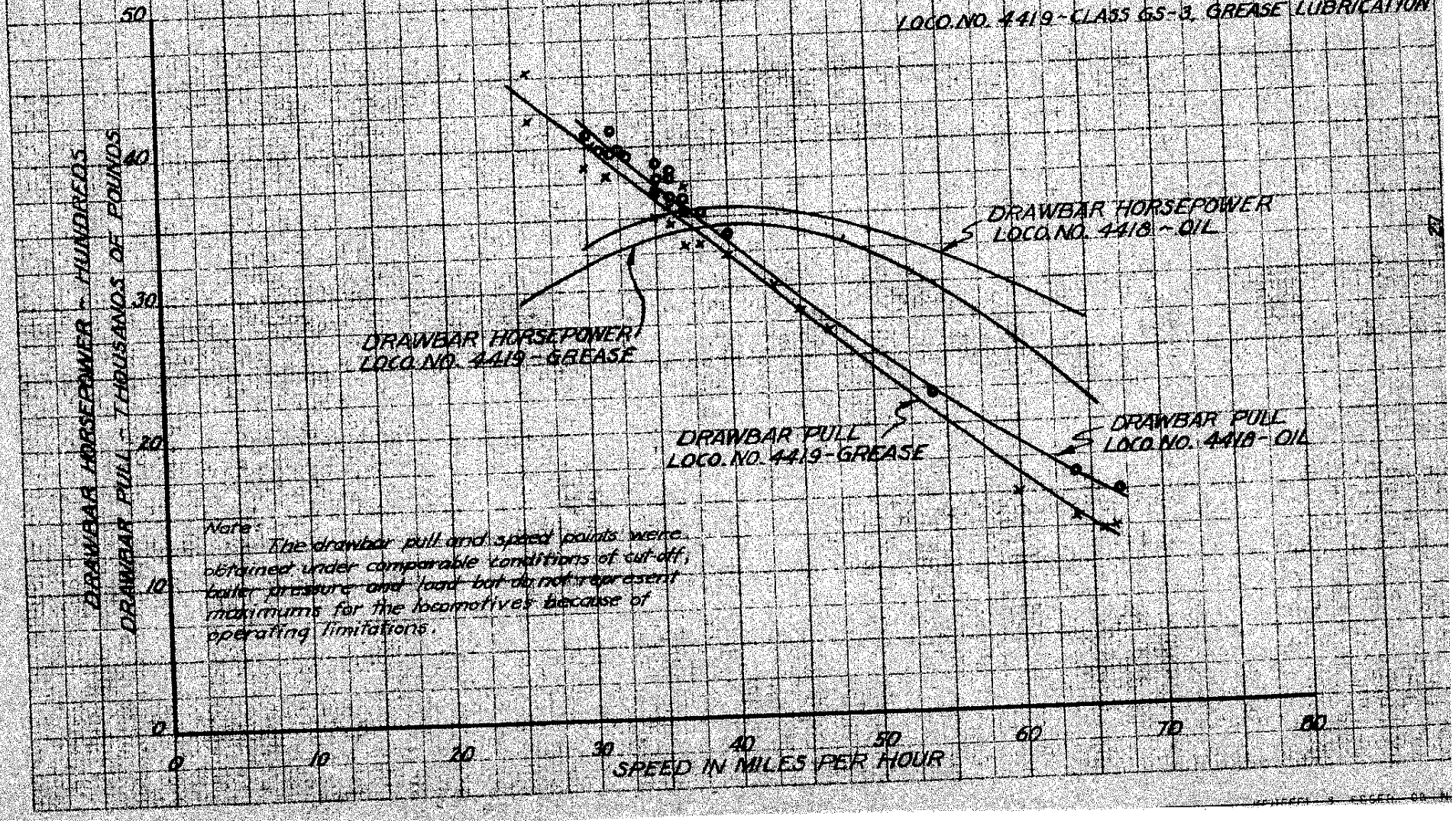

SPEED - MILES PER HOUR
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13
DISTANCE IN MILES
DATA FROM 75 M.P.H. RUN,
TRAIN NO. 76, 15 CARS, 1313
TONS INCLUDING TEST CAR.
AVERAGE GRADE = +.0012 3%
ACCELERATION CURVE
LOCO. NO. 4418 - CLASS 6S-3
Southern Pacific Lines
Office of Gen'l Sup't. Motive Power
San Francisco, Calif. Feb. 4, 1941

COMPARATIVE RESULTS BETWEEN OIL LUBRICATED ENGINE NO. 4418
AND GREASE LUBRICATED ENGINE NO. 4419
DYNAMOMETER CAR TEST NO. 8

TEST DISTRICT	LOS ANGELES TO SANTA BARBARA		SANTA BARBARA TO SAN LUIS OBISPO		SAN LUIS OBISPO TO SANTA BARBARA		SANTA BARBARA TO LOS ANGELES	
LOCOMOTIVE NUMBER	4418	4419	4418	4419	4418	4419	4418	4419
TYPE OF LUBRICATION	OIL	GREASE	OIL	GREASE	OIL	GREASE	OIL	GREASE
NOZZLE DIAMETER-INCHES	8	8	8	8	8	8	8	8
LENGTH F/H SLEEVE-INCHES	4	4	4	4	4	4	4	4
TEST RUN NUMBERS	1,3 & 5	3,5 & 7	1,3 & 5	1,3 & 9	4 & 6	6,8 & 10	4 & 6	4,6 & 8
DISTANCE-TIME-SPEED								
TOTAL TIME OVER DISTRICT-HRS. MIN.	2:33.6	2:35.3	2:43	2:43	2:53.5	2:41.6	2:49.5	2:52
STANDING TIME DURING RUN-HRS. MIN.	0:03.6	0:05.3	0:0	0:00.3	0:10	0:04.6	0:04	0:04
ACTUAL TIME RUNNING-HRS., MIN.	2:30.0	2:30.0	2:43	2:42.6	2:43.5	2:37	2:45.5	2:48
NUMBER OF STOPS DURING RUN	1.3	1.6	0	0.3	1	0.6	1	1
DISTANCE RUN-MILES	104.1	104.1	119.4	119.4	119.4	119.4	104.1	104.1
AVERAGE SPEED (BASED ON RUN TIME)	41.6	41.6	43.9	44.0	43.8	45.7	37.7	37.2
TRAIN DATA								
NO. CAR IN TRAIN, INC. TEST CAR	14.3	13.6	14.3	14.6	15.5	15.0	15.5	15.3
WEIGHT OF TRAIN, EXC. LOCO. M'S	2486	2380	2486	2553	2702	2606	2702	2677
WEIGHT OF TRAIN, EXC. LOCO. TONS	1243	1190	1243	1276	1351	1303	1351	1338
TON MILES, EXC. OF LOCO.	129,396	123,879	148,414	152,354	161,310	155,578	140,640	139,290
AVERAGE PRESSURES LBS./ SQ. IN.								
BOILER PRESSURE	278	276	275	278	279	277	276	276
STEAM CHEST PRESSURE	153	144	155	181	202	180	147	139
EXHAUST STEAM PRESSURE	2.6	4.0	2.1	5.3	2.6	3.8	4.1	5.6
AVERAGE TEMPERATURES °F								
TEMPERATURE OF WATER IN TENDER	74.6	74.5	74.6	72.0	69.0	69.0	73.5	72.5
TEMPERATURE OIL IN TENDER	155	188	168	191	189	185	192	176
TEMPERATURE OIL AT BURNER	140	161	149	167	162	160	176	158
OIL AND WATER USED								
OIL FIRED-GALLONS	988	927	1069	1179	1047	1067	1068	1089
WATER USED FROM TENDER-GALLONS	11,414	10,104	12,327	12,038	12,692	13,796	13,497	12,143
AVERAGED RESULTS-								
GALLONS WATER FROM TENDER-PER 1000 T. M.	88.2	82.0	83.1	79.0	79.0	88.7	95.9	87.2
GALLONS OIL FIRED-PER 1000 T. M.	7.63	7.48	7.20	7.74	6.49	6.86	7.59	7.82
DRAWBAR H. P. HOURS, ADJUSTED	3,453	3,124	4,225	4,416	4,158	3,789	3,974	3,751
LBS. OIL PER DRAWBAR H. P. HRS., ADJ.	2.38	2.47	2.11	2.22	2.10	2.34	2.24	2.42
SAVING IN FUEL RESULTING FROM OIL LUBRICATION								
A. BASED ON LBS. OIL PER DRAWBAR H.P. HR.		3.6%		4.9%		10.7%		7.4%
B. BASED ON GALS. OIL PER 1000 T. M.		-2.0%		7.0%		5.4%		2.9%

Southern Pacific Lines
Office Gen'l Sup't Motive Power
San Francisco, Calif. Jan. 17, 1941.

LOCO. NO. 4418, OIL LUBRICATION, VS. LOCO. NO. 4419, GREASE LUBRICATION
DRAWBAR PULL AND DRAWBAR HORSEPOWER
DEVELOPED ON TRAINS NOS. 75 AND 76
(Adjusted to level track)



Note: The drawbar pull and speed points were obtained under comparable conditions of cut-off, boiler pressure and load but do not represent maximums for the locomotives because of operating limitations.

DISCUSSION

Averaged Data and Results-Locomotive 4418 in conjunction with the curve of Feedwater temperatures vs: Back Pressure.

In the tabulation, data from all runs are included with the exception of that for Run No. 2. On this run, trouble was experienced with the dynamometer equipment.

A study of the data shows that increasing the nozzle diameter took more steam away from the feedwater heater than was compensated for by the reduction of the spray valve sleeve to 3 inches and in spite of the reduced back pressure the net effect was to increase the oil rate. This also holds for the 2" length of sleeve but it is less pronounced. For the 1¼" length of sleeve the oil rate has dropped back to the rate for the 8" nozzle and 4" sleeve.

When the sleevewas removed entirely there was a definite improvement. However, the Dynamometer Car tapes show that with the 1¼" sleeve the operation of the feedwater hot pump was satisfactorily steady and regular, but that the operation with the sleeve removed was not.

The curve of Feedwater Temperature vs: Back Pressure shows that the feedwater temperatures with the 1¼" sleeve are very close to those obtained with the sleeve removed and hence the 1¼" length of sleeve is very near, if not, the critical value and trial of an intermediate length would not be warranted.

During the test runs, the major portion of the run was made at back pressures of less than five lbs. per square inch and it is in these lower back pressures that the largest benefit is derived

from the shortened spray valve sleeve.

Temperature Loss in Delivery Pipe of Feedwater Heater

Feedwater temperature measurements were made at the boiler check and at about 15 inches from the pump, there being about 16 feet of intervening unlagged 2½" iron pipe.

As might be expected, the temperature drop was more for the low back pressures as these low values occur at the higher speeds and the consequent higher air velocities and turbulence occur when low power output requires slow pump operation. This slow movement of the feedwater requiring a longer time in the pipe results in a greater loss in temperature. As the test runs were made at night and with air temperatures of 50° to 65°F., the temperature drop shown on this curve probably represents a maximum to be expected on this class of locomotive on this division, but if operated in colder climate the loss in heat would be much greater.

Fuel and Water Saving with Feedwater Heater

This curve is based on an assumed operation with a live steam injector as compared with the actual operation with the feedwater heater using the 1½" spray valve sleeve, and illustrates the benefits of a feedwater heater on a heat recovery basis. An additional saving would result from the higher boiler efficiency obtained with feedwater heater operation and from the reduction of back pressure which also occurs.

The water saving is not affected by the drop in temperature of the feedwater as it flows from the pump to the boiler but the fuel saving is and would be higher if there were no loss in the delivery pipe connecting the hot water pump and the boiler check.

Oil and Water Rate vs: Horsepower for Full Throttle Operation

As previously brought out, because of limited test conditions, certain of the data obtained was not comparable to tests made in freight service, and in order to obtain some indication of what might be expected under more continuous load operation these curves of oil and water rates were obtained from portions of the Dynamometer Car tapes wherein the operation was continuous and steady.

The fuel oil rate shows a betterment over the consumption determined for the other classes of locomotives that have been tested. The rates as shown on this curve range from 1.81 to 1.96 lbs.of oil per D.B.H.P.Hr., while the rates obtained in a similar manner during tests of an S.P. class locomotive range from 1.92 to 2.18. Although the rates are not based on entirely comparable conditions the differences are sufficient to indicate a very definite improvement in fuel economy, particularly as in those obtained with older types of power there was no train heat to supply.

In regard to the water rates shown, it should be noted that this rate includes steam to all auxiliaries and that required to heat the train, also blow off water which at times may be as high as 13%. These water rates are roughly the values obtained in other tests, but tend to run somewhat less even with inclusion of the water necessary for the steam heat and blow off water. This is no doubt because of the roughly 25% higher boiler pressure which would cause an appreciably lower steam rate to cylinders and because of the increase in superheat resulting from the type "E" superheater.

Theoretical and Developed Drawbar Pull and Drawbar Horsepower vs: Speed - Locomotive 4418

This curve was obtained from the 75 miles per hour run because normal operation during the test did not develop the capabilities of the locomotive for the various reasons previously mentioned.

Prior to this test there was little comparable data for determining the performance of these high speed oil burning passenger locomotives and the theoretical curve shown here represents the estimated maximum output based on hypothetical data. For the major portion of the curve the difference between the theoretical and actual drawbar pull is 2,000 pounds, the main divergence occurring at the higher speeds.

The back pressure curve indicates that above about 55 miles per hour the locomotive was not worked up to maximum capacity as the back pressure fell off above that speed; dropping rapidly between 60 and 65 miles per hour. This would indicate that the cutoff was shortened too much to develop full power at the higher speeds as is borne out by the fact that the last three points on the curve, from 70 to 75 miles per hour, show the pull changing only a very small amount as the speed increased five miles per hour.

The locomotive handled 16 heavy weight cars readily, with reserve power far in excess of that developed on these tests, especially at higher speeds. A comparison of the curve Drawbar Pull Developed at various speeds, Page 24 with that shown on Page 27. shows that on acceleration test where locomotive was worked more nearly to capacity than on trains 75 and 76 the drawbar pull developed by locomotive was 1,500 lbs. greater at 30 miles per hour, 2,500 at 40

miles per hour, 2,800 at 50 miles per hour and 2,500 at 60 miles per hour.

ACCELERATION CURVE

The acceleration curve taken from the 75 miles per hour run starting from Salinas, shows a speed of 65 miles per hour was reached in 5.4 miles and 70 miles per hour was reached in 8.5 miles, with 15 cars weighing a total of 1,313 tons. As this curve was made on a slight opposing grade, it can safely be used for schedule computations on level line, and does not represent the maximum at speeds above 55 miles per hour as shown by back pressure curve, Page 24.

Comparative Results, Between Oil Lubricated Engine No. 4418 and Grease Lubricated Engine No. 4419

This data is based on the test runs made with both engines in standard condition. Runs were selected from those made with locomotive 4419 on the basis of comparable operating conditions as nearly as possible. That is, on the basis of the same number of cars, stops and the same average speed as in the runs used for the averages for locomotive 4418. On this basis it was not always possible to use the same run over both districts.

The results show that over every district the oil lubricated engine had a lower oil per drawbar horsepower hour and on all districts but one, the oil per 1,000 ton miles was lower. However, the oil per drawbar horsepower hour is based on the work actually performed at the drawbar back of the tender but the ton miles do not take into account a variable amount of drifting and braking and are not as accurate a basis of comparison.

The oil rates show a variation with the different districts

and to compensate for this variation, an over all figure could be considered as being a better basis of comparison. This then gives a fuel rate of 2.20 pounds of oil per drawbar horsepower hour for the oil lubricated locomotive and one of 2.35 for the grease lubricated locomotive. The difference in these rates shows a 6% improvement attributable to the reduction in driving journal friction resulting from the change from grease to oil as a lubricant.

This 6% indicates, that on the average, and when working steam under comparable conditions, the oil lubricated locomotive would consume between one half and six tenths of a gallon less fuel per mile than an identical locomotive using grease for the lubrication of the driving journals.

Drawbar Pull and Drawbar Horsepower Developed on Trains Nos. 75 and 76, Locomotives 4418 and 4419

These curves show that for comparable operating conditions, that is, cut-off, boiler pressure and related items, the reduced friction of the oil lubricated driving journals results in a minimum increase of roughly 1,000 pounds, with a greater increase in pull resulting at the higher speeds. This minimum increase in pull represents roughly 100 horsepower for a speed of 40 miles per hour. Then, based on the minimum full throttle oil rate of 1.8 pounds per drawbar horsepower hour, this horsepower would be equal to 180 pounds or 21.6 gallons of oil per hour. Dividing by the number of miles per hour shows the increase in power represents a saving of roughly one-half gallon of fuel oil per mile. At the higher and lower speeds the saving would be greater. This saving agrees very well with that shown by the over all oil rates of the two engines.

Conclusions and Recommendations

1. Oil lubrication results in a major improvement in the performance of the locomotive, resulting in a saving of from 0.5 to 0.6 gallon of fuel per mile when locomotive is working steam, and increasing drawbar pull at equal speed and cut-off about 1,000 pounds between the limits of 30 to 50 miles per hour, and would be greater at both lower and higher speeds, because of reduced friction drag. Application of oil lubrication should be extended on this and other classes of modern power.

2. Present spray valve sleeves in the feedwater heaters on this class of power are too long and should be reduced to 1¼ inches to give maximum heating of feedwater. This results in an increase of about 12°F in the temperature of the feedwater, resulting in somewhat over 1% fuel saving on heat recovery basis only.

3. Tests showed no appreciable advantage in the 8¼ inch exhaust nozzle as compared to the standard 8 inch nozzle, although the locomotive steamed well with either size. In the absence of positive evidence of improvement with the 8¼ inch nozzle, it is recommended that the present standard 8 inch nozzle be retained while locomotives remain in present service. When transferred to division where locomotives are worked at higher capacities, the larger nozzle would be beneficial and would result in fuel economy.

4. Check made during progress of the test showed that feedwater pump capacity could be increased with advantage, a change which was incorporated in the design of our new class GS-4 locomotives.

5. The importance of proper insulation of feedwater hot pump delivery pipe to reduce heat loss between feedwater heater and boiler

was developed. Substantial saving in heat loss can be prevented on present and on new equipment by applying proper insulation; this is being done on new GS-4 class locomotives now being built.

Office Genl.Supt.Motive Power,
Southern Pacific Company,
San Francisco, California,
February 12th, 1941.