SOUTHERN PACIFIC COMPANY

PROGRAM OF RESEARCH

ON

OIL BURNING STEAM LOCOMOTIVES

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CONFIRMATORY TESTS

WITH

DYNAMOMETER CAR AND ENGINE SP-4401

Office of General Supt. Motive Power
San Francisco, California
March 23rd, 1951.

Dynamometer
Test No. 14

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SOUTHERN PACIFIC COMPANY

- PROGRAM OF RESEARCH ON OIL BURNING STEAM LOCOMOTIVES -

CONFIRMATORY TESTS WITH DYNAMOMETER CAR AND ENGINE SP-4401

FOREWORD

This report covers confirmatory tests conducted with dynamometer car and engine SP-4401 (Class GS-1) as the concluding phase of research program on oil burning steam locomotives, authorized by GMO-35006. At the outset of this research program, basic dynamometer car tests were made with this same locomotive equipped with present standard arrangements as used by Southern Pacific Company (Pacific Lines) and Texas and New Orleans Railroad. Results of these basic tests were included in report of Dynamometer Test No. 11, dated July 31, 1947. During the intervening time between the basic tests and the confirmatory tests, extensive standing tests were conducted at special test plant located at Sacramento, California. During course of standing tests, each component of the combustion system was analyzed and improvements developed where necessary. The improvements developed by the standing test and by model tests at Battelle Memorial Institute, Columbus, Ohio, were applied to Engine SP-4401 and confirmatory dynamometer car tests were conducted with these improvements to evaluate and confirm the benefits to be derived under actual road operating conditions. Results of these confirmatory tests are contained in this report.

The following improvements developed by the standing test and model tests were installed in engine SP-4401 for the confirmatory dynamometer car tests as compared with the arrangements used in the basic tests:

Item 1. Cylindrical basket type spark arrester to remove restrictions to gas flow through smokebox, replacing Master Mechanic's front end arrangement.

Item 2. Gyrojet tubular type burner to provide better atomization and combustion of fuel oil, replacing Von Boden drooling type burner.

Item 3. Improved burner application using outboard support with burner centered in Venturi shaped fixed air opening for better mixing of primary combustion air with oil spray from burner.

Item 4. Improved design firepan of angular type with tapered trough to eliminate dead spaces, reduce drumming, and provide better stability, replacing round bottom firepan used by Pacific Lines or angular pan used by Texas and New Orleans Railroad.

Item 5. Improved drafting arrangement to eliminate flapper type side dampers used by Pacific Lines with modified drafting and hooded firedoor used by Texas and New Orleans Lines and to provide for simpler operation of adjustable dampers from one control.

Item 6. Larger smoke stack 24" inside diameter to provide improved exhaust jet characteristics, replacing standard 20" inside diameter stack, and located 10" instead of 13½" above exhaust nozzle.

Item 7. Larger exhaust nozzle 9-1/2" diameter with 1" cross split to permit material reduction in back pressure and increase in cylinder output, replacing 8" nozzle with 3/4" split.

Item 8. Improved firing valve with tapered orifice to permit closer regulation of flow rate of fuel oil.

Item 9. Insulation of firebox wrapper sheets and boiler shell under combustion chamber to reduce heat loss through these sheets.

Item 10. Improved bricking arrangement to provide better heat transfer and reduce weight of firebrick carried by pan.

Item 11. Spray type top boiler check to equalize temperature distribution in boiler.

Item 12. Removal of obstructions from smoke stack such as booster piping, sand ejectors and feedwater exhaust pipes.

Item 13. Improved baffle type oil tank heater on tender to provide better heat distribution to oil leaving tank outlet.

Item 14. Smokebox door gasket to prevent air leaks into smokebox.

At start of confirmatory tests, engine SP-4401 was also equipped with Security circulator units in order that evaluation of these units on oil burning steam locomotive could be made under conditions of road operation. Engine was also equipped with Westinghouse Pacific Coast Brake Company's automatic firing control operating on draft differential between smokebox and firebox. This control was so arranged that manual operation could be assumed at any time desired without difficulty.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made based on the results of confirmatory dynamometer car tests as contained in this report. These conclusions and recommendations pertain to GS class locomotives for the operating ranges shown in report when equipped with the improvements developed by standing test program, as itemized on pages 2 and 3.

1. FUEL SAVING AND RELATED IMPROVEMENTS:

An over-all average fuel saving of 8% can be realized with the improved arrangement over the present standard Pacific Lines arrangement. The average fuel saving over the Texas and New Orleans Railroad arrangement can amount to approximately 9.5%. These savings are shown on Graph No. 1 for freight service and Graph No. 2 for passenger service. In view of the substantial fuel savings available, it is recommended that all GS class locomotives be equipped with the standing test improvements and that investigation be made of applying similar improvements to other types of large steam locomotives with heavy fuel consumption, in order that available fuel savings can be realized. This study is now being undertaken on AC class locomotives and road tests are currently in progress.

In addition to reduction in fuel consumption, confirmatory dynamometer car tests with GS class locomotive also showed the following related benefits in performance with the improved arrangement.

(a) Water Rate: An increase in evaporation of 9.4% over present Pacific Lines arrangement and 11.6% over present T&NO arrangement for the same typical fuel rate can be accomplished.

This would mean that lower fuel rate would be required for equivalent water rate and is illustrated on Graphs No. 4 for freight Service and No. 5 for passenger service.

(b) Boiler Efficiency: An increase of 6.9% in boiler efficiency, including feedwater heater, and 6.8% increase in efficiency, without feedwater heater can be realized over Pacific Lines arrangement. The savings over T&NO arrangement would be 8.5% including feedwater heater and 7.7% without feedwater heater. These savings are illustrated on Graphs 6 and 7.

(c) Maximum Indicated Horsepower was 4550 at 45 miles per hour as compared with 4400 at same speed with T&NO arrangement and 4130 at 42 miles per hour with Pacific Lines arrangement. This reflects an increase in maximum indicated horsepower of 3.4% over T&NO Lines and 10.2% over Pacific Lines arrangements. This is illustrated graphically on Graph 8.

(d) Maximum Mean Effective Pressure expressed as percentage of instantaneous steam chest pressure at representative speed of 40 miles per hour was 65%, compared to 61% with T&NO Lines arrangement and 57% with Pacific Lines arrangement, an increase of 4% and 8% respectively, as shown on Graph 8.

(e) Maximum Starting Drawbar Pull without booster, was 61,000 pounds, as compared with 57,700 pounds with T&NO Lines arrangement and 56,700 pounds with Pacific Lines arrangement, an increase of 5.8% and 7.6% respectively, as illustrated on Graph 9.

(f) Maximum Drawbar Horsepower of 3780 was attained at 40 miles per hour as compared with 3520 with T&NO Lines arrangement at the same speed and 3340 with Pacific Lines arrangement at 37 miles per hour, an increase of 7.4% and 13.2% respectively. This improvement is shown graphically on Graph 9.

(g) Back Pressure because of improvements in combustion system, was reduced an average of approximately 40% over the range tested. This reduction is illustrated graphically on Graph 10 and accounts for the increased cylinder output and reduced fuel consumption.

(h) Carbon Dioxide content in exhaust gases over operating range tested, ranged from 13.2 to 14.2% as compared with 10.0% to 11.9% with present Pacific Lines arrangement between firing rates of 425 and 700 gallons fuel oil per hour and 7.3 to 9.9% with T&NO standard arrangement between firing rates of 585 and 700 gallons per hour. This indicates a decided improvement in combustion conditions, attributable to the redesigned arrangement.

(i) Excess Air ranged from 13 to 23% as compared to excess air ranging from 35 to 60% with Pacific Lines arrangement between firing rates of 425 to 700 gallons fuel oil per hour. With the T&NO arrangement, excess air ranged from 66 to 117% between firing rates of 600 to 700 gallons per hour. This indicates that improved system more nearly approaches the optimum combustion conditions than either of the present standard arrangements.

2. AUTOMATIC FIRING CONTROL:

During initial series of tests, engine SP-4401 was equipped with automatic firing control developed by Westinghouse Pacific Coast Brake Company. This firing control, which operated by draft differential between smokebox and firebox, was found to function as claimed in regulating oil flow rate in response to changes in draft differential. However, in its present state of development, this automatic firing control is not considered practicable for steam locomotive use, primarily because it did not have the necessary capacity under maximum firing rates, and steam pressure consequently dropped under these conditions. Furthermore, it was necessary for the fireman to adjust manually the proportion of fuel fired relative to the draft differential in order to maintain boiler pressure at the various rates of steam demand. Adjustment of draft differential by changing the damper setting was not sufficiently flexible to cover variations in the amount of fuel required. For example, when the locomotive was under heavy load or the locomotive booster was in operation, it was necessary to set the dampers wide open, which did not permit any further adjustment of the draft differential by damper control alone. While the automatic firing control worked best at lower firing rates, additional development is required for an adjustable cam that would proportion the fuel flow properly at the higher firing rates. In view of the shortcomings in the present arrangement and the additional complications encountered by its installation, further applications of the automatic firing control are not recommended at this time.

3. SECURITY CIRCULATOR UNITS:

During initial series of confirmatory tests, Security circulator units were installed in firebox and combustion chamber to determine performance under actual operating conditions. It was found that with the recommended front end arrangement the circulator units caused restriction in proper flow of gas from firebox and resulted in trouble with gas accumulation in cab of locomotive. Upon removal of circulator units during subsequent series of tests, this trouble was eliminated. Therefore, it is evident that to provide proper firing conditions with circulator units, it would be necessary to decrease the effective size of the exhaust nozzle, which in turn would raise the back pressure and offset any possible advantage of the circulator units. There was no fuel economy determined from the use of the circulators. Because of the complications involved in their installation and the obstruction to flow of gases through firebox necessitating reduction in nozzle size, further applications of circulator units on oil burning steam locomotives are not recommended.

DESCRIPTION OF TEST LOCOMOTIVE

Engine SP-4401 is of the 4-8-4 type, built by Baldwin Locomotive Works and first placed in service in August, 1930.

The general dimensions and design of the locomotive are shown on Figure 1.

The engine has two simple cylinders using steam at 250 pounds per square inch boiler pressure. The 12" diameter piston valves are controlled by a Walschaert valve motion and by an Alco power reverse gear. The piston valve maximum travel is 7-1/4"; steam lap 1-3/4"; lead 1/4"; exhaust clearance 3/16"; maximum cutoff 73-1/2% of stroke.

The boiler is a conical, radial stayed type, with sloping back head, inside dry pipe, type "E" superheater with end of units located 48" from back tube sheet, and a multiple front end throttle. The boiler is supplied by a Worthington type 5-S feedwater heater, capacity 9000 gallons per hour, and a Nathan non-lifting injector, capacity 7500 gallons per hour. The feedwater hot pump has an SA type steam valve gear.

The feedwater pumps, feedwater anti-freeze line, the air compressors, booster, booster heater, blower, oil heater, blow back, atomizer, tank heater, and cab heater use superheated steam. The injector, turbo generator, hydrostatic lubricator, lubricator heater, cylinder cocks and train heat line use saturated steam.

The axle bearings, shoes and wedges are oil lubricated.

Engine SP-4401 was tested with dynamometer car for the basic tests of the Program of Research on Oil Burning Steam Locomotives and at the Standing Test Plant at Sacramento, during the second phase of the program.

Improvements developed at the Standing Test Plant and model tests at Battelle Memorial Institute were applied to SP-4401 for confirmatory road tests and feasibility of application to other types of power.

Cylindrical basket netting spark arrester was applied as shown on Figure 2, replacing the Master Mechanic's Front End arrangement. The basket netting spark arrester reduces the draft loss in the front end to a minimum by affording less restriction to the flow of gases. To further remove restriction to flow of gases, the booster exhaust and cold pump exhaust had been removed from stack. Smokebox door gasket was applied to prevent air leaks into smokebox. Nozzle was increased from 8" diameter with 3/4" cross split (effective area of 34.4 square inches) to the 9-1/2" with 1" cross split (effective area of 45.8 sq. in.) or an increase in effective area of 33%. Stack was correspondingly increased from 20" to 24" inside diameter.

Gyrojet oil burner, Figure 3, applied as shown on Photos 1 and 3, centered in Venturi shaped fixed air opening, replaced the Von Boden drooling burner. The better atomization of the fuel oil attainable with gyrojet burner enables fireman to maintain closer control when firing boiler. Design of firing valve, Figure 4, permits closer regulation of oil flow to burner at lower firing rates and coupled with better atomization of gyrojet burner, spot firing and firing up can be more closely regulated without waste of fuel oil.

Taper firepan replacing the Pacific Lines' round bottom firepan or T&NO Lines' angular pan is illustrated by Figures 5 and 6; Figure 5 showing arrangement as tested with the circulators (also shown by Photo 2) and Figure 6 showing arrangement as tested without circulators. Taper firepan has Venturi shaped fixed air opening around burner through which primary air for combustion enters firepan.

Below this fixed opening on the burner wall is an adjustable opening which, together with secondary air opening at bottom of firepan, is controlled by dampers interconnected to lever at fireman's location in cab. Lever operating both front and bottom dampers is on firing valve stand and is provided with toothed quadrant for ready adjustment. Photo 4 shows bottom damper in open and closed position. Firepan is tapered to follow dispersion pattern from gyrojet burner and to eliminate dead spaces at front corners of pan and minimize drumming. Advantages of taper firepan include improved drafting arrangement eliminating flapper type side dampers such as used with round bottom firepan, providing simpler operation of adjustable dampers from one control, easier fabrication and installation, easier method of support, improved bricking arrangement providing for better heat transfer and reducing weight of firebrick carried by pan.

Firebox wrapper sheets and boiler shell under combustion chamber below the running board were insulated to reduce heat loss through these sheets.

Steam space boiler check of spray type was applied in addition to side check. Steam space boiler check was used to take advantage of the better heat distribution afforded by this check as compared to side check.

Tender was equipped with improved oil tank heater (baffle type) Figure 7, showing the direction of flow of oil through the preheater section, upper tier, to the lower tier and its passage around baffle plates to oil outlet. Improved heater assures a flow of hot oil to burner at all times and makes it possible to obtain desired oil flow without maintaining entire contents of tank at high temperature.

Westinghouse Pacific Coast Brake Company's automatic firing control was applied to engine as shown on Photo 5. Top photo shows installation inside cab on fireman's side at deck. Bottom photo shows installation below deck. System was designed to afford semi-automatic firing of boiler (only manual operation being movement of damper to regulate air flow), and was operated by an air flow reader which measured draft differential between smokebox and firebox, actuating oil feed valve. System also included valve for atomizing steam which was to be operated in the same manner as oil fired valve, but as atomizing steam requirements are not directly proportional to firing rate, straight line cam on this device made atomizing steam valve unsuitable, but it is possible that an adjustable cam could be designed to give desired relationship. Further, oil feed valve did not have required capacity at high firing rates. With this system, a pressure of 10 psig was maintained on oil to burner by a reciprocating steam pump, surge chamber, and pressure regulating valve installed under deck of cab on fireman's side in location shown by bottom view on Photo 5.

CONDITION OF TEST LOCOMOTIVE AND PREPARATION FOR TEST

Engine SP-4401 had been released from shop after Class 3 repairs at Sacramento on August 21, 1950, and was in good condition. The valves were set just prior to the test by trailing the engine. A record was made of the cutoff in percent of stroke with the reverse lever in the corner, and for each position of the reverse lever in forward motion, moved in increments of five teeth each on the quadrant from position of maximum cutoff to position of minimum cutoff. Reference marks were cut on the power reverse gear guide to show the travel of the reverse gear crosshead for each of these positions, as a check on the accuracy of the device installed in the cab to indicate the amount of cutoff for each quadrant tooth setting of the reverse lever in forward motion.

DESCRIPTION OF APPARATUS

In the dynamometer car, drawbar pull, speed, buff, boiler and brake pipe pressures, fuel and water used, hot pump strokes, injector, safety valve and blow-off cock operation, as well as time intervals and track travel were recorded on the chronograph chart, illustrated by Photo 9 (a). This shows a general view of chronograph table in dynamometer car, including the recording pens, counters and gages.

In addition to the data recorded on the chronograph chart, observers took other data readings on the locomotive and in the dynamometer car at three minute intervals while locomotive was operating with full throttle. Photo 9 (b) shows the Brown exhaust nozzle pressure recorder mounted on panel to the rear of chronograph table. Photo 9 (c) shows the Brown Smoke Density Indicator-Recorder which made a continuous record of smoke density as measured photoelectrically at the stack. Photo 9 (d) shows the Brown Indicating-Recording Pyrometers mounted on panel ahead of chronograph table and connected with iron-constantan thermocouples in smokebox, oil tank and water side of firebox sheets for determining flue gas temperatures, temperatures of oil in tank at bottom, center and top, and waterside firebox sheet temperatures.

A Brown electronic potentiometer of push button type using iron-constantan thermocouple circuits was used for determining other temperatures.

Observer in cab of locomotive took pressure, draft, throttle position, cutoff position and water glass readings. At top of Photo 6 is a general view of engineer's side of cab showing engineer's controls, test gages and manifold. At bottom of photo is a general view of fireman's side of cab showing fireman's controls and test gages. Indicator cards were taken for computing indicated horsepower. Indicator rigging and piping to the right cylinder being shown at top of Photo 7. Also shown is portion of pilot shelter built over pilot for protection of observers.

Flue gases were analyzed for CO_2 content. Flue gas aspirating motor and pump, washer and separator are shown on bottom of Photo 7.

Selsyn transmitter and connection made with transverse lever, shown at top of Photo 8, was used to obtain cutoff position in dynamometer car. Selsyn repeater for this transmitter was located at back of panel above chronograph table, cutoff position being indicated on calibrated dial at lower left corner of panel as shown by Photo 9 (a).

Selsyn transmitter located under roof of cab (engineer's side) and connected with throttle lever, as shown at bottom of Photo 8, was used to obtain throttle position in dynamometer car. The Selsyn repeater for this transmitter was located at back of panel above chronograph table and throttle position indicated on calibrated dial at lower right corner of panel as shown by Photo 9 (a).

The basic data taken, under normal operating conditions, included fuel and water rates to the boiler; firebox and smokebox drafts; steam pressure in the boiler, in atomizer line at burner and in the exhaust passage; steam pressures and temperatures in the superheated steam pipes to the cylinders, of exhaust steam to the feedwater heater, and at the exhaust nozzle; temperatures of cold and hot feedwater, of fuel at the meter, fuel oil in the oil tank, flue gases in the smokebox, waterside firebox sheet temperatures and flue gases in the smokebox, height of water in the boiler gage glasses; hot water pump strokes; cutoff, throttle opening, speed, CO_2 readings, Ringlemann smoke densities; and indicator cards. Composite samples of fuel oil were taken during each test run and density, moisture content, heat value of oil as fired and when corrected for moisture content were determined by test crew in oil laboratory on auxiliary test car SP-2300. Samples of boiler water were taken at the start and finish of each test run, to determine concentration of dissolved solids in grains per gallon.

Coach SP-2300 was outfitted as an auxiliary test car, supplementing the working and living accommodation space of dynamometer car. Seats were removed from one half of car and tables, benches and oil laboratory were installed for use by test crew. Other half of car outfitted for living accommodations of test crew.

Onan diesel generator supplying 115 volt AC power for test equipment was mounted in leading vestibule of auxiliary car with circuits connected through plugs and receptacles to dynamometer car and test locomotive.

TERRITORY

Preliminary tests were made with engine and test cars to check operation of engine with improvements developed at Sacramento Standing Test Plant and also to check test apparatus. Preliminary tests were made in freight service from Sacramento to Oakland; Oakland to Roseville; Roseville to Fresno; Fresno to Bakersfield and Bakersfield to Los Angeles, California.

Freight tests were run between Los Angeles and Indio, California; profile of the line used shown on Figure No. 8.

Passenger tests were made between Los Angeles, California and Tucumcari, New Mexico, trains 44 and 43.

TRAINS

The test freight trains were moved without helper service, except in two instances when a helper engine was used to start train when it had been stopped in sidings on heavy grades. Freight trains were varied from the full tonnage ratings for GS-1 class locomotives to develop a range of horsepowers and speeds. Trains were operated as above to obtain data comparable to that of basic tests.

Passenger trains were operated without helper except on the grade from Colton to Beaumont and from Indio to Beaumont, California.

FUEL OIL

Fuel oil used during these tests was the regular high viscosity residual blended oil furnished by Standard Oil of California, from their El Segundo refinery, having a calorific value ranging from 17792 to 18135 BTU per pound, moisture free. Typical analysis for this fuel oil during the period of test was as follows:

Gravity, °A.P.I., 60°F. --------	8.3
Lbs. per Gal., 60°F. -----------	8.430
Flash Point, °F. (closed cup) --	210
Viscosity, SSF., 122°F. --------	166
" SSU., 210°F. --------	137
Ash, % -------------------------	.05
Water and Sediment, % ----------	.2
BTUs per lb., gross, 60°F. -----	18178
BTUs per gal., gross, 60°F. ----	153240

Ultimate Analysis (by weight)

Carbon, % ----------	86.0
Hydrogen, % --------	9.6
Nitrogen, % --------	0.84
Sulphur, % ---------	1.6
Oxygen, % ----------	1.9
Ash, % -------------	0.06

CHANGES MADE DURING TEST

The following combinations of oil burning arrangement, nozzle cross split size, and feedwater heater spray valve sleeve length were tested on engine SP-4401 as shown:

Equipment Used

Runs	Oil burning Arrangement	Nozzle Cross Split Size	FWH Spray Valve Sleeve Length
1-8, incl.	Taper Firepan with Circulators	1"	2-1/2"
9-20, incl.	Taper Firepan with Circulators	1"	None
21 & 22	Taper Firepan with Circulators	1-1/8"	None
23 & 24	Taper Firepan with Circulators	1-1/4"	None
27-36, incl.,39&40	Taper Firepan without Circulators	1"	None
37 & 38	Taper Firepan without Circulators	7/8"	None

First phase of tests was made with the taper firepan with Security circulators. Runs 1 to 8, inclusive, were made with a 2-1/2" sleeve on feedwater heater spray valve.

Sleeve was removed from spray valve to take advantage of the higher feedwater temperatures and this arrangement was tested on runs 9 to 20, inclusive.

The circulators restricted the draft in the firebox and to alleviate this condition the effective nozzle area was decreased from 46.0 sq. in. to 43.2 sq. in. by applying 1-1/8" cross split (runs 21 and 22).

The increase in back pressure produced by decreasing the effective nozzle area aided the draft, but at the expense of lowering CO_2 and consequent higher excess air values. Points obtained with this arrangement did not cover a sufficient portion of horsepower output range to warrant establishing a curve on fuel rate although the points obtained were comparable to those with the 9-1/2" nozzle and 1" cross split.

The effective nozzle area was further decreased to 40.4 sq. in. by applying 1-1/4" cross split (runs 23 and 24). Results with this cross split further substantiated the findings of the 1-1/8" cross split regarding back pressure, **draft**, CO_2 and excess air.

Second phase of tests was made with the taper firepan without circulators to test the effect of removal of circulators with respect to their restriction of draft in firebox.

Effective nozzle area was increased to 48.8 sq. in. by replacing 1" cross split with 7/8" (runs 37 and 38) to determine whether engine could be worked to lower back pressures satisfactorily. Back pressures obtained with this nozzle were lower than those with 1" cross split, however the amount of air entrained was the minimum suitable for combustion and this combination might prove too critical for regular use.

DATA SHEETS

The compilations of the observed and calculated data are shown in the tabulations on Data Sheets Nos. 1 to 9, inclusive, and follow the order of the combinations of equipment tested as outlined in the section "Changes Made During Test".

The curves of graphs for dynamometer test number 14 were determined from the data obtained with 1" cross split, without FWH spray valve sleeve, with and without circulators (runs 9-20,incl,; runs 27-36, incl.; runs 39 and 40).

The test runs between Los Angeles and Indio were numbered consecutively, as 1 East, 2 West, and abbreviated 1 E, 2 W, etc. Passenger test runs were designated by inserting the letter P between run number and trip direction letter. Each test run was divided into periods, during full throttle operation, in which conditions of locomotive operation were reasonably consistent, and each of these were assigned an area number, having reference to the area under the drawbar pull curve on the dynamometer chronograph chart for the period selected. Run numbers were combined with area numbers, as 1 E 1, 4 W 2, etc., to indicate the portion of the chronograph chart and observed data used for the calculations of the average results.

Data shown for pressures, temperatures, drafts, CO_2 and excess air, cutoff percentage and speed are average values for each item for the duration of the area.

Oil rates shown were calculated from the figures shown for Oil fired, dry, corrected to $70^{\circ}F$. and for Boiler Blowoff. This figure also included the meter correction factors.

Water rates shown were calculated from the figures shown for

Water from Tender.

Steam rates shown were calculated from the Boiler Efficiency calculations.

Average Developed Adjusted Drawbar Horsepower was calculated from the average area of the drawbar pull and corrected to level tangent track.

DISCUSSION OF DATA AND RESULTS

The detailed data collected and calculated during this series of tests are shown on data sheets 1 to 9, inclusive. For convenience in analyzing these results graphically, relationships between certain variables have been plotted and appear on opposite side of report. The following discussion will explain the significance of the graphical results shown:

Graph No. 1 - Fuel Rate versus Average Developed Adjusted Drawbar Horsepower - Freight Service.

This graph shows the fuel rate expressed in gallons of oil per 1000 adjusted drawbar horsepower hours plotted against the average developed adjusted drawbar horsepower based on tests run in freight service. Three lines have been plotted on this graph, the upper two representing results from basic tests with T&NO Lines standard arrangement and Pacific Lines standard arrangement and the lower line indicating results obtained during confirmatory tests with improved arrangement. From this relationship it is evident that, over the output range tested, the improved arrangement affords a substantial fuel saving over either of the present standard arrangements. The improvement over the Pacific Lines arrangement is approximately a straight line relationship, amounting to 7.57% saving at 2000 horsepower; 8.08% at 2500 horsepower and 8.58% at 3000 horsepower or an average of approximately 8% over the range in question. Compared to the T&NO arrangement, the improvement is 11.80% at 2000 horsepower; 11.18% at 2500 horsepower and 10.50% at 3000 horsepower, or an average of approximately 11% over the range.

This saving is accounted for by the improvements in the combustion system, permitting enlargement of the effective nozzle area and operation at reduced back pressure which results in increasing cylinder horsepower, or in effect, giving equivalent cylinder horsepower at lower fuel rate.

Graph No. 2 - Fuel Rate versus Average Developed Adjusted Drawbar Horsepower - Passenger Service.

This graph represents the same relationship as Graph No. 1, except it is based on data obtained in passenger service comparing the T&NO Lines arrangement with the improved arrangement. This relationship shows a fuel saving of 7.89% at 2500 horsepower and 8.13% at 3000 horsepower, or an average saving of about 8% over the range tested. Combined with fuel saving of 11% in freight service, the overall average reduction in fuel consumption for both passenger and freight service over T&NO Lines arrangement would be 9.5%.

Graph No. 3 - Fuel Rate versus Average Developed Adjusted Drawbar Horsepower - Details.

This graph shows the detail of individual points plotted in the development of Graphs Nos. 1 and 2.

Graph No. 4 - Water from Tender versus Firing Rate - Freight Service.

This graph represents the relationship between gallons of cold water per hour from tender tank (corrected for boiler blowoff) and firing rate, gallons of oil per hour (corrected for boiler blowoff). As in previous graphs, the two basic arrangements and the improved arrangement are plotted for comparison. In general this graph shows that for a given firing rate more water is evaporated or conversely, for a given rate of evaporation, lower firing rate is necessary. Considering a typical firing rate of 650 gallons per hour (10.8 gallons per minute) the increased evaporation with improved arrangement amounts to 9.37% over Pacific Lines standard arrangement and 15.1% over T&NO Lines standard arrangement.

Graph No. 5 - Water From Tender versus Firing Rate - Passenger Service.

This graph represents similar information to Graph No. 4 except that it is based on data taken in passenger service. Taking a typical firing rate in this service, namely 700 gallons per hour (11.7 gallons per minute), improved arrangement showed an increase in evaporation equivalent to 8.1% over T&NO standard arrangement. Combined with increased water rate of 15.1% in freight service, the over-all average increase in evaporation for both passenger and freight service over T&NO Lines arrangement would be 11.6%.

Graph No. 6 - Boiler Efficiency (including feedwater heater) versus Firing Rate - Passenger and Freight Service.

This graph illustrates relationship between boiler efficiency (including feedwater heater) expressed in percent as compared to firing rate in gallons of oil per hour (corrected for boiler blow-off), showing results obtained both in passenger and freight service. Results reflect the increased efficiency available with the improved arrangement due to better atomization of fuel, reduction in excess air required, better firing control and other improvements in the combustion and feedwater system. Considering a typical firing rate of 650 gallons per hour (10.8 gallons per minute) the improved arrangement shows an increased boiler efficiency (including feedwater heater) of 6.9% over Pacific Lines arrangement and 8.5% over T&NO Lines standard arrangement.

<u>Graph No. 7</u> - <u>Boiler Efficiency (less feedwater heater) versus Firing Rate - Passenger and Freight Service</u>.

This graph is similar to Graph No. 6 except that it represents actual boiler efficiency, without regard to feedwater heater. Again considering a typical firing rate of 650 gallons oil per hour (10.8 gallons per minute), the improved arrangement showed an increase in basic boiler efficiency of 6.8% over the Pacific Lines arrangement and 7.7% over the T&NO Lines arrangement.

<u>Graph No. 8</u> - <u>Indicated Horsepower and Mean Effective Pressure versus Speed - Freight Service</u>.

This graph shows the relationship between indicated horsepower and speed and also mean effective pressure expressed as percent of steam chest pressure to speed in miles per hour, for the two basic and one improved arrangement. The indicated horsepowers shown in all cases are maximum achieved. The results indicate that with the improved arrangement a maximum indicated horsepower of 4550 was reached at 45 mph as compared with a maximum of 4400 at same speed with T&NO Lines arrangement and maximum of 4130 at 42 mph with Pacific Lines arrangement. This represents increase in maximum indicated horsepower of 10.2% over Pacific Lines arrangement and 3.4% over T&NO Lines arrangement.

The mean effective pressure (mep) was plotted on the basis of percent of steam chest pressure, the mep being obtained from indicator cards and the steam chest pressure being the instantaneous pressure at time card was taken. In this way a more accurate comparison of the three arrangements could be made rather than plotting the value of mep alone and not considering the variable steam chest pressure. As in the case of indicated horsepower, the mep percent represents the maximum values. On this basis, taking a representative speed of 40 mph, the improved arrangement showed a mep of 65% steam chest pressure as compared with 61% with T&NO Lines arrangement and 57% with Pacific Lines arrangement or an increase of 4% over T&NO Lines arrangement and 8% over Pacific Lines arrangement.

Graph No. 9 - Drawbar Pull and Drawbar Horsepower versus Speed.

This graph represents relationship between drawbar pull in thousand pounds and drawbar horsepower in hundreds over the range of speeds tested. Values for drawbar pull and drawbar horsepower represent the maximum attained. Considering the results plotted, it will be noted that the starting drawbar pull, exclusive of booster, with the improved arrangement was 61,000 pounds as compared with 57,700 pounds with T&NO Lines arrangement and 56,700 pounds with Pacific Lines arrangement or an increase of 5.8% over T&NO Lines arrangement and 7.6% over Pacific Lines arrangement. In regard to drawbar horsepower, the improved arrangement showed an increase over either of the two basic arrangements. Maximum drawbar horsepower with the improved arrangement was 3780 at 40 mph as compared to 3520 with T&NO Lines arrangement at the same speed and 3340 with

Pacific Lines arrangement at 37 mph, or an increase of 7.4% with T&NO Lines arrangement and 13.2% with Pacific Lines arrangement.

Graph No. 10 - Back Pressure versus Firing Rate.

This graph represents the relationship between back pressure in pounds per square inch gage (psig) and firing rate in gallons of oil per hour (gph), corrected for boiler blowoff, and is one of the most important relationships illustrating the advantages of the improved arrangement, inasmuch as with these improvements in the combustion system it is possible to operate at a substantially reduced back pressure. Plotted on this graph are the lines representing back pressure range with Pacific Lines standard arrangement (8" nozzle and 3/4" split) as compared with the improved arrangement (without circulators) using 9-1/2" nozzle and 1" cross split. Over the range of firing rates considered, the Pacific Lines arrangement produced back pressures of 8.4 psig at 425 gph to 19.6 psig at 750 gph as compared to the improved arrangement with 5.5 psig at 425 gph and 10.6 psig at 750 gph. This represents a reduction in back pressure with the improved arrangement of from 34.5% to 46.0% or an average reduction of approximately 40%. Also plotted on this graph is a back pressure versus firing rate relationship using improved arrangement with 9-1/2" nozzle and 1-1/8" cross split. This information is included to show the effect of increasing the size of the cross split. As is evident, the back pressures with the larger cross split were higher, and in order to obtain maximum economies available with the improved arrangement, it is preferable to use the 1" split on GS class locomotives.

Graph No. 11 - Carbon Dioxide versus Firing Rate.

This graph represents the relationship between Carbon Dioxide (CO_2) in percent over the range of firing rates in gallons of oil per hour (corrected to boiler blowoff). With the improved arrangement percent of CO_2 varied from 13.2% at 425 gph to 14.2% at 700 gph as compared to Pacific Lines arrangement of 11.5% at 425 gph and 11.9% at 700 gph. However, it will be noted that the CO_2 content with Pacific Lines arrangement decreased at the intermediate firing rates, readings being as low as 10.0% while with the improved arrangement the CO_2 percent increased gradually over the range of firing rates. With the improved arrangement the higher CO_2 content in exhaust gases is a measure of the improvement in obtaining combustion of fuel with the minimum amount of air which is necessary for highest combustion efficiency. From data available from basic tests, it is evident that the percent of CO_2 with the T&NO Lines standard arrangement is lower than that of the Pacific Lines arrangement, ranging from 9.9% at 585 gph to 7.3% at 700 gph.

Graph No. 12 - Excess Air versus Firing Rate.

This graph is correlated with Graph No. 11 and represents the percentage of excess air supplied to fire box at the various firing rates in gallons of oil per hour (corrected to boiler blowoff). At firing rate of 425 gph, improved arrangement was successfully operated with 23% excess air as compared to 39% with the Pacific Lines standard arrangement. At 700 gph improved arrangement operated with 13% excess air as compared to 35% with Pacific Lines arrangement. However, at intermediate firing rates the Pacific Lines arrangement permitted excess air as high as 60%, while the improved arrangement decreased gradually over the range of firing rates. The T&NO Lines arrangement from basic test data available, operated with excess air running from 66% at 600 gph to 117% at 700 gph, which is entirely too high. Reduction in amount of excess air with the improved arrangement is another indication of the benefits derived, inasmuch as boiler efficiency is directly affected by this factor. If large amounts of excess air are involved, a loss in boiler efficiency results. Therefore, it is most desirable to keep the percentage of excess air to the minimum. Being able to do so is a function of the proper design of the combustion system, including oil burner, firepan, drafting arrangement and front end proportions.