RESEARCH PROGRAM

ON

OIL BURNING

STEAM LOCOMOTIVES

*

FIREPAN TESTS

*

ENGINE SP-4401

*

LOCOMOTIVE STANDING TEST PLANT

SACRAMENTO, CALIFORNIA

OFFICE GENL. SUPT. MOTIVE POWER
SOUTHERN PACIFIC COMPANY
SAN FRANCISCO, CALIFORNIA

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* Diagrams of Firepan Designs, Index of Tests, Data Sheets, Graphical Results and Photographs are bound separately on back of front cover for convenience of reference.

FOREWORD

Among the studies undertaken during the Research Program on oil burning steam locomotives authorized by GMO-35006 was the evaluation of firepan designs and drafting arrangements, including the Pacific Lines standard round bottom firepan and the T&NO flat bottom firepan, to determine any possible fuel economies, such as those available through reduction in back pressure, by modification in firepan design or method of air admission.

The results of these firepan tests are contained in this report, designated as Report ST-4, which contains not only comparative results from tests of designs of firepan currently used by Pacific Lines and T&NO and variations thereof, but also complete results of investigations into other firepan and air admission arrangements including two Dutch Oven designs, aerodynamically designed bell mouth side air ports and the steam-air jet system of air admission suggested by Battelle Memorial Institute, and adaptations of air admission used by other major railroads on oil burning steam locomotives. In addition, several modifications of present Pacific Lines standard air ports were tested and major relocation of air ports at different positions on firepan were explored and tested for relative performance.

Information obtained by these tests will be of value in determining the final recommended changes in the combustion system. Results obtained also indicate that certain minor changes to existing firepan can be made pending completion of ST-5 study on oil burners and the overall Research Program.

RECOMMENDATIONS

The following recommendations and conclusions are made, based on results of observations and tests conducted on Locomotive SP-4401 and studies made in connection with firepan design and air admission arrangements as explained in detail in this report.

1. LIMITING FACTORS IN FIREPAN DESIGN AND METHOD OF AIR ADMISSION:

The design of oil burner and the degree of atomization obtainable therefrom have a primary influence on the size, location and distribution of air openings into the firepan. The present standard Von Boden Burner is of the outside mixing type, sometimes designated as "drooling" type, and requires relatively high velocity air to provide sufficient turbulence and mixing of oil spray with air for combustion. Inadequate air velocity results in poor intermixing of air and oil streams and adversely affects the efficiency of combustion with this type of burner. Therefore, when using the Von Boden type burner, air openings in firepan and size of exhaust nozzle must necessarily be proportioned to provide the required velocity of air flow. This, of course, limits the possibility of improvements in firepan arrangement with this type of burner. The ST-5 series of tests on oil burners will encompass study of numerous modifications in burner design and providing an improved burner for road service can be developed by the ST-5 tests, further improvements in firepan arrangement as indicated by these ST-4 studies can be incorporated in the final recommended combustion system.

In view of the above, it is therefore recommended that consideration of any major changes in firepan design and air admission be deferred until completion of ST-5 oil burner tests.

2. <u>EVALUATION OF FIREPAN DESIGN AND DRAFT ARRANGEMENT: PACIFIC LINES VS. T&NO:</u>

From structural considerations, the T&NO flat bottom design firepan is superior to the Pacific Lines round bottom pan due to greater stability, freedom from warpage, and better support of brick work. However, method of air admission into the Pacific Lines firepan is superior with the present standard Von Boden burner and results in higher boiler efficiency and lower excess air. A summary of comparative test results and observations is shown below.

<u>a</u>. <u>Boiler Efficiency</u>: With comparable smoke box arrangement, Pacific Lines firepan provided boiler efficiencies from 1½ to 2% higher than T&NO firepan over range of firing rates tested.

<u>b</u>. <u>Excess Air</u>: Excess air admitted with Pacific Lines arrangement, over the firing rates tested, was more uniform with Pacific Lines arrangement. Excess air admitted with T&NO pan arrangement was approximately 12% higher than with Pacific Lines arrangement at low firing rates. At about the middle of firing range excess air percentages with both arrangements equalized and remain nearly equal up to the maximum firing rate tested.

<u>c</u>. <u>Fire Box Draft</u>: Over the range tested, fire box draft with Pacific Lines firepan was 3½" to 4½" higher than with T&NO firepan, having dampers adjusted for best performances, although exhaust nozzle pressuresfor both firepans at a given firing rate were com-

parable. With the present standard Von Boden type burner, this higher fire box draft at a given exhaust nozzle pressure is necessary in order to obtain better turbulence and intermixing of combustion air with oil. The greater available air openings with the T&NO arrangement result in lower entering air velocities.

d. Design Features: The principal feature of the T&NO design firepan is the simplicity of the angular design and construction as compared with the variable radius round bottom Pacific Lines pan. The T&NO design is better adapted to structural bracing than the round bottom pan. The bottom hopper arrangement on the T&NO pan facilitates removal of loose brick and carbon from fire box. The T&NO design pan also permits better application of fire brick.

Advantages of the Pacific Lines round bottom pan are that it is better designed for radial admission of secondary air in the critical combustion area near flash wall and eliminates the necessity for providing admission of air through fire door opening. Due to the large radius on the bottom of Pacific Lines firepan, longitudinal misalighment of burner is not so critical as it is with the T&NO pan having a relatively narrow trough, although with Pacific Lines side air admission, any unbalance in air entry from either side, such as faulty operation of automatic dampers, will have a detrimental effect on the fire.

e. Maintenance: From observations on the test locomotive, it is evident that Pacific Lines round bottom pan is more subject to warping and resultant misalignment than the T&NO pan. This tendency can be minimized by application of transverse braces under round bottom firepan similar to those used on T&NO pan and it is recommended that suitable cross braces be applied to existing round bottom pans.

To facilitate removal of fallen brick and carbon from bottom hopper, it is recommended that a clean-out door be applied to Pacific Lines firepan hopper similar to that used by T&NO.

However, it is recommended that any action on the above two improvements be deferred until completion of ST-5 study on oil burners and development of final firepan design.

3. <u>IMPROVEMENTS IN EXISTING DRAFT CASTINGS</u>:

Present design of draft ring castings can be improved based on tests and observations. It is recommended that bottom draft ring, design ST-201, (Fig.4-36), with inward tapering sides be adopted for increased service life and better air velocity distribution. Improved side draft rings with similar characteristics to design ST-200 (Fig. 4-35) and ST-202 (Fig. 4-37) should also be adopted for the same reasons.

On oil burning AC class locomotives now equipped with long narrow side draft castings, redesigned rectangular castings identified as design ST-214 (Fig. 4-38), further modified with inward tapered sides, should be applied to improve combustion.

4. <u>BATTELLE BELL MOUTH PORTS</u>:

Tests and observations made with bell mouth design side air ports as recommended by Battelle indicated that while these ports are properly designed from an aerodynamic standpoint, they will not operate satisfactorily with the present standard Von Boden type burner which requires high velocity air for turbulence. Should the ST-5 burner test develop a burner which will operate efficiently with low velocity air supply, further consideration can be given to the bell mouth design air ports.

5. STEAM JET AIR INJECTION:

The injection of combustion air into firepan by means of high velocity multiple steam jets, as suggested by Battelle, indicated improved firing conditions and boiler efficiency as well as possibility for operation at lower exhaust nozzle pressures. This improvement resulted from the better turbulence of air-oil mixture created by the high velocity steam-air mixture injected into the firebox. The disadvantages of steam-air jet installation are the additional steam consumption required and the complications in design. Another objection to steam-air jet installation is that if jets on one side of firepan became clogged or otherwise inoperative in road operation, poor combustion and loss of boiler steam pressure would result. If satisfactory mixing of oil and combustion air can be obtained by improved burner design, it would be preferable to the use of steam-air jets to augment the mixing obtained with present burner.

6. DUTCH OVEN ARRANGEMENTS:

During this series of tests, two designs of Dutch Ovens were installed and tested in T&NO design firepan. The first installation was in accordance with recommendations of American Arch Company and the second was designed by T&NO Fuel Engineer who is cooperating with work at the standing test plant. The T&NO design Dutch Oven, being of larger proportions, showed superior results with the present standard burner, principlally due to the reduction in carbon formation in the fire brick tunnel. The Dutch Oven installation did not indicate any improvement in fuel performance but did provide better temperature distribution in firebox and lower smoke density at certain firing rates with present burner.

However, from tests and observations made on the Dutch Oven installation at standing test plant, it would appear that difficulties would be experienced in road operations in maintaining Oven construction. Any failure of Dutch Oven brick work which restricted or blocked mouth of tunnel would lead to disruption of fire and possibility of road failure. It also appears that in actual road service, the installation of Dutch Ovens would require a greater skill and more attention on the part of the fireman in order to obtain proper operation, in addition to more careful inspection and increased maintenance of this arrangement required at Terminals. Proper burner alignment is essential with the Dutch Oven as any misalignment will cause formation of carbon in or adjacent to oven resulting in poor steaming if not actual road failure.

In view of the experience at standing test plant, it is believed that the disadvantages of the Dutch Oven outweigh the advantages and further consideration of this installation is not recommended.

DISCUSSION OF FIREPAN ARRANGEMENTS

In connection with this test series, a number of Class 1 railroads operating oil burning steam locomotives were canvassed to determine the types of firepans and drafting arrangements in use. The information furnished was condensed into schematic drawings illustrating general features of arrangements representative of those in use on the various foreign lines. These drawings are shown in Figures 4-3 to 4-17 inclusive. Figures 4-1 and 4-2 are similar illustrations of the firepan and drafting arrangement standard on most Pacific and T&NO Lines locomotives respectively.

The essential features of the most promising of the foreign line firepans were simulated for test purposes, as will be noted from illustrations of test arrangements on the graphs of data. In addition, tests were made of arrangements developed during the course of the program by the Battelle Memorial Institute and by observations of results currently obtained.

When possible, adjustable features were incorporated in the test installations of air ports to accelerate the progress by permitting variations of size, shape and location under actual firing conditions. Burners were in most instances applied to adjustable mounting brackets to allow adjustment while boiler was under fire.

Fig. 4-1 - Southern Pacific Co. (Pacific Lines) operating 1321 oil burning steam locomotives.

This sketch shows the existing standard firepan and drafting arrangement for GS-1 class locomotives on Pacific Lines and is typical of those of most other classes. The draft arrangement is known as the "Modified Draft" and was developed in tests made during 1930 because a change to heavy, viscous, Dubbs type fuel oil from a lighter more fluid fuel had resulted in excessive formation of carbon, smoking, and fuel flow difficulties, particularly with the then designated "Northern District" horizontal drafting arrangement. "The Northern District" arrangement was a firepan of the same shape as now used but primary air supply entered through air ports in burner wall and secondary air through a baffled fire door.

The firepan is continuously curved between side sheets in an approximately semi-conical shape with radius at front greater than that at back; these features being combined in such manner as to provide a uniform width brick shelf at side sheets and a floor that is horizontal at the longitudinal section. The continuously changing radius of the pan does, however, interpose difficulties in the fitting of draft castings and chutes.

This style firepan was developed prior to 1915 at which time it was patented and the following from Patent No. 1,128,444 is quoted as a matter of interest:

> "The provision of a bottom pan having a floor of continuously curved transversely segmental form,-----has been found, in practice, to be of substantial advantage, in the particular of inducing a swirling or curved motion of the current of the flame discharged at the burner

nozzle, from the middle to the sides of the combustion space in the firebox, the result of which is to effectively fill the combustion space therein, and utilize the liquid fuel. The continuously curved segmental floor also enables the volume of combustion space to be increased below the plane of the burner, without involving objectionable downward projection of the bottom pan adjoining the mud ring, or between the side members thereof, and the direct connection of the supporting plate to the mud ring facilitates its insertion and detachment when required. We have further found in practice, that the period of service of the lining of the segmental floor of the bottom pan, is materially increased, and that the accumulation of carbon in the firebox is practically eliminated."

It should be noted that while the elimination of carbon was then attributed to the style of firepan, the subsequent use of a different fuel resulted in excessive deposits despite use of a pan of similar contour.

The existing standard drafting arrangement applied to this so-called "round bottom" firepan consists of a small, usually 8" x 8", opening at burner with main air supply entering radially to firepan at flash wall through air ports at each side of a bottom center opening, also at flash wall, which is for manually controlled use primarily when engine is drifting or standing.

The damper boxes or chutes, for the side air openings are so arranged that hot pieces of brick or carbon cannot drop out of firepan on right of way. These boxes, or chutes, are fitted with draft operated dampers that are counterweighted to remain closed with the low drafts usual while engine is standing and drifting, during which time combustion air is allowed to enter through center opening which has an appropriate hopper and manually controlled damper.

The draft operated dampers are weighted merely to close at times of little or no draft for the purpose of automatically preventing the entry of cold air into the hot firebox when firing rate is reduced to drifting or spot fire and they are not intended to exert any control over the air supply for the higher firing rates when throttle is open.

The operating instructions issued in 1930 covering the use of the modified draft are of interest and are quoted below:

"With Modified Draft arrangement on locomotives, there are three dampers - two balanced dampers, one on each side of fire pan, and a middle damper in bottom of firepan which opens into hopper. The two balanced dampers open automatically from the action of the exhaust. The middle damper is operated manually from the cab.

"(1) <u>In road service</u>, after the engine starts to work, the middle damper should be closed, as the automatic dampers are then open and furnish the necessary air for combustion.

"(2) When the engine is shut off for drifting, or while standing, the automatic dampers close, and it is then necessary to open the middle damper and regulate it to supply the necessary air for combustion. This middle damper should be closed again when the engine resumes work.

"(3) Under certain working conditions, the amount of air admitted through automatic dampers might not be quite enough for best results. When such is the case, the middle damper can be regulated to admit additional air; but care should be exercised to not admit excess air which causes fuel waste, carbon, damage to firebox sheets from ununiform (sic) temperatures, and interferes with free steaming of locomotive.

"(4) On switch engines with the modified draft arrangement, it is not practical to close and open the middle damper every time the engine is making short moves. Therefore, the middle damper can be adjusted to the position that gives most satisfactory results and left in that position. However, the middle damper should be closed when making long moves.

"(5) On Road engines when making short moves and when switching, the same instructions apply as given above for switch engines.

"(6) The proper use of atomizer is very essential with the Modified Draft arrangement. The fuel should be heated so that it will properly atomize. When using the heavy Dubbs Oil, it should be heated to, and maintained at, 180 degrees; and with the lighter fuels, at 140 degrees. The amount of atomizer used should not be enough to cause fire to flash out around dampers or door, and should be sufficient to prevent oil striking floor of fire pan."

The modified draft firepans are equipped with glare shields at the side air ports. Photograph 4-1 shows the shield, modified by application of hinges for the test installation. Photograph 4-2 shows the side draft chute with automatic damper in closed position. The damper is corrugated to increase its resistance to warping from heat. Photograph 4-3 shows the damper in open position during test at high steaming rate. Bright area in left of air port casting is fire which is not swept from surface by entering air due to inwardly flared shape of casting. This condition also exists at top and right surfaces, tending to burn out the castings in these areas.

In actual service it is important that these automatic dampers be maintained to operate freely, for should one stick closed or partially so, the heavy inrush of air through opposite side causes unequal distribution of fire in firebox. On some

Divisions with strong prevailing seasonal winds fire distribution is also disturbed by a preponderance of air entering the windward air port.

The present Pacific Lines standard bottom hopper is reportedly often found completely plugged as it does not have a front clean-out door to permit removal of the accumulated brick and carbon. The taper of bottom draft casting also tends to aggravate the obstruction of this air opening because of wedging of the debris. In addition, the hopper often warps and burns in service while damper is closed and during these tests a large hole was burned through hopper as a result of hot carbon dropping into it.

In actual service, carbon accumulations on floor of pan and flashwall in area of center air port cause serious overheating of the firepan floor sheet, and buckling, warping and sagging of the pan is caused in this area. This damage to firepan also occurred during the standing tests.

These issues are pointed out since they must be considered in determining an optimum design of pan and draft arrangement.

Fig. 4-2 - T&NO operating 401 oil burning steam locomotives.

This figure illustrates the Standard Firepan used by the T&NO Lines. This pan has an upward slant to the portion of pan near side sheets to retain the brickwork on side shelf and then slopes down to form trough for flame path. Burner is mounted in port near front of firepan and fire is directed rearward toward flash wall at back head. Primary air admission is through burner port, and the remainder enters through baffler firedoor and through bottom hopper. Fireman can regulate air flow through fire door but has only partial regulation of air flow through bottom hopper, there being a fixed opening in hopper as well as a manually operated damper door. There is no side air admission. This pan and drafting arrangement is similar to the "vertical draft" used by Pacific Lines on the Southern District prior to the adoption of the round bottom pan with "modified draft".

Burner port is not square as on the Pacific Lines firepan, but is designed for most of the primary airflow to flow under the burner as is shown by Photo 4-11. Bottom hopper has a fixed opening at front, opening upward and front face of hopper is hinged to permit cleaning of fallen brick and carbon from hopper. Lip is provided at damper opening, at rear, to retain the fallen brick and carbon while engine is en route and reduce possibility of starting fires. Baffler fire door has a long tubular extension on peephole to assure that sand enters firebox when cleaning flues and to avoid blow back of sand on enginemen.

Floor of pan is level and sloping sides are at an uniform angle. Because of this and the slope of the mudring, width of the side shelf varies, being widest at burner wall.

Fig. 4-3 - Texas & Pacific Ry. Co. operating 208 oil burning steam locomotives.

This pan is very similar to Fig. 4-1, the principal difference being, the bottom is semi-cylindrical for its entire length. The air admission is similar to Pacific Lines, except that the bottom port is larger and has no damper. In addition the side ports are not equipped with dampers.

A similar draft arrangement was tried, at Sacramento Standing Test Plant, during the trials with the movable bottom port, but did not prove satisfactory on the Pacific Lines type of firepan.

Fig. 4-4 - Western Pacific RR Co. operating 136 oil burning steam locomotives.

The bottom of pan is similar to Pacific Lines standard except that side air admission is through 5-3/8" tubes on each side. Each tube is equipped with a weighted damper.

Bottom admission air and air admission through burner port are controlled by fireman.

Fig. 4-5 - Great Northern Ry. Co. operating 414 oil burning steam locomotives.

This firepan has a troughed bottom, with trough cylindrical in cross section.

Air admission is at front wall around burner and four tubes on each side of firepan near flash wall. These tubes each have a weighted damper at their entrance. The fireman can regulate air admission beneath burner at front wall by means of a damper.

Fig. 4-6 - Chicago, Milwaukee, St. Paul & Pacific RR Co. operating 49 oil burning steam locomotives.

This firepan is almost flat bottomed but with a slight curvature of very large radius. All air admission is around and below burner. Air admission below burner can be regulated by fireman.

Fig. 4-7 - Spokane, Portland & Seattle Ry. Co. operating 53 oil burning steam locomotives.

This is a semi-cylindrical round bottom type of pan with all the air admission around burner. Fireman can regulate air flow by use of a damper.

Fig. 4-8 - The Kansas City Southern Ry Co. operating 81 oil burning steam locomotives.

This is a round bottom semi-cylindrical type of pan with air admission around burner, through bottom hopper and 4 tubes on each side.

Fig. 4-9 - Florida East Coast Ry. Co. operating 72 oil burning steam locomotives.

The bottom of this pan is practically flat but with a slight curvature. Air admission is through bottom hopper and below burner both of which have dampers regulated by fireman.

Fig. 4-10 - St. Louis Southwestern Ry. Co. operating 138 oil burning steam locomotives.

This is a trough type pan with trough trapezoidal in cross section. Air admission is through bottom hopper, around burner and at each side of burner. Part of this air is controlled through use of dampers by the fireman.

Fig. 4-11 - Northern Pacific Ry. Co. operating 65 oil burning steam locomotives.

The bottom of this pan has a shallow trough. Air admission through bottom hopper and below burner can be regulated by fireman.

Fig. 4-12 - Chicago, Rock Island & Pacific RR Co. operating 282 oil burning steam locomotives.

This is a trough type pan with air admission through bottom hopper, around burner, and through 5 tubes on each side.

Fig. 4-13 - Union Pacific RR operating 441 oil burning steam locomotives.

The bottom of pan is a rather shallow trough. Air admission is around burner, through a bottom hopper and through two narrow longitudinal slots on each side of trough.

Fig. 4-14 - The Atcheson, Topeka & Santa Fe Ry System operating 1141 oil burning steam locomotives.

This is a trough type of pan with air admission through bottom hopper, around the burner, and through small diameter tubes on each side.

Fig. 4-15 - Chicago, Burlington & Quincy RR Co. operating 76 oil burning steam locomotives.

This is also a shallow trough type firepan with air admission around the burner, through bottom hopper and through 20 tubes on each side.

Fig. 4-16 - Chicago and North Western Ry Co. operating 110 oil burning steam locomotives.

This firepan has a slightly depressed bottom firepan with a Dutch Oven around the burner. Air admission is through bottom hopper, around burner and through 9 tubes on each side.

Fig. 4-17 - Canadian National Rys. operating 98 oil burning steam locomotives.

This firepan has a front firing burner, the only one of this type covered by these firepan sketches. Flash wall is next to boiler throat sheet and it appears that locomotive is equipped with a brick arch. Air admission is through bottom hopper and around burner through burner port.

DESCRIPTION OF TESTS

The ST-4 series of tests was divided into two parts: The first part was the series with Pacific Lines Firepan and these test arrangements bear the prefix FDS. The second part covering the series with the T&NO Firepan bears the prefix FDT.

For ready reference, the various test arrangements and designations are shown in "Firepan and Draft Arrangement Tests - Engine 4401" preceding the curves in opposite section.

Each test arrangement bears a prefix as noted above, following which is an identifying number. Following the identifying number is a letter designating the smokebox arrangement. For example "FDS-12-P" would indicate test was run with Pacific Lines firepan, arrangement number 12 and smokebox arrangement P.

Engine 4401, during dynamometer tests and SN series of tests, as covered by previous reports was equipped with original (long) superheater units with return bends 24" from firebox tube sheet. These units were also used for part of the FDS series, namely, to and including test arrangement, FDS-11-T. Remaining tests in the FDS series, i.e., FDS-12 A to 29 Q and the FDT series were with short units. After test FDS-11-T, units had worn to the extent they had to be replaced. Replacement units were only available with return bends 48" from tube sheet (short units), in accordance with the present standard for GS Class locomotives which was adopted to increase the service life of the unit return bends. Several runs were made with short units based on previous data and from these runs a new curve of Exhaust Nozzle Pressure vs. Exhaust Nozzle Temperature was drawn to take into account the reduction in superheated steam temperature. Comparison of these curves for long and short units is shown on Fig. 4-34.

Figures 4-32 and 4-33 show the effect of shortening superheater units. Figure 4-32 compares arrangement SNA from report ST-2 with series FDS-12-A which uses the same smokebox and firebox arrangement but with the new short units. Figure 4-33 compares arrangement SNL with series FDS-12-P. The only difference other than the length of units was that SNL had a 10" stack height whereas series FDS-12-P had a 13½" stack height.

It will be noted from a study of these curves that shortening units decreased the temperature of steam to cylinders, increased the water rates and reduced excess air. All of which means that as regards the boiler itself, shortening units 24" improved its performance: This gain in evaporation may be offset in road operation as more of the lower temperature steam may be used by the cylinders to develop the same indicated horsepower, as compared with the higher temperature steam.

This survey, and the tests, were conducted with the view of developing a method of drafting firepans now in service so that, if possible by some minor change, resistance to air flow into the firepan would be reduced and thereby allow locomotive operation with more open exhaust nozzles and consequently lower cylinder back pressure. It was also intended to supplement the changes recommended for locomotive front-end arrangements in report No. ST-2 and to serve for the interim period prior to completion of the full research program and application of the final recommended arrangement.

These changes were consistent with the objectives of the original survey for this Research Program prepared by Battelle Memorial Institute, which indicated potential fuel savings of the order of 10% at locomotive outputs ordinarily used, by reduction of cylinder exhaust pressure. These changes also followed, in great part, the trend of their developments from our road and their model tests, and included test of their design of low resistance air ports.

The primary purpose of this ST-4 group of tests was: the trial of various combinations and sizes of draft ports, draft chutes, dampers, steam-air jets and finally a Dutch oven in an endeavor to find a suitable arrangement that could be easily applied to existing firepan equipment, or that could be recommended for further test; and to develop information that could be used in connection with the final design of firepan for achieving maximum fuel savings from locomotive operation with low cylinder back pressure. The modifications tested are those that could readily be applied by shop forces and, in some instances, by roundhouse forces.

One of the main objectives was the prevention of carbon deposition on the firepan brickwork. Smokeless combustion at the usual firing rates and the elimination of smoke densities above No. 1

Ringelmann at high firing rates was another objective. The properties of various sizes of basket type cross splits were explored in view of the desirability of finding a design suitable for use with the air ports developed. A smooth quiet fire which does not drum or flash out of the various draft ports and without a tendency to burn against the face of the draft rings thus decreasing their durability was another requirement. An arrangement that would perform satisfactorily with low atomizing steam pressures and therefore lowered auxiliary steam consumption, with reasonably uniform firebox sheet and boiler sheet temperature distribution was a final objective.

In order to provide test conditions similar to those encountered in locomotive road operation, and to place the tests on a comparable basis, the same automatically controlled adaptation of Mr. W. F. Collins' steam desuperheating system used for tests covered in prior standing test plant reports, was used for these tests. Feed water hot pump exhaust was vented to atmosphere instead of to feed water heater chamber, to insure more consistent exhaust steam pressures and draft gage readings. The T&NO method of venting the feedwater heater spray chamber was used. A sleeve 3½" long was applied around the Worthington feed water pump cold water spray valve for temperature control.

The detailed discussion of the individual tests and trial arrangements follows, including reference to "figure numbers" which illustrate the arrangements tested, graphical results of the tests, test designation numbers which identify data from "Summary of Data Sheets" used for plotting graphical results, and photographs by figure number reference.

DISCUSSION OF DATA AND RESULTS

This test series was developed in logical sequence, starting with the test of the aerodynamically correct elliptical approach air ports designed by Battelle, as shown on photo 4-4, arrangement FDS-1. These were enclosed by a louvered glare shield built to allow free air entry and to shut off glare from the fire, as shown on photos 4-5 and 4-6.

The elliptical approach air ports presented minimum resistance to air flow, directed radially into the round bottom firepan, and supplied a relatively high percentage of excess air. However, they were unsatisfactory because they did not provide sufficient turbulence for proper mixing of the air stream with the fuel particles and resulted in heavy carbon accumulation in the firepan as shown on marked photo 4-7.

Arrangements FDS-2, 3 and 4 were equipped with modified bell mouth side draft ports, as shown on photo 4-8. These modified air ports were arranged to direct the air horizontally with moderate resistance into the area where carbon has always developed as shown on photo 4-9. They reduced or prevented deposition of carbon in the firepan, but smoke was excessive at high firing rates and high atomizer pressures were required.

These arrangements included the application of a rounded approach to a 2-5/8" x 17" fixed opening in front of the bottom hopper, as shown on photo 4-10. The T&NO type of oil burner port was also applied per photo 4-11. This port was larger in area than the standard 8" x 8" burner port and the potentiality for increased air flow through it was further improved by the addition of a bell mouth approach around sides and bottom per photo 4-12.

The T&NO baffler door damper was tried in wide open position with arrangement FDS-2, at a high firing rate, but aside from a considerable drop in firebox draft and some increase in excess air, there was no visible improvement in the fire and the smoke density increased. Difficulty was experienced in sanding boiler flues effectively due to reduced firebox draft and interference of fire door baffler.

In an effort to reduce temperature concentration on the side firebox sheets in the area above the front of the air port and lower the fire in the firebox, the firepan arrangement FDS-2 was further modified by the addition of two 5" ID boiler tubes on each side of firepan, 30" and 48" ahead of the main air ports. These round draft tubes had a flared approach and were equipped with removable plugs, per photos 4-13 and 4-14. Several combinations of ports open, closed, and partly closed were tried, and only when the large side openings were blocked to approximately 1-1/2" x 17-1/2" was drumming and shooting of fire out of the draft ports eliminated. Under this condition the arrangement smoked continuously. The small amount of carbon that formed on the flash wall when firing up, quickly burned off when throttle was opened. The additional air ports provided an excellent means to observe the fire but did not produce any appreciable change of differential between the two side sheet water side temperatures and there was some increase in the temperature at the door sheet. In view of the results of these trials, the 5" ID side draft tubes were bricked closed.

Arrangements FDS-5 and 6 employed side draft castings in accordance with Fig. 4-35 (ST-200). The purpose of these rings was to provide a practical method of directing air flow into the firepan area where carbon forms, at an angle between radial and level. These castings were a modification of standard side draft rings, with the same outer frame and lower lip. The side lips were inclined towards each other to conform with smooth air flow and to reduce the tendency of the rings to overheat. The upper lip was built to support the firebrick and guide the air stream into the firepan at an angle slightly above horizontal as shown on photos 4-15, 4-16, and 4-17. The size of the outer opening was the same as that of the standard draft rings, also length of the opening at the throat. Standard side draft chutes were used. The open bell mouth fixed port on the bottom hopper and rounded approach on the T&NO type burner port were continued in use.

Arrangement FDS-7 was the same as FDS-6 except that the outer edge and axis of the standard side dampers and draft chutes were lowered 6", increasing the effective opening of the side draft ports by allowing additional clearance between the top of the damper when open and the upper lip of the draft port, photo 4-18. The damper was horizontal in open position.

Arrangements FDS-5, 6 and 7 reduced smoke density, deposited relatively little carbon and provided fairly high evaporation and boiler efficiencies. Of these, No. 7 was the best. This arrangement also produced reasonably low and uniform temperatures of the firebox sheet above the fire door.

A bottom draft ring per Fig. 4-36 designed to reduce failure from overheating of the lips by reversing the inclination of the standard ring lips was applied for arrangements 6 and 7, as shown on photo 4-19.

In order to reduce further the amount of carbon and endeavor to increase the amount of excess air available for the purpose of employing larger exhaust nozzles, the ST-202 (Fig. 4-37) castings were developed. These were designed to direct air into the firepan at an angle between the horizontal and that of the ST-200 draft castings. The outer port size was increased 1-3/4" over the ST-200 size measured along the curvature of the firepan. The upper lip was designed to direct air horizontally into the firepan, and the lower lip was designed to align with the edge of the adjoining bricks to render unnecessary the rounding of this edge. The side lips were inclined upwards, the same as the side lips on the ST-200 castings as shown on photos 4-20, 4-16, and 4-17.

This type of draft ring was used with the T&NO style burner port with rounded approach, and the bell mouth fixed hopper port for arrangements FDS-8, 9 and 10 and also for FDS-11 except that in this instance the standard 8" x 8" burner port was used. The 6" lower, cut down side draft chutes per photo 4-18, and bottom draft ring ST-201, photo 4-19 were continued. These arrangements required high burner atomizer pressures to provide the required degree of turbulence to prevent smoke, but this caused excessive drumming of the fire. Use of a Sheedy inside mixing type of burner with arrangements FDS-9 and 10 resulted in excessive smoke.

Practically no carbon deposited on the floor of the firepan when using the ST-202 type of draft rings, and carbon on the flash wall was about 8" thick after a run of four hours.

After testing these arrangements it wås necessary to renew the superheater units. The new units applied were 24" shorter than the set removed and the unit ends were then located 48" from the back tube sheet to conform with the present standard. As this resulted in a reduction of superheated steam temperature of 40° to 50°, it was necessary to establish the performance data curves of the basic oil burning arrangement equipped with shortened superheater units, 8" nozzle and 3/4" cross split, and in addition, of the same arrangement equipped with 8¼" nozzle and 1/2" cross split. The new exhaust pressure temperature curve used for setting the exhaust steam temperatures was 40° to 50° lower than that used for previous tests in this series to simulate the heat drop obtained by working steam through the engine cylinders in road operation. The standard arrangement equipped with shortened superheater units, which was tested to establish basic performance data for comparison with later arrangements developed was numbered arrangement FDS-12.

The glare shield used with the standard arrangement, FDS-12, is illustrated by photo 4-1. The standard draft chute with damper closed is shown on photo 4-2, and chute with damper open during test at a high steaming rate is shown on photo 4-3; the side glare shield was raised for these pictures.

The bottom hopper damper and the fixed front hopper port were closed.

Using the 3/4" cross split and 8" nozzle there was moderate drumming of the fire at the low steaming rate. The fire was smooth at the high steaming rates. Low atomizer steam pressures were used, and no carbon accumulation was visible during or at close of test. Excess air at the high rate was 40%. Movement of air around the glare shields, over the damper surface and through the standard draft ports provided the turbulence necessary for good combustion with the standard type oil burner.

When using the 1/2" cross split on the 8¼" nozzle with this arrangement, the fire drummed heavily at a low steaming rate with clear color from the stack at all atomizer pressures. The fire was steady at higher steaming rates when the atomizer pressure was set at 20 pounds. Color from the stack was clear to slightly hazy, and darkened intermittently at the high firing rate. At the end of the high rate, a large piece of carbon about 12" in diameter was visible in the firebox. Excess air was 18.4%, relatively low when compared with other arrangements tested with the 8¼" nozzle, 1/2" cross split and shortened superheater units.

The following six arrangements were tested in pairs in which data were taken for each test rate with the 2-5/8" x 17" fixed bell mouth air port at front of the bottom hopper open versus closed:

Firepan FDS Arrag't. No.	Bell Mouth Hopper Port	Side Draft Drawing No.	Rings Position	Fig. No.
13	Open	ST-215-A	Standard Position	4-39
14	Closed	ST-215-A	Standard Position	4-39
15	Open	ST-202	3½" above standard	4-37
16	Closed	ST-202	3½" above standard	4-37
17	Open	ST-215-B	3½" above standard	4-39
18	Closed	ST-215-B	3½" above standard	4-39

Arrangements FDS-13, 14, 15, and 16 were equipped with side draft chutes having the axis and outer edge of damper and chute lowered 6" below standard, photo 4-18. Arrangements FDS-17 and 18 employed standard side draft chutes, photo 4-2. All arrangements used the 8" x 8" standard burner port and the T&NO type of oil burner. The side draft rings were the ST-202 castings, photo 4-20, or variations of the ST-202 with outer opening 1" smaller measured along curvature of firepan. Arrangements FDS-15, 16, 17 and 18 explored the effect of raising the draft ring castings 3½" above the standard position.

Raising the ports 3½" increased excess air somewhat, and the fixed bell mouth air port on front of the bottom hopper increased excess air slightly, but also increased the smoke density. All of these arrangements required high atomizer steam pressures to provide turbulence for smokeless combustion, and all smoked excessively at high firing rates.

Arrangement FDS-19 was the same as FDS-18 with the addition of three 5½" air flues located on each side of firepan ahead of the regular side draft chutes, and built with a flared approach. The bottom hopper damper was open. It was necessary to hold the modified draft dampers partly closed by supplementing the standard damper weights with an additional 50 pounds on each. This restricted the air ports sufficiently to provide the turbulence required by the Von Boden burner. The fire drummed vigorously at all rates. The flue gasses were clear to slightly hazy most of the time except for infrequent slightly darker puffs. Air from the side draft chutes entered the firepan at an elevation higher than usual. The arrangement was not satisfactory due to the heavy carbon deposit which accumulated on floor of the firepan.

Arrangement FDS-20 was tested to develop the effect of locating the side draft ports at a greater distance from the flash wall than standard. The ST-202 (Fig. 4-37) draft rings were installed 24" ahead of standard position. Standard side draft chutes, 8" x 8" burner port and the T&NO burner were used. Drumming of the fire varied from fairly heavy at the low rate to light at the high rate. It was noted that a small reduction in the area of the burner port would stop drumming with this arrangement. The test indicated that some benefit could be derived by increasing the distance between side ports and flash wall particularly at high steaming rates. Fairly heavy atomizer steam pressures were required. A relatively thin deposit of carbon formed on the firepan floor. No carbon remained on the flash wall at the end of the test, and the brickwork was brilliantly hot.

The effect of locating the side draft ports at an increased distance from the flash wall was further demonstrated in trial where the ST-200 (Fig. 4-35) side draft ports were installed 10" ahead of the flash wall. The fire was quiet and the smoke density moderate during these trials except when the bottom hopper damper was open. Some carbon accumulated on the flash wall during the low firing rates, but most of it was consumed later during the high firing rates. However, when the boiler was hand fired during a high steaming rate to recover boiler pressure lost by injector operation, there were some puffs of No. 2 Ringelmann smoke density.

Arrangement FDS-21 was tested to develop the advantage of a long, narrow side draft port. Draft ports 32½" long by 5-3/4" were cut in the firepan. Standard shape elongated side draft chutes were applied. The 8" x 8" burner port and T&NO oil burner were used. The bottom hopper ports were closed. With this arrangement, drumming of the fire was fairly heavy at low firing rates. The fire was high in the firepan and did not contact the rear floor brickwork. At high firing rates the fire appeared to fill the firebox but there was heavy smoke. The boiler flues sooted up considerably in spite of extra sanding. Changing atomizer pressure had no beneficial effect in reducing smoke density. Boiler efficiency dropped at the high rates. Based on these results, side draft ring, Fig. 4-38, was developed for trial application to AC class locomotives and test in road service.

Arrangements FDS-22, 23, 24, 25, 26, 27, 28 and 29 consisted of various combinations of four and six multiple side draft ports which were selected as the optimum arrangements in the trials of various combinations of the 8 side draft ports. The arrangement of ports, port plugs and constricting plates used in the preliminary trials are shown on photos 4-21 and 4-22. The 8" x 8" burner port was restricted in height by blocking off a space 3/4" to 2-3/4" in height at the bottom of the port.

The side draft castings were in accordance with Figs. 4-40, 4-41, and 4-42. The ST-258 (Fig. 4-40) draft ring was the same as the ST-202 (Fig. 4-37) casting except that the throat opening lengthwise of the firepan was reduced to 7½" versus the original 17". The outer draft ring port dimension was increased 2" for ST-259 (Fig. 4-41), and 4" for ST-260 (Fig. 4-42), measured along curvature of firepan; these draft rings were otherwise identical with the ST-258 (Fig. 4-40) side draft ring.

Open top side draft chutes were used starting with arrangement FDS-26. Of these arrangements, Nos. FDS-24 and 27, with which the four rear side draft ports were used, appeared to develop the highest evaporation and boiler efficiency. These functioned with an 8" exhaust nozzle equipped with a 5/8" x 3" basket cross split which has a larger effective area than an 8-1/4" nozzle equipped with the 1/2" cross split.

Tests of these arrangements demonstrated that the vertical angle at which the oil burner was mounted was critical. When burner was set level, or at an angle above two degrees, the smoke darkened. One or two degrees elevation from level provided the clearest stack condition. An elevation of one degree caused some carbon accumulation on the floor of the firepan at low firing rates. This carbon was partially consumed at high firing rates. Arrangement No. FDS-27, for example, provided high evaporation and boiler efficiency with relatively little smoke or drumming. Fairly high atomizer pressures were beneficial with these arrangements.

In order to try out the principle features utilized in firepan design by other oil burning railroads, the following arrangements were made:

(1) Trials were made of adjustable openings located on the bottom centerline of the firepan, together with various combinations of burner tilt, burner port size, atomizer pressure, bottom opening location and different arrangements of side air port sizes without particular success in preventing smoke or carbon.

(2) Trials were made using a damper and hopper on the front of the firepan in connection with four or six side air ports, and the oil burner located 21" above the bottom of the firepan. Any opening of the front hopper damper except a very small one resulted in the fire lifting away from the bottom of the firepan, excessive smoke and drumming of the fire.

(3) Trials were also made using the several combinations possible of four side ports, two on each side of the firepan and observing the effect with and without the front pair of side draft ports open. The center bottom hopper was blocked off. The lip of the oil burner was 17" above top of the floor brick. The burner port was 8" x 7" and the burner was set, by observing atomizer steam impingement, to a location near the lower part of the flash wall.

With most combinations the fire was lifted too high in the firepan. Use of the four rear ports with the front side ports shut gave the best results. By slightly restricting the bottom of the forward pair of side ports and blocking off the lower half of the rear pair of side ports, it was possible to obtain a clear fire with no smoke at a high firing rate. As it was questionable whether this performance could be duplicated using some practical arrangement without making extensive trials, no regular tests were made. A closely similar arrangement using side draft ring castings, Fig. 4-35, was tried, with apparently good results as long as the bottom hopper was closed. This was the final trial with the round bottom type of firepan.

It was evident that the largest effective nozzle area that could be used with the standard 20" stack, the Standard Von Boden Burner, and these final draft arrangements applied to the round bottom firepan, was that equivalent to an 8" nozzle equipped with a 5/8" x 3" basket cross split.

The T&NO flat bottom type of firepan was applied to the test locomotive, and arrangement FDT-1 consisted of the T&NO standard oil burning arrangement. This was tested to obtain basic data using superheater units with return bends 48" from the front tube sheet.

Arrangement FDT-2 was the same as FDT-1 except that a rounded approach was applied along the lower edge of the burner port for the purpose of increasing the amount of air flowing around the oil burner. Another rounded approach was applied to the rear edge of the fixed air opening at front of the bottom hopper, to smooth air flow into the bottom hopper. Relatively high atomizer pressures were used. The fire was quiet at low firing rates, and drummed heavily at high firing rates. The color from the stack was clear at the start increasing in density to No. 1 Ringelmann before the end of the low rate. For the higher rates, the haze from the stack was heavy with some puffs of dense smoke. A knob of carbon extended out 12" from the flash wall at the end of these tests. Although there was no carbon deposited on floor of the firepan this arrangement equipped with 8¼" nozzle and ½" cross split did not provide sufficient turbulence to prevent smoke. Results were better with the more restrictive 8" nozzle equipped with the 5/8" x 2" basket cross split.

Arrangement FDT-3 employed Battelle steam-air jets which were designed to develop high turbulence in the firebox in contrast with the smooth air flow from Battelle elliptical approach air ports tested in connection with the round bottom firepan as in arrangement FDS-1. The application of the steam-air jets is shown on photos 4-23, and 4-24. Steam pressures to the four steam-air jets were 150 and 160 pounds and atomizer steam pressures to the burner were high. The test of this arrangement demonstrated that under the control of an expert fireman this arrangement could be operated with a minimum of smoke and no carbon when equipped with an exhaust nozzle of the apparent area of the 8" nozzle in conjunction with the ½" x 3" basket cross split. Supplementary air from the baffler door was required. The bottom damper was closed at first but was opened slightly to cool the bottom hopper which became red hot. This test proved the value of turbulence in connection with the use of the Von Boden type of oil burner.

Arrangement FDT-4 consisted of the T&NO firepan equipped with five $5\frac{1}{2}$" OD draft tubes on each side of the firepan set close to the floor brick, starting 3-3/4" ahead of the front face of the flash wall, similar to the firepan draft arrangement used by other oil burning railroads. The oil burner port was 8" x $8\frac{1}{2}$" and the T&NO burner was set level. During these tests the color from the stack was No. 1/2 Ringelmann, increasing to No. 1 Ringelmann and darker smoke during the two high firing rates. Frequent sanding of the flues was necessary. It was apparent that a nozzle with the effective area of an 8" diameter equipped with the 1/2" x 3" basket cross split was too large for this arrangement when using the Von Boden type oil burner and 20" diameter stack. Two available Battelle steam-air jets were tried after the regular test runs but these had no particularly beneficial effect.

Trials were made later using the same arrangement as FDT-4 except that the five $5\frac{1}{2}$" OD draft tubes on each side of the firepan were replaced by forty 2" ID draft tubes on each side of the firepan, a total of 80 tubes arranged in eight vertical rows of five tubes each per side (or conversely five horizontal rows of 8 tubes each). The lowest horizontal row of tubes had centers located 2" above the floor brick and the rear vertical row had centers located $4\frac{1}{2}$" ahead of the flash wall. The arrangement is shown in photos 4-25 and 4-26.

Carbon formed rapidly at the lower rear side draft tubes. At certain atomizer pressures large volumes of smoking oil would spray out of the tubes in this area. Blocking plates were applied to cover some of the front tubes but carbon continued to form rapidly in some of the lower draft tubes in spite of frequent cleaning. Use of one Battelle steam-air jet in each side of firepan ahead of the 2" draft tubes showed no beneficial effect.

Smoke density was not improved over that typical of the T&NO standard drafting arrangement. It was evident that relief from carbon formation, drumming, and other undesirable features of firepan arrangements was not assured by application of multiple side draft tubes to the T&NO firepan, and that this arrangement equipped with the standard type oil burner would not be efficient with an exhaust nozzle having the effective area of an 8" nozzle equipped with the 1/2" x 3" basket cross split.

Arrangements FDT-5, 6, 7, 8 and 9 consisted of three variations of Dutch oven design in the T&NO firepan. These were tested with sizes of oil burners, burner ports, burner locations, and side draft ports recommended as current practice, or that had appeared to promise good results in preliminary trials. There were two horizontal rows of eight 2" ID draft tubes in each side of the firepan with center of the lower row 8" above the floor brick, and 6" between centers of the two horizontal rows. They corresponded with the first and third upper rows of draft tubes, photo 4-26. Vertical center line spacing was 4-3/4" between tube centers starting 4½" ahead of the flash wall. The Southern Pacific design of Dutch oven used in arrangements FDT-7, 8 and 9 is shown on photo 4-27. The type of Dutch oven in arrangement 5 is shown on photo 4-28; Dutch oven in arrangement 6 was 9" shorter with corners of brick rounded at tunnel exit.

The Dutch ovens had a steadying effect on the fire, improved the uniformity of firebox water side sheet temperatures as plotted on figure 4-29, as compared to sheet temperatures recorded when testing the T&NO standard arrangement, plotted on figure 4-28. However, they did not prevent carbon accumulation. The setting of the oil burner was critical in order to stop impingement of atomized oil on the sides of the oven which caused carbon formation and eventually dark smoke. No fuel savings were indicated and it was obvious that a larger exhaust nozzle could not be used effectively with these arrangements, using the present standard oil burner.

This concluded the series of tests to show the effect of modifications in size, shape, and location of draft ports, method of air admission and Dutch oven installations. While some improvement was possible by changes in air openings employed with the present standard oil burner, it would be desirable to complete the ST-5 series of tests with various types of oil burners before recommending a modified firepan. The degree of atomization with the present standard burner is not entirely satisfactory and may be subject to considerable improvement by refinement in burner design. Following this development, the necessity for turbulence created by the method of air admission may be less critical. Therefore, the optimum combination of burner and firepan drafting arrangement for recommendation will depend on results of the ST-5 series of tests as related to results of the ST-4 series of tests.

Figure 4-25 is a plot of comparative results of the Pacific Lines firepan draft tests made with the long superheater units. The results are plotted at the firing rate of 5000 pounds of oil per hour, and are arranged in descending order of exhaust nozzle pressure, psig; where these were equal, they are arranged in descending order of firebox drafts, in inches of water.

It will be noted that draft arrangement No. 7 using the Fig. 4-35 side draft rings and the figure 4-36 bottom draft ring resulted in consistently high boiler efficiencies, and high hot water rates which are equivalent to the steaming rates of the locomotive.

Results from test arrangements SNA and SNL from the SN series of tests covered in report ST-2 are plotted for comparison. The firepan draft and smokebox arrangement used for test SNL is the present Pacific Lines standard arrangement used on class GS-1 locomotives.

Figure 4-26 is a plot of comparative results of the Pacific Lines firepan draft tests made with the present standard short superheater units. These results are also plotted at the firing rate of 5000 pounds of oil per hour, and are arranged in the descending order of exhaust nozzle pressures, psig.

Arrangements 24-Q and 27-Q resulted in the highest hot water rates and boiler efficiencies. Both of these arrangements were equipped with four small side draft rings patterned after the ST-202 (Fig. 4-37) draft ring and were located two on each side near the rear of the firepan. Arrangement 24-Q was not equipped with side draft chutes, and would, therefore, not be suitable for road service. It was tested as a preliminary arrangement.

Arrangement 12-P is the present Pacific Lines standard firepan draft and smoke box arrangement for GS-1 class locomotives, while 12-A is the same arrangement except that it was equipped with an 8" diameter exhaust nozzle and 3/4" Pacific Lines cross split, in accordance with the arrangement which was previously standard.

Figure 4-27 is a plot of comparative results of the T&NO firepan draft tests made with the present standard short superheater units. These results are plotted at the firing rate of 5000 pounds of oil per hour, and are arranged in the descending order of exhaust nozzle pressures, psig.

Arrangement 1-X is the present standard T&NO firepan draft and smokebox arrangement, except that the sand ejector was not included, and it differs from arrangement 1-V (which includes the T&NO sand ejector) in the depth of insertion of the 1/2" cross split in the exhaust nozzle. In the former, the cross split was inserted 1/8" deep in the nozzle, while in the latter the cross split was inserted 3/8" deep.

It will be noted that arrangement 3-Y which was equipped with Battelle steam-air jets resulted in the highest boiler efficiency and hot water rate with respect to low exhaust nozzle pressures; however, further development of this arrangement has been deferred pending the results of the ST-5 series of oil burner tests.

Figure 4-34 is a plot of the variation of exhaust nozzle temperature versus exhaust nozzle pressure, which was used in setting exhaust nozzle temperature for the firepan draft tests. The curve of higher temperatures was used with the long superheater units while the curve of lower temperatures was used after short superheater units were applied. The cylinder spray water rate was proportioned to reduce the exhaust steam temperatures to the values plotted for the exhaust pressure desired. The curves were drawn to produce the average heat drop per pound of steam worked through the engine cylinders characteristic of road operation of GS-1 class locomotives, which are equipped with type "E" superheaters.

Figure 4-24 indicates the differential between the temperature of saturated steam (versus steam pressure in the feed-water spray chamber), and the temperature attained by the feedwater when the spray valve has a 2½" or 3½" length of sleeve, or no sleeve.

It will be noted that this differential increases at the lower pressures, which will enable the use of shorter sleeves with the more open exhaust nozzles utilized, in order to maintain the proper margin between feedwater temperature and saturated steam temperature for the lower pressures involved.

For the ST-4 series of tests the locomotive was equipped with the 3½" sleeve.

Figure 4-30 indicates the apparent areas of exhaust nozzles tested which were equipped with basket cross splits as shown on figure 4-43.

The area scale represents the areas of round nozzles less the projected area of a ½" standard cross split. The steam flow through these nozzles is found in the usual way, by following a vertical line from the area selected to its intersection with the line indicating the steam pressure at the exhaust nozzle. Directly opposite this point of intersection, the steam flow rate through the nozzle can be read on the left scale. This will be the exhaust steam flow rate for a nozzle equipped with a standard Pacific Lines ½" cross split, for a GS-1 class locomotive with type "E" superheater having unit return bends located 24" from the back flue sheet.

The exhaust steam flow rate through any of the seven nozzles equipped with basket bridge cross split can also be read on the left scale directly opposite the intersection of the selected nozzle curve with the required nozzle pressure line; and vertically below this intersection point of curve and pressure line, the apparent nozzle area can be read. The apparent area is the equivalent projected area of a round nozzle equipped with a ½" Pacific Lines standard cross split that would produce an equal exhaust steam flow for the same nozzle pressure.

Figure 4-31 is similar to Figure 4 - 30, except that it covers exhaust steam flow for GS-1 class locomotives equipped with type "E" superheater, with unit return bends located 48" from the back flue sheet.

Figure 4-22 shows graphically for direct comparison the test results of the Pacific Lines standard oil burning and smoke box arrangement versus the T&NO standard oil burning arrangement, equipped with comparable smokebox arrangement. The nozzle and cross split size were the same. The ½" cross split was set 3/8" deep in the nozzle in accordance with the Pacific Lines standard. (The T&NO standard specifies 1/8" deep). This was the only variation from the T&NO standard smokebox, which also requires a sand ejector. The other difference between the two smoke box arrangements tested was the use of the low resistance basket spark arrestor in the Pacific Lines standard arrangement and its omission in the T&NO standard arrangement.

The damper setting and atomizer pressures for the T&NO arrangement were those which produced the optimum fire and minimum smoke density.

It will be noted that the firebox draft for the Pacific Lines firepan is 3½" to 4½" of water higher than that for the T&NO firepan, and the boiler efficiency ranges correspondingly 1½ to 2% higher for the Pacific Lines firepan.

Figure 4-28 is a graph of variation of firebox and boiler sheet temperatures at different firing rates for T&NO firepan arrangement FDT-1-V which is very closely similar to standard T&NO arrangement. Figure 4-29 is a similar graph for T&NO firepan arrangement FDT-8-Z which had the enlarged design of Dutch Oven. From a study of these graphs it will be noted that temperature distribution was more nearly uniform when using Dutch Oven. It will also be noted that sheet temperatures in firebox had less variation between low and high firing rates when Dutch Oven was used.

DETAILED DISCUSSION OF INDIVIDUAL TESTS

Fig. 4-44 - Test FDS 1-A with 8" nozzle, 3/4" cross split, 13½" stack height, Battelle design bell mouth side draft ports, standard burner port, and bottom hopper closed.

There was a certain amount of drumming of the fire at all rates. Drumming was at a minimum at 5 psig atomizer steam pressure. Although there was relatively little smoke, the carbon deposit in the firepan was much larger than that deposited in previous tests with standard air openings. At high steaming rates, carbon built up rapidly, especially on the lower edge of the side ports and between rear edge of these ports and the flash wall. At end of test, the right side and front end of bottom hopper were red hot due to carbon falling through bottom draft port into hopper. Excess air at the high rate was 63%.

Fig. 4-45 - Test FDS 1-L with 8-1/4" nozzle, 1/2" cross split, 10" stack height, Battelle design bell mouth side draft ports, standard burner port, and bottom hopper closed.

Haze from stack was quite dark. Drumming was heavy, driving smoke, fire and sparks from fire door and peephole. Carbon formation in firepan was excessive and extended from flash wall to within a short distance from oil burner. Bottom hopper became red hot at front end and test at the high rate was discontinued 10 minutes early due to potential fire hazard, when boiling oil began to flow from bottom hopper. This was caused by carbon accumulation in firepan. Air entering side ports appeared to rise vertically. Excess air was relatively high, but tests with this arrangement were discontinued because exceptionally large amounts of carbon formed.

Fig. 4-46 - Test FDS-2J with 8" nozzle, 1/2" cross split, 10" stack height, modified bell mouth side draft ports restricted by brick on bottom, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

Fire drummed at the lower steam rates with some flame flashing from burner port and, periodically, at the higher rates. No carbon was deposited in the firepan but there was intermittent heavy haze from the stack at the high firing rate. Air entering these ports appeared to flow into pan horizontally, raising the fire above bottom of firepan at flash wall and between side ports. Excess air at the high rate was 26.6%.

Fig. 4-47 - Test FDS 3-J, with 8" nozzle, 1/2" cross split, 10" stack height, modified bell mouth side draft ports, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

The fire was smooth, particularly at the low rates, but did drum and flash out of draft and burner ports at times. There were intermittent puffs of approximately No. 2 (Ringelmann) smoke at the higher rates. A small amount of carbon formed on the flash wall when firing up, but quickly burned off when throttle was opened.

Firepan was free of carbon throughout test runs. Excess air at the high rate was 29.5%.

<u>Fig. 4-48 - Test FDS-3-O</u>, with 8" nozzle, 5/8" x 3" basket bridge cross split, 10" stack height, modified bell mouth side draft ports, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

Fire was fairly quiet but there was some drumming accompanied by flashes of flame from side and burner ports. Smoke color was fairly dark, particularly at the high steaming rates. No carbon was deposited in firepan. Excess air was relatively high compared to other arrangements with same cross split and nozzle diameter. Excess air was 24% at the high rate.

<u>Fig. 4-49 - Test FDS 4-J</u>, same arrangement as for Test FDS 3-J except that the bottom hopper port was closed.

At low steaming rate the fire was smooth with very slight haze at the stack. At high steaming rate, the fire drummed intermittently with some flashes of flame from side and burner ports, but was smoother than fire when hopper was open; stack haze was heavy with puffs of No. 2 smoke periodically. No carbon was deposited in firepan. Excess air at the high rate was 29.2%.

<u>Fig. 4-50 - Test FDS 5-L</u>, with 8-1/4" nozzle, 1/2" cross split, 10" stack height, side draft rings per Fig. 4-35, standard draft chutes, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

Fire drummed with some flame coming out of draft and burner ports. The stack was clear, with some puffs of haze at the high steaming rates. A moderate amount of carbon formed on the flash wall and on the floor of the firepan.

Fig. 4-51 - Test FDS 6-P, with 8-1/4" nozzle, 1/2" cross split, 13½" stack height, side draft rings per drawing ST-200, standard draft chutes, bottom draft ring per Fig. 4-36, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

The fire was quiet at the high steaming rate with haze from stack fairly dark at the start, lighter towards end of run. There was periodic drumming at the low rates with spurts of light haze from stack and some flame from the draft ports. Some carbon was deposited in the firepan. Excess air at high rate was 21.5%.

Fig. 4-52 - Test FDS 6-Q, with 8" nozzle, 5/8" x 3" basket cross split, 13½" stack height, side draft rings per Fig. 4-35, standard draft chutes, bottom draft ring per Fig. 4-36, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

Fire drummed with periodic flame from ports. A small ridge of carbon formed at bottom edge of side ports and some carbon built up on flash wall. Stack was clear except for puffs of light to medium haze.

Fig. 4-53 - Test FDS 7-Q, with 8" nozzle 5/8" x 3" basket cross split, 13½" stack height, side draft rings per Fig. 4-35, draft chutes with outer edge and damper axis lowered 6", bottom draft ring per Fig. 4-36, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

Fire drummed periodically with some spurts of flame out of draft and burner ports. Color from stack was clear to a slight haze in puffs. A relatively small knob of carbon formed on the flash wall, and a small ridge formed just below each side port. The amount of carbon formed in a day's run appears to be less than the amount that formerly accumulated in 45 to 90 minutes of running with the standard ports. Excess air was a little less than that with arrangement FDS 3-O, relatively high for 8" diameter nozzle and 5/8" x 3" basket bridge cross split.

Fig. 4-54 - Test FDS 7-R, with same arrangement as FDS 7-Q, except that nozzle was equipped with a 3/4" x 3" basket bridge cross split. Edges of brick at bottom of side ports were cut off for better air distribution.

The fire drummed at 30 psig atomizer steam pressure, at the high steaming rate, but was quieter at 7 psig. Stack was clear to slightly hazy. There were some puffs of No. 2 smoke at the start of the high rate, but the stack was clear at the end of this rate. Drumming was moderate to medium at all of the test rates, accompanied by spurts of flame out of oil burner port and side draft ports. A small mound of carbon formed at base of each side port and extended 8" ahead of ports. There was also some carbon on the flash wall.

The puffs of excessive smoke stopped when flow meter on atomizer steam line was bypassed. Excess air at the high rate was 22.8%.

Fig. 4-55 - Test FDS-7-S, with same arrangement as FDS - 7Q except nozzle was equipped with a 5/8" x 2" basket bridge cross split.

Drumming of fire was light to moderate and intermittent, with some flashes out of draft ports. Color from stack was clear to slightly hazy in puffs. At end of test runs there was a knob of carbon on the upper flash wall, extending about 12" from wall. The small ridge of carbon that forms at the base of the side draft ports was lower than the ridges for the previous runs with the side draft rings shown on Fig. 4-35. Excess air indicated for the high rate was 28.6%.

Fig. 4-56 - Test FDS 7-T, with same arrangement as FDS 7-Q, except nozzle was equipped with a 1/2" x 2" basket bridge cross split.

Drumming of fire was light at 5 psig. wye pipe pressure; fairly heavy at 10 psig wye pipe pressure, and moderate at the high steaming rate. There were periodic flashes of fire out of draft and oil burner ports. At the low steaming rate with atomizing steam pressure of 8 psig there were some puffs of No. 2 smoke; for the higher steam rates, color from stack was clear to slightly hazy. At the end of test the knob of carbon on the flash wall extended out about 12" from wall and small mounds of carbon had formed ahead of the side draft ports. Excess air for this arrangement was relatively high compared with other arrangements equipped with 8" nozzle and

1/2" x 2" basket cross split, and was 22.1% at the high rate.

Fig. 4-57 - Test FDS-7-U, with same arrangement as FDS-7-Q, except that nozzle was equipped with a 3/4" x 4-1/2" basket bridge cross split.

Fire drummed moderately at the high steaming rate, medium heavy at the intermediate rates and lightly at the low rate. Flame flashed out of draft and oil burner ports periodically. Color from stack was clear to slightly hazy, with somewhat darker puffs at the high rate. When firing up, fire dragged the floor of firepan and the knob of carbon on flash wall was about 1 foot closer to floor of firepan than usual. At end of test there was no carbon head on the flash wall, but the deposit of carbon on the floor of the firepan was heavier than usual, with some extending forward almost to the oil burner. 21.8% excess air was indicated at the high rate.

Fig. 4-58 - Test FDS-8-U, with same arrangement as FDS-7-Q except that the nozzle was equipped with a 3/4" x 4-1/2" basket cross split and side draft rings were in accordance with Fig. 4-37.

Fire drummed moderately with some flashes out of oil burner port and draft ports. Color from stack was clear to slightly hazy. Haze was darker in puffs at the high steaming rate. A knob of carbon about 10" thick formed on the flash wall when firing up and during first part of the low rate. No carbon formed on the firepan floor. A layer of fused material 3" thick had been removed from floor of firepan just prior to this test which probably assisted in preventing carbon from depositing on floor. It was considered desirable to increase the percentage of excess air found to be available with this arrangement. Excess air at the high rate was 18.0%.

Fig. 4-59 - Test FDS 8-Q, with 8" nozzle, 5/8" x 3" basket bridge cross split, 13½" stack height, side draft rings per Fig. 4-37, draft chutes with outer edge and damper axis lowered 6", bottom draft ring per Fig. 4-36, T&NO burner port with rounded approach, 2-5/8" x 17" bell mouth port in front of hopper open.

Atomizer steam pressure with this arrangement was high for the clearest stack condition, ranging from 60 to 90 psig, and apparently caused excessive drumming. An 8" pyramid of carbon formed on the flash wall. There was periodic flame out of the draft ports and range of color at stack was from slight haze to darker haze in puffs. Less excess air was indicated for this arrangement than for the other arrangements equipped with 5/8" x 3" basket bridge cross split and 8" exhaust nozzle.

Fig. 4-60 - Test FDS 9-Q, with same arrangement as FDS 8-Q, except that T&NO type burner was replaced by a modified Sheedy burner, in which a series of 3/32" holes reamed with a No. 00 taper pin reamer replaced the 1/32" slit type atomizer slot. The combined area of the atomizing holes was approximately that of the original 1/32" slot.

Color from the stack was as dark, or possibly darker, than for previous tests, in spite of a slight gain in excess air as indicated by flue gas analysis. With the Von Boden burner in prior tests high atomizer steam pressure was used to produce the clearest stack but a rapidly drumming fire resulted, while with modified Sheedy burner used in this test, high atomizer pressure did not appear to be of any particular benefit in clearing the stack, and produced such heavy drumming that it was not feasible to test with high atomizing steam pressure. It was difficult, also, to maintain a low spot fire with this burner.

Fig. 4-61 - Test FDS 9-T, with same arrangement as FDS 9-Q, except that aspirating air inlet to the burner was open in this test.

Atomizer was tried at various steam pressure settings, and the air inlet on the modified Sheedy oil burner was used in open and closed positions. If the air through the oil burner had any effect, it was not readily apparent from observations.

Fig. 4-62 - Test FDS 10-T, with same arrangement as FDS 8-Q, except that nozzle was equipped with a 1/2" x 2" basket bridge cross split and an unmodified Sheedy oil burner was used in this test, with air port in burner open or closed as required.

Starting the fire was difficult because the oil from oil burner did not appear to be atomized regardless of the steam pressure used. However, after several attempts during which considerable oil ran out of the firepan, the fire was started and boiler brought up to working pressure successfully.

When the air inlet in the burner was closed, the oil flow was spasmodic and it was necessary to open the air valve. This smoothed out the fire sufficiently to raise steam to working pressure, but when the steam throttle was opened, the air valve had to be closed, as oil would flow back out of air inlet. It was found that with more than a low oil rate, oil would flow from burner air inlet when atomizer steam pressure was less than 40 psig. Most of the tests were conducted with air inlet closed.

There was a dark haze from stack on all except the low rate, and a small amount of carbon formed ahead of the left side draft port apparently due to the fact that burner was pointed slightly to the left in order to equalize sheet and superheated steam temperatures on each side of boiler.

Fig. 4-63 - Test FDS 11-T, same arrangement as FDS-8-Q except that exhaust nozzle was equipped with a 1/2" x 2" basket bridge cross split, and the standard 8" x 8" oil burner port was reapplied to the firepan; a Von Boden oil burner of the T&NO type was applied, level, at same height as the Sheedy burner which was removed.

By using a sufficiently high atomizer steam pressure, about 95 psig, a practically clear stack was maintained at the low rates. At the high rate there was a heavy haze from the stack, although atomizer steam pressure was 190 psig which was the maximum pressure available. At the 14 psig wye pipe pressure rate, there was dark haze from the stack notwithstanding the 160 psig atomizing steam pressure setting. Drumming of fire was not excessive. No carbon was deposited in firepan.

Fig. 4-64 - Test FDS 12-A, with 8" nozzle, 3/4" standard cross split, 13½" stack height, SP standard draft rings, chutes, and oil burner port, superheater units shortened 24", with ends 48" from back tube sheet. Oil burner tilted up slightly to point about 14" up on flash wall above floor of pan. New exhaust pressure-temperature curve used for setting exhaust steam temperatures was about 40-50° lower than that used for previous tests in this series, to compensate for the drop in temperature of superheated steam with shortened superheater units. Bottom hopper damper and front hopper port closed. Excess air at the high rate was 40%.

Atomizer steam pressure of 10 psig was used for the low steam rates and 20 psig for the high steam rates. No carbon accumulation was visible during or at end of test. There was moderate drumming at the low rate. Fire was smooth at the higher steam rates.

Fig. 4-65 - Test FDS 12-P, with same arrangement as FDS 12-A, except equipped with an 8¼" nozzle and 1/2" cross split.

The fire drummed heavily at all atomizer steam pressures at 5 psig wye pipe steam pressure with stack color clear. Fire was steady at the 10 psig wye pipe steam pressure and 20 psig atomizer with clear color from stack, but would drum at 40 psig atomizer pressure. Fire was steady and stack clear to slightly hazy at 14 psig wye pipe pressure, 20 psig atomizer. There was a slight haze from stack at the 17 psig wye pipe pressure, 20 psig atomizer, which darkened intermittently. At the end of this rate, a large piece of carbon about

12" in diameter was visible in firebox. Excess air was relatively low compared with other arrangements with 8-1/4" nozzle, 1/2" cross split and shortened superheater units. It was 18.4% at the high rate.

Fig. 4-66 - Test FDS 13-P, with 8-1/4" nozzle, 1/2" cross split, 13½" stack height, combination side draft rings having the lower half of draft ring ST-200 (Fig. 4-35) at the top and the lower half of ST-202 (Fig. 4-37) at the bottom, as shown on Fig. 4-39(ST-215A). Draft chutes with outer edge and axis of damper 6" lower than standard, standard 8" x 8" burner port with T&NO type oil burner, 2-5/8" x 17" bell mouth port in bottom hopper open.

At 5 psig wye pipe pressure and atomizer steam pressure of 60 psig, fire was steady, with slight haze from stack occasionally. At 10 psig wye pipe pressure, there was very slight drumming and some haze from the stack, with atomizer at 60 psig. At 14 psig wye pipe pressure, color from stack was fairly clear and fire was smooth with 80 psig atomizer pressure. 80 psig atomizer pressure was required at the 17 psig wye pipe pressure.

Air flow was increased over that available with the standard side draft castings, although considerably more steam was required to atomize the fuel. The fire was lifted away from the flash wall and from the floor of firepan between the air ports. Haze from the stack was considered somewhat darker at all of the steaming rates than that with standard side draft castings.

Fig. 4-67 - Test FDS 14-P, with same arrangement as FDS 13-P, except that 2-5/8" x 17" port in bottom hopper was closed.

There was no consistent or appreciable difference between observed characteristics of tests FDS-13-P and FDS-14-P.

<u>Fig. 4-68 - Test FDS 15-P</u>, with 8¼" nozzle, 1/2" cross split, 13½" stack height, side draft rings per Fig. 4-37 raised approximately 3-1/2" above standard location, T&NO type oil burner, standard 8" x 8" burner port, draft chutes located at standard position, with outer edge and axis of side dampers lowered 6", 2-5/8" x 17" bell mouth port in bottom hopper open.

Atomizing steam pressures used ranged from 40 to 110 psig. Fire drummed somewhat at all of the steaming rates. There was periodic haze from the stack at the low rate, none at 10 psig wye pipe pressure, heavy haze at 14 psig wye pipe pressure and heavy haze that was periodically lighter at the 17 psig wye pipe pressure. The effect of raising side draft castings 3½" was to lower some of the fire in the firepan. Excess air was somewhat higher than that available with standard draft ports, but haze from stack was darker at the high steam rates than that with standard draft castings.

<u>Fig. 4-69 - Test FDS 16-P</u>, with same arrangement as FDS-15-P, except that 2-5/8" x 17" bell mouth port in bottom hopper was closed.

Atomizing steam pressures used were 40, 60, 90 and 110 psig, at 5, 10, 14 and 17 psig wye pipe steam pressures, respectively. There was some drumming at all except the high steam rate. Stack was clear at the low rate with some haze at 10 psig wye pipe pressure fairly heavy haze at 14 psig wye pipe pressure and heavy haze at

17 psig wye pipe pressure. Excess air percentage was slightly higher when bell mouth port in bottom hopper was open (test FDS-15-P) but stack color was somewhat lighter when port was closed, except at high rate where haze was equally heavy for both arrangements.

Fig. 4-70 - Test FDS 17-P, 8¼" nozzle, ½" cross split, 13½" stack height, combination side draft rings 3½" above standard position, having ST-200 (Fig. 4-35) upper half at the top and ST-202 (Fig. 4-37) lower half at the bottom as shown on Fig. 4-39 (ST-215-B), and standard side draft chutes. Standard 8" x 8" burner port with T&NO type oil burner, 2-5/8" x 17" bell mouth port on hopper open.

At 5 psig wye pipe pressure, 40 psig atomizer, stack was clear. At 10 psig wye pipe pressure, 70 psig atomizer, there was intermittent mild drumming with light colored haze from stack. At 14 psig wye pipe pressure, 180 psig atomizer, haze from stack was light, to somewhat heavier, periodically. At 17 psig wye pipe pressure, with atomizer valve wide open at 190 psig steam pressure, there was heavy dark haze from stack. This arrangement did not furnish as high a percentage of excess air at the high rate as arrangement FDS-15-P, in which the side draft rings per Fig. 4-37 were elevated 3½".

Fig. 4-71 - Test FDS 18-P, with same arrangement as FDS-17-P except that the 2-5/8" x 17" bell mouth port on hopper was closed.

At 5 psig wye pipe pressure, and 30 psig atomizer pressure, the fire was fairly smooth, with light haze from the stack. At 10 psig wye pipe pressure, 70 psig atomizer, results were similar. At 14 psig wye pipe pressure, 140 psig atomizer, there was a dense light colored haze from stack. At 17 psig wye pipe pressure, and 190 psig atomizer steam pressure, there was a heavy dark haze from stack. This arrangement did not furnish as high a percentage of excess air at the high steam rate as arrangement FDS-16-P, in which the side draft rings per Fig. 4-37 were elevated 3½".

Figs.4-72&4-95-Test FDS 19-P, with 8-1/4" nozzle, 1/2" cross split, 13½" stack height, side draft rings per Fig. 4-39 (ST-215-B), elevated 3½" above standard position, standard draft chutes, with side damper weight supplemented by an additional 50 lb. weight, three 5½" flues with bell mouth approach on each side of firepan for additional side draft ports, hopper damper open and 2-5/8" x 17" bell mouth port in front of hopper closed, standard 8" x 8" burner port with T&NO type oil burner.

Atomizer steam pressure of 40 psig was the best setting for the four steam rates tested. The fire drummed vigorously at all rates with a small amount of fire flashing out of one flue port and oil burner port periodically. Color from stack was quite clear at all rates showing only a faint haze most of the time with infrequent slightly darker puffs. Observations during the course of the tests showed carbon forming at sides of flash wall and along floor, extending from front flue ports to flash wall. Carbon deposit on floor was heavy at end of tests.

Various combinations of side flue ports from all open to four plugged with weights removed from side dampers were tried before start and after conclusion of this test with unsatisfactory results, such as raising fire too high at flash wall, dark smoke, and fire flashing out of ports 6 to 12 inches. The oxygen content of the flue gases increased 1% with weights removed from side dampers and all flue ports open, but heavy smoke resulted.

Figs. 4-73 and 4-96 - Test FDS 20-P, with 8-1/4" nozzle 1/2" cross split, 13½" stack height, side draft rings per Fig. 4-37, applied to pan approximately 24" ahead of standard position, standard draft chutes, T&NO type oil burner and standard 8" x 8" oil burner port. Hopper damper & port closed.

Atomizer steam pressures used ranged from 20 to 106 psig. At 5 psig wye pipe exhaust steam pressure there was a clear stack, medium heavy drumming with fire flashing out of the side draft ports and oil burner port. At the other steam rates, there was periodic medium heavy to light drumming which caused some flame to flash from burner port. The fire was fairly steady at the high rates and appeared to be an incandescent white, with slight haze from the stack. Some carbon formed on the floor of the firepan between the air ports, mostly on the right side. At the end of these tests, there was an irregular layer of carbon about 2" to 4" thick on the floor of the pan, starting at the forward edge of the draft rings and tapering down toward the rear of the firepan.

When the tests were completed, there was no carbon on the flash wall and all parts of the brickwork were brilliantly hot. With this arrangement, it was found that a very small reduction in area of the oil burner port would stop the fire from drumming. The spot fire appeared to be the most satisfactory when carried with low atomizer on floor of pan between side draft ports.

Figs. 4-74 and 4-97 - Test FDS 21-P, 8-1/4" nozzle, 1/2" cross split, 13½" stack height, 32½" x 5-3/4" side draft ports, standard type draft chutes, T&NO type oil burner, standard 8" x 8" oil burner port, center draft port per Fig. 4-36, with bottom damper and 2-5/8" x 17" bell mouth port in bottom hopper closed.

Atomizer steam pressures used ranged from 45 to 84 psig. At the low steaming rate the stack was clear, with fairly heavy drumming of the fire. At the next higher rate, the stack was clear with slight haze periodically and intermittent drumming. At the two high rates smoke was dark and the boiler flues sooted up considerably in spite of extra sanding, which probably accounted in part for the drop in boiler efficiency at the high rates. At all of the rates the fire was periodically flashing out of the oil burner port.

Holding dampers partly closed, reduction of area of burner port, and changes in atomizer pressure had no beneficial effect in reducing smoke density. At the low rates, the fire was high in the firebox. At the high rates, the fire appeared to fill the firebox and at end of tests all of the brickwork was hot.

Undesignated trials were run, using 8 side draft ports, 4 on each side equipped with side draft ring castings, Fig. 4-40. No side draft chutes were used. Each side port could be closed when desired by means of hinged firebrick plugs as shown on Photos 4-21 and 4-22. Burner port was 8" x 8", and could be restricted in area by an adjustable plate at the bottom. Several combinations of 4 and 6 side ports open were tried: Observations covered a 10 minute period after atomizer and burner port had been adjusted to optimum setting for quiet fire and clearest stack condition. The engine was equipped with $8\frac{1}{4}$" nozzle and 1/2" square cross split and was operated at a steam rate of 14 pounds wye pipe pressure. Oil meter outages were taken for each 10 minute run. Bottom damper was closed.

	Port No.				
Draft Ports, Right side -	4	3	2	1	Smokebox or front end of locomotive →
Draft Ports, Left side -	4	3	2	1	

A tabulation of the arrangements tried, and the results, are as follows:

Arrg't.	Side Draft Ports Open Left	Side Draft Ports Open Right	Excess Air %	Reduction in Burner Port (Ins)	Atomizer Pressure Psig	Fire Box Draft (Ins)	Fuel Rate g.p.m.	Smoke Ringelmann	Appearance of Fire
A	1,3	1,3	40	None	6	9.6	11.81#	Clear to ½ R in puffs	Clean quiet fire no flame out of ports
B	1,2	1,2	37	None	122	8.9	12.26	1 R	Quiet, red & smoky at flash wall, 7" carbon on flash wall
C	1,2,4	1,2,4	49	2½	98	6.6	12.37	0.1 to 1 R	Smooth. Flame out bottom of side ports, carbon on floor bricks.
D	1,2,3	1,2,3	51	2½	100	6.6	12.52	0.1 to 1 R	Smooth. Flame out of lower corners of side ports. *
E	1,3,4	2,3,4		3	160			Clear	Carbon formed in firepan. Oil flowed from right front port. @
F	2,3,4	1,3,4	36	2½	112	7.7	12.16	Clear to slight haze	Heavy drumming, drums fire out of draft ports. No carbon.
G	3,4	3,4	33	1½	96	9.2	12.12	Clear to slight haze	Smooth. Some light drumming. No carbon. No fire out of ports.
H	2,3,4	2,3,4	38	4	108	6.9	12.21	Clear to ½ R	Moderate periodic drumming, drums fire from side ports.

\# Oil Meter Sticking: Necessary to clean.
* Following this test, carbon was removed from firepan.
@ Burner tilted upward.

Arrg't.	Side Draft Ports Open Left	Side Draft Ports Open Right	Excess Air %	Reduction in Burner Port (Ins)	Atomizer Pressure Psig	Fire Box Draft (Ins)	Fuel Rate g.p.m.	Smoke Ringelmann	Appearance of Fire
I	1,3,4	1,3,4	41	2½	118	7.6	12.21	Clear	Medium to fairly heavy drumming, & fire out of Ports.
J	2,3	2,3	40	1	118	9.3	12.14	Clear to ½ R	Smooth. No fire out of ports. (8" carbon on flash wall in 35 minutes)
K	2,4	2,4	36	None	100	9.9	12.02	Clear to slight haze	Medium drumming with fire out of side & fire door ports.
L	1,3	2,4	40	None	60	10.4	12.01	Clear to ½ R	Moderate periodic drumming, drums flame out of fire door port.
M	3,4	2,3	35	3/4	50	9.4	11.88	Clear	Clear, white and smooth. 7" carbon from prior tests fell from flash wall. No fire out of draft or fire door ports.
N	1,2,4	1,3,4	42	3	140	7.8	12.17	Clear to slight haze puffs.	Medium continuous drumming, white fire, some smoke from door port.

Starting with test "B", a considerable amount of carbon formed on the floor of the firepan and after test "D" the carbon was cleaned out of firebox. Arrangement "E" was then tried, and carbon began to form immediately on the bottom of the firepan, fuel oil was running out of some of the side ports and also the bottom hopper. The fire was put out and the burner, which had been set level, was tipped upward to point a little below the fire door. After this was done, no further trouble was experienced with carbon on the floor, or oil running out of the air ports.

It was necessary to restrict the 8" x 8" burner port 2" to 2½" when using 3 ports open on each side, in order to reduce drumming. The restriction had no appreciable effect when 2 ports were open on each side of firepan, as the fire was fairly smooth with the full 8" x 8" burner port.

With arrangement "M" in which the side port openings were staggered the carbon which had formed on the flash wall during the trial of arrangement "J" fell to the floor of the firepan, apparently due to force of the air current from the left rear draft port.

All arrangements could be operated with a practically clear stack by proper adjustment of the atomizer steam pressure, but the fire drummed considerably with arrangements having six side air ports open: Drumming was excessive, and fire unstable when all eight side air ports were open.

The excess air for 6 side ports open was only 3 or 4 per cent higher than for 4 side ports open, evidently on account of the continuous drumming and flame shooting out of the 6 side air ports.

As excess air was higher from analysis of gas samples than it had been previously for the same smokebox arrangement, the optimum arrangements were selected for regular test runs. Because of the effect of changing the angle of the burner, on carbon deposition, an adjustable burner bracket was applied to the locomotive, to allow adjustment to height and angle of burner elevation, during trial adjustments.

Figs. 4-75 and 4-98 - Test FDS 22-P, with 8¼" nozzle, ½" cross split, 13½" stack height, basket spark arrester, 4 multiple side draft ports per Fig. 4-40 (two rear ports 3 and 4 on the left side, and two middle ports 2 and 3 on the right side); 3½" T&NO type oil burner, standard 8" x 8" oil burner port restricted 3/4" in height at bottom; no side draft dampers or chutes; center damper and port closed.

Runs were made at 5, 10, 14, & 17 pound wye pipe pressures. At 5 pound wye pressure, 28 psig atomizer steam pressure was used. Fire appeared somewhat dull over the flash wall, and there were some puffs of smoke from the fire door port, with medium heavy drumming. At the 10 psig wye pressure there was medium continuous drumming of fire with 40 psig atomizer pressure; when atomizer pressure was reduced to 14 psig later, the drumming stopped. Fire was quiet at the two higher rates. Atomizer was set at 36 psig for the 14 pound rate, and at 39 and later at 60 psig for the 17 pound rate. The small deposit of carbon which accumulated on the flash wall during the low rates fell to floor of the firepan shortly after start of the high rate. Excess air from smokebox gas samples ran from 53% at the low rate to 28% at the high rate. At conclusion of the high rate, bottom hopper was opened, with controls at same setting, and this increased the excess air 1.5%. Color from the stack was usually clear with occasional puffs of light haze.

This same arrangement was tried later without designation, using a 5/8" x 3" basket cross split on an 8" nozzle, standard burner port reduced 1" at bottom, with burner applied to a bracket adjustable for height and vertical angle in even degrees starting with level 5 and 9 psig wye pressure rates were tested. Stack was clear with light haze in puffs. There was medium drumming of fire at low rate, and quiet fire at the next rate. Atomizer pressure was held at 4 pounds at the low rate, and 8.5 pounds at the higher rate. With low atomizer, a heavy deposit of carbon accumulated between the ports and on the flash wall. At start of a 13 pound rate there was heavy smoke which could not be cleared. Excess air was 32% for both low rates.

Figs. 4-76 and 4-99 - Test FDS-23-P, with 8¼" nozzle, ½" cross split, 13½" stack height, basket spark arrester, 6 multiple side draft ports per Fig. 4-40 (the 3 rear ports on each side of firepan restricted to approximately 3-3/4" vertical height of draft openings by adjustable plates), 3½" T&NO type oil burner, standard 8" x 8" burner port restricted 2½" in height at bottom; no side draft dampers or chutes, center damper and port closed.

Tests were run at 5, 10, 14 and 17 pounds wye pipe pressures. Excess air was 41% at the low rate and 19% at high rate. Stack was clear with puffs of slight haze at the lower rates, but at the higher rates the smoke density was about #1 Ringelmann, with puffs of heavier density, and could not be cleared by increasing atomizer steam pressure. Some carbon formed on the floor of the firepan opposite both rear side draft ports on the left side and ahead of the forward port on the right side. The fire was quiet at the high rates, but had a light periodic drum at the 5 pound rate, which was heavier prior to restriction of burner port before start of test run.

Figs. 4-77 and 4-100 - Test FDS-24-Q with 8" nozzle, 5/8" x 3" basket cross split, 13½" stack height, basket spark arrester, 4 multiple side draft ports per Fig. 4-40 (the two rear ports on each side of firepan, unrestricted); 3½" T&NO type of oil burner, burner port 8" x 6½" high, adjustable burner bracket; no side draft dampers or chutes; center damper and port closed.

Tests were run at 5, 9, 12 and 15 pound wye pipe pressures. Excess air ranged from 34% at the low rate to 18% at the high rate. There was slow medium heavy drumming at the five pound rate with flashes of flame from the draft ports; stack indications were clear to a light haze. At the 9 pound rate there was medium to fairly heavy continuous drumming with some flame from side ports; color from stack clear to slightly hazy. There was periodic light drumming at the 12 and 15 pound rates with color from stack clear to about #1/2 Ringelmann smoke and somewhat darker puffs.

Atomizer pressures used were 0.0, 58, 64 pounds at the lower rates respectively, 62 and 76 pounds at the high rate. The fire appeared white for these tests, with practically no carbon on floor of firepan, although burner tip had been lowered from position of previous tests. There was a pointed knob of carbon on the flash wall, extending forward about 8", at the end of the 15 pound test.

For an additional trial at the 15 pound rate, plugs were removed from twelve 2" ID draft tubes arranged to pass through flash wall of firepan. This caused fire to lift away from bottom of firepan and dark smoke at stack. Smoke could not be reduced to a satisfactory density by variation of atomizer pressure, or by closing all of the side draft ports, or any pair of them. When the four rear side draft ports were reopened and the 12-2" ID draft tubes through flash wall were closed, the fire and color from stack returned to the condition of the previous test.

Figs. 4-78 and 4-101 - Test FDS-25-Q, with 8" nozzle, 5/8" x 3" basket cross split, 13½" stack height, basket spark arrester, 4 multiple side draft ports per Fig. 4-41, 5 (2 rear ports on each side of firepan, unrestricted), 3½" T&NO type oil burner, raised 1" to center it in 8" x 6½" height burner port, burner tilted 4° above level on adjustable bracket; no side draft dampers or chutes; center damper and port closed.

Tests were run at 5, 9, 13, and 15 pound wye pipe pressures. Atomizer steam pressures were 10, 12, 37 and 46 pounds respectively. Drumming of fire was periodic, of light to medium intensity at the lower rates, and fairly heavy at the higher rates, increasing with increased atomizer pressure. Color from stack was clear at the low rate, and clear with puffs of light haze at the other rates. Flame periodically licked out of the draft ports at the lower edge which was unusual for this shape of casting and may have been caused by the absence of draft chutes. At the end of these test runs there was 8" of carbon on the flash wall, and a considerable amount on floor of firepan, formed mostly during the low rates.

<u>Figs. 4-79 and 4-102 - Test FDS-26-Q,</u> with same arrangement as for test FDS-25-Q, except that open top draft chutes were applied under the side draft ports.

Four test runs were made at wye pipe pressures of 5, 9, 12 and 15 pounds. The air chutes modified the flow of air into the firepan so that the fire was lifted away from the flash wall, and the #1 Ringelmann smoke from the stack could not be cleared at the two high rates by adjusting atomizer pressure. Color from stack was clear to slightly hazy at the lower rates. Some carbon formed on floor of pan opposite and ahead of the forward side ports. When atomizer pressures were raised there was an increase in drumming. Fire was fairly quiet at the high rate, with 88 pounds atomizer, although there was some periodic drumming. The fire would reach the base of the flash wall only part of the time.

During the foregoing series of test runs the oil burner was set at 4° tilt above horizontal. After test series was completed, the burner was moved down to level position in steps of 1° and the effect on fire and stack color observed. At 2° the stack cleared to a fairly light continuous haze, and at 1° tilt, the stack was clear with puffs of light color. The fire moved back to contact the lower flash wall at both of these burner settings but appeared to impinge more fully on the wall at the 1° angle, except that it would withdraw momentarily which may have accounted for the smoke puffs. When the burner was made level, the smoke from the stack became dark. An atomizer pressure of 160 pounds was required to clear the smoke after burner tilt was reduced; however, during the regular tests 160 pounds atomizer pressure showed no beneficial results although up to 80 pounds pressure was necessary.

There was no carbon in the firepan at the end of the day, and it was noted that the fire did not lick out over bottom edge of the draft castings with draft chutes applied.

Figs. 4-80 and 4-103 - Test FDS 27-Q, with same arrangement as FDS-26-Q, except that oil burner was adjusted to a tilt of 1° above horizontal.

Tests of 5, 9, 13 and 15 pound wye pipe pressures were run. With this burner setting, the fire filled the firepan although heavy atomizer pressures were necessary. During the two low rates carbon formed rapidly on the floor of the firepan and eventually on the flash wall. There was some haze from the stack at the low rates, and relatively little drumming of the fire.

During the two high rates the color from stack was clearer and carbon in the firepan was partly consumed. Drumming of fire was slight. A knob of carbon on the flash wall extended forward about 5" at end of these runs.

For observation of effect on the fire after the four regular test runs were finished, the burner port was changed to 8" x 8" size. At the 15 pound rate the fire seemed improved, the atomizer pressure could be reduced to half previous pressure without objectionable smoke, and much of the carbon deposit burned up. However, on changing to the 5 pound rate, the fire drummed considerably with flame flashing out of the draft ports. The burner was then lowered to the center of the 8" x 8" burner port, but no improvement in drumming was noted. It was found that only a slight closing of the burner port stopped the drumming.

<u>Figs. 4-81 and 4-104 - Test FDS 28-Q,</u> with same arrangement as FDS 26-Q except that the oil burner was set level and the side draft castings were in accordance with Fig. 4-42. On account of smoke and drumming at 5 pound wye pipe pressure it was necessary to restrict the side port openings to 9½" vertical height before starting the test runs.

Tests were run at 5, 9, 12 and 15 pound wye pipe pressures. Atomizer steam pressures of 21, 56, 101 and 142 pounds were used. At the three low rates smoke was clear with puffs of very slight haze. There was medium continuous drumming of the fire. There was periodic drumming of the same intensity at the high steaming rate. The fire was quiet at the high rate with 10 pounds atomizer pressure, but had a light periodic drum at 13 pounds atomizer. There was some #1/2 Ringelmann smoke at this rate and a few puffs of #1 Ringelmann smoke.

A moderate amount of carbon remained on the firepan floor at the close of these test runs, starting about 2 feet from the oil burner and extending to forward edge of bottom hopper port. The top of this deposit was about 2" above the bottom of the side draft ports. There was 2" of carbon on the flash wall.

Figs. 4-82 and 4-105 - Test FDS 29-Q, with same arrangement as FDS 26-Q, except that the oil burner had a 1° tilt above horizontal, and four side draft ports near center of the firepan were used; the two forward side draft ports were in accordance with Fig. 4-40 and the two rear ports, in accordance with Fig. 4-42. Burner port was 8" x 5¼" in height due to restriction at the bottom of the 8" x 8" standard port.

At the 5 pound wye pressure rate the oil burner was level. There was no visible smoke at the start but later there were dark puffs of smoke periodically. Oil consumption for this rate was heavier than usual. A considerable amount of carbon formed in the firepan. This carbon was broken up at the end of this rate and spread over the floor, but could not be removed.

For the 9, 12, and 15 pound wye pressure rates, the burner was given a tilt of 1° above level. This maintained a bright clear fire and practically a clear stack, with only a few puffs of slight haze.

Excess air was increased appreciably with this arrangement. Atomizer pressures of 12, 30, 80 and 98 pounds were used. There was light periodic drumming of the fire. Carbon formed at the rear of the forward side ports.

Undesignated trial was made of adjustable center openings in the round bottom firepan at 5 and 15 pound wye pipe pressures. The arrangement was the same as for test FDS 29-Q, except that an opening 46" long by $15\frac{1}{2}$" wide had been cut in the bottom of the firepan starting $13\frac{1}{2}$" from the flash wall (because of the existing center draft port) and guides were applied outside of pan to allow four fire bricks (15" x $8\frac{1}{2}$") to slide on individual steel plates so that an air port of 8-5/8" x $13\frac{1}{2}$" could be moved along center of firepan in increments of $8\frac{1}{2}$".

Trials were made of various combinations of burner tilt, burner port size, atomizer pressure, bottom opening location, together with different combinations of side air port sizes, without any notable success in avoiding smoke or carbon.

At the 5 pound rate it was possible to obtain a clear stack using bottom opening in second position from the rear with both side air ports partly restricted. At the 15 pound rate this same position of the bottom opening gave the best results; which were not sufficiently satisfactory to warrant regular test runs of this arrangement.

At the low rate using the fourth and fifth positions from the rear for the bottom opening, there was relatively little drumming. The stack was clear with some puffs of #1 Ringelmann smoke. The fire extended only a short distance from the burner before turning up, leaving the major portion of the firebox bare of flame.

Undesignated trial was made with 8" nozzle and 5/8" x 3" basket cross split using hopper and draft ports in the burner wall together with various combinations of four and six rear side draft ports. Burner was elevated so that the bottom of the burner was approximately 21" from the bottom of the firepan, measured outside of pan. An air opening was cut in the front end of firepan at the center, starting 2½" above bottom of pan, measured outside. This air opening was 11" high and 27" wide, surrounded by a short sheet metal hopper with a damper over the front opening, hinged at the top for controlling air supply.

At a low steaming rate an apparently excellent arrangement was obtained with the front hopper slightly open and the rear port on right and left side open with a restriction at the top of about half the height of the port. With this combination the fire was steady and there was no carbon or smoke.

At the high steaming rate, however, no satisfactory arrangement could be found, and difficulty was experienced in maintaining full boiler pressure. Any opening of the front hopper damper except a very small one caused fire to lift away from bottom of firepan, excessive smoke, drumming fire, and smoke out of the firebox ports.

Undesignated trials were run with the 8" nozzle with 5/8" x 3" basket cross split using the several possible combinations of four side ports, two on each side of firepan, other arrangements, and observing the effect with and without the front pair of side draft ports open. The two forward ports on each side of firepan were in accordance with Fig. 4 - 40, and the two rear ports on each side were in accordance with Fig. 4 - 41. The standard center bottom hopper was blocked off. The lip of the oil burner was 17" above top of the floor brick. The burner port was 8" wide by 7" high and the burner was tilted down considerably, having been set by atomizer steam with no fire, and the steam directed at the lower part of the flash wall. With this setting, the burner lip was about 2" above the bottom of the burner port, inside the firebox.

With most combinations, the fire was lifted too high in the firepan. Use of the four rear ports gave the best results. It was found that slightly blocking the lower edge of the forward pair of these rear ports tended to lower the fire in the firepan, and when the bottom half of the two rear ports was also blocked off, it was possible to obtain a clear fire with no smoke at the 15 pound wye pipe pressure. This arrangement was not run at any other steam rate and it is questionable whether any practical arrangement could be devised to duplicate this performance without extensive trials.

At the end of these trial runs there was a deposit of carbon about 5" thick on the flash wall, starting 12" above the bottom.

Undesignated trial was made with 5/8" x 2" basket cross split, 8" nozzle and round bottom firepan equipped with two side air ports per Fig. 4-35, each set 10¼" ahead of the flash wall at about standard height, using open top draft chutes and standard glare shields. Burner lip was 17" above the fire brick on the firepan floor, and burner tilted down. Wye pipe pressures tried were 5, 9, 13 and 17 pounds. The fire was quiet and did not drum except when the standard center hopper was opened. Air from the center hopper was detrimental, causing smoke to darken, drumming, and driving some smoke out of fire door port. When center hopper was closed, the fire was smooth and white; stack clear with puffs of light haze. The temperatures at water side of fire door sheet were lower than usual. When flues were sanded at end of the 9 pound wye steam rate, relatively little soot came from the stack.

During the trials the center hopper damper was opened, permitting observation of the flash wall. There was some carbon, mostly in a vertical line on the flash wall. The center hopper was opened slightly and much of the carbon burned, and evidently some more burned at the 17 pound rate as little remained at end of test.

At the 17 pound rate, manual firing was tried. The boiler pressure was allowed to drop back to 220 pounds, then the firing rate was increased to bring boiler pressure back to normal. This increased the smoke density to #1 Ringelmann with some puffs of #2 Ringelmann.

While it appears that this arrangement was quite good it did not steam quite as readily as the last standard arrangement tested with the 8" nozzle and 1/2" cross split. For this reason regular tests were not run.

Fig. 4-83 - Test FDT 1-B, with 8" nozzle, T&NO 3/4" cross split, 13½" stack height, basket spark arrester, no sand ejector, T&NO standard firepan and oil burning arrangement.

Four 1/2 hour tests were run at wye pipe pressures of 6, 10, 15 and 19 pounds, using atomizer pressures respectively of 20, 22, 30 and 63 pounds. The baffler door damper was set at 3" open.

At the 6 pound rate the fire drummed when the bottom damper was closed. It was set at 7 chain links or wide open for the test. Color from stack was clear. There was a little flame intermittently out of the burner port apparently due to light periodic drumming.

At the 10 pound rate there was medium drumming, some flame from burner port, and a clear stack. Bottom damper was open 6 links.

At the 15 pound rate there was a little light periodic drumming and some flame from draft and burner ports. The stack was usually clear, with puffs of smoke of about #1/2 Ringelmann. Bottom damper was open 6 links.

At the 19 pound rate, the bottom damper was opened wide. The fire drummed at medium intensity, with a little flame out of draft and burner ports. Stack was clear to slightly hazy in puffs. A layer of carbon about 4" thick, extending out about 18" from the flash wall on the right side of firepan above the bottom draft port, had accumulated during these test runs.

Firebox door sheet temperature at water side, thermocouple location No. 4, was higher than any previously noted, the pyrometer indicating up to 525° F at the high rate.

Excess air ran from 47% at the low rate to 26% at the high rate. The fuel used for this test was somewhat lighter than average, weighing 8.189 pounds per gallon.

Fig. 4-84 - Test FDT 1-V, with 8¼" nozzle, 1/2" cross split set with lower edge 3/8" below nozzle top, T&NO sand ejector, no spark arrester, T&NO firepan and oil burning arrangement.

Tests were run at wye pipe pressures of 5, 10, 14, and 17 pounds, with atomizer pressures respectively of 12, 20, 32 and 37 pounds.

At the 5 pound rate the bottom damper was opened 6 links to minimize drumming and opening the fire door butterfly damper to 5" appeared to reduce further the intensity of drumming and color from the stack.

At the other test settings the butterfly had to be closed to 3½" to keep fire from flashing out of burner port and bottom draft port, with bottom damper open 7 links.

Atomizer pressures had to be low to minimize drumming but it was necessary to increase pressure at the higher rates to reduce the color from the stack.

Color of the smoke was clear to hazy at the lower rates, with a tendency to darken at the higher rates, becoming about #1 Ringelmann with somewhat darker puffs at the 17 pound rate.

Carbon at the end of this test was about 4" thick on the bottom and sloping sides of the firepan and extended from about the center of the pan back towards the bottom draft port and flash wall.

Fig. 4-86 - Test FDT 2-V. With same arrangement as FDT 1-V except that a piece of 5½" OD flue sectioned lengthwise was applied along lower edge of the burner port to provide a rounded approach for the purpose of increasing the amount of air flowing around the oil burner; a similar piece of flue was applied to the lower edge of the upper front vertical plate of the bottom hopper to smooth the air flow through the fixed front draft opening.

Tests were run at 5, 10, 14 and 17 pound wye pipe pressures, using 20-50, 59-69, 60 and 84 pounds atomizer pressure respectively.

At the low rate the fire door butterfly damper was set 2" open and center damper was closed; at the 10 pound rate the butterfly was opened 3½"; at the 14 pound rate the butterfly was set at 2½" and bottom damper opened 3 links; at the 17 pound rate the butterfly was left at 2½" and the center damper opened 7 links.

The fact that the atomizer pressures were higher than on previous FDT tests probably accounted for the carbon which accumulated on the flash wall. A knob of carbon extending out about 12" from the flash wall remained at the end of the high rate.

Fire was quiet at the low rate with no flame out of burner port; color from stack was clear at start, density increasing to about #1 Ringelmann before end of rate. Drumming was medium at the intermediate rates and heavy at the high rate, driving 3 to 6" of flame periodically out of burner port, and below edge of front hopper port. There was heavy haze from the stack with some darker puffs. Excess air ran from 31½% at the low rate to 16½% at the high rate. Undesignated test was made with same arrangement as FDT 2-V except that the T&NO sand ejector had been removed. Water from the feedwater heater pump entered the boiler through the top spray check instead of through the standard side check.

Four tests were run at 5, 8, 12 and 16 pounds wye pipe pressure, with atomizer pressures of 60, 41, 34-50 and 82 pounds respectively.

For the 5 pound rate, the fire door butterfly damper was set at 2" open; bottom damper 3 links open. There were infrequent intervals of medium drumming. Stack was clear with puffs of #1/2 Ringelmann smoke.

For the 8 pound rate the butterfly damper was 2" open, bottom damper 3 links open. There was medium to heavy periodic drumming, forcing flame about 6" out of burner port and some below bottom draft ring. Stack was clear with puffs of #½ Ringelmann and darker smoke.

For the 12 pound rate the butterfly damper was 2½" open and bottom damper open 5 links. Smoke, drumming, and flame out of ports were about the same as for the 8 pound rate.

For the 16 pound rate, the butterfly damper was open 3½"; bottom damper 7 links open. Drumming was medium, with the fire periodically flashing about 6" out of burner port. Stack was clear with puffs of #1 Ringelmann smoke. There was apparently less smoke during these tests than during tests FDT-2-V with sand ejector and side boiler check, however the difference was small.

There was about 8" of carbon remaining on flash wall after these runs.

Fig. 4-87 - Test FDT 2-W, with same arrangement as FDT-2-V except that the T&NO sand ejector was removed and engine equipped with an 8" nozzle and a 5/8" x 2" basket cross split.

A series of tests were run at 5, 8, 11, 14 and 17 pound wye pipe pressures, using atomizer pressures of 24, 37, 41, 50 & 40-49 pounds.

The fire door butterfly was open 4½" for the first four rates and 3½" for the 17 pound rate. The bottom damper was closed for the first two rates, and open 2, 4 and 6 links respectively for the three high rates.

Drumming was light at the low rate increasing to medium and heavy continuous drumming at the 17 pound rate.

Fire was visible below the bottom draft ring and periodically 3" to 12" of flame flashed out of burner port.

Stack indications were usually clear with some puffs of slight haze. At the 17 pound rate the puffs darkened to #1/2 Ringelmann with some #1 Ringelmann smoke.

8" of carbon remained on the flash wall at end of test runs.

Excess air ranged from 34.7% at the low rate to 25.3% at the high rate.

Fig. 4-85 - Test FDT-1-X, with same arrangement as FDT-2-V except that there was no sand ejector, and bottom edge of the ½" cross split was set 1/8" below the top of the 8¼" nozzle; the rounded approach to burner port and to fixed draft opening in the hopper were removed.

The test series were run at wye pipe pressures of 5, 9, 13 and 16 pounds. Atomizer pressures were 20 pounds for the two low rates, 40 and 48 pounds at the 13 pound rate, 80 pounds at the high rate.

At the 5 pound rate, color from stack was clear. Drumming of fire was fairly heavy. Bottom damper was shut and fire door butterfly damper open 4½". The bottom hopper was red hot on each side near connection with firepan. Excess air was 23.8%.

At the 9 pound rate, color from stack was clear to slightly hazy. Drumming of fire was of medium intensity. The bottom damper was open 3 links and butterfly damper was open 3½". Excess air was 25.3%.

At the 13 pound rate, color of smoke was clear to #1/2 Ringelmann, increasing in density to #1 Ringelmann between periods when flues were sanded. Drumming of fire was fairly heavy. The bottom damper was open 5 links and butterfly damper open 3". Excess air was 20.9%.

At the 16 pound rate, color of smoke varied from clear to #1 Ringelmann, increasing to #2 Ringelmann between sandings of flues.

Flues were sanded approximately every 10 minutes. Drumming of fire was medium heavy. Bottom damper was open 6 links of damper chain; butterfly damper was open 3½". Excess air was 18.3%.

Drumming caused fire to flash out of burner port from 4" to 10" at the various firing rates, and was visible most of the time 6" to 8" below bottom draft ring. At the end of these tests there was a little carbon on the flash wall, and a trace on the brick work at the left side of the bottom draft port. Carbon was about 4" to 6" thick at the bottom right corner of the brickwork at side of and extending a little ahead of the bottom draft port and to about 12" up on the side brickwork above bottom port.

Preliminary Tests - Steam Air Jets: In order to determine those combinations of five steam air jets on each side of firepan, which would justify more extensive testing, preliminary trials were made using Battelle recommended steam air jets. These devices have been extensively used on coal burning locomotives by other railroads to combat smoke conditions, particularly in eastern or midwestern cities where air pollution ordinances are in effect.

These "pilot" runs were made with 5 lbs. wye pipe pressure, 8¼" dia. nozzle, and ½" standard shape cross split with bottom edge 1/8" below top of nozzle. T&NO oil burning arrangement and firepan were standard other than application of steam air jets as shown on Photos. 4-23 and 4-24. Neither spark arrester nor sand ejector were used in this test.

In order to indicate various combinations of steam air jets explored a method of designation was devised and made a part of this report.

Arrangement of : R 0 0 0 0 0 Smokebox
Steam-air jets.: L 0 0 0 0 0 or front end of ⟶
Jet Designation: A B C D E Locomotive.

Note 1: Unless designated by R or L letter designation of Jet refers to both left and right steam jets in operation.

Note 2: Unless otherwise noted, those jets not mentioned have air opening clear but no steam through jet.

Arrgt. No.	Jets		Steam Pressure at Jet (Psig)	Observed Data
1	Jet E		150 lb.	No. 3 smoke - cleared at 10 lb. atomizer.
2	Jet E		200 lb.	Bottom hopper red hot - Opened bottom damper.
3	Jet E		100 lb.	Stack clear - few puffs of slight haze.
4	Jet D D E	L R	100 lb. 80 lb. 100 lb.	Exhaust Nozzle Press. 3.8 lb; Firebox Draft 2.3"; Smokebox Draft 5.3"; clear stack, Butterfly open 2", fire out of front end of hopper.
5 @ 9:55 AM	Jet C D E		50 lb. 100 lb. 100 lb.	Exhaust Nozzle Press., 4.0 lb; Firebox Draft 2.6"; Smokebox Draft 5.8"; Hopper damper wide open. Stack clear. Fire out of front of bottom hopper and about 4" out of burner port.
6 @10:01 AM	Jet B C D E		50 lb. 50 lb. 100 lb. 100 lb.	Exhaust Nozzle Press. 4.1 lb; Firebox Draft 2.3"; Smokebox Draft 5.7"; atomizer 12#. Hopper wide open, Butterfly open 2". Fire out of front of hopper, and hopper red hot, sides and front. Two or three inches of fire out of burner port.
7 @ 10:10	Same as 6 above.			Bottom damper closed; atomizer 44 lb. Exhaust Nozzle Press. 4.1 lb; Firebox Draft 3.3"; Smokebox Draft 6.3". Hopper cooler but still red hot. Stack clear at first, then No. 1 smoke. Sanded flues 10:15, stack clear followed by increasing haze No. ½ to No. 1 Ringlemann smoke.

Arrgt No.	Jets	Steam Pressure at Jet (Psig)	Observed Data
7 (cont'd).			No fire out of burner port, but some below edge of hopper front port.
8 @ 10:30	All jets 50#		Bottom damper closed; atomizer 20 lb. Exhaust Nozzle Press 4.25 lb. Firebox Draft 4.0"; Smokebox Draft 7.2"; sanded @ 10:40. Stack clear to No. ½ Ringelman Fire drummed lightly. Fire again out of front bottom port and through leaks around top of hopper. Hopper red hot. Smoke appeared at back of hopper.
9 @ 10:45	A 50#; BC 100#; DE 50#		Oil on frame back of hopper began to smoke. Opened bottom damper 2 links. Exhaust Nozzle Press 4.1 lb; Firebox Draft 2.5"; Smokebox Draft 5.5". Atomizer 20 lb; smoke clear to ½ Ringelman in puffs. Hopper cooler but remained red hot with steady flame blowing 6" below front edge of hopper port, on inside of hopper. Fire quiet. No fire out of burner port.
10 @ 11:00	A 50#; BC 100# D 50#; E 150#		Too much smoke.
11 @ 11:02	A 50#; BC 100#; D 50#		Exhaust Nozzle Press 4.1#; Firebox Draft 2.8"; Smokebox Draft 5.9"; stack clear to puffs of slight haze.
12 @ 11:06	A,B,D 50#		Hopper red hot; oil flowing into hopper at front. Stack clear.
13 @ 11:09	A 100#		Tried to effect a setting to lift fire at back of pan.
14 @11:10	All steam jets shut off		Stack clear to very slight haze in puffs. Exhaust Nozzle Press 4.0#; Firebox Draft 3.0"; Smokebox Draft 6.0"; Dripping oil at front of bottom port stopped. Bottom hopper remained red hot; bottom hopper opened to 6 links; atomizer 39 lb; Firebox Draft 2.4"; Smokebox Draft 5.6".
15 @ 11:25	BC 100#		Just prior to changing burner angle to 3 degrees above level.

Arrgt No.	Jets	Steam Pressure at Jet (Psig)	Observed Data
16 @ 11:30	A -	100#	Changed burner angle to 3 degrees above level. Ringlemann #5 smoke.
17 @ 11:35	B,C,D	100#	Changed burner angle to 1 degree above level. This position maintained for duration of remaining trials.
18 @ 11:36	A B,C	110# 100#	Atomizer 39 lb; No. 1 to No. 2 smoke. 2 buckets of sand through flues.
19 @ 11:42	A,B,C	100#	Bottom damper open 6 links; butterfly open 3"; hopper cooled below red heat. 2" of fire periodically below front edge of hopper port. Stack No. ½ to No. 1R.
20 @ 11:45	A,B A,B,C	100# on R side 100# on L side	Smoke No. 1 R.
21 @ 11:50	Same as #20 except Jets E partly blocked off or shut.		Exhaust Nozzle Press 4.0 lb; Firebox Draft 2.2"; Smokebox Draft 5.2"; smoke slight haze to #½ Ringelmann.
22 @ 11:55	A,B A,B,C D,E partly blocked shut.	100# right; 100# left side;	Exhaust Nozzle Press 3.9 lb; Firebox Draft 2.2"; Smokebox Draft 5.1"; smoke No. ½ R; asbestos board blocks used on air jets opened up on R side to about ½ open. Hopper not red hot.
23 @ 12:02	A B C D,E	100# 75# 50# blocked shut.	Bottom damper open 6 links; butterfly open 3"; Exhaust Nozzle Press 3.9 lb; Firebox Draft 2.3"; Smokebox Draft 5.2"; atomizer 38 lb. Smoke slight haze with #1 Ringelmann puffs. Sanded flues at 12:10; tried atomizer from 50 lb; to 80 lb and set on 60 lb at 12:11; E port on R side ½ open account block slipped; stack clear with puffs of No. ½ to #1 R smoke. No fire out of burner port and very little visible below front edge of bottom hopper.
24 @ 12:15	A,B,C D,E (D partly open on R side)	50#; blocked shut.	Exhaust Nozzle Press 4.0 lb; Firebox Draft 2.4"; Smokebox Draft 5.2"; atomizer 60 lb. Dampers unchanged. Smoke slight haze to ½ Ringelmann.

Arrgt No.	Jets	Steam Pressure at Jet (Psig)	Observed Data
25	A,B,C D,E blocked shut; (D partly open on R side)	50#	Butterfly damper opened wide to reduce smoke.
26 @ 12:40	A,B,C No air jets blocked.	50#	Exhaust Nozzle Press 8.8 lb; Firebox Draft 7.2"; Smokebox Draft 12.7"; atomizer 96 lb; bottom damper closed; Butterfly open 3". No fire from burner port, but some below front edge of bottom port. Smoke No. ½ to No. 1 R. At 12:58 very slight haze to No. ½ R.
27 @ 1:00	A,B all tubes open	50#	Exhaust Nozzle Press 9.9 lb.; Firebox Draft 7.5"; Smokebox Draft 13.8"; atomizer 104 lb; bottom damper closed; Butterfly open 2". Smoke #1 Ringelmann.
28 @ 1:09	A	50#	Exhaust Nozzle Press 10.1 lb; Firebox Draft 7.6"; Smokebox Draft 14.3"; atomizer 104 lb; bottom damper shut; Butterfly open 2"; moderate drumming. Smoke No. ½ to No. 1 Ringelmann.
29 @ 1:18	Steam jets shut off; all tubes open.		Exhaust Nozzle Press 10.1 lb; Firebox Draft 7.8"; Smokebox Draft 14.1"; moderate drumming; sanded flues at 1:22; atomizer 104 lb; changed to lower pressure then back to 102 lb. at 1:25. Very slight haze to No. ½ R in puffs.
30 @ 1:29	D E F	100# 50# Right side 80# Left side	No. 2 smoke.
31 @ 1:33	D 100#; E 200 #		No. 2 smoke.
32 @ 1:35	D	100#	All air tubes open. Slight haze (No.½ Ringelmann in puffs at times) stack practically clear periodically. No flame out of burner port, but extended 3" below front edge of hopper port.

Arrgt No.	Jets	Steam Pressure at Jet (Psig)	Observed Data
32(Cont'd)			At 1:40 Butterfly open 1"; bottom damper closed; atomizer 104 lb.
33 @ 1:41	C,E D	100#Right side; 100#Left side; all tubes open.	Exhaust Nozzle Press 10.25 lb; Firebox Draft 6.6"; Smokebox Draft 12.8"; atomizer 100#; Butterfly open 3"; bottom damper closed; No. 1/2 to No. 1 Ringelmann smoke in puffs. No fire out of burner port but extended 2" below front edge of hopper.
34 @ 1:50	C,D	100#	Exhaust Nozzle Press 9.5 lb; Firebox Draft 6.4"; Smokebox 12.2". Bottom damper closed; Butterfly Damper open 3"; sanded at 1:54. Atomizer 100 lb. After sanding, Exhaust Nozzle Press 10.1 lb; Firebox Draft 6.6"; Smokebox Draft 12.7".
35 @ 2:00	B,C C,D	100#Right side 100#Left side	Exhaust Nozzle Press 10.2 lb.; Firebox Draft 6.6"; Smokebox Draft 12.9". Smoke No. ½ to No. 1 Ringelmann.
36 @ 2:06	B,C	100#Right side	Trial only. No data obtained.
37 @ 2:07	B,C	100#	No. 1 plus Ringelmann smoke. No other data obtained.
38 @ 2:09	B,C	100#Brick in E	No. 2 smoke. No other data obtained.
39 @ 2:15	B,C	100#;Brick in E Brick in D Right side only.	No. 2, then No. 3, plus smoke.
40 @ 2:18	A,B,C	100# Right side; Brick in E both sides	Smoke No. ½ to No. 1 Ringelmann periodically.
41 @ 2:22	Same as 40 except closed Butterfly from 3" open to 2" open		Exhaust Nozzle Press 10.0 lb. Firebox Draft 7.2"; Smokebox 13.5". No. 1 to No. 2 Ringelmann smoke.
42 @ 2:28	A B C E Blocked closed.	150# 125# 100#	Smoke No. ½ to No. 1 and some No. 2. Ringelmann.

Arrgt No.	Jets	Steam Pressure at Jet (Psig)	Observed Data
43 @ 2:33	Same as 42 except that front port of bottom hopper was closed by a board which left an opening about 1" x 8" on Right side.		Hopper became red hot on left side at the connection with firepan. No. 1 to No. 2 Ringelmann smoke. Exhaust Nozzle Press 10.25 lb; Firebox Draft 10.1"; Smokebox Draft 16.1". Sanded at 2:38. After sanding, smoke No. 1 to No. 2 Ringelmann.
44 @ 2:43	A 150#; B 125#; C 100#; D 50#; E blocked closed. Hopper front blocked same as 43.		Trial only. No data obtained.
45 @ 2:45	Same as 44		Bottom damper open 2 links, Butterfly damper open 3 3/4". Atomizer tried from 64 lb to 124 lb and set on 98 lb. At 2:49, closed bottom damper. Tried Butterfly damper on closed and 5" open; set on closed at 2:51. Tried atomizer on 140 lb. and set on 83 lb. Stack clear to very slight haze in puffs.
46 @ 2:59	A,B,C,D E blocked; Butterfly and bottom damper closed. Bottom front port blocked.	150#	Atomizer 100 lb; sanded at 3:00 pm. Atomizer 104 lb; Exhaust Nozzle Press 10.2 lb; Firebox Draft 11"; Smokebox Draft 16.5". Slight haze at stack.
47 @ 3:07	A,B,C,D	150#	Trial only. No Data obtained.
48 @ 3:10	A,B,C,D	140# E 50# on Right side; ABCD 150#; E 100# on Left side.	Smoke about No. ½ Ringelmann. No other data obtained.
49 @ 3:15	Same as 48 except E 100# Right side-		Smoke ½ Ringlemann, plus. No other data obtained.

All arrangements after and including 43 had hopper front port blocked closed, except for the 1" x 8" open slot from center to Right side of hopper. Burner at 1° tilt, approximately, after #17.

3:17 Closed throttle.

3:18 Removed block from front bottom port and set C on 40#.

3:19 Shut jets off.

Block of carbon about 6" thick at center was found on floor pan ahead of bottom port, with about 8" clear space from bricks on R side and 4" clear space from bricks on L side. It was estimated that carbon extended about 16" lengthwise of pan.

Undesignated trials were run using same arrangement as for FDT-1-X, except that firepan was equipped with 10 Battelle steam air jets. The bottom draft port was bricked closed. The four rear steam air jets on each side were used and the front pair plugged.

Wye pipe pressures were 5, 9, and 13 pounds.

At the 5 pound rate, atomizer pressure was 64 pounds, steam pressure to air jets, 100 pounds, Butterfly damper 2" open. The fire was quiet and stack clear. Excess air, 23.1%.

At the 9 pound rate, atomizer pressure was 102 pounds, steam pressure to air jets, 150 pounds, butterfly damper open 4". The fire was quiet. Color from stack, clear, with some slight haze in puffs. Excess air, 18.4%.

There was light drumming of the fire at the 13 pound rate with atomizer pressure of 137 pounds. Adjustment of steam-air jets and Butterfly damper was not changed. Color from stack was clear to very slightly hazy. Excess air, 15.3%.

Following this, a 16 pound wye pressure rate was set up for observation. Butterfly damper and steam jet pressures were not changed. Atomizer pressure was 133 pounds. Fire was quiet. There was very slight haze from the stack. Excess air, 15.3%.

Following the 5 pound rate, steam to the steam-air jets was cut off. Except for a slight increase in haze there appeared to be little change in performance.

When changing to the next higher rate, steam jet pressures on the left side were set at 100 pounds; on the right side were left at zero pounds for a short time. This arrangement caused dense smoke and drop in boiler pressure to 185 pounds.

There was no carbon visible in firepan at the end of this series of trials.

<u>Figs. 4-88 and 4-106 - Test FDT-3-Y,</u> with 8" nozzle, ½" x 3" basket cross split, no spark arrester or sand ejector, T&NO firepan and oil burning arrangement. Firepan was equipped with 10 Battelle steam air jets, with the second and third from front on each side in operation and the others bricked closed.

A series of tests were run at 5, 8, 11 and 14 pounds wye pipe pressure. Atomizer pressures were about 80 pounds for the two low rates; 100 and 140 pounds for the two high rates. Steam pressure to the steam air jets was 150 pounds for the first 3 rates and 160 pounds for the high rate.

The bottom damper was closed, except for about the last 20 minutes of the 8 pound rate when damper was opened 1 link because hopper was red hot on the sides near the top. The hopper remained at red heat on the left side during the 11 and 14 pound rates. The Butterfly damper was open 3" for the two low rates, and 6" for the two high rates. The hopper front port was open for all except the 14 pound rate, at which rate it was covered.

The fire was quiet at low and high rates, with light to medium periodic drumming at the intermediate rates. Excess air at the high rate was 11.2% with very slight haze from the stack. Color from the stack was clear to slightly hazy at lower rates.

Fire appeared 6" below edge of front hopper port and periodically 12" out of burner port at the 11 pound rate; 2" below edge of front hopper port at the 8 pound rate, but did not flash out of either port during the high rate.

There was no carbon in the firepan at the end of this test series.

Figs. 4-89 and 4-107 - Test FDT - 4 -Y, with 8" nozzle, ½" x 3" basket cross split, 13½" stack height, no sand ejector or spark arrester; the T&NO firepan and oil burning arrangement except for application of five 5½" O.D. draft flues on each side of firepan close to floor, starting 3-3/4" ahead of front face of flash wall. Oil burner port was 8" x 8½".

Four tests were run at 5, 8, 11 and 14 pounds wye pipe pressure, using atomizer pressures ranging from 40 to 100 pounds. Front hopper port was closed. Butterfly damper was open 2" at the low rates, 2½" and 4½" at the two high rates. The bottom damper was closed for the low rate, open 3 links for the 8 pound, 4 links at 11 pounds and wide open at the 14 pound rate.

The fire was quiet with some light drumming which increased at the high rate. It was necessary to sand flues frequently.

Although preliminary trials of this arrangement indicated good possibilities, during these tests the color from the stack was #1/2 Ringelmann increasing to #1 Ringelmann and sometimes darker smoke at the two high rates.

Undesignated trials were made using the same arrangement as FDT-4-Y except that the five 5½" O.D. side draft flues on each side of the firepan were replaced by 40-2" ID draft tubes on each side, a total of 80 tubes arranged in 8 vertical rows of five tubes each per side. The lowest row of tubes had centers located 2" above the floor brick. The back row of tubes had centers located 4½" ahead of flash wall. Horizontal spacing was 4-3/4" between centers of tubes; vertical spacing, 3" between centers.

Using the 8" nozzle and 1/2" x 3" basket cross split, a 5 pound wye pipe pressure rate was set up. Carbon formed rapidly at the lower and rearmost side draft tubes and at certain atomizer pressures large volumes of smoking oil would spray out of the tubes in this area.

Blocking plates were applied to cover some of the forward tubes but carbon still formed rapidly in some of the lower rear draft tubes on the left side, in spite of the fact that these were frequently cleaned.

After some time, however, the visible formation of carbon stopped and all holes remained clear with blocking plates removed and all side draft tubes in use. Thereafter, many combinations of bottom damper and Butterfly damper settings were tried with different atomizer pressures, but the stack could not be cleared beyond what it was with the standard T&NO drafting arrangement.

The steam rate was then raised and further trials made of the various draft adjustments with no benefits observable for these arrangements as compared with many others tried in past tests.

These trials indicated that relief from carbon formation, drumming, and other undesirable characteristics of firepan arrangements is not assured by the application of multiple small side draft tubes to the T&NO firepan, and further, that an application of this kind would not permit use of an exhaust nozzle relatively as open as an 8" nozzle equipped with a 1/2" x 3" basket cross split in road service.

Figs. 4-90 and 4-108 - Test FDT-5-X, with 8¼" nozzle, ½" cross split having bottom edge set 1/8" below top of nozzle, 13½" stack height, no spark arrester or sand ejector, T&NO firepan and oil burning arrangement with following modifications: Firepan was equipped with an American Arch Company design Dutch over; there were two horizontal rows of eight 2" ID draft tubes in each side of firepan, with horizontal center line of lower row 8" above floor brick in firepan and 6" between centers of the two rows. Vertical centerline spacing was 4-3/4", starting 4½" ahead of flash wall for tube centers. One half brick was laid in the burner port to prevent oil from running out of bottom of port which was 8½" high by 9" wide, effective area. The St. L & S.W. 3" burner was applied centrally in burner port with the lip extending 2" beyond the inner surface of the firepan sheet containing the burner port. Pressure of steam to atomizer was taken at the burner in place of near the oil burning manifold, to agree with St. L. & S.W. practice.

Four tests were run at wye pipe pressures of 17, 13, 9 and 5 pounds; atomizer pressures at burner were respectively 20, 16, 17 and 18 pounds. The bottom damper was open 6 links for the 17 and 13 pound rates, and 7 links for the 9 and 5 pound rates. The Butterfly damper was open wide for all rates except the 9 pound rate and for the first 10 minutes of the 5 pound rate, when it was 2" open.

Color from the stack was slightly hazy with puffs of about No. 1 Ringelmann smoke at the 17 pound rate. For the other rates color from stack was clear to slightly hazy, with some puffs of #½ to 1 Ringelmann smoke. Stack became clear at the 5 pound rate when the Butterfly damper was wide open. The fire was quiet for these tests.

The carbon on the flash wall at the end of these tests was 10" thick and there was some carbon on the lower sides of the Dutch oven. There was no tendency for fire to flash from burner port, and bottom hopper remained relatively cool. Dutch oven and brickwork appeared to be quite hot over an hour after shutting down.

Figs. 4-91 and 4-109 - Test FDT-6-X, with same arrangement as FDT-5-X except Dutch oven had been shortened 9", and the corner of the brickwork at exit of the oven had been rounded off to a 4" radius.

Four 30 minute tests were run at wye pipe pressures of 17, 13, 9 and 5 pounds, using atomizer pressures respectively of 41, 34, 36 and 20 pounds at burner. The bottom damper was open 7 links for the three high rates and 5 links for the 5 pound rate. The Butterfly damper was open 4" and the hopper front port was closed for all rates.

The fire was quiet during these tests. Color from the stack appeared clear to slightly hazy most of the time with some indications of darker puffs although these were obscured by the heavy clouds of white exhaust steam due to atmospheric conditions.

At the high rate, the Dutch oven appeared to be free of fire but at the lower rates there was progressively more fire in the oven, which appeared quite hot at time of shutting down. Fire was periodically visible at edge of burner port during the 3 lower rates.

There was no carbon in the oven at the end of these tests. Carbon on the flash wall was irregular, about 10" thick at the maximum. Excess air ranged from about 20 to 38%.

These tests did not indicate any outstanding benefits from this type of Dutch oven.

Figs. 4-92 and 4-110 - Test FDT-7-V, with same arrangement as FDT - 6-X except that the 1/2" cross split was set so that bottom edge was 3/8" below top of nozzle. Dutch oven was replaced by one 27" wide (9" wider than previously), 20" high, and about 40" long, having an arched top made of wedge shaped brick. There was no spark arrester, but the T&NO sand ejector was installed.

Tests were run at 17, 13, 9 and 5 pounds wye pipe pressure, using atomizer pressures respectively of 30, 28, 20 and 22 pounds at the burner.

Bottom damper was open 2 links for the 17, 13 and 5 pound rates, and 1 link for the 9 pound rate. The Butterfly damper was open 5" at the 17 and 13 pound rates, and 2" at the 9 and 5 pound rates. The hopper front port was closed.

The fire was quiet for all of these rates. At the high rate, the stack was clear with puffs of haze from time to time. The Dutch oven appeared to be full of fire, extending to edge of the burner port. Excess air was about 20% for this rate.

At the 13 pound rate, conditions were similar except that carbon was observed forming on the flash wall, and at end of this rate was 17" thick.

For the 9 pound rate, more of the air appeared to be drawn through the oven and the side ports than for the higher rates. At this rate and the 5 pound rate, somewhat less fire appeared to be in the Dutch oven than during the high rates when the dampers were opened wider. Fire extended intermittently to the edge of the burner port. Bricks near the port were brightly hot and some slag drippings extended down in the port. Excess air was about 37% at the low rate and the stack was clear.

At the close of these tests the carbon on the flash wall appeared to taper from 2" thick at the top to about 15" thick at the bottom. It was noted that bottom hopper became very hot when bottom damper was open less than two links at the low rates.

Figs. 4-93 and 4-111 - Test FDT-8-Z, with same arrangement as FDT-7-V, except that a 5/8" x 2" basket cross split was applied to the 8¼" nozzle, and a 3½" SP Pacific Lines standard oil burner was used, set to point about 14" up on flash wall, with face of oil outlet approximately 2" in from outside of firepan sheet.

Four 30 minute tests were run at wye pipe pressures of 16, 13, 9 and 5 pounds, using atomizer steam pressures pespectively of 30, 28, 20, and 21 pounds. The bottom damper was open 3 links for the 16 pound rate, and 2 links for the three lower rates. Butterfly damper was open 5" at the 16 pound rate, and was closed 1" progressively for each lower rate, ending with 2" opening for the 5 pound rate.

The fire was quiet during these tests. The color from the stack was approximately #½ Ringelmann with some puffs of #1 to #2 Ringelmann smoke.

No unusual conditions developed during these test runs except that during the latter part of the 5 pound rate the smoke was perceptibly darker and the oil and water rates increased beyond the usual variation.

At the close of these tests it was noted that an arm of carbon on the left side of the Dutch oven extended about a foot towards the rear and towards the center of the firepan at about burner height.

Carbon on the flash wall appeared to taper from a thin section at the top to 15" or more near center height of wall.

Undesignated test was made using same arrangement as FDT-7-V except that the ½" cross split was set so that bottom edge was 1/8" below top of the 8-1/4" nozzle. There were sixteen 2" ID draft tubes open on each side of firepan, arranged in four horizontal and four vertical rows. There was a 5" space between floor bricks in firepan and the center of the bottom row of draft tubes, with 3" spacing between horizontal center lines of the rows. There was 4½" between flash wall and the vertical center line of the rear row of draft tubes, with 4 3/4" spacing between center lines of the vertical rows of tubes. The oil burner was the standard 3½" SP type set to point about 14" up on the flash wall. Burner port was 9" x 8½" high, and the bottom draft port was 6" x 19¼".

Trials were made using wye pipe pressures of 16, 13, 9 and 5 pounds with atomizer pressure of about 20 pounds at the burner.

The engine smoked excessively at the high rate, and the smoke could not be cleared by any combination of damper openings and atomizer pressure. When the bottom damper and the Butterfly damper were wide open and the hopper front port was covered, the smoke density was reduced somewhat.

For the three lower rates, the top row of side draft tubes was closed, leaving twelve 2" ID draft tubes open on each side, in three horizontal rows. The smoke ranged from #1/2 to #1 Ringelmann at the 13 pound rate; and was clear to slightly hazy at the two low rates, with light drumming of the fire.

This arrangement of side draft tubes had appeared to reduce the amount of carbon on the flash wall in earlier trials but due to smoking at high rates, it did not merit further testing.

At the conclusion of these trials, a makeshift changeover was made to two horizontal rows of the side draft tubes, using the first and third upper horizontal rows of 2" ID side draft tubes, 8 tubes per row, and a total of 16 tubes on each side. The other side draft tubes were plugged. The steaming rate was again raised to the high setting. The smoke density appeared much reduced, although there were puffs of #1/2 Ringelmann smoke periodically and a few puffs of #1 Ringelmann.

When these trials were completed, an arm of carbon about 4" x 2" was observed to protrude from the left side of the Dutch oven at about burner height, extending diagonally toward the center and rear of the firebox. There was also a deposit of carbon on the floor of the oven and a piece about 8" thick on the flash wall.

Figs. 4-94 and 4-112 - Test FDT-9-AA, with same arrangement as FDT-7-V except that the bottom edge of the 1/2" cross split was set 1/8" below top of the 8¼" nozzle. The standard 3½" Von Boden oil burner was used. Burner port was 9" x 8½" high and the bottom draft port was 6" x 19¼". There were two horizontal rows of eight 2" ID draft tubes in each side of firepan, with the center of the lower row 8" above the floor brick in the firepan, and 6" between centers of the two rows. Spacing of the draft tubes was 4-3/4" between vertical center lines, starting 4½" ahead of the flash wall. The front hopper port was covered.

Tests were run at 17, 13, 9 and 5 pound wye pipe pressures, using atomizer pressures of 29, 26, 20 and 19.5 pounds respectively at the burner.

For the 17 pound rate the bottom damper was open 7 chain links, and the Butterfly damper was open 4". Color from the stack was clear at first with some slight haze which increased to #1/2 Ringelmann smoke. Excess air was 24%.

For the 13 pound rate the bottom damper was open 5 links; the Butterfly damper, 4". Color from the stack was clear with some puffs of very slight haze which darkened somewhat as the test progressed. Excess air was 32%.

For the 9 pound rate the bottom damper was open 3 links and the Butterfly damper 3". The color from the stack was clear with some very slight haze. Excess air was 38%.

For the 5 pound rate the stack indications were the same as for the 9 pound rate. The bottom damper was open 3 links and the Butterfly damper 2". Excess air was 46%.

The fire was quiet during the tests and the Dutch oven appeared quite hot.

Carbon about 8" thick was observed on the flash wall at the end of these test runs. There was also some carbon on the lower right side of the firepan extending from the flash wall about 18" forward. There was no carbon in the Dutch oven.

RESULTS AND CONCLUSIONS

I. Conclusions.

a. Reduction in required draft:

Inadequate atomization of the oil by the Von Boden gravity flow steam atomizing "drooling" type oil burner necessitates combustion air entering the firebox at sufficiently high velocities to assure high turbulence and the consequent breaking up and intermixing of the deficiently atomized oil with the air.

For this reason, air ports must be more restrictive than desirable and any appreciable enlargement of exhaust nozzles, beyond those currently used, to secure an increase in cylinder power output is precluded by the requirement of high firebox draft.

This conclusion is borne out by the combustion performance with the two extremes in the degree of turbulence in the firebox, namely, the minimum turbulence during tests with the Battelle design elliptical approach draft castings and the high state of turbulence with the Battelle design steam-air jet draft arrangement.

b. The comparative performance of the Pacific Lines and T&NO Lines firepans can be explained on the basis of conclusion "a", that is, the lower entering air velocities with the T&NO air openings.

The T&NO draft arrangement for GS-1 class locomotives has available air openings totaling 600 square inches versus 390 square inches, on the same basis, for Pacific Lines drafting.

The normal effect of larger air openings is lower firebox draft and lowered velocity of the entering air with reduced turbulence and intermixing of the combustion air and oil.

With the damper adjustments found best during tests, the draft in firebox with T&NO arrangement was 3½" to 4½" of water lower than firebox drafts during corresponding tests with Pacific Lines pan and the boiler efficiencies were 1½% to 2% lower.

c. The "Dutch Oven":

1. Application of the Southern Pacific design, enlarged "Dutch Oven" improved the performance of the T&NO style firepan in regard to temperatures of firebox sheets, which were more uniform with the oven, and tendency to smoke which was much reduced.

2. No definite fuel saving could be established for the Dutch Oven but some saving could possibly accrue in service because of the more uniform temperatures of firebox sheets and the excellent small fire performance of such burners as the Von Boden burner with the Dutch Oven. This could be of good advantage for fuel savings in territory with long descending grades.

3. Use of the Dutch Oven would not permit further enlargement of the exhaust nozzle without other firepan modifications.

4. Use of the Dutch Oven increased the gas temperatures in certain rear areas of firebox and those nearer the tube sheet were somewhat lower compared to arrangement without the oven.

5. The Dutch Oven deteriorated after relatively short ser-

vice. It appears that this device would materially increase maintenance costs due to its poor service life and its relatively rapid deterioration would increase possibility of road failures from collapse of arch and blocking of flame path. Alignment of burner and proper atomizer use is very critical with this device to prevent oil impingement on walls of oven or flash wall.

d. The bottom draft ring illustrated on Fig. 4-36 is superior to present standard design as it more nearly conforms to normal air flow. This feature extends the life of the castings as improved air flow provides for better cooling. The taper of ring results in interception of less radiant heat. This improved draft ring tends to maintain velocity of air, and due to its construction it is self cleaning. Carbon and fallen brick do not tend to wedge into casting and reduce opening.

e. In view of the improved service life of bottom draft ring on Fig. 4-36 the use of side draft rings more in conformity to the designs shown on Fig. 4-35 and 4-37 would extend the life of the side rings.

f. The use of steam-air jets reduced smoke density and carbon formation with corresponding increase in boiler efficiency and enabled the employment of lower nozzle pressures through use of a more open exhaust nozzle. Although these jets would enable the use of lower back pressures than now currently used, the steam available for use by engine cylinders, would be reduced by the amount of steam required by the jets. Thus the reduction in back pressure would not be a total gain as auxiliary steam requirements would be correspondingly increased. If the jets on one side of the engine were to become clogged or otherwise inoperative in road operation, dense smoke and a drop in steam pressure would result.

II. Recommendations.

a. Due to the requirements of the present burner for high velocity air to provide proper combustion, and the possibility of providing an improved burner with lower draft and air velocity requirements allowing corresponding reduction in back pressure, major changes to standard firepan should be deferred until completion of burner tests in the ST-5 series.

b. The standard Pacific Lines round bottom pan should be reinforced to reduce sagging by the addition of three transverse steel braces fastened to mud ring passing under and supporting the firepan.

The method used by the T&NO as shown on Fig. 4-23 illustrates this type of bracing, except that braces should conform with curvature of lower portion of firepan.

c. The design of bottom draft ring shown on Fig. 4-36 is superior to the present standard design and should be used when replacements are necessary. This form of draft ring will not burn out quickly as the standard because it intercepts less radiant heat and is cooled better by the entering air as it conforms more nearly to normal air flow than the present design. In addition, it does not cause a low pressure area around the face of the ring which draws fire from the firebox against this surface which results in burning out the ring.

d. From observations and test data, the use of long narrow side draft ports is not as beneficial as draft castings more nearly square located adjacent to flashwall. On AC class engines, the side draft casting should be removed and a draft casting similar to Fig. 4-38 be applied in lieu thereof.

e. The present Pacific Lines firepan and style of bottom draft casting is not readily self-cleaning, in that taper of casting is such that, fallen brick, carbon or other debris become wedged in the opening greatly restricting effective area. It then becomes necessary for shop forces to enter firebox in order to clean this opening and remove extraneous material through the draft casting.

To provide for readily cleaning draft casting and bottom hopper of fallen debris and other material, a clean-out door should be provided at front face of bottom draft hopper. This clean-out door will permit hopper to be cleaned easily and quickly by shop forces with minimum delay or effort. The present damper door at the rear of the hopper is not accessible or readily usable for cleaning the bottom draft hopper.

The following notes and conclusions are the results of observation by members of the test staff and are included as a matter of interest and information:

(1) A large proportion of the combustion air entering firebox through burner wall or adjacent thereto has a deleterious effect on

the fire and on the performance of boiler, with the Von Boden type of burner, causing drumming and smoking despite increase in excess air. Presumably this is due to the oil spray containing an inadequate amount of particles fine enough to support combustion without the benefit of traversing a longer path exposed to the heated brickwork, and radiation from the fire above.

(2) With the Von Boden burner and modified draft, air directed over the fire did not improve performance. The overfire air appeared to keep the flame down, and interfered with its turning at flash wall, tended to by-pass over the fire, reducing firebox temperature and resulting in increased smoke.

(3) It was noted from observations of the various test arrangements that air which is directed so that it enters horizontally kept carbon formation to a minimum, however, there was a tendency to smoke at higher rates.

(4) A more efficient design of air ports, taking aerodynamic conditions into consideration, will give sufficient air at high enough velocities with greatly reduced effective area. The air flow is more uniform across these air openings with little or no areas of greatly reduced velocity or eddy currents. The "flow coefficient" for such a design of port would be better than present air port castings.

This would indicate that lower ratio of air port opening area to boiler flue area could be used, because of the better flow conditions through a more efficiently designed air port casting, which would have the effect of reducing loss of incandescent heat through the smaller area draft ports.

(5) Some carbon formation in firebox seemed to accompany the arrangements giving the higher boiler efficiencies, while conversely, increased smoke usually accompanied poor efficiencies.

(6) Consideration should be given to design of firepan and near throat sheet and front wall of pan, to reduce eddy currents, or areas of reduced velocity as otherwise, sand used for cleaning flues will deposit in pan. Every effort should be made to facilitate the movement of the cleaning sand through firebox so that maximum cleaning effect results and firepan is not partly filled with an accumulation of glazed sand.

(7) The Pacific Lines firepan loses much of the benefit of heat from brickwork heating oil stream while oil is still close to burner, because of the relative flatness of firepan near burner wall. It is possible that some type of fire trough can be designed to better preheat the oil in oil stream prior to combustion.

(8) Observations made during various test runs, showed that increased turbulence in the air entering burner port with Von Boden burner would reduce or eliminate drumming. The addition of rounded approaches or other smooth entrances to burner port increased drumming. At times, extremely slight protuberance of a probe of some kind would abruptly halt vigorous drumming.

It is possible that an 8" x 8" burner port, bell mouthed to a 6" x 6" throat would have a beneficial effect.

(9) Vertical air entry from bottom hopper should be very close to flashwall when using Von Boden type burners and modified draft.

Moving bottom draft ring forward resulted in poor performance.

(10) Air entries should be so located and proportioned that air can neither "short circuit" nor channel through flame and enter flues without mixing with burning fuel oil. Such air chills sheets and merely increases excess air without benefit to combustion.

(11) Alighment and tilt of burner is very important. Flame should be longitudinally centered in firebox. The effects of a flame firing to either side of center could readily be noted in smokebox temperature distribution, and also in difference between steam temperatures of the right and left steam pipes to the engine cylinders.

When burner is set with too much vertical tilt, there is a tendency for excessive smoke and for unburned oil to escape from fire door peephole. The temperature of the firebox sheet over the firedoor also increases excessively, and the locomotive smokes at the higher firing rates.

Conversely, when the burner vertical angle is set too low, carbon will deposit on the firepan floor.